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A SURVEY AND ANALYSIS OF ULTRA-HIGH-FREQUENCY MEASUREMENT OF DOSIMETRY TECHNIQUES

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ATOMIC WARFARE DIRECTORATE
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A SURVEY AND ANALYSIS OF ULTRA-HIGH-FREQUENCY MEASUREMENT OF DOSIMETRY TECHNIQUES

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MAY 1954

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Major Daniel Williams of the Radiobiology Laboratory, Atomic Warfare Directorate, contributed materially to this work with his analyses of the biological interests in the potential microwave hazard problem in general, without which we would have had no logical aim. He was also very helpful in arranging opportunities for technical consultation such as the calibration work at Rome Air Development Center.

Much of the actual experimental work and data analysis was done by Miss Mary T. Finigan. She is also an able illustrator as evidenced by the graphs and drawings included in this report.

I INTRODUCTION

Experimental work by various agencies has indicated the possibility of tissue damage by microwave radiation, such as encountered in radar equipment.[1] In order to assist in the analysis of this potential health hazard, this laboratory has undertaken the preliminary development of several types of simple and inexpensive ultra-high-frequency field measuring devices.

This report gives an account of the work done to date on the problem of measurements and dosimetry techniques as concerned with possible radar radiation hazards. In general, the problem under consideration is to examine for feasibility and to carry through primary development, various systems of UHF field measuring and field integrating devices. These devices are to be used as tools in biological research to be conducted by various parties in the U. S. Air Force.

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[1]Information on the biological aspects may be found in the following papers:

J. F. Herrick and F. H. Krusen, "Certain Physiological and Pathological Effects of Microwaves", AIEE Summer General Meeting, June '52 - Conference Paper.

J. W. Clark, "Effects of Intense Microwave Radiation on Living Organisms", Vol. 38, No. 9, Sept. '50, Proc. IRE.

D. B. Williams, Maj., USAF, J. P. Monahan, M. D., W. J. Nicholson, 1/Lt. USAF, AF Cambridge Research Center, "Time and Power Thresholds of Experimental Cataract Production by 12.3 cm Microwave Radiation".

Some of the devices are also to serve as proposed designs for production items in the event that such production becomes desirable and authorized. Further, all of the devices and systems herein described may be considered as suggestions for lines of research by other interested agencies. No attempt has been made in this report to evaluate the biological effects of microwave radiations. Animal studies have indicated that the problem is worthy of serious consideration and the work herein described has been based on this assumption.

This report will deal with the following: power flux measuring devices and systems; special problems of dosimetry techniques; specific descriptions of experimental devices examined; and recommendations for future study.

II POWER FLUX MEASURING DEVICES

There are several systems applicable to UHF power flux measurements. One of the simplest is the neon photometer. This consists of a photoelectric cell and meter which measures the light output of a small neon bulb (Westinghouse type NE-2). The photocell and meter combination is conveniently available in the form of photographic exposure meters. The light output of the neon is linearly proportional, within limits, to the excitation. If a dipole or folded dipole is used to excite the bulb, the linearity of the light function holds for power fluxes less than 0.2 watt/cm^2. Above this point, the linearity of the light function becomes poor. The system runs into light saturation at about 0.5 watt/cm^2 and the life of the bulb is very short; on the order of three or four minutes. The wire leads of the NE-2 bulb, when extended in a line at right angles to the bulb, are approximately the right dimensions to form a half-wave dipole at 2600 megacycles. At lower frequencies this is somewhat short and account must be taken of this lowered radio-frequency efficiency.

Another system of power flux measurement depends on the rectification and d.c. measurement of the received energy. The simplest system of this type is the shunt half wave rectifier which may consist of a germanium or silicon crystal rectifier with leads extended to form a half wave dipole. Connections from a d.c. voltmeter or microammeter are made on the leads near the body of the rectifier, and the meter reading is proportional to the root-mean-square value of the power flux. A major disadvantage of this system is that it requires the crystal rectifier to dissipate as heat one half of the intercepted energy.

A series rectifier has the advantage of not requiring large heat dissipations, but does require the use of a folded dipole, or dipole and quarter-wave stub. If a plain dipole is used, a charge accumulation on the dipole elements biases the system out of operation. With a folded dipole or quarter-wave stub, a full wave rectifier may be used.

A third system of UHF power flux measurement is the radiofrequency thermocouple. This system has not been investigated here, but general requirements may be stated. The thermocouple is to be heated by energy from a dipole and should therefore have an impedance of 50 to 100 ohms. The sensitivity should be on the order of 0.001 amp or more output per watt radio-frequency input. Investigation of the commercial availability of such items is in order. Current output is proportional to root-mean-square power flux.

When considering pulsed radio-frequency signals, such as radar, additional considerations enter into measuring techniques. Peak power fluxes on the order of several hundred watts/cm^2 are often encountered. This is well beyond the linear region of the NE-2 bulbs, and would drive them far into saturation on each pulse. Even if antenna sensitivity were radically reduced, the neon photometer would be useless, as the dynamic range of the neon bulb is infinitesimal compared to the dynamic range of a radar pulse.

With pulsed radio-frequency, rectifier systems divide into two types, peak reading and average root-mean-square reading. The average reading types are applicable to either pulse or continuous radiation, and readings are proportional to the average value of the wave-train envelope. The electrical time constant of the system must be kept short compared to the pulse repetition period.

In the peak reading type, the electrical time-constant is made long compared to the pulse repetition period. This is done by adding a large capacitor in parallel with the d.c. load. The product $R_{load} \times C_{load}$ should be about ten times the longest pulse repetition period in seconds. The load current, and hence the meter reading, is now proportional to the peak value of the pulse envelope.

The peak reading meter has the advantage of requiring only small current surges through the rectifier. The main disadvantage is that the duty cycle of the pulse train must be known in order to compute average power flux.

Thermocouple systems need no special consideration in pulse work. They depend only on the conversion of radio-frequency current into heat, and the output will be proportional to the root-mean-square value of the signal.

III SPECIAL PROBLEMS OF DOSIMETRY

There are two basic requirements in dosimetry: a recording device must be worn on the person; and the device must furnish an integrated record of the total intercepted energy, independent of time. The first consideration includes the need for stability and duplication in the antenna pattern. A large fixed reflector plane will help minimize the effect of small antenna movements with respect to the body. If the dosimeter is to be worn in such a manner that body movements are not influential, such as on a cap visor, the reflector may be eliminated or tailored to give the most desirable sensitivity pattern.

The consideration of dosage integration may be approached in several ways. The simplest again concerns the neon photometer, with a photographic film as the recording element. Here the film exposure is a known function of light intensity and time. Suitable density filters inserted between the film and the neon bulb will give a high contrast at the dosage level of greatest interest. In using the neon photometer, it is necessary to be sure that the bulb is fired during all the period of exposure. The bulb must also be operated in the linear region of its light curve. This limits use of the neon devices to peak power fluxes ranging between 0.01 and 0.20 watt/cm^2, the linear range observed in this laboratory.

A second form of dosimetry is an electrochemical color change carried out by direct current supplied from either a rectifier system or a thermocouple as described above. One simple example of a suitable reaction would be electrolysis of sodium chloride solution with phenolphthalein indicator. Solution quantities, concentrations, etc., should be chosen to give a sharp contrast indication at the dosage of interest. If the solution is suspended in some carrier such as agar-agar,the ion diffusion rate may be made small compared to the electric-field ion migration rate. The progress of a color change line along a U-tube between electrodes may be taken as a dosage measurement. This sort of process could also be carried out on a damp-blotter carrier. The first requirement for efficient operation is that the chemical reaction be monovalent, that is, one ion pair per charge unit transfer.

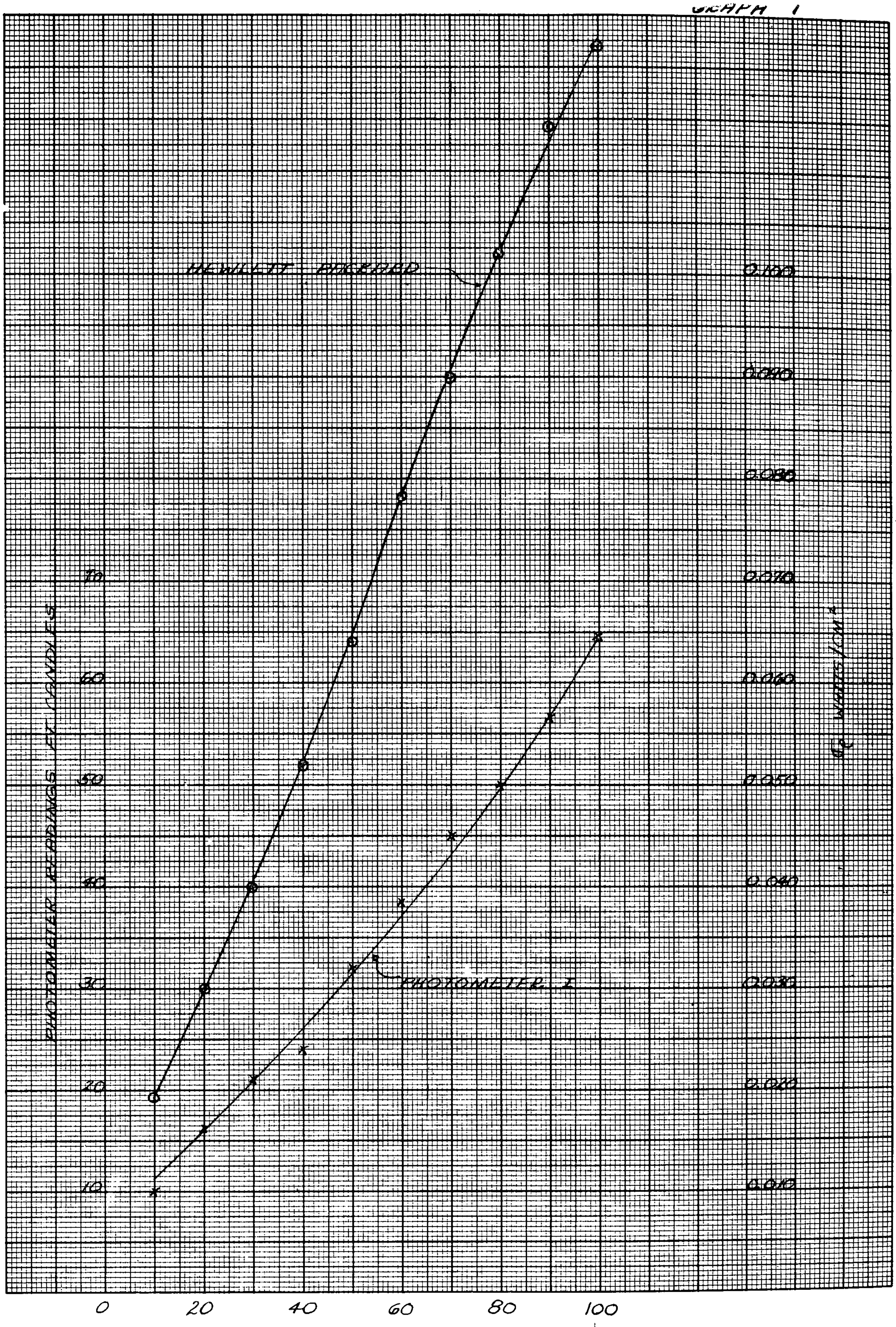
Special considerations for pulse dosimetry are the same as for pulse measurement. Peak and root-mean-square reading systems are again available. A peak reading rectifier system will probably give a more linear dosage function with an electrochemical indicator, as it can be made relatively independent of the conductivity changes which will occur in the liquid as the dosage progresses.

If elaborate analytical facilities are available, there is no need for a visible color change reaction, but from the viewpoint of economy, convenience and speed, a visual indication electrochemical reaction seems most practical.

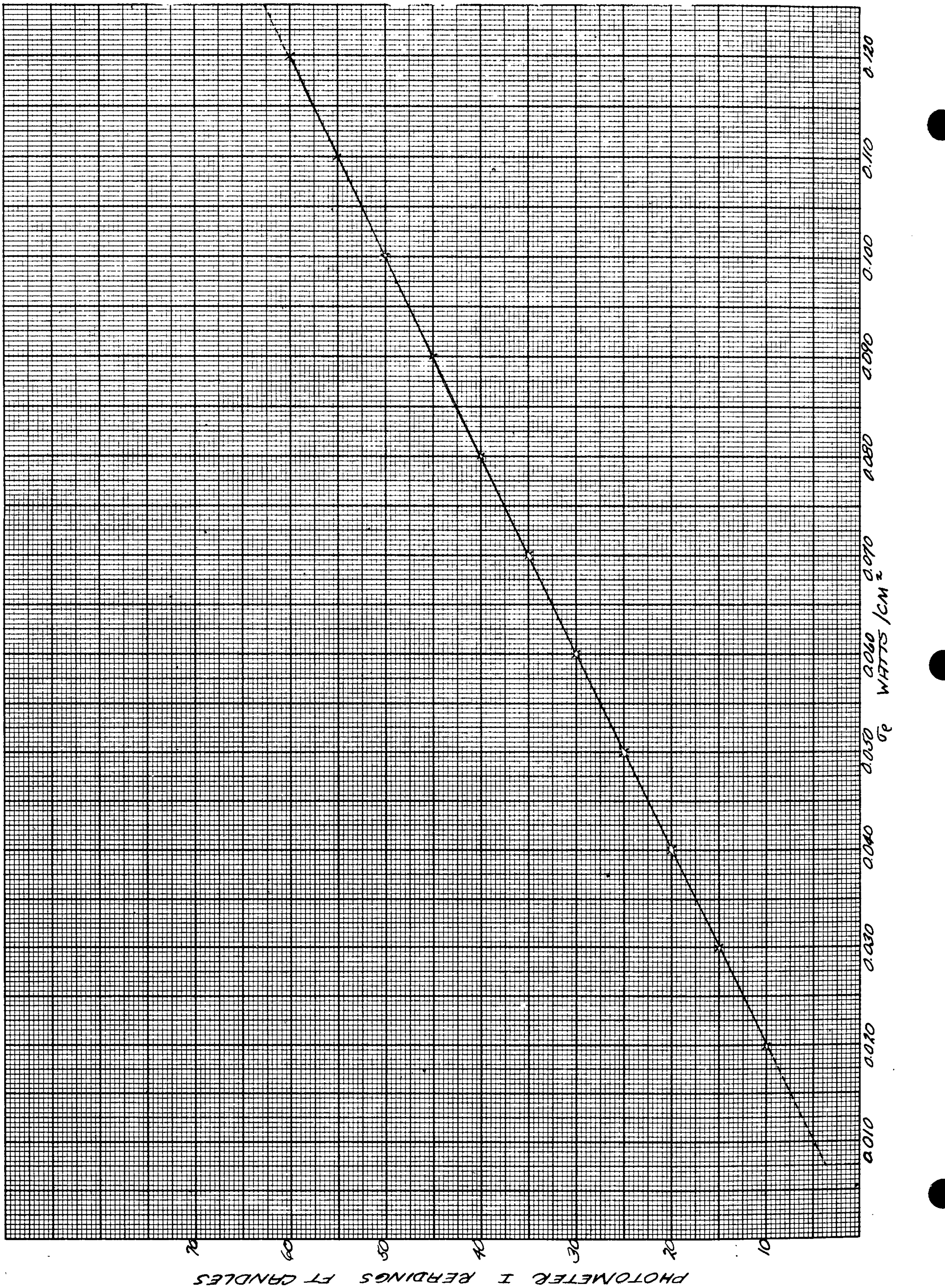
IV EXPERIMENTAL MODELS AND CALIBRATION

All models of power flux meters described in this section have actually been constructed and tested. All calibrations are based on measurements taken with a Hewlett-Packard UHF Power Meter at Rome Air Development Center. The instrument designated "Photometer I" was calibrated against the Hewlett-Packard meter and was then used as a secondary standard to calibrate the other instruments as they were constructed.

Calibrations were carried out in this manner. The UHF source (continuous wave "Microtherm") was set up so as to radiate with vertical polarization into a space giving small reflection components. The Hewlett-Packard UHF power meter probe was placed at a convenient distance (approximately 6") and then moved to the nearest standing wave peak. Power flux measurements were taken for Microtherm output settings from 10% to 100% at 10% intervals. These intervals were convenient and easily duplicable. This gave the radio-frequency field calibration for the reference point in terms of the Microtherm output parameter. The power meter probe was then removed and the antenna of Photometer I inserted and adjusted to the same standing wave peak (same position relative to radio-frequency field). Variation of the source output parameter was then repeated and Photometer I readings noted. These two functions are shown in Graph I. A graphical parameter elimination was then performed and the result appears linearized in Graph II. Graph II and the Instrument "Photometer I" were then used as a secondary standard in the calibration of all the other instruments



GRAPH 1 - % Power - Microtherm.



GRAPH 2 - Photometer I Readings

described below. The procedure was identical to that described above, with Photometer I in place of the Hewlett-Packard UHF power meter.

Photometer I consists of a General Electric type DW-48 photographic exposure meter (with hood removed), a NE-2 neon bulb with leads extended to form an antenna, and a white lined light tight enclosure arranged as in Figure 1.

A second photometer instrument, Photometer II, was constructed and directly calibrated against the Hewlett-Packard meter. This instrument used a broad band dipole and large (9") reflector screen. At all convenient reference distances, there was a large standing wave set up between the reflector screen and the microtherm radiator. This made it impossible, with the time and facilities available, to obtain significant calibration data. The exposure meter used in this instrument had a logarithmic meter function which made the dynamic range of the system quite small. As the system was generally unsatisfactory and exhibited no unique characteristics, no further information on it will be given here.

The first rectifier instrument examined was a shunt diode and dipole. This instrument is useable only for power fluxes lower than 0.055 watt/cm^2. At this level, the heat dissipation requirement of the system exceeds the capability of the diode. See Graph III for the characteristics curve and Figure II for circuit diagram. The characteristics illustrated in Graph III are those of thermal equilibrium. This is unimportant below the 0.055 watt/cm^2 level, and the meter responds rapidly to power flux changes. Above 0.055 watt/cm^2 (the right half of the curve) the response lag becomes that required for

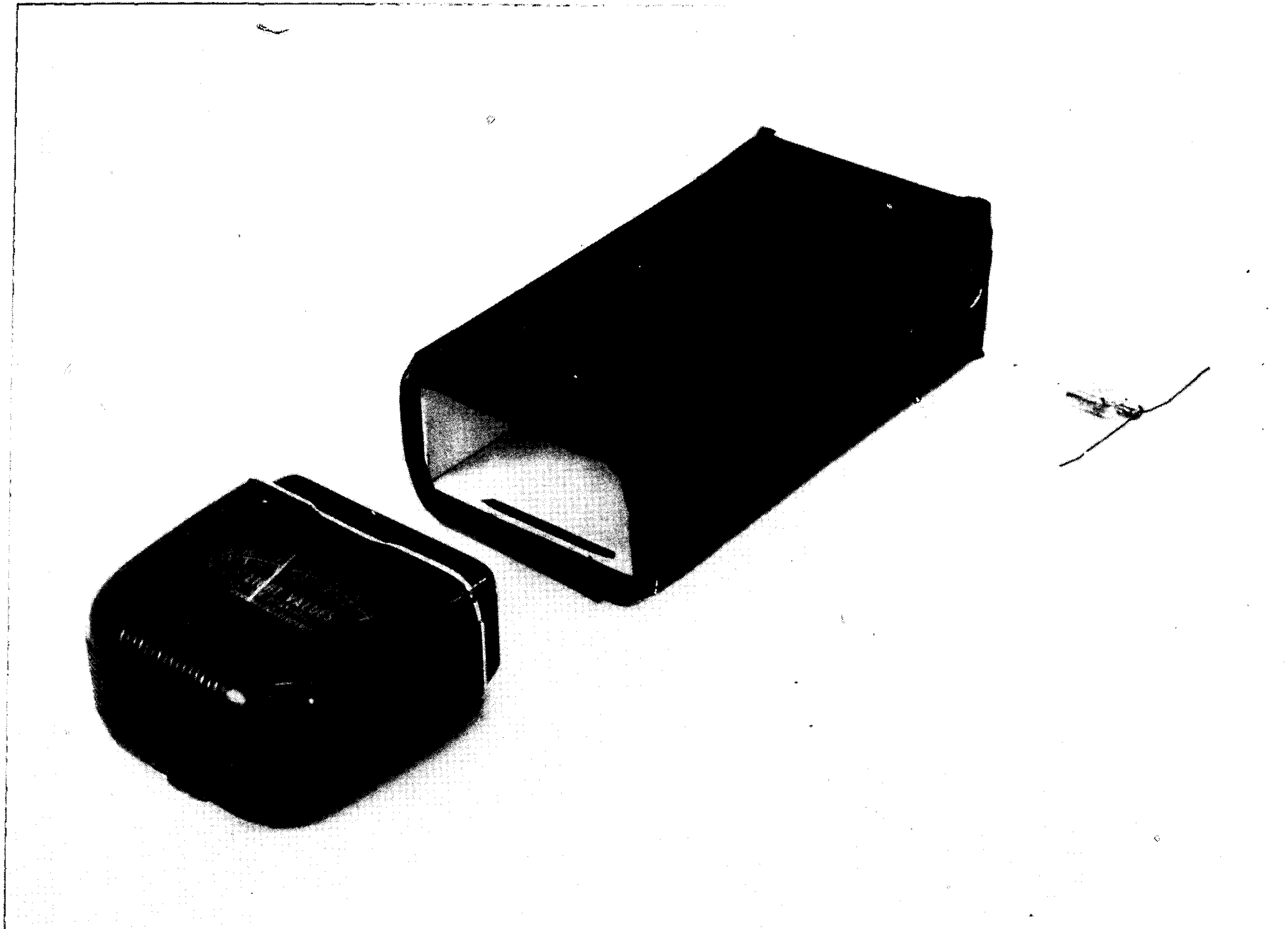
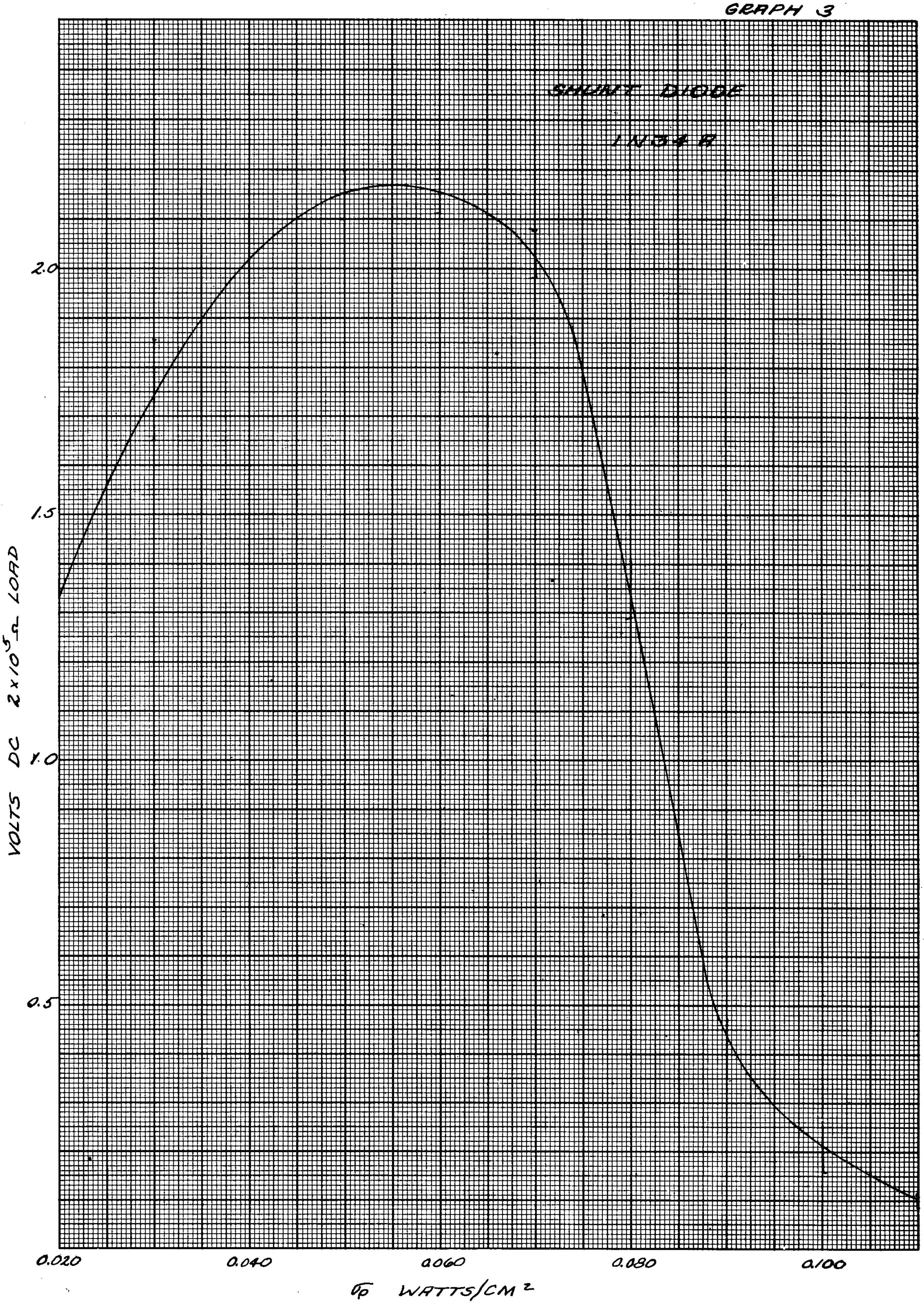


FIGURE 1 - Light Meter



GRAPH 3 - Shunt Diode

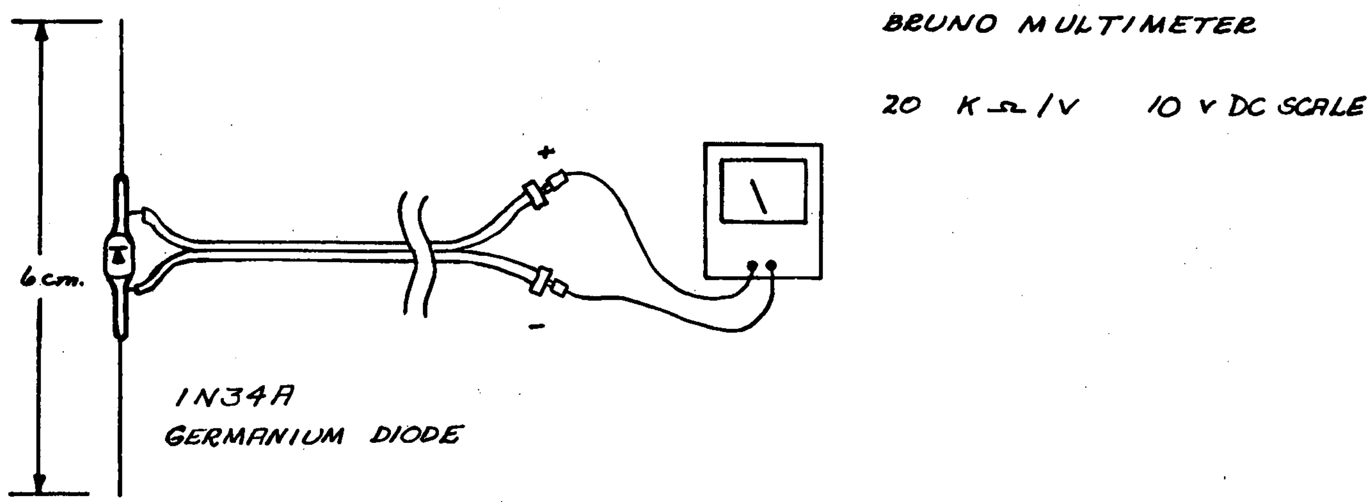


FIGURE 2

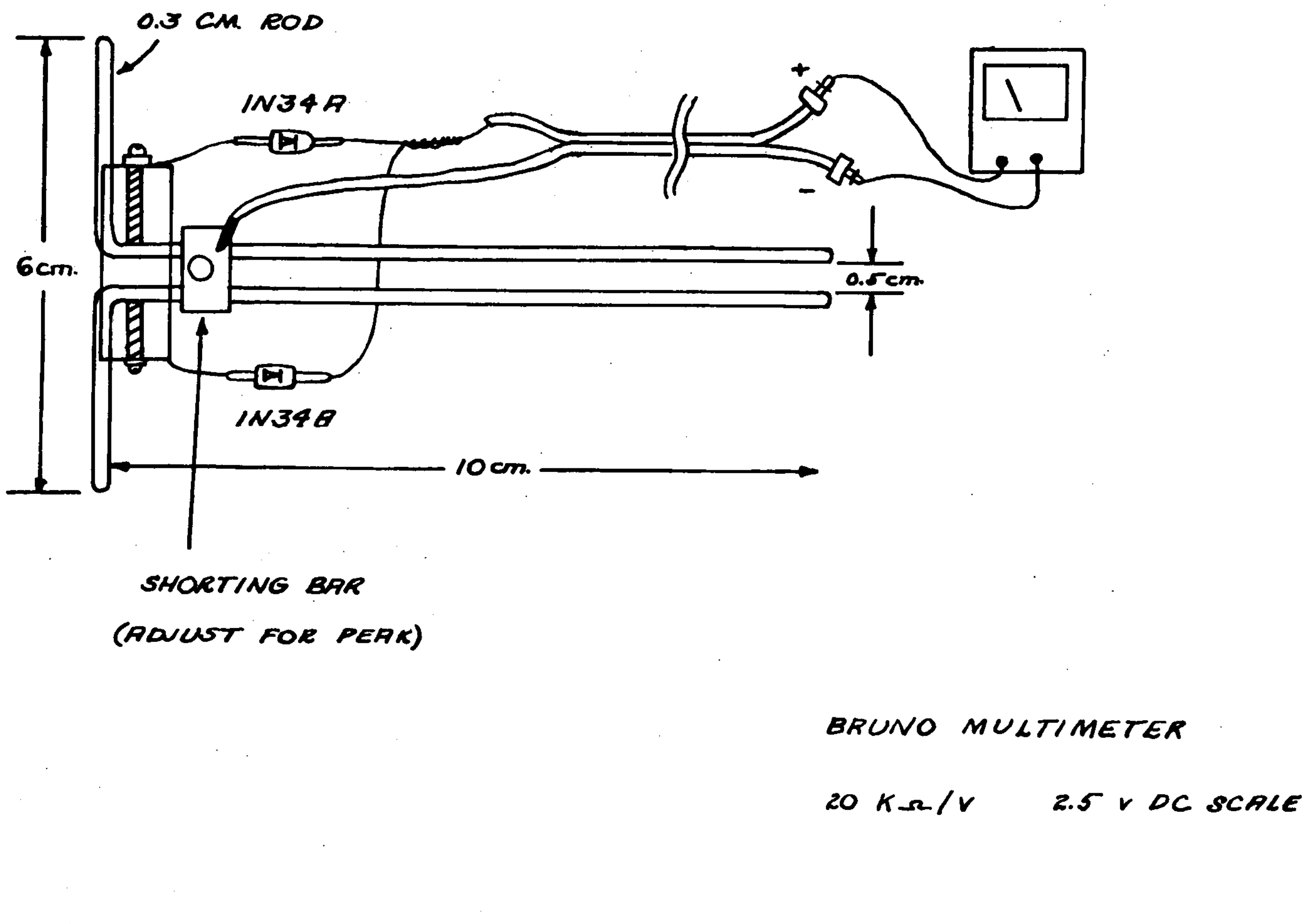
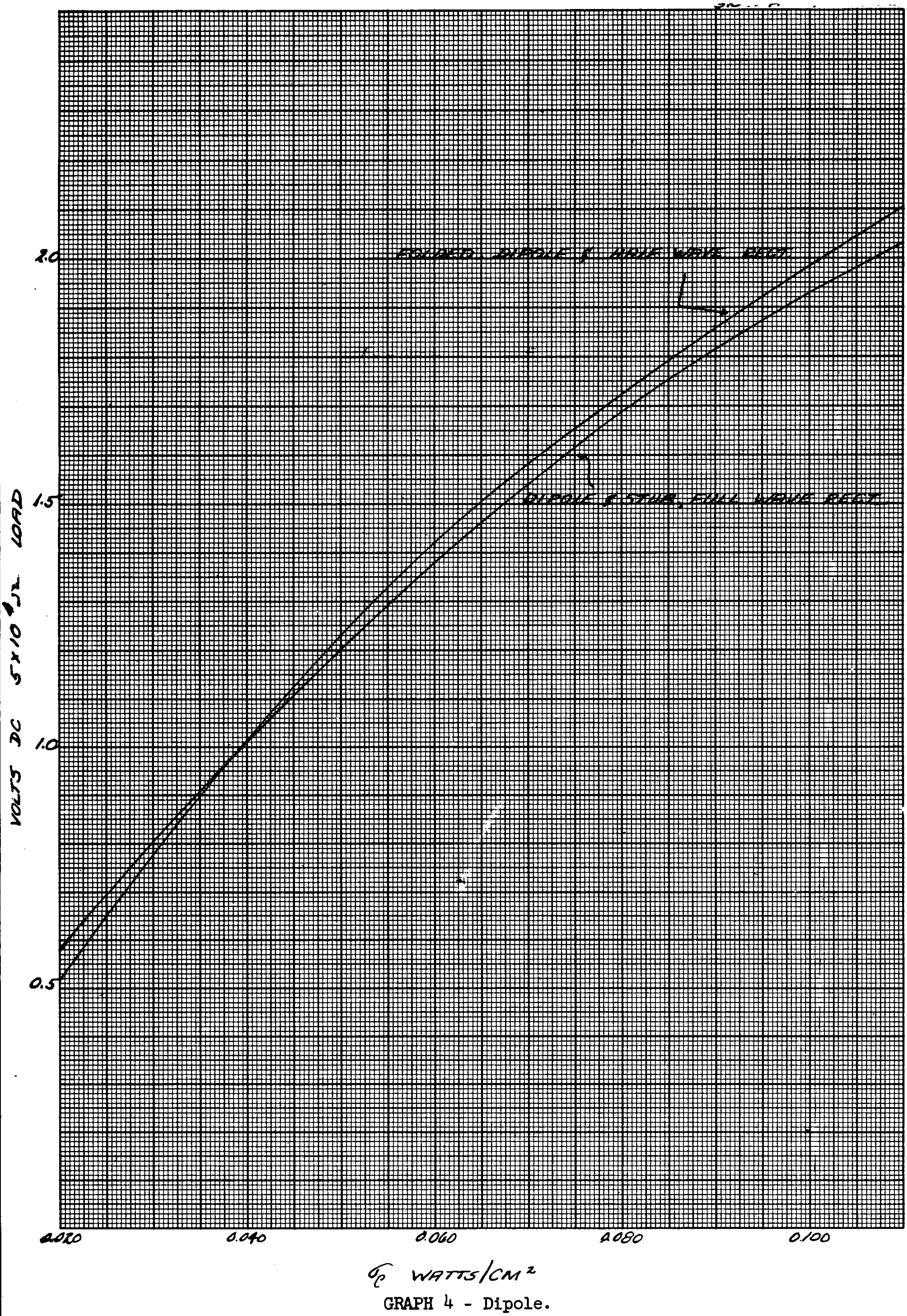


FIGURE 3

thermal equilibrium. In this latter region, the function is neither reliable or reproducible to any useful degree. Figure II illustrates the physical appearance of the instrument. A 1N 34 A germanium diode is used with leads extended to form a half wave dipole. The length of the leads from the diode to the meter is not critical and may be anything up to 8 or 10 feet. In general, this system is unsatisfactory for the desired applications.

A more satisfactory system is that employing a full wave rectifier driven by a dipole and quarter-wave stub. Figure III and Graph IV give the circuit diagram and calibration of this system. The response is smooth at least up to power fluxes of 0.110 watt/cm^2, and probably much higher. Opportunity has not been available to date to check this system with pulse type radiations, but no reasons are immediately apparent why this system should not be satisfactory. As shown, the meter reading is proportional to the root-mean-square power flux. This system has the disadvantage of being considerably dependent on the stub adjustment shorting bar, Figure IV. It also requires two diodes.

The most satisfactory and simplest system tested to date is the folded dipole half-wave rectifier. The calibration of this system is also given in Graph IV and is almost identical to that of the dipole and stub system. Calibration on this system was carried out to power fluxes of 0.110 watt/cm^2. At this level, the highest conveniently available, it may be seen from Graph IV, that the calibration function is not very linear. Nevertheless, the function still has a large slope and shows no signs of saturation. The non-linearity exhibited in



GRAPH 4 - Dipole.

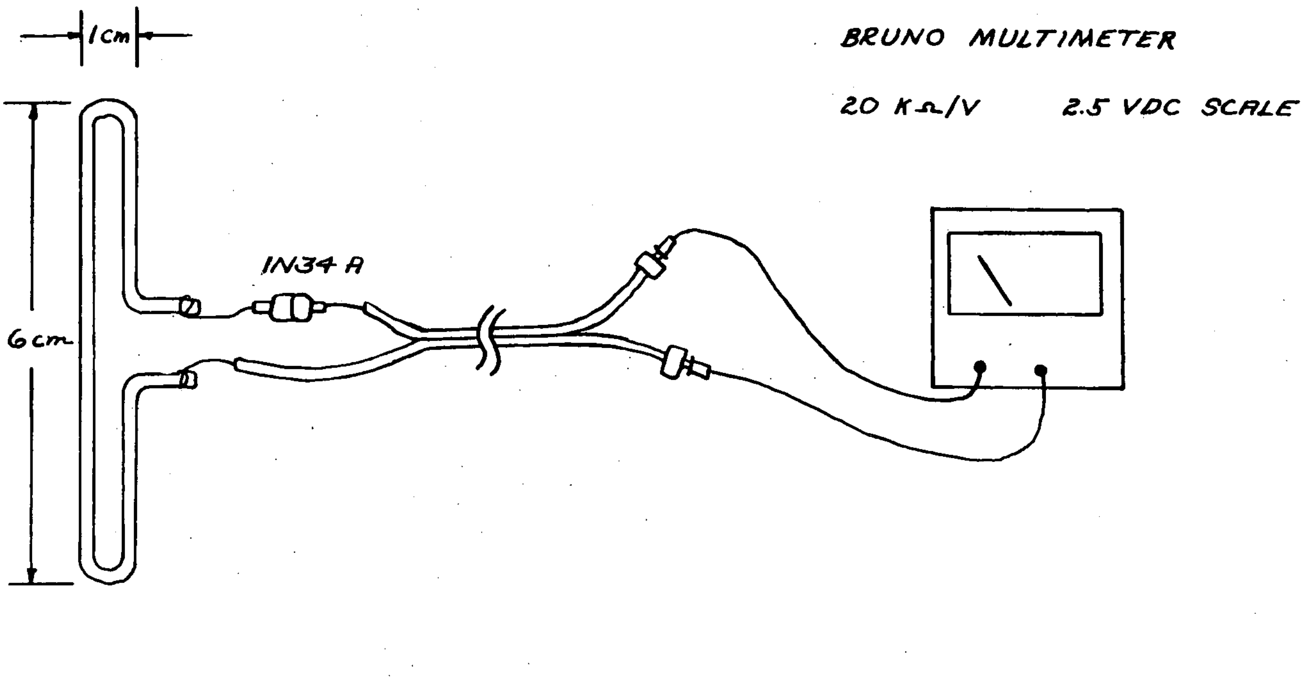


FIGURE 4

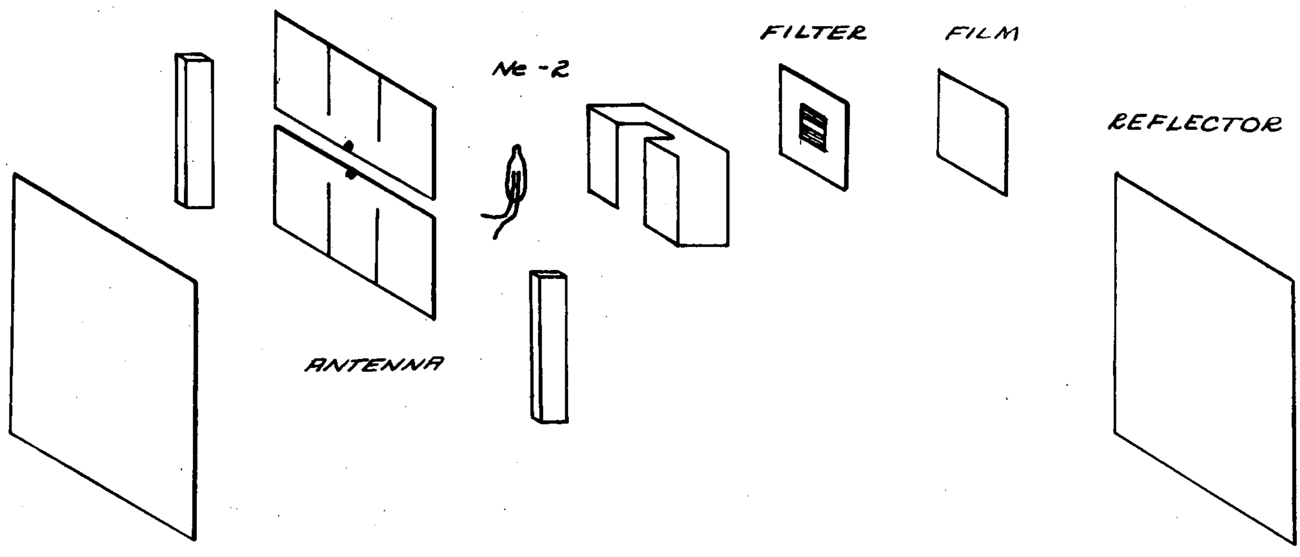


FIGURE 5

Graph IV is in no way detrimental in using this system as a power flux meter. The circuit diagram of the folded dipole system is given in Figure IV. A folded dipole is much less frequency-sensitive than a dipole, and for this particular case the system should be useable for wavelengths from 10 cm to 14 cm without corrections. The load resistance is 50,000 ohms, furnished by a standard 20 K ohm/volt multimeter on a 2.5 volt scale. As shown in Figure IV, the system gives meter readings proportional to the root-mean-square power flux. It may be converted to a peak reading meter by adding a 0.1 mfd capacitor in parallel with the meter terminals.

A photo-dosimeter was developed and constructed but as it proved unsatisfactory for all but low level continuous radiations, no calibration was made on this device. It is illustrated in Figure V, the important assemblies being shown in exploded view. Continuous wave power fluxes up to about 0.2 watt/cm^2 can be integrated with this device. Extremely dense filters may be used, as plenty of light is available for the exposure of even relatively insensitive film.

V RECOMMENDATIONS FOR FURTHER STUDIES

Inasmuch as the study of radiation damage to body tissue will require research instrumentation adapted to the special needs of this problem, it will be necessary to develop further the instruments described in this report.

Specifically, work should be continued on the low level continuous wave measuring and dosimetry devices previously described. It is certain that there will be for some time a continuing interest in continuous wave irradiation as a research tool. No great emphasis need be placed on this phase, however.

The pulsed radiations of radar sets are those which will ultimately be of greatest interest. Therefore a source of pulsed radio-frequency should be obtained, both for instrumentation and biological research.

Chemical aspects of electrochemical indicator solutions should be analyzed, at least theoretically, for the purpose of deciding the optimum constituency. It is assumed in making this recommendation that some sort of visual indication electrochemical dosimetry will be desired eventually.

Thorough calibration and cross calibration of all instruments to be used should be carried out <u>directly</u> against some reference standard in order to obtain greatest accuracy. In referring calibrations to secondary standards, cumulative errors are unavoidably introduced. It would be most desirable to obtain a UHF power meter or field strength meter such as previously described for direct use in all future measurements. This could be used then as a primary calibration standard.

Dynamic ranges of neon bulbs of various sorts should be examined in order to gather data for future possible special purpose applications. If neon bulbs are to be used in any future work, accurate data must be obtained on their light/energy function, firing time, energy efficiency, etc., in order that significant design approaches may be pursued.

Properties of commercially available radio-frequency thermocouples should be surveyed, in order to decide the feasibility and desirability of future work along this line.

A problem related to Radar Dosimetry, and included in the greater problem of biological radiation damage studies, is that of insuring the continuance of safe operating habits by radar personnel. To aid in this aim, and to serve as a danger level warning, a simple neon flasher can be developed. It need consist of no more than a neon bulb with leads trimmed to reduce the firing sensitivity to whatever is decided to be a dangerous power flux.

As a final suggestion, the use of incandescent bulbs as a photometer light source should be investigated. These may also prove feasible for photographic dosimetry techniques. Particular attention should be given to the shape of the light/energy function as this must be fitted to the light sensitivity function of photographic film in a constant-product relationship, that is, the end result of dosimeter exposure must be film darkening a function <u>only</u> of integrated power flux, and <u>not</u> of <u>time</u> and flux <u>levels</u>.

APPENDIX: UHF TECHNIQUES

In working with UHF, special consideration must be given to the use of insulating materials. In the region of 3000 megacycles, glass is completely useless. Lucite and plexiglass are better but introduce substantial losses. Polystyrene, available in many commercial variations, is one of the most practical insulating materials and one of the most readily available. It has a very low power factor and a rather low dielectric constant.

In construction with polystyrene, care must be taken as to the various glues, resins, welds, etc., to be used in the structure. The properties of the <u>interface</u> between segments of polystyrene may contribute large losses if this area is in contact with any of the conducting elements. A very thin film of carbon-tetrachloride makes an excellent weld-type bond between pieces of polystyrene. "Q-Dope" by General Cement Co. is more convenient to use but is somewhat less satisfactory electrically.

Transmission lines and transmission line sections are another important tool in UHF techniques. A transmission line is simply a two-conductor cable for radio-frequency energy. Transmission lines always introduce losses and at UHF these losses are so high that waveguides are generally used instead. For short distances or for special "trick" circuits, transmission lines are still useful. Transmission line lengths are usually measured in wavelengths or fractions thereof. The electrical or effective length of a line is always more than the real physical length. Thus, a line 8 cm long physically may have an electrical length of 10 cm, or 1 λ at 3000 megacycles. This effect is due to dielectric properties of insulators and conductors used and is more pronounced at higher frequencies. The exact relationship varies and is best determined empirically.

The quarter-wave stubs are special cases of transmission line application. A line of electrical length $\lambda/4$, open at the far end, appears electrically as a series resonant circuit; that is, a very low impedance. A $\lambda/4$ line, shorted at the far end, appears as a parallel resonant circuit; that is, a very high impedance. Thus, for $\lambda/4$ stubs, a shorted stub appears as an open circuit and an open stub appears as a short circuit, just the opposite of what might be expected.

Several antenna systems lend themselves well to dosimetry. One such is a non-flared square cut waveguide section. The sensitivity pattern of this system is a cardioid of revolution, axis coincident with the waveguide axis. This pattern is a close approach to the hemispherical one desired for dosimetric applications. Energy is removed from the waveguide by a short probe. The major disadvantage of this system is the bulkiness of the structure.

The simplest antenna is a half-wave dipole, whose physical dimensions are about 0.47λ tip to tip. The sensitivity pattern is a toroid coaxial with the antenna. Maximum sensitivity lies in the perpendicular bisecting plane of the dipole. A reflector plane, spaced one quarter wavelength behind the dipole, doubles the front sensitivity and reduces the back sensitivity to zero. The use of a reflector also makes the antenna less sensitive to nearby objects, a property desirable for dosimetry applications.

A variation of the dipole is the folded dipole. This is a simple dipole with the tips connected by a parallel bar. The parallel bar offers a d.c. return circuit, making the antenna useable with series rectifier circuits. In addition, the center of the parallel bar is electrically neutral, offering a return point for full wave rectifier circuits.

These are a few of the more important factors to be kept in mind in designing UHF devices. Qualified personnel and extensive reference material will be needed for more thorough application of UHF techniques.