A RADIO FIELD STRENGTH SURVEY OF WKAR

THESIS FOR DEGREE OF B. S.

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A RADIO FIELD STRENGTH
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THESIS

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Statement Of Problem

The work of taking field strength measurements of radio station WKAR was undertaken primarily to ascertain the directional effects of the radiating system, the shielding effects of the antenna supporting structures and surrounding buildings, and to determine if there were any erratic conditions on or about the college campus which might effect the transmission of radio signals. Letters and reports received at the station from radio listeners throughout the country indicate very clearly that the signals are not being received with equal efficiency in all directions. The tests performed, and reported in this thesis, were expected among other things to definitely decide if local conditions were responsible for the variation in transmission efficiency in different directions from the station.

Other problems or special side issues were to be solved and dealt with as they arose in the natural course of taking measurements as were the subjects suggested by advisors as the work progressed.

Reports of this nature naturally include a description of the station, of field apparatus, methods of calibration and procedure, and a discussion of difficulties encountered in the field and results obtained.

In addition to all this, it is thought advisable to include somewhat of the theory involved in such a test. For instance, the theory of wave propagation and directional characteristics of different types of antennas. A discussion of this theory follows.

Theory of Wave Propagation

The space about an antenna carrying alternating current is occupied by two fields each comprising an electromagnetic and electrostatic component. One of these, known as the induction field, is surging back and forth from the antenna. No energy is lost to this field from the antenna circuit. The induction field is familiar to any electrical engineering student as the phenomenon of induction is produced by it. The induction field is comprised of electric and magnetic components which are in time and space quadrature with each other.

There is another field present known as the radiation field. This field represents energy which is transferred to the medium surrounding the antenna and never returns to it. The radiation field is also divided into electric and magnetic components, but unlike the components of the induction field these two components are in time phase and at any point rise and fall simultaneously. Figs. 1 and 2 show the phase relation between the electric and magnetic field. The reason given for the presence of the radiation field is that in rapidly changing fields all the energy does not have time to return to the antenna and travels away from the antenna with the speed of lights.

The space surrounding any conductor carrying alter-

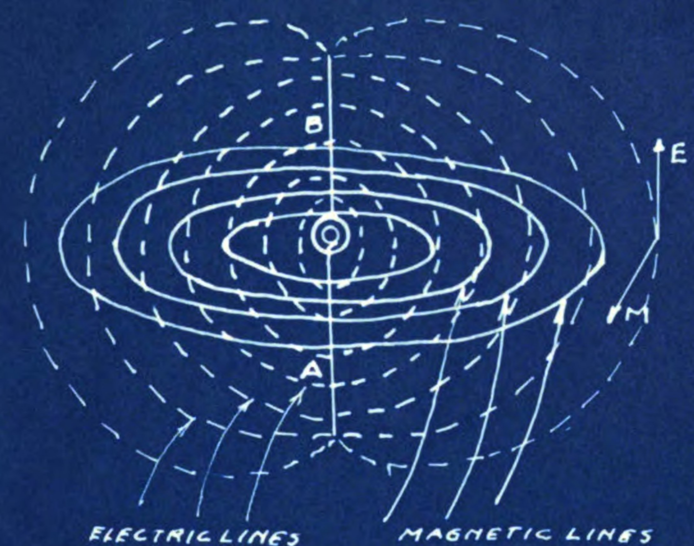
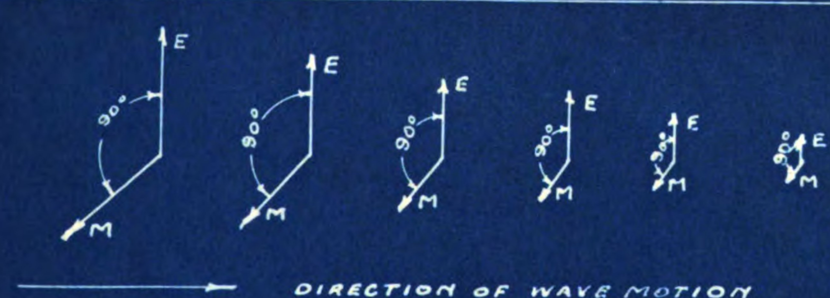


FIG. 1.



SHOWING RELATION BETWEEN ELECTRIC AND MAGNETIC COMPONENTS OF RADIATION FIELD AS WAVE ADVANCES AWAY FROM ANTENNA E AND M AREIN SPACE QUADRATURE BUT IN TIME PHASE

FIG. 2

nating current of any frequency will be occupied by both induction and radiation fields. However, in the case of the lower frequencies such as the commercial frequencies used for power transmission most of the energy has time to return to the conductor and for this reason the radiation field will be negligible. On the other hand, when higher frequencies are used such as radio frequencies the field is changing so rapidly that a great portion of the energy does not return to the antenna and the radiation field becomes of importance. The induction field will still be present but inasmuch as this field varies inversely as the square of the distance and the radiation field varies as the first power, the induction field will become negligible at a short distance from the antenna.

The above theory is according to Morecroft's in Chapter 9 of Principles of Radio Communication.

The induction field becomes negligible at distances greater than one wave length. At distances equal to $\frac{\lambda}{2\pi}$ the fields are equal. For points closer to the antenna than this the induction field predominates. For points farther away the radiation field predominates and the induction field falls off rapidly with the distance and becomes negligible.

This theory is according to H. H. Dellinger in Principles of Radio Transmission and Reception With

Antennas and Coil Aerials, which appeared in the October 1919 issue of the A.I.E.E. Journal. In the same article Mr. Dellinger presented a mathematical proof that the induction field varies as the square of the distance while the radiation field varies as the first power. Morecroft evidently accepts this proof as authoritative, and it is repeated here.

DERIVATIONS OF THEORETICAL FORMULAS

1. Radiation From An Antenna

"Formula (8) below, giving the radiated magnetic field at a distance from an antenna, is a well-known formula. It has been given by various writers, and is the only one presented in this paper that requires any deep consideration of fundamental electromagnetic theory. The result is in fact implicit in Maxwell's classical treatise, 'Electricity and Magnetism'. The derivation given here is much more direct and brief than the others the author has seen, and is given only for that reason. The derivations of formula (10) and following ones are still simpler, and will be of more interest to most readers.

"The units used in this paper are international electric units, the ordinary electric units based on the ohm, ampere, centimeter, and second. (See paper by the author on 'International System of Electric and Magnetic Units', Scientific Paper of the Bureau of Standards No. 292)

The unit of magnetic field intensity is the gilbert per cm., often called the cgs. unit. The only exception to the use of units of the international system is in certain of the practical formulas where lengths are expressed in meters or miles where so stated.

"In the following discussion is calculated the magnetic field intensity produced by a flat-top antenna, having electric current of uniform value throughout the length of the vertical portion. Most antennas in practise approximate closely this condition.

The symbols used are:

i = instantaneous current

I_o = maximum value of current

I = effective value of current

H_t = instantaneous value of magnetic field intensity

H_o = maximum value of magnetic field intensity

H = effective value of magnetic field intensity

h = height of aerial

d = distance from sending aerial

ω = 2π times frequency of the current

t = time

λ = wave length

c = velocity of electric waves = 3×10^{10} cm. per second

Subscripts s = sending, r = receiving, a = antenna, c = coil.

"In Fig. A the upper heavy line represents the flat top of the antenna, and the lower heavy line the grounding area. Suppose a current is flowing, having the instantaneous value i in the vertical portion. The magnetic field intensity at any point due to a varying current is different from that due to a steady current. Consequently the field cannot be calculated in the same way that the magnetic field intensity of a straight wire is ordinarily calculated. When the current is varying, the magnetic field intensity is calculated by the aid of a quantity called the vector potential in such a way that the variation with time is taken into account. The instantaneous value of the vector potential of current in the vertical conductor at a distance d in a plane perpendicular to the conductor, is

$$A = \frac{(i)h}{d} \tag{1}$$

where (i) indicates that for any time t the value of i is taken for the instant $(t - d/c)$.

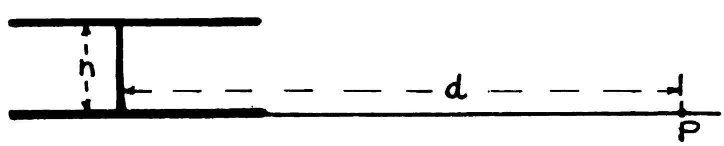


Fig. A - Calculation of Magnetic Field at a Distance From An Antenna.

Suppose the current in the antenna is a sine-wave alternating current,

$$i = I_0 \sin \omega t \tag{2}$$

Therefore $(i) = I_0 \sin\omega(t - d/c)$

$$A = \frac{h(i)}{d} = \frac{h I_0}{d} \sin\omega(t - d/c) \quad (3)$$

The magnetic field intensity is calculated from the vector potential by the general relation $H_t = 0.1$ curl A, which for this simple case of a straight conductor becomes

$$H_t = \frac{1}{10} \frac{\partial A}{\partial d} \quad (4)$$

the direction of H_t being perpendicular to the plane of h and d. From equation (3)

$$H_t = -\frac{h \omega I_0}{10\, c\, d} \cos\omega(t-d/c) - \frac{h I_0}{10\, d^2} \sin\omega(t-d/c) \quad (5)$$

"This equation gives the magnetic field intensity at any point P at a distance d from the antenna. The second term represents the ordinary induction field associated with the current, while the first term is the radiation field. At a considerable distance the second term is negligible because the second power of d occurs in the denominator. The first term then represents the magnetic field radiated from an antenna at the distance d from the antenna. The distance d is measured along the earth's surface, because the waves follow the curvature of the earth's surface instead of proceeding straight out into space. For a considerable distance from the antenna, the maximum value of the magnetic field intensity during a cycle is therefore

$$H_0 = \frac{h \omega I_0}{10\, c\, d}$$

Expressing in terms of effective values,

$$H = \frac{h \omega I}{10\, c\, d} \qquad (6)$$

"Henceforth H means the radiated field unless it is specifically stated to be the total field. The last equation may be expressed in terms of wave length instead of by the relation

$$\frac{\omega}{c} = \frac{2\pi}{\lambda} \qquad (7)$$

Therefore $$H = \frac{2\pi}{10} \frac{h\, I}{\lambda d}$$

Using the subscript s to indicate that it is the sending rather than the receiving antenna which is considered,

$$H = \frac{2\pi}{10} \frac{h_s\, I_s}{\lambda\, d} \qquad (8)$$

"This derivation follows the conceptions presented in the early pages of Lorentz, 'The Theory of Electrons'. It is equivalent to Hertz's intricate proof, but is more direct. The way in which the result is expressed here accords more closely with the physical ideas and with actual practise, being expressed in terms of current rather than electric charge, since it is current that is actually measured in an antenna and the current furthermore is generally uniform in the vertical portion of the antenna.

"Formula (8) gives the radiated magnetic field from a sending antenna at a distance d along the earth's surface. The units are the gilbert per cm. for H, the ampere for I, and the centimeter for all lengths, as previously stated.

"Undamped alternating current in the antenna was assumed. The same result, however, is obtained if the current is damped. At very great distances from the sending aerial, the magnetic field is less than that calculated by formula (8), because of absorption of the power of the wave as it travels along. This may be taken into account by multiplying the right-hand member of (8) by a correction factor F_1. The value of this factor for daytime transmission over the ocean, derived from the experiments of L. W. Austin, Scientific Paper of the Bureau of Standards No. 159; 1911, is

$$F_1 = \epsilon^{-0.000047\, d/\sqrt{\lambda}} \qquad (9)$$

for d and both in meters. This correction ordinarily needs to be applied only when the distance is greater than 100 kilometers."

This proof that the radiation field varies inversely as the first power of the distance does not agree with experimental data presented by Lloyd Espenschied in an article entitled "Radio Broadcast Coverage of City Areas" which appeared in the A.I.E.E. Journal for November, 1926. Parts of Espenschied's conclusions and curves are shown below. The parts concerning fading is not pertinent to the above proof, but it has not been cut from the article because it contains some interesting conclusions upon wave propagation and because the curves concerning fading are necessary to show the decrease in field intensity.

-------"The Character of Radio Broadcast Transmission.

"The ideal law for broadcast distribution would be one whereby the transmitted waves are propagated at constant strength over the zone to be served and then fall abruptly to zero at the outside boundary. All receivers within the area would be treated to signals of equal strength and no interference would be caused in territories beyond. The kind of law which nature has actually given us involves a rapid decadence in the strength of the waves as they are propagated over the service area and then instead of a rapid cutoff a persistence to great distances at field strengths which although often too low to be generally useful is sufficient to cause interference in other service areas. This situation is illustrated in Fig. 3. The upper curve shows the relation between intensity and distance, the lower portion the interpretation of this curve in terms of areas of reception. The attenuation traced by the heavy line of the curve is that of the components of radiation which is propagated directly along the earth's surface. It is this radiation which is ordinarily utilized for reliable broadcast receiption. The shaded portions near the outer ends of this curve are intended to indicate the appearance of variations in the signal intensity which occur at greater distances, particularly at night and which are known as fading.

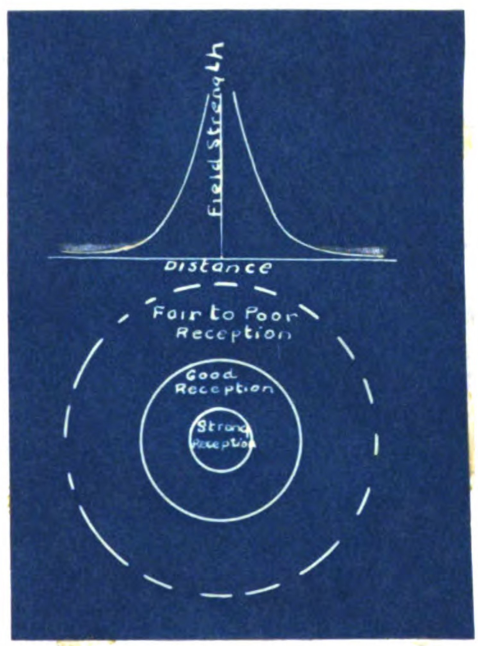


Fig. 3 - The Attenuation of Broadcast Waves in Reference to the Areas Served.

The evidence of recent researches, particularly those made at short wave lengths, indicates that these fading variations are due to radiated energy which has left the earth's surface at the radio transmitter and has been reflected back to the earth's surface from a conducting stratum in the upper atmosphere. At broad cast frequencies the reflected wave component is observed at night, but has not been noticed during the day. At locations close to the transmitting station the effect of the reflected component is negligible as compared with the strength of the directly transmitted waves. At increasing distances the directly transmitted waves die away to very low values and the indirectly transmitted waves begin to show up and become controlling at the longer distances. The fluctuations themselves appear to be due in part if not entirely to variations in the reflected waves themselves resulting perhaps from fluctuations in the conditions of the upper atmosphere.

Thus it seems clear that radio transmission involves wave components of two types, one which delivers directly to the receiving area immediately surrounding the broad cast station a field capable of giving a reliable high grade reception, and another transmitted through the higher altitudes which permits distant reception but not with the reliability and freedome from interference required of high grade reproduction."

Mr. Espenschied shows at this point the results of field measurements upon WEAF in New York and WCAP in Washington. The shaded portions show the variation due to fading. The daylight curve will be of interest to this thesis in that it shows that the decrease of field intensity with distance is not a straight line function.

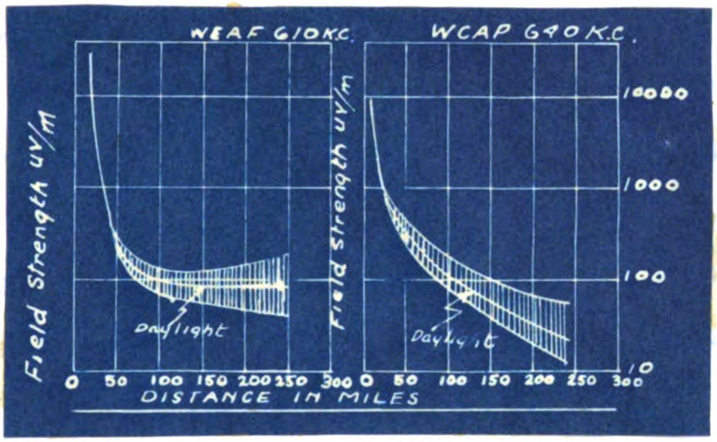


Fig. 4 - Results of a Few Measurements Upon the Reduction in Field Strengths With Distance Indluding Distances at Which Fading Occurs.

Mr. Espenschied's paper continues "A fact which is of importance to our understanding is that fading which ordinarily is noticed at distances of the order of 100 miles; may under some conditions become prominent at distances as short as 20 miles from the transmitting station. Such short distance fading has been experienced in receiving WEAF in certain parts of Westchester County, New York. (See "Some Studies in Radio Broadcast Transmission" by Brown. Martin and Potter Proceedings I.R.E., February, 1926) It appears to be a case where unusually high attenuation caused by the tall building area of Manhattan Island has so greatly weakened the directly transmitted wave as to enable the effect of the indirect wave component to become pronounced at night.

"In general the attenuation suffered by the normal surface-transmitted wave varies over wide limits depending upon the terrain which is traversed. This is disclosed by the curves of Fig. 5, which shows the drop in field strength with distance for a 5 KW station for each of the following conditions:

a. No absorption, the inverse distance curve, $a = 0$

b. Sea water, for which absorption is relatively small ($a = 0.0015$)

c. Open country and suburban areas ($a = 0.02$ to 0.03) as measured in the vicinity of New York and Washington, D.C.

d. Congested urban areas ($a = 0.04$ to 0.08 as measured for Manhattan Island.

"The factor a will be recognized to be the absorption factor of the familiar Austen-Cohen empirecal formula.

$$e = 0.009 \frac{\sqrt{P}}{d} \cdot e^{\frac{a\,d}{\sqrt{\lambda}}}$$

P = radiated power in watts

d = distance in kilometers

= wave length in kilometers

a = absorption factor

e = volts per meter.

"The first term represents the decrease due merely to the spreading out of the waves, the second term the decrease due to the absorption of the wave energy by the imperfect conductivity of the earth's surface."

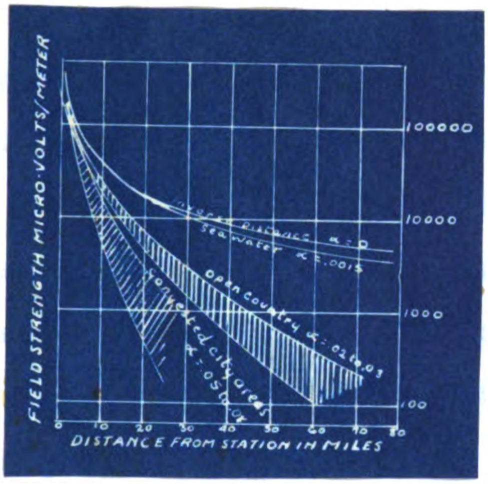


Fig. 5 - Effect of the Terrain in Reducing the Field Strength of a Broad Cast Transmitting Station

The curve in this print which is of particular value to this thesis is the inverse distance curve. It is undoubtedly true that absorption had a great deal to do with reducing field intensity at a point some distance from the transmitter. The inverse distance curve takes into consideration no absorption, hence any decrease in field strength is caused by the natural dying out of the wave due to increasing distance.

It is not clear how Mr. Espenschied obtained such a curve. Probably by adding the absorption factor to the ordinate of one of the other curves. The important thing about this curve as compared with Dellinger's mathematical proof is that the field strength varies inversely as the distance to some power greater than unity.

Another excerpt from Mr. Espenschied's paper follows: "-------A question which naturally arises is that of how strong a field as measured in this way is required for satisfactory reception. It is too early in the art to answer this question very definitely, for it depends first upon the standard of reception which is assumed with respect to quality of reproduction and freedom from interference and second upon the level of interference. The intefference, both static and man-made varies widely with time and location. It is, therefore, obviously impossible to give anything more than a very general interpretation of the absolute merit of field values. Observations made by a number of engineers over a period of several years in the New York City area, having in mind a high standard of quality and freedom from interference, indicate the following:

1. Field strengths of the order of 50,000 or 100,000 microvolts per meter appear to be about as strong as one should ordinarily desire. Fields much stronger than this impose a handicap upon those wishing to receive some other station.

2. Fields between 50,000 and 10,000 μ v/m represent a very desirable operating level on which is ordinarily free from interference and which may be expected to give reliable year round reception except for occasional interference from nearby thunderstorms.

3. From 10,000 to 1,000 μ v/m the results may be said to run from fair to good and even poor at times.

4. Below 1,000 μ v/m reception becomes distinctly unreliable and is generally poor in summer.

5. Fields as low as 100 μ v/m appear to be practically out of the picture as far as reliable, high quality entertainment is concerned.

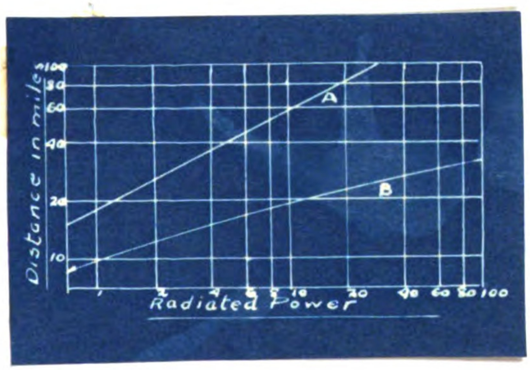


Fig. 6 - Showing the increase in Radiated Power Required to Increase the Range at Which a Field of 10,000 μ v/m is Delivered.

Curve A - Without absorption.

Curve B - With absorption.

"It is seen from the three preceeding figures that a 5 KW station may be expected to deliver a field of 10,000 micro-volts per meter some 10 to 20 miles away and a 1,000 micro-volt field not more than 50 miles.

From this it will be evident that the reliable high quality program range of a 5 KW station is measured in tens of miles rather than in hundreds.

"Rough though this interpretation of field strength is, it indicates clearly the need which exists for the employment of higher transmitting powers. The range goes up with increase of power disappointingly slowly. Even were no absorption present in the transmitting medium, the range in respect to over-coming interference would increase only as the square root of the increase in power. This is shown in curve A of Fig. 6.

"It shows that a station which actually radiates five KW of power would deliver a 10,000 μ v/m field at about 40 miles, a 20 KW station the same field at distance 80 miles. Actually with absorption present the distances are less. This is shown by curve B which gives the corresponding relations for the absorption observed for suburban and country terrain. To extend the 10,000 μ v/m field from some 15 out to 30 miles would necessitate an increase in the radiated power from about 5 to 100 KW."

It can be seen upon comparing the theory and proofs of the foregoing authors that Espenschied differs radically from Morecroft and Dellinger. The field which Espenschied measures is most assuredly the radiation field spoken of by both Morecroft and Dellinger, because the measurements are made at a considerable distance from the transmitter. It is not easy to understand just why the reflected wave spoken of by Espenschied should be so much stronger than the direct wave. Assuming spherical propagation of waves and neglecting absorption of the so-called direct wave it must necessarily follow that the intensity of the fields at the point of reflection and at a corresponding point along the earth's surface would be the same because thus far the two are of the same nature, namely that of the radiation field and any decrease in intensity will be due to the spreading out of the spherical wave. The area of a sphere increases with the square of the radius, therefore, the intensity of any charge on the surface should decrease as the square of the radius. From the point of reflection it is hard to say just what the nature of the reflected wave is, but at any rate in order to reach any spot on the earth's surface the reflected wave must travel much farther than the corresponding direct wave. It may be that the difference in the absorption factors of the lower and higher strata is large enough to account for the greater strength of the reflected wave.

Zenneck and Seelig handle this subject in a slightly different manner. They say that the electrostatic and electromagnetic components of the radiation field or space waves, as they call this field, each vary inversely as the first power of the distance. All authors on the subject seem to agree that the electric and magnetic components of the radiation field are in time phase though in space quadrature, and that the flow of energy is perpendicular to each of these component directions. If we assume that these components are equal and that each varies inversely as the first power of the distance then it followw that the radiation field varies as the inverse square of the distance. This theory agrees with Espenschied's experiments.

Directional Effects of Antennas

Inasmuch as the main object of this field strength survey was the determination of the directional effects of the radiating system of WKAR, it will be well to investigate the directional effects of various forms of antennae. The following extract was taken from pages 90 and 91 of "Radio Engineering Principles" by Lauer and Brown.

"The energy radiating qualities of an antenna depend on the shape of the fields of the antenna, that is, on the strength of these fields in the various directions around the antenna. It is known that the shape of the circuit directly and fundamentally affects the shape of the field. This will be studied here in somewhat greater detail in the case of antenna circuits.

"Consider a vertical wire antenna, shown in plan view by point A in Fig. 7 , and assume that a number of observers equipped with receiving circuits, all identical, are scattered about the antenna. Assume also that each one of the receiving circuits has some device which permits of measuring the current induced in it when the antenna circuit "A" is oscillating. Now if the observers move toward or away from the antenna "A" until they all obtain the same current reading in their receiving circuit, they will finally find themselves on a circle having "A" as its center. This shows that a vertical wire antenna radiates with equal strength in all directions.

"A similar test repeated with an inverted "L" antenna results in a radiation curve illustrated in Fig. 7-B, where "G" is the grounded end and "F" the free end of the antenna. A "T" shaped antenna, being esentially made up of two inverted "L" having a common vertical portion, has a curve similar to that shown in Fig. 7-C. A V-shaped antenna, consisting of a double "L" antenna with the horizontal portions in the form of a "V" with a common vertical portion, has a radiation curve as shown in Fig. 7-D.

"The directional properties of receiving antennae are the same as those of transmitting antennae. As a general rule it may be said that the maximum directional effect is in the plane containing the antenna aerial and lead-in wires, and in the direction of the lead-in end of the antenna. If, as in the case of a "V" antenna, this plane is not well defined, then the directional effect is in the plane containing the lead-in wire and the geometrical center of gravity of the aerial."

The plan view of the antenna and counterpoise of WKAR is shown in Fig. 8. According to the preceeding data on directional properties of antennae, the maximum directional effect would be expected to lie in a vertical plane that passes lengthwise through the antenna. The effect of the counterpoise design, antenna supporting structures, nearby buildings, etc. on the directional properties of the antenna were matters of conjecture and were left to be decided by the results of the survey.

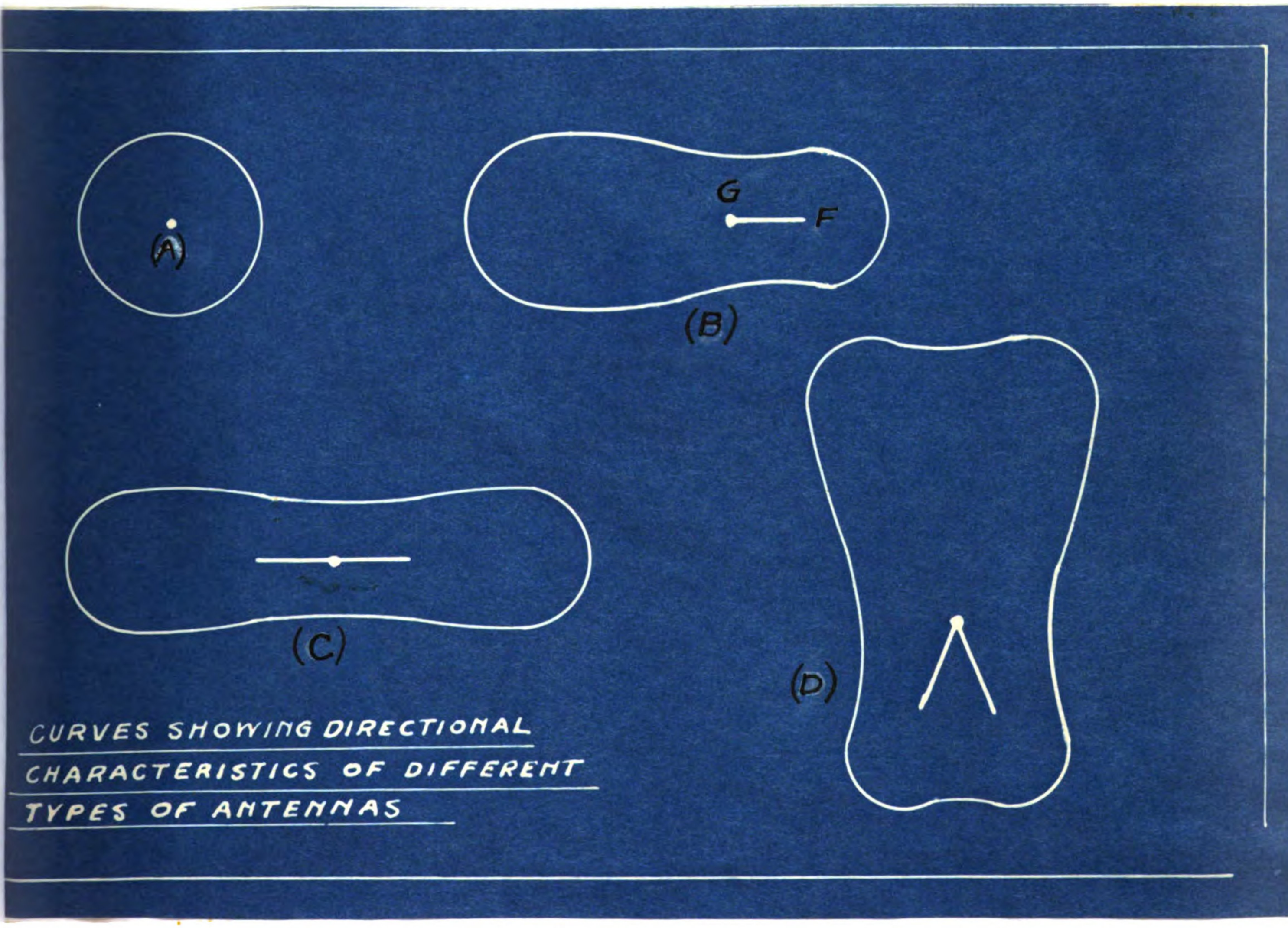


FIG. 7.

Description of Radio Station WKAR

The transmitting room of WKAR is located on the second floor of the Michigan State College power house. The transmitter has been constructed and put into operation by the technical staff of the station.

The transmitter has a rated output of 1000 watts. Four W.E. 212 D tubes rated at 250 watts each are used in parallel for the oscillators. Eight W.E. 212 D tubes are used in parallel for the modulators, while two W.E. 211 D tubes rated at 50 watts each are connected in a push pull stage for speech amplifiers. The Heising system of modulation is used.

In this particular test we are mainly interested in the oscillating circuit, so this will be the only one taken up in detail. The modulator and speech amplifier tubes were removed during the field test to prevent a waste of power.

The oscillating circuit is a closely coupled Meisner employing a tank circuit for the elimination of harmonics.

From the set a feeder tube goes through the roof to a small pent house where the antenna and counterpoise tuning condensers and inductances are located. The tank, plate, grid, feeder and antenna circuits are all metered.

Radiating System

The radiating system consists of a T-type antenna and a fan-shaped counterpoise. The antenna has four

Operating Room at 7KAR.

No. 9 phosphor bronze enameled wires held in place by 24 foot wooden spreaders. The whole is supported between a triangular steel tower and a steel water tower by a galvanized steel cable connected to the spreaders by larger pyrex strain insulators. The antenna hangs at an average height of 175 feet above ground. The counterpoise consists of 23 No. 9 enameled copper wires supported at the center by a copper ring connected to and insulated from a large soil pipe near the pent house. The wires are supported at the outer edge by No. 6 galvanized wire strung between the triangular tower to a building back of the generator room and from the building to the water tower. The counterpoise wires are of equal length.

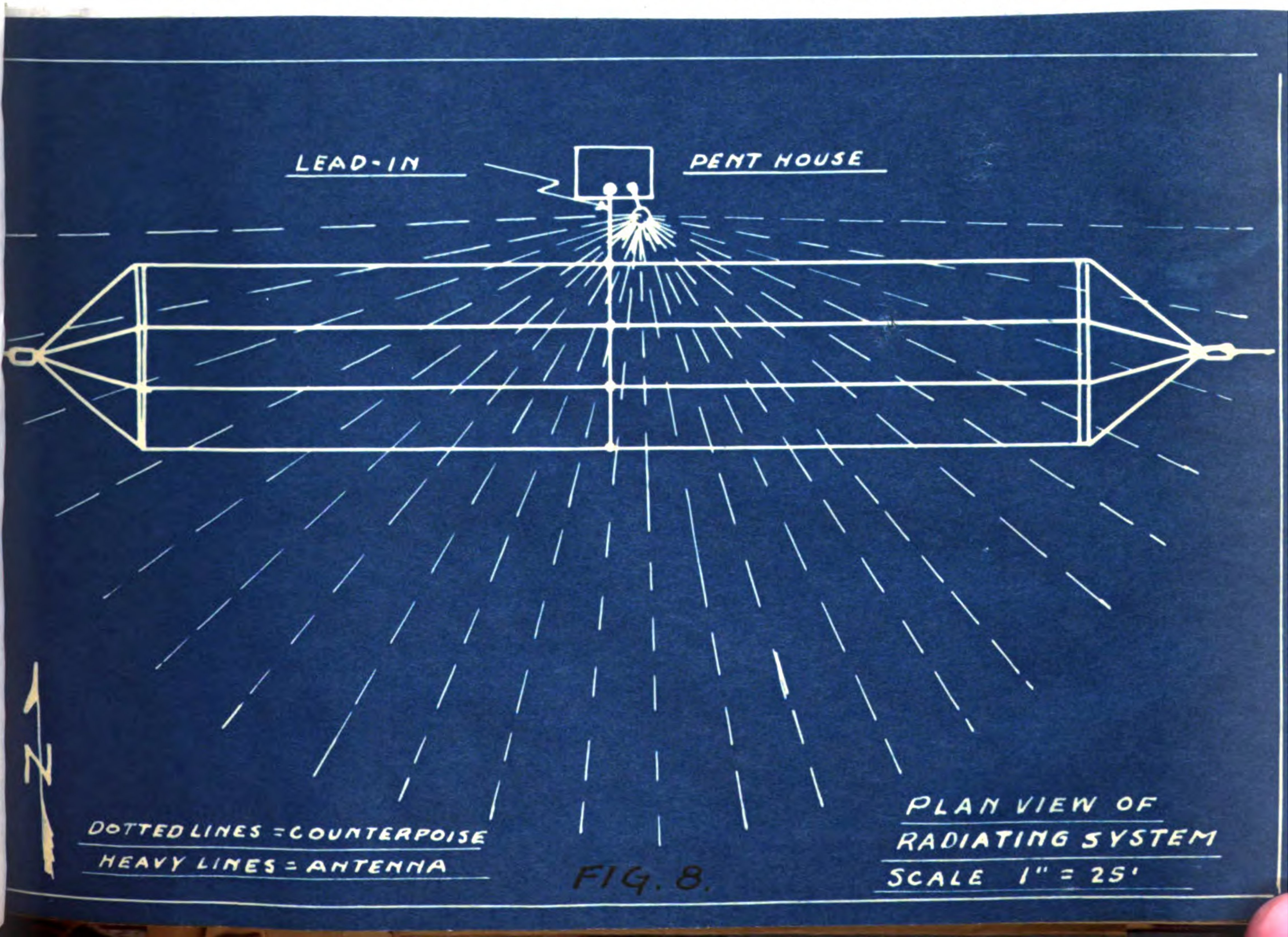
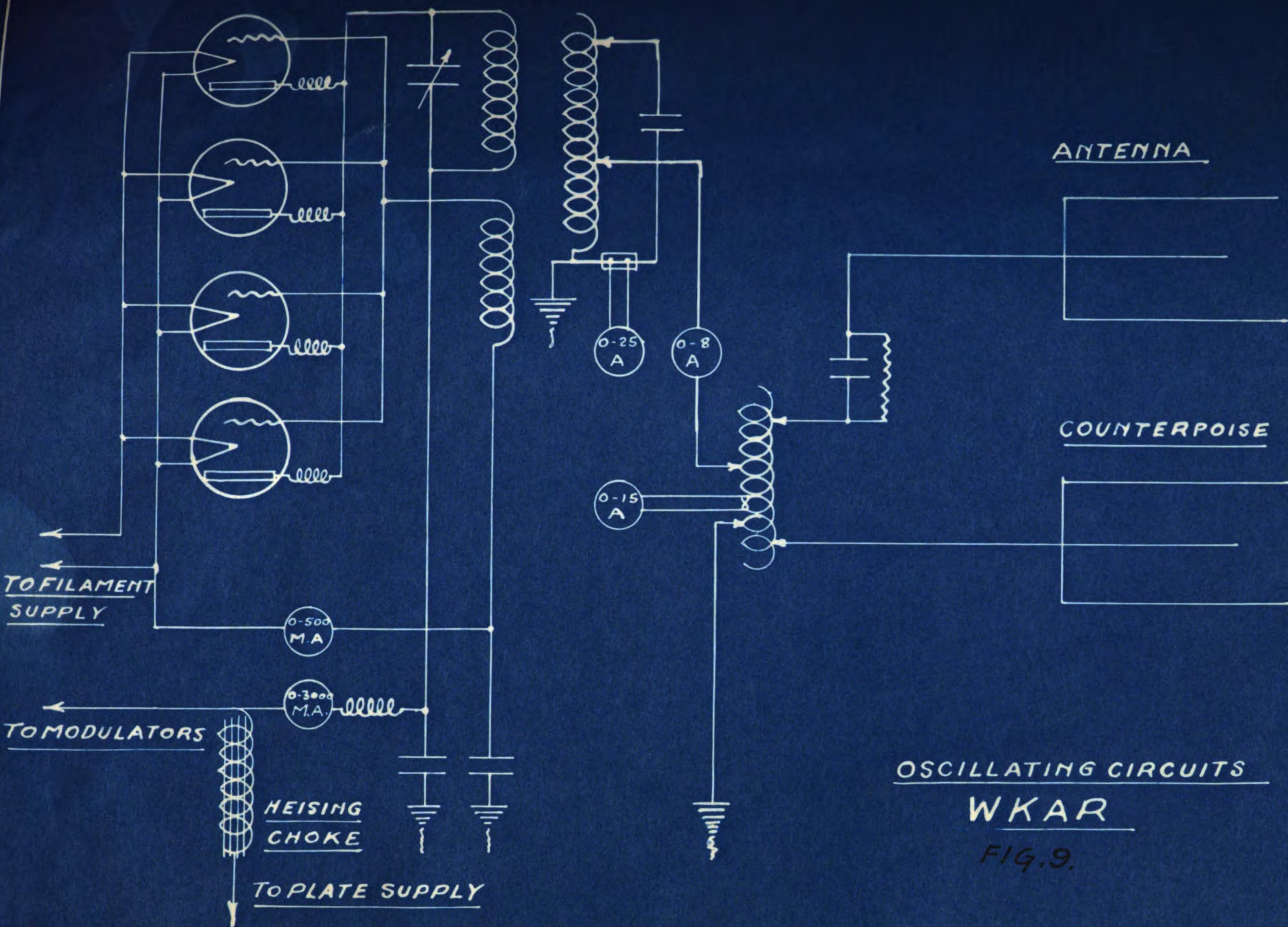


FIG. 8.



OSCILLATING CIRCUITS

WKAR

FIG. 9.

They are insulated from the galvanized supporting wire by pyrex insulators. The copper ring at the center is connected to the tuning inductance by a heavy copper strap. The counterpoise is grounded at a node to stabilize the system and facilitate tuning.

The radiation resistance of the system is approximated to be 14 ohms.

Station Surroundings

The station is surrounded by many buildings, as one can see from the maps used in the field test. Some of the buildings have a great deal of steel in their structure. Consequently they might be expected to absorb considerable energy.

An interesting example of this was noted in the building upon which the triangular tower rests. This particular instance happened before the present counterpoise was installed. It may be added here that the phenomenon has not been observed since. This building has steel window frames with steel rods attached to hold the windows open if desired. Ghostly voices and music were reported to be heard in one room of this building at certain times. Investigation showed that these times coincided with the broad casting periods of the station. Further investigation brought to light the fact that if one of the window rods happened to touch a radiator under the window during the broad casting period the rod would

Home of WKAR.

talk and sing. It was this discovery that prompted the construction of the present counterpoise.

Station Operation During the Test

In a test of this kind it is imperative that conditions at the station be kept constant in order that a constant field may be laid down. As one of the authors of this thesis is an operator at the station, it was decided that he should operate the station while the other took the field readings. At times the other station operators were good enough to take the station watch. This greatly facilitated the test for two could work much faster making field tests than one.

Although all meters were kept as constant as possible especial attention was paid to keeping the frequency and the antenna current constant. The reason that these two readings were considered the most important is because the radiated power of an antenna is computed as the square of the antenna current times the radiation resistance and because the radiation resistance varies with the square of the frequency.

Radiation Resistance

Radiation resistance is defined by the formula $P = I^2R$, where I is the antenna current and P is the radiated power. The total antenna resistance is affected by several factors

1. The resistance of the conductor.

2. The resistance of neighboring closed circuits.
3. Magnetic material close enough to the antenna to be magnetised.
4. Losses in the dielectric of any condenser in the circuit.
5. Corona losses from parts of the circuit.
6. Radiation of electromagnetic energy.

More simply stated antenna resistance is divided into two components.

A. Loss resistance (including losses caused by the first five above factors).

B. Radiation resistance.

The radiation loss is the useful part of antenna losses and makes it possible to deliver signals at a distance from the antenna. For this reason the radiation resistance is the more important component of the antenna resistance and should comprise the larger part. It is important then to be able to separate the radiation resistance from the total antenna resistance in order to arrive at the power transmitted.

There are many methods of measurement and many formulas for arriving at the radiation resistance. The formulas are all more or less approximate inasmuch as they are all greatly affected by the type of antenna and local conditions.

Dellinger gives the following formula for a flat top antenna at wave lengths considerably greater than the fundamental.

$$R_a = (39.7\left(\frac{h}{\lambda}\right)^2$$

Morecroft is responsible for the following formula for a simple antenna

$$R_a = 160\,\pi^2\,\frac{L^2}{\lambda^2}$$

It is not necessary to go further into the theory of radiation resistance for purposes of this thesis. The point we wish to show is that all formulas for radiation resistance show that the resistance varies as the inverse square of the wave length or as the square of the frequency.

Hence by keeping the frequency constant the radiation resistance is kept constant. As the formula for radiated power is

$$P = I^2R$$

if the current and radiation resistance are kept constant, the radiated power must also be constant. In other words, there is a constant field laid down in the space surrounding the antenna.

Unavoidable variations of antenna current of .05 amperes were noted during the test, the antenna current varying from 10.55 to 10.65, but for the most part the current remained steady at 10.6 amperes.

The frequency was maintained constant to within a few cycles of 1080 KC by means of comparison with a General Radio Company's Standard Piezo Crystal Oscillator, approved and calibrated by the Bureau of Standards.

Apparatus

The apparatus necessary for taking field strength measurements of a radio transmitting station consists of a completely equipped specially designed radio receiver and apparatus for calibrating the receiver to some standard. The calibrating apparatus necessary can be decided upon only after the final design of the receiver has been completed. The receiver for this work is a device for determining the relative intensity or strength of "field" set up about a radio transmitting antenna and consists of the following essential parts; (1) an antenna, (2) a tuning device, (3) some form of detector, (4) an indicating device.

An antenna is necessary for the interception of the transmitted signals and may be any of the existing types. A tuning device or scheme is necessary to bring the antenna and the associated circuits to resonance with the transmitter frequency. A detector that will respond to the received high frequency currents is necessary to actuate the indicating device. The indicator should be a device that will permit the comparison of intensity of signals received at different places and at different times. The detector might be of crystal or vacuum tube type. Because of its greater sensitivity and more nearly constant operating characteristics, the vacuum tube detector is the only kind that will be considered.

Factors Affecting Design of Receiver

The various factors affecting the design of such a receiver are; (1) the means available for transportation of the device, (2) the character and condition of the land where measurements are to be taken, (3) the relative power of the transmitter under consideration, (4) the distance from the transmitter of the points where measurements are to be taken. Obviously, it must be built sturdy enough to withstand the jolts and jars that it is likely to receive in being carried about, and also be duly protected if it is to be subjected to adverse weather conditions. The effect of the preceding factors upon the design of such a test set will be taken up in the order named.

The means available for transportation of the receiver and the character and condition of the land where measurements are to be taken are factors closely related to each other. It is plainly evident that the character of the land may seriously affect or restrict the use of some desirable and available means of transportation. If readings are to be taken over a large area in the streets of a city, an automobile is generally used. Again, if readings are to be taken about the countryside, an automobile can be used to get near the areas under question, but the receiver will have to be carried by hand in order to reach points in the fields. To take readings in city streets within a small area, a hand cart would be useful. If the land approximates the conditions prevailing on the campus at Michigan State College, the only practical method for moving the receiver about is to carry it by hand. The small area of the campus, the comparatively short distances between points where readings are to be taken, and the character of the land prohibits the use of an automobile. The campus is dotted with trees, buildings, gardens, fences, etc., so carrying the receiver by hand was the only logical means of transportation. If the outfit is to be carried exclusively in an automobile, a bulky receiver using the conventional large and heavy storage batteries would not be objectionable. Some thought must be given to limiting weight and size of the set if it is to be moved around on a hand cart. Finally, if the set is to be carried about by hand, its weight and bulk must be the smallest possible that is consistent with reliable operation and sturdy design.

The relative power of the transmitter under consideration and the distances from the transmitter of the points where readings are to be taken are factors which affect the necessary sensitivity of the receiver. If the transmitter is of low power or if measurements are to be taken at comparatively long distances from it, the receiver must, of course, be extremely sensitive and powerful in order that the weak signals received may be made to actuate an electric meter of some sort. Conversely, if the transmitter is of high power or the distances between measurement points and the transmitter are small, a less sensitive receiver may be used.

As stated before, the receiving device must be strong enough to withstand the jolts and jars that it is likely to receive in being carried about. In view of this fact, any vacuum tubes used should be preferably mounted in spring cushion sockets and mounted so as to be protected from any direct blow. Readings are not usually taken in windy or stormy weather, so the precaution of protecting the apparatus from the elements can usually be disregarded.

As the radio frequency field is being investigated it is satisfactory and preferable to transmit an unmodulated carrier wave. This eliminates one source of error in the readings due to possible changes in the percentage of modulation, and also reduces the interference caused by the transmitter to a minimum. This fact will influence the design of the receiver considerably. It would be undesirable to determine the relative strength of the received signal by means of an audibility meter on the receiver because the ear is a rather poor judge of variation in sound intensities. It is generally conceded that measurements taken by this method would be accurate no closer than twenty-five per cent. This then eliminates entirely the desirability of modulating the carrier wave and the use of an audio frequency amplifier to increase the sensitivity of the set. The usual method of noting the change in strength of the received signals is to notice the change in plate current through the last tube by means of a millimeter. The value of plate current through the tubes of a properly balanced audio frequency amplifier is practically unaffected by changes in the strength of the received signal, so an amplifier of this type would be useless also on a receiver that was equipped with a millimeter for the measurement of modulated signals.

It follows that the only remaining means for increasing the sensitivity of a simple receiver used for this work is the addition of radio frequency amplifiers. The kind of receiver generally used for field strength measurement work is the super-heterodyne or a multi-stage tuned radio frequency type. Both types were originally considered for use in the work covered by this thesis. It was suggested that a one tube receiver might be sufficient for our use in view of the power of the college station (1000 watts) and the small area that was to be covered. Preliminary tests proved the suggestion correct and the final design work was concentrated on a one tube device.

Details of Receiver Used

The type of antenna to be used was the first point to be decided upon. It was suggested that a small vertical antenna supported by a "fish pole" be used, but this idea was finally discarded in favor of the loop antenna. The loop antenna has the advantage of being less unwieldy and easier to move about among the many trees on various parts of the campus. Also, the loop possesses well known directional effects which would make it possible to determine the direction of wave propagation at the various points. It was proposed that if erratic loop positions were noted during the testing, some interesting points might be brought up.

The tuning of the circuit was simple, being done by a variable "air" condenser connected in parallel across the loop. Preliminary tests on an experimental set-up showed that this condenser (with a maximum capacity of 250 mf.) was difficult to adjust to obtain resonance in the loop circuit, so a "midget" vernier condenser (with a maximum capacity of about 25 mmf.) was connected in parallel with the main tuning condenser. Final tuning was accomplished with the small condenser.

As stated before, a vacuum tube was used for the detector. "Grid bias method of detection" was used as it permitted the variation in sensitivity of the detector by varying the amount of grid bias. This feature is valuable when taking readings extremely close to the transmitting station as will be shown later. The indicating device was in the form of a milli-ammeter in the plate circuit of the vacuum tube. The connections of the receiver as it was finally used are shown in Fig. 10

The list of parts used is as follows:

1 - loop or coil antenna

1 - 250 mmf. variable air condenser

1 - 3" dial for above condenser

1 - 25 mmf. variable air condenser equipped with knob

1 - UV-199 type vacuum tube

1 - UV-199 type vacuum tube socket

1 - S.P.S.T. filament switch

1 - 25 ohm rheostat equipped with knob

1 - 0 to 4 V. voltmeter

1 - 0 to 1 MA milliameter

2 - 4.5 V. "C" batteries

1 - 22.5 V. "B" battery (small size)

1 - small shelf bracket

1 - tripod and small plane table

3 - small "C" clamps

Miscellaneous - mounting board, screws, connecting wire, etc.

The loop antenna was made up of eleven turns of No. 14 bare stranded copper wire wound pancake style in

SCHEMATIC DIAGRAM OF FIELD TEST SET

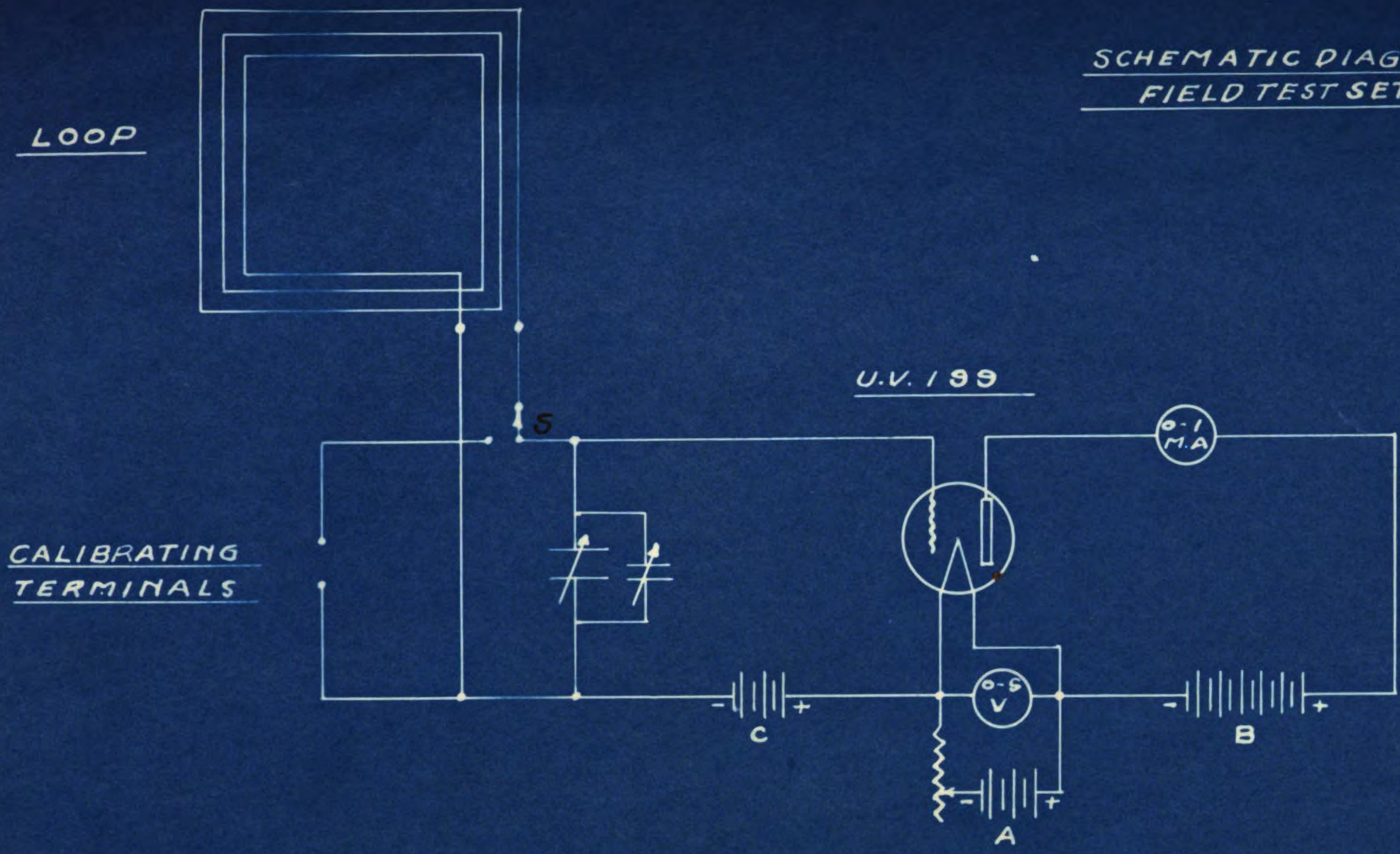
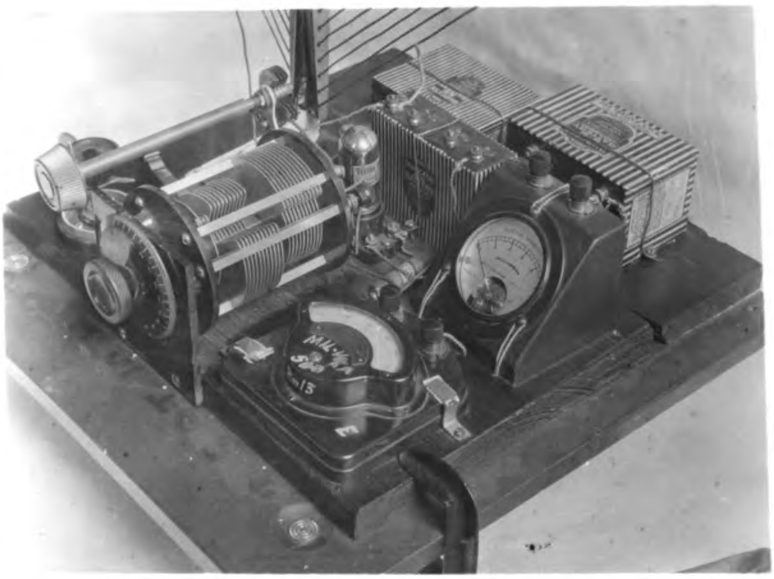


FIG. 10.

Field Set.



" Close-up" of Field Set.

a square form. The adjacent turns were 3/8" apart and the outside turn was 30" square. A dry cell type UV-199 vacuum tube was used so that a small "A" battery could be used in order to save space and keep the weight as low as possible. The filament of this tube draws .06 ampere at 3 volts and a regulation "C" battery was used for filament supply. Incidentally, this battery gave satisfactory service for all the testing done. The other "C" battery was used for the grid bias. A small size "B" battery was used in order to minimize the weight. The voltmeter was used to determine the filament voltage which was adjusted by means of the rheostat.

Theory of Receiver

The action of the receiver will now be taken up from a theoretical standpoint. We will first consider the directional properties of the loop antenna. Fig. 11 contains a schematic diagram of a loop. Consider an electromagnetic wave approaching the loop in its own plane in a direction shown by the arrow. This wave will cut conductor "A" and a short time later will cut conductor "B". The time interval will necessarily be small because the wave travels with the speed of light. Conductors "A" and "B" are the same length, therefore, the voltages induced in them will be equal in magnitude. Both voltages are induced in the same direction in space (both up or both down) and in opposite directions consid-

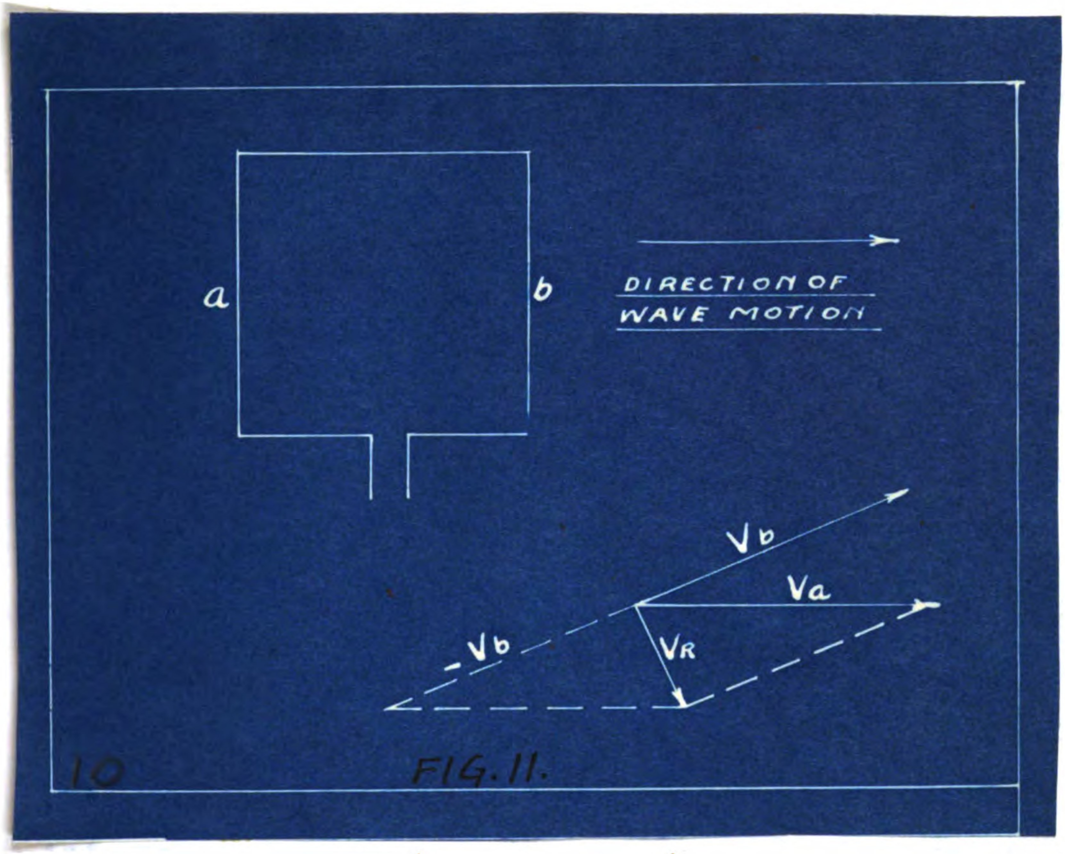


FIG. 11.

ing the circuit around the loop. A phase difference exists between the two voltages because of the time taken for the wave to travel the width of the loop. A resultant voltage "V_R" as shown in the vector diagram of Fig. 11 then exists across the terminals of the loop. The top and bottom portions of the loop are ineffective as far as induced voltages are concerned, these parts serving only to complete the circuit. If the loop is now turned so that its plane is perpendicular to the plane of wave propagation, the wave will strike the conductors "A" and "B" at the same time. There will be no phase difference between the two voltages now and consequently no resultant voltage at the terminals of the loop. Thus it is seen that these two positions are the ones at which maximum and minimum voltages will be obtained in the loop. By turning the loop until the maximum signal strength is obtained, the direction of the plane of wave propagation is obtained by noting the position of the loop.

A loop antenna, just as any coil of wire, possesses inductance, the magnitude of which depends upon its physical constants such as the number of turns, size of turns, etc. The loop is tuned to resonance with the incoming wave with a variable condenser connected across its terminals and so the desired value of its self-inductance depends upon the frequency or frequencies to be received and the capacitance of the variable condenser to be used. When the condenser is adjusted so that its negative reactance equals the positive reactance of the loop at the incoming frequency, the circuit is said to be in resonance. The impedance of the circuit, around through the condenser and loop, is thus reduced to its effective resistance. The current flowing through the loop and the potential across its terminals will now be a maximum and the transmitter is said to be properly "tuned in". The terminals of the loop are connected to the input circuit of the vacuum tube the action of which will now be considered.

Theory of Vacuum Tube

A vacuum tube for radio use consists of a filament, grid, and plate mounted in an evacuated glass bulb or tube. Connecting leads from the elements are brought out to convenient prongs on the outside of the tube for connections to the associated apparatus. The plate is in the form of a thin metal sheet bent around the filament. The grid is a coil of fine wire with wide spacing between adjacent turns and is interposed between the filament and plate.

When the filament is heated sufficiently by the passage of an electric current through it, electrons fly off into space from the filament surface. These electrons will be attracted to the plate if it is maintained at a positive potential with respect to the filament. Maintenance of the desired positive potential on the plate is the purpose of the "B" battery. The grid is used to control the magnitude of the stream of electrons between the filament and plate. If the grid is at a negative potential with respect to the filament, the electrons are kept from passing to the plate. As the grid is closer to the filament than the plate, a small negative potential on the grid will prevent electrons from reaching the plate, even though it is maintained at a relatively high positive potential. If the grid is positive, electrons will flow to the plate.

CHARACTERISTIC
VACUUM TUBE
CURVES

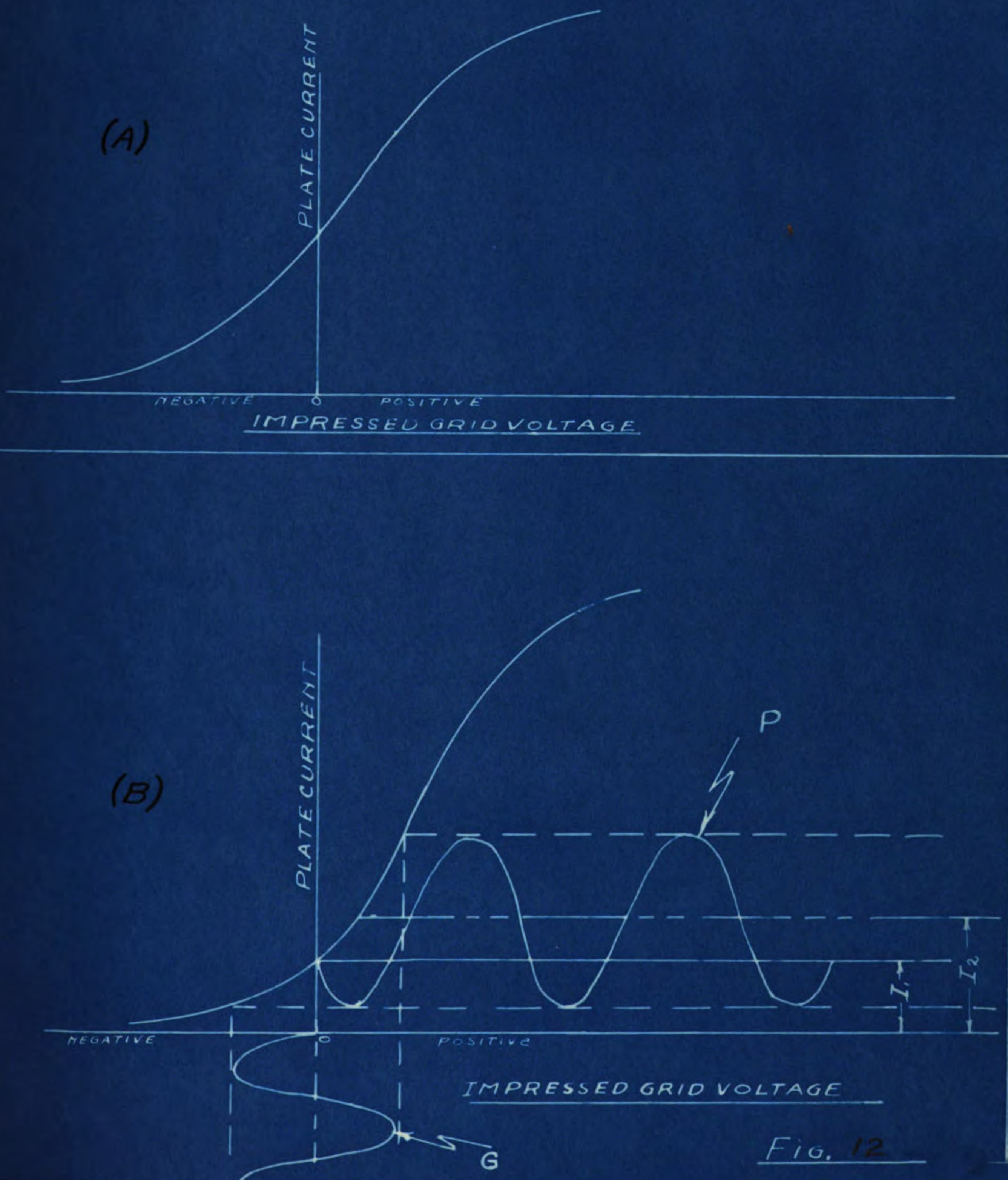


Fig. 12

Fig. 12-A is a characteristic vacuum tube curve. It can be seen that the plate current increases or decreases depending on whether the grid is made positive or negative. The operating characteristic of the tube as it was used in the field tests is shown in Fig. 12-B. The curve is shifted to the right from the position shown in Fig. 12-A, this being due to the presence of the grid bias or "C" battery shown in Fig. 9. From Fig. 12-B, it is seen that a given negative potential applied to the grid circuit will not cause the plate current to decrease as much as it will increase when a positive potential of the same magnitude is applied. Also, if an A.C. voltage wave is applied to the grid circuit as wave "G", the plate current will vary as shown by wave "P". The mean value of plate current in this case is "I_2" and is greater than its initial value "I_1". The increase noted above is, of course, dependent upon the value of impressed grid voltage and therefore a certain value of plate current obtained means that a definite voltage is being applied to the grid.

Calibration Sheet No. 3 shows the operating characteristics of the tube used in the field tests. The value of impressed grid voltage or voltage induced in the loop can be determined by noting the plate current or milliameter reading on the receiver and then referring to this curve. Grid voltages greater than 11.5 volts were not used because of the flattening out of upper portion of the curve. To receive signals of greater strength than this, the operating characteristic of the tube was changed as shown in Calibration Sheet No. 6. This change was produced by increasing the grid bias voltage from -4.5 to -12 volts. The set was unsuitable for the measurement of weak signals of course when the high grid bias was used.

Calibration of Field Set

From the preceeding discussion of vacuum tube characteristics it will be noted that the exact operating characteristics or curve of the tube must be determined before it will be known what grid voltage a certain value of plate current represents. The determination of the characteristic curve is commonly referred to as "calibration". This is done by impressing various known values of A.C. voltage on the grid circuit and noting the corresponding values of plate current. A sixty cycle A.C. voltage is a satisfactory and convenient source of grid voltage to use for calibration purposes. The calibrating apparatus used in this work is shown schematically in Fig. 13. It consists of a slid-wire potentiometer and

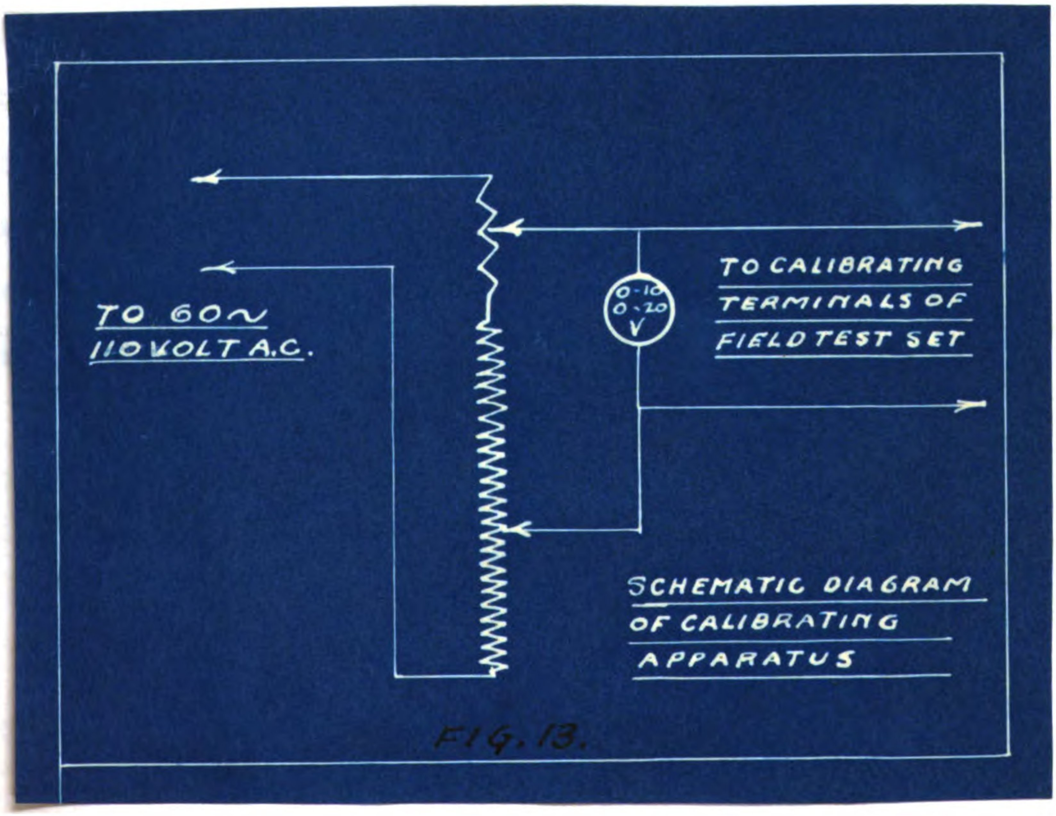


FIG. 13.

an A.C. voltmeter. The 110 volt A.C. lines were used for a source of voltage. The potentiometer was made up as shown of a high resistance rheostat connected in series with a low resistance rheostat. The low resistance rheostat was useful in obtaining fine variations in the voltage impressed on the grid. The sliding contacts of the rheostats were connected to the voltmeter and calibrating terminals of the receiver as shown in the above mentioned figure.

The switch "S" shown in Fig. 10 was used to disconnect the vacuum tube grid from the loop and connect it to the calibrating terminal. This was done when the tube was to be calibrated in order that the loop would not "short" the source of grid voltage. The calibrating terminals were connected to the calibration apparatus and the small "A" battery on the receiver replaced by three standard size dry cells in order to prolong the life of the "A" battery used for field work. The grid voltage was varied in small steps and the corresponding grid voltages and plate currents recorded. The desired curve could then be plotted from the observed data.

Procedure

Units Used For Standard

Practically all field strength measurements reports which have appeared in the I.R.E. Proceedings and other technical magazines, have been reduced to absolute units of microvolts per meter. This procedure is used to great advantage in measurements covering large areas where data on the effective reception is desired and where comparison with other stations is to be made. All field measurements of this nature have taken from two to three years to complete.

In this test it was not desired to find out the effective reception over the area, but rather to find the shape of the field existing in close proximity to the antenna. Having somewhat less than three months in which to complete the test and write the report, the authors did not deem it advisable to go to the trouble of reducing the readings to the standard microvolts per meter, but took the easier course of reducing the reading to absolute values of voltage induced in the loop. As these values would be relative the shape of the field could be easily found by plotting these readings on a map of the area covered and drawing curves through the points where equal voltage was induced in the loop.

Method of Locating Points

A map of the campus was obtained from the Buildings and Grounds Department of the College, and on this map were drawn concentric circles with the station location as a center. The radii of adjacent circles differed by 100 feet. The radius of the minimum circle was 400 feet while that of the maximum was 2200 feet. Readings inside the 400 foot circle were thought unnecessary and lack of time prevented taking readings farther out than the limits of the map given us. Radii were drawn 15° apart, the intersections of the radii and circles being taken as points at which to make readings. The circles were lettered and the radii were numbered. Each point can be referred to by its own definite symbol, for instance, the intersection of circle B and radii 5 is referred to as point B-5. Fig. 14 shows clearly this method of reference. A point was easily located on the terrain by noting the position of the point on the map and sighting on close-by buildings and roads shown on the map.

Method of Taking Measurements

At the beginning of each test the field was laid down five minutes before measurements were started, in order that stable conditions would be reached by the transmitter. At each point after setting up the plane table the filament voltage was adjusted to exactly 3 volts. The set was tuned to resonance with the variable condensers and the loop tuned to the point of maximum reading. The milliameter reading was then recorded and the direction in which the loop pointed was observed. Any decided variation from the direction of the antenna was noted. The filament switch was then opened and the apparatus carried to the next point.

On very windy days the field work was discontinued because the ordinary loop aerial gives unsatisfactory results under such conditions. The reason for this is that the vibration of the wires varies the distributed capacity of the loop and affects the tuning considerably.

Reducing the Field Data to Absolute Values

The field data for each day were reduced to absolute values of loop voltage by referring them to their respective calibration curves. After these values had been obtained from the curves they were plotted in their respective positions on the map as is shown in Fig. 15. Curves were then drawn through points of equal voltage. These curves were accepted as showing the general shape of the field laid down within the limits of the map.

Explanation of Data

When the test was started two vacuum tubes were used. Their characteristics were different as can be seen by comparing curves A and B of Calibration Sheets Nos. 1 and 2. The tube having the characteristic curve A was referred to as the high tube by reason of its having a higher amplification constant. The tube having the characteristic curve B was referred to as the low tube. The low tube was broken after a few days use so the rest of the readings were made with the high tube.

After several days of testing the tube calibration was used for two sets of field readings, the set preceeding and the set succeeding the calibration data. It was found by experience that the B and C voltage held constant over this period. In calibrating the tube two or three sets of readings were taken and the average of these used to plot the calibration curves. In the following data sheets the field data is recorded as follows:

Position	Plate Current I_p	Loop Voltage or grid potential E_g

In some cases, in the report E_g is referred to as loop voltage and in other cases as grid potential. The two are identical.

The calibration data is recorded as measured grid potential E_g, plate current I_p and average plate current Avg I_p.

Log sheets of the station data were also included in order to show that conditions at the transmitter were practically constant. The regular station log sheets were used. These sheets were originally intended to be used for one day's data, but to save space we used them for several days data.

Field Data Taken April 16, 1928

Used "high" tube.

Data referred to curve "A" of tube calibration sheet #1.

Position	E_p	E_g
D-24	.95	9.7
E-24	.95	9.7
F-24	.93	9.5
G-24	.92	9.4
H-24	.86	8.9
I-24	.815	8.55
J-24	.66	7.25
K-24	.6	6.55
L-24	.62	6.9
M-24	.6	6.55
D-1	.99	10.0
E-2	.9	9.25

Field Data Taken April 18, 1928

Used "low" tube.

Data referred to curve "B" of tube calibration sheet #1.

Position	I_p	E_g
D-23	.73	11.6
E-4	.72	11.3
E-23	.79	13.8
F-1	.81	14.5
F-2-1/2	.73	11.6
F-2	.76	12.6
F-4	.66	9.8
F-23	.78	13.3
G-1	.75	12.2
G-2	.74	11.9
G-3	.75	12.2
G-4	.64	9.4
G-23	.7	10.8
H-1	.7	10.8
H-2	.71	11
H-3	.66	9.8
H-4	.6	8.65
H-23	.64	9.4
I-1	.66	9.8
I-2	.68	10.25
I-3	.62	9.0
I-4	.6	8.65

Position	I_p	E_g
J-1	.7	10.8
J-2	.67	10
J-3	.61	8.8
J-4	.62	9.0
K-1	.61	8.6
K-2	.63	9.2
K-3	.56	7.9
L-1	.6	8.65
L-2	.64	9.4
M-2	.55	7.75
N-2	.53	7.4

Field Data Taken April 20, 1928

Used "high" tube.

Data referred to curve "A" of tube calibration sheet #2.

Position	I_p	E_g	Position	I_p	E_g
B-23	.87	9.25	I-23	.62	6.9
B-22	1.0	11.5	J-23	.59	6.65
D-22	1.0	11.5	K-23	.54	6.2
E-22	.9	9.75	L-23	.60	6.75
F-22	.845	9.05	M-23	.58	6.55
G-22	.8	8.55	N-23	.55	6.3
H-22	.75	8.05	O-23	.52	6.05
I-22	.69	7.5	P-23	.40	5.05
J-22	.64	7.1	Q-23	.48	5.7
K-22	.64	7.1	R-23	.44	5.4
L-22	.625	6.95	S-23	.46	5.55
M-22	.55	6.3	S-24	.47	5.6
N-22	.525	6.1	R-24	.47	5.6
O-22	.495	5.85	Q-24	.49	5.8
K-21	.59	6.65	P-24	.51	6.0
J-21	.6	6.75	O-24	.54	6.2
I-21	.64	7.1	N-24	.55	6.3
H-21	.69	7.5	M-24	.59	6.65
G-21	.65	7.2			
F-21	.87	9.35			
E-21	.75	8.0			

Field Data Taken April 23, 1928

Used "low" tube.

Data referred to curve "B" of tube calibration sheet #2.

Position	I_p	E_g
C-11	.83	15.5
D-11	.77	13.2
E-11	.69	10.6
A-11	.82	15.2
F-11	.63	9.3
E-12	.74	12.15
F-12	.71	11.2
G-12	.61	8.9
H-12	.6	8.75
E-12	.67	10.2
D-13	.73	11.8
D-10	.7	10.9
E-10	.64	9.5
F-10	.62	9.1
G-10	.62	9.1
H-10	.60	8.9
J-10	.55	8.0
J-11	.5	7.25

Field Data Taken April 25, 1928

Used "high" tube.

Data referred to curve "A" of tube calibration sheet #2.

Position	I_p	E_g
L-10	.48	5.7
M-10	.46	5.55
N-10	.425	5.25
O-10	.41	5.1
P-10	.4	5.05
Q-10	.39	4.95
R-10	.37	4.8
S-10	.34	4.55
S-9	.29	4.1
R-9	.34	4.55
Q-9	.33	4.45
P-9	.35	4.6
O-9	.3	4.2
N-9	.38	4.9
M-9	.42	5.2
L-9	.43	5.3
K-9	.43	5.3
J-9	.45	5.45
I-9	.46	5.55
H-9	.55	6.3
G-9	.62	6.9
F-9	.6	6.75

Position	I_p	E_g
E-9	.75	8.05
D-9	.86	9.2
C-9	.95	10.5
B-8	.74	7.95
C-8	.84	9.0
D-8	.74	7.95
E-8	.65	7.15
F-8	.58	6.55
G-8	.52	6.05
H-8	.47	5.6
I-8	.4	5.05
J-8	.41	5.1
K-8	.4	5.05
L-8	.4	5.05
M-8	.23	3.6
N-8	.37	4.8
O-8	.35	4.6
P-8	.33	4.45
Q-8	.33	4.45

Field Data Taken April 26, 1928

Used "low" tube.

Data referred to curve "B" of tube calibration sheet #2.

Position	I_p	E_g	Position	I_p	E_g
B-7	.77	13.2	F-5	.6	8.75
C-7	.65	9.7	G-5	5.2	7.55
D-7	.61	8.9	H-5	4.7	6.8
E-7	.6	8.75	I-5	5	7.25
F-7	.53	7.7	J-5	4.8	6.95
G-7	.47	6.8	D-3	7.7	13.2
H-7	.51	7.4	D-11	4.3	6.2
I-7	.53	7.7	Q-11	3.8	5.5
I-6-1/2	.49	7.1	R-11	3.8	5.5
L-7	.45	6.5	S-11	3.7	5.35
M-7	.45	6.5	S-12	3.75	5.4
K-6	.45	6.5	R-12	3.9	5.65
J-6	.5	7.25	Q-12	3.9	5.65
I-6	.44	6.35	P-12	4	5.8
H-6	.52	7.55	O-12	4.2	6.05
G-6	.44	6.35	N-12	4.6	6.65
E-6	.7	10.9	M-12	4.7	6.8
D-6	.66	9.9	L-12	4.7	6.8
B-6	.81	14.8	K-12	4.75	6.9
B-5	.84	16	J-12	4.75	6.9
C-5	.72	11.5			
D-5	.73	11.8			

Field Data Taken April 30, 1928

Used "low" tube for first five readings and this data referred to curve "B" of tube calibration sheet #2 ("low" tube was broken at this time.) Used "high" tube for the remaining readings, data referred to tube calibration sheet #3.

Position	I_p	E_g	Position	I_p	E_g
G-11	.64	9.5	J-13	.43	5.4
H	.57	8.25	I-13	.51	6.1
I	.52	7.55	H-13	.57	6.6
J	.5	7.25	G-13	.6	6.9
K	.47	6.8	F-13	.63	7.1
L-11	.41	5.2			
M-11	.33	4.5			
N-11	.38	4.95			
O-11	.41	5.2			
S-13	.34	4.6			
R-13	.36	4.8			
Q-13	.39	5.05			
P-13	.4	5.15			
O-13	.4	5.15			
N-13	.44	5.5			
M-13	.47	5.7			
L-13	.5	6			
K-13	.49	5.9			

Field Data Taken May 2, 1928

Data referred to tube calibration sheet #3.

Position	I_p	E_g	Position	I_p	E_g
C-20	.97	10.85	N-19	.41	5.2
D-20	.85	9.2	O-19	.4	5.15
E-20	.8	8.7	P-19	.39	5.05
F-20	.75	8.2	Q-19	.375	4.95
G-20	.705	7.8	S-19	.36	4.8
H-20	.64	7.2	F-18	.675	7.5
J-20	.575	6.65	G-18	.6	6.85
K-20	.54	6.35	H-18	.6	6.85
L-20	.475	5.75	I-18	.52	6.15
M-20	.48	5.8	J-18	.51	6.05
N-20	.46	5.65	K-18	.47	5.75
O-20	.44	5.45	L-18	.46	5.65
P-20	.4	5.15	M-18	.4	5.15
Q-20	.39	5.05	N-18	.41	5.2
R-20	.38	4.95	O-18	.39	5.05
S-20	.37	4.9	P-18	.37	4.9
G-19	.53	6.25	Q-18	.36	4.8
I-19	.59	6.8	R-18	.35	4.7
J-19	.53	6.25	S-18	.34	4.6
K-19	.5	6.0			
L-19	.49	5.9			
M-19	.465	5.7			

Field Data Taken May 3, 1928

Varying power test - field set located on position near I-17

Referred to tube calibration sheet #4.

Antenna current	I_p	E_g	Antenna current squared
10.8	.58	6.4	127.5
10.6	.57	6.3	112.3
10.4	.55	6.15	108.1
10.3	.545	6.1	106
10.0	.535	6.0	100
9.5	.52	5.9	90.25
8.9	.50	5.75	79.1
8.4	.475	5.55	70.5
7.8	.455	5.25	60.9
7.2	.425	5.1	51.9
6.5	.40	4.9	42.3
6.0	.38	4.75	36
5.5	.355	4.55	30.25
5.0	.34	4.4	25
4.6	.32	4.25	21.2
4.0	.28	3.9	16
3.5	.25	3.65	12.26
10.6	.57	6.3	112.3

Field Data Taken May 3, 1928

Data referred to tube calibration sheet #4.

Position	I_p	E_g	Position	I_p	E_g
I-17	.57	6.3	L	.475	5.55
J-17	.52	5.9	M	.455	5.35
K-17	.47	5.5	N	.43	5.15
L-17	.46	5.4	O	.4	4.95
M-17	.39	4.85	P	.37	4.7
N-17	.40	4.95	Q	.35	4.5
O-17	.39	4.85	R	.4	4.95
P-17	.40	4.95	S	.35	4.5
Q-17	.36	4.6			
R-17	.35	4.5			
S-17	.345	4.45			
H-17	.48	5.55			
G-17	.64	6.9			
F-17	.68	7.2			
E-17	.77	7.9			
D-16	.85	8.55			
E-16	.75	7.75			
F-16	.7	7.35			
G-16	.65	6.95			
H-16	5.9	6.45			
I-16	5.6	6.2			
J-16	4.6	5.4			
K-16	4.6	5.4			

Field Data Taken May 4, 1928

Data referred to tube calibration sheet #4.

Position	I_p	E_g
M-21	.45	5.3
N-21	.46	5.4
O-21	.49	5.65
P-21	.43	5.15
Q-21	.41	5.0
R-21	.40	4.95
S-21	.37	4.7
E-14	.70	7.35
F-14	.69	7.25
G-14	.59	6.45

Field Data Taken May 5, 1928

Data referred to tube calibration sheet #3.

Position	I_p	E_g
D-15	.78	7.95
E-15	.75	7.7
F-15	.71	7.4
G-15	.65	6.9
H-15	.66	7.0
I-15	.53	6.0
J-15	.37	4.7
K-15	.42	5.1
L-15	.49	5.65
M-15	.36	4.65
N-15	.39	4.9
O-15	.41	5.05
P-15	.4	4.95
Q-15	.39	4.9
R-15	.37	4.7
S-15	.34	4.5

Field Data Taken May 7, 1928

Data referred to tube calibration sheet #5.

Position	I_p	E_g
L-1	.61	6.6
M-1	.59	6.45
N-1	.56	6.2
O-1	.52	5.9
P-1	.5	5.75
Q-1	.5	5.75
R-1	.48	5.6
S-1	.47	5.5
N-14	.41	5.05
O-14	.425	5.15
P-14	.42	5.1
Q-14	.4	4.95
R-14	.39	4.9
S-14	.38	4.8
L-14	.51	5.8
K-14	.525	5.95
J-14	.53	6.0
I-14	.55	6.15
H-14	.52	5.9

Field Data Taken May 11, 1928

Data referred to tube calibration sheet #6.

Pos.	I_p	E_g
D1	5.6	15.9
B3	8.9	22.9
B11	7.4	19.1
A11	6.75	17.8
A10	9.	23.2
C3	6.55	17.5
C2	7	18.3
D2	5.75	16.1
C1	7.7	19.8
B9	7	18.3
A1	8.3	21.2
B1	7.9	20.2
B2	8	20.5
C2	7	18.3
A4	8.1	20.75
B4	9.1	23.6
C4	6.6	17.55
D4	5	15
A5	6.75	17.75
A6	7.7	19.8
A7	7.55	19.4
A8	8.9	22.9
A9	8.7	22.3

Pos.	I_p	E_g
D10	7.6	19.5
C10	5.8	16.2
B12	9.7	27
C12	9	23.2
D12	8.4	21.5
A13	2	11.1
C13	5.1	15.1
C14	5.2	15.3
B14	6.5	17.4
A14	8.2	21
A15	7.75	19.9
B15	6.7	17.7

Field Data Taken May 26, 1928

Data referred to curve sheet #6.

Pos.	I_p	E_g
C-15	5.5	15.75
A-16	6.9	18.1
B-16	6.7	17.7
C-16	5.3	15.5
A-17	8.2	21
B-17	6.6	17.5
C-17	5.8	16.2
D-18	5.1	15.15
C-18	6	16.55
B-18	6.8	17.9
A-18	8	20.5
A-19	9.5	25.5
B-19	8.5	21.75
C-19	6	16.55
D-19	5.3	15.5
E-19	4.5	14.3
D-21	1.0	10
C-21	2.75	12
A-21	5.2	15.3
A-24	7.6	19.5
B-24	6	16.5

Field Data Taken May 29, 1928

A check on doubtful areas.

Data referred to tube calibration sheet #7.

Pos.	I_p	E_g
D-10	8.1	10.5
G-10	7.05	9.1
K-10	3.8	6.1
M-10	3.5	5.85
O-10	3	5.4
Q-10	2.7	5.1
S-10	2.45	4.9
E-1	0.5	
F-1	9.3	13.5
G-1	8.5	11.5
H-1	7.5	9.7
I-1	7.3	9.4
J-1	6.9	8.9
K-1	5.9	8.0
K-23	4.9	7.1
J-23	5.2	7.4
I-23	5.7	7.8
H-23	4.5	6.75
G-23	7	9.1
F-23	8.1	10.5
E-23	7.6	11.5
D-23	8.9	12.2

Tube Calibration Data Taken April 13, 1928

Plotted on tube calibration sheet #1 (curve "A" is for "high" tube; curve "B" is for "low" tube)

E_g	I_p High Tube	I_p Low Tube
0	.4	.7
1	.55	.9
2	1.0	1.4
2.5	1.3	1.75
3	1.8	2.15
3.5	2.3	2.5
4	2.8	2.8
4.5	3.4	3.3
5	4.0	3.7
5.5	4.6	4.0
6	5.2	4.3
6.5	5.8	4.7
7	6.4	5
7.5	6.9	5.3
8	7.45	5.6
8.5	8	5.95
9	8.5	6.25
9.5	8.9	6.6
10	9.2	6.7
10.5	9.35	6.85
11	9.6	7
11.5	10	7.15
12		7.3
12.5		7.5
13		7.7
13.5		7.8
14		7.9
14.5		8.1
15		8.2
15.5		8.3
16		8.4
16.5		8.5
17		8.6
17.5		8.7
18		8.75

Tube Calibration Data Taken April 25, 1928

Plotted on tube calibration sheet #2 (curve "A" is for "high" tube; curve "B" is for "low" tube.

E_g	I_p Low Tube	I_p High Tube
0	.6	.3
1	.8	.45
2	1.4	.95
2.5	1.75	1.3
3	2.1	1.75
3.5	2.45	2.25
4	2.8	2.75
4.5	3.15	3.35
5	3.5	3.95
5.5	3.8	4.5
6	4.2	5.1
6.5	4.5	5.7
7	4.8	6.3
7.5	5.15	6.95
8	5.5	7.5
8.5	5.8	8
9	6.15	8.5
9.5	6.4	8.75
10	6.5	8.95
10.5	6.7	9.45
11	6.9	9.75
11.5	7.05	10

E_g	I_p Low Tube
12	7.3
12.5	7.5
13	7.7
13.5	7.8
14	7.95
14.5	8.1
15	8.2
15.5	8.3
16	8.45
16.5	8.55
17	8.65
17.5	8.7
18	8.75

Tube Calibration Data Taken May 2, 1928

Plotted on tube calibration sheet #3.

E_g	I_p
0	.25
1	.4
2	.98
2.5	1.3
3	1.8
3.5	2.25
4	2.73
4.5	3.35
5	3.83
5.5	4.5
6	5
6.5	5.65
7	6.15
7.5	6.78
8	7.28
8.5	7.78
9	8.25
9.5	8.8
10	9.23
10.5	9.4
11	9.63
11.5	10.0

Tube Calibration Data Taken May 4, 1928

Plotted on tube calibration sheet #4.

E_g	I_p
0	.25
1	.48
2	1.0
2.5	1.4
3	1.83
3.5	2.4
4	2.9
4.5	3.5
5	4.0
5.5	4.7
6	5.35
6.5	5.98
7	6.63
7.5	7.25
8	7.9
8.5	8.3
9	8.95
9.5	9.38
10	9.9

Tube Calibration Data Taken May 7, 1928

Plotted on tube calibration sheet #5.

E_g	I_p
0	.25
1	.45
2	1.0
2.5	1.[illegible]5
3	1.78
3.5	2.28
4	2.88
4.5	3.45
5	4.05
5.5	4.63
6	5.33
6.5	5.98
7	6.63
7.5	7.28
8	7.88
8.5	8.55
9	9.18
9.5	9.63

Tube Calibration Data Taken May 9, 1928

Plotted on tube calibration sheet #6.

E_g	I_p
10	1.0
11	1.85
12	2.75
13	3.5
14	4.3
15	5.0
16	5.65
17	6.2
18	6.75
19	7.25
20	7.75
21	8.25
22	8.65
23	8.9
24	9.15
25	9.4
26	9.55
27	9.7
28	9.8
29	9.9

Tube Calibration Data Taken May 29, 1928

Plotted on tube calibration sheet #7.

E_g	I_p	E_g	I_p
1	0	13	9.6
2	.25	13.5	10.0
2.5	.45		
3	.8		
3.5	1.1		
4	1.5		
4.5	2.0		
5	2.55		
5.5	3.1		
6	3.7		
6.5	4.2		
7	4.7		
7.5	5.45		
8	6.0		
8.5	6.45		
9	7.0		
9.5	7.4		
10	8.0		
10.5	8.0		
11	8.35		
11.5	8.65		
12	9.0		
12.5	9.35		

Form 243-G
Report of Daily Operation

Michigan State College, Service Radio

SEE COLUMN AT LEFT (Day) (Date) 1928

DATE	FILAMENTS On	FILAMENTS Off	FILAMENTS Time	CARRIER On	CARRIER Off	CARRIER Time	CURRENT Osc. Pl.	CURRENT Mod. Pl.	CURRENT Sp. Amp.	CURRENT Fil.	VOLTAGE Plate	VOLTAGE Fil.	VOLTAGE Ampl.	VOLTAGE Ex	GRID CURRENT Oscil.	GRID CURRENT Modl.	GRID CURRENT Sp. Am.	RADIO FREQUENCY Tank	RADIO FREQUENCY Feeder	RADIO FREQUENCY Antenna	Frequency		Oper. Sine
4/16	4:18	5:03		4:20	5:03	43	1525	500		77	1625	15.1	135	109	279			20.5	3.9	10.4	1080		Clar
4/18	3:00	5:00	2:00	3:02	5:00	1:58	1530			24	1600	14.6			280			20.5	3.9	10.6	"		Bob
4/20	3:00	5:01		3:00	5:01		1600				1650	15.2		110	285			20.4	3.9	10.6	"		Ball Rec
4/23	3:20	5:10		3:20	5:10		1530			24	1600	14.6		109	285			20.7	3.9	10.6	"		Bob
4/25	3:00	5:00	2:00	3:04	5:00	1:56	1550			24	1600	14.6			280			20.7	3.9	10.6	"		Bob
4/26	9:30	11:45		9:32	11:45		1550			25	1600	14.7		106	280			20.5	3.8	10.5	"		Bob
4/26	11:46	12:28	2:58	11:46	12:28	2:56	1550	480		78	1650	15.2		106	280			20.6	3.8	10.6	"		Bal
4/30	3:26	5:00		3:26	5:00		1575			24	1620	15.6		106	285			20.6	3.8	10.6	"		Bal
5/2	3:19	5:00		3:19	5:00		1575	460		77	1650	15.2		118	270			20.0	3.7	10.4	"		Re

RUNNING LOG

ITEM	Checked by. Time	REMARKS
Studio Lines		
Union Lines		
Lansing Lines		
Church Lines		
Gymnasium Lines		
Demonstration Lines		
Stadium		
Reo Lines 1		
Reo Lines 2		
Special Lines		
Lines		
Lines		
Lines		
Piezo Crystals		

ITEM	Checked by. Time	REMARKS
Studio Batteries 1		
Studio Batteries 2		
Studio Amplifier		
Studio Monitor		
Local Amplifier		
Station Amplifier		
Relay Battery		
Station Amp. Battery		
14 Volt Battery		
Exciter Battery		
Exciter		
Filament Generators 1		
Filament Generators 2		
High Voltage Gen. 1		
High Voltage Gen. 2		
Eliminator		
Receiver Batteries 1		
Receiver Batteries 2		
Public Address Batteries		
Transmitter Bias Batteries		

Form 243-G
Report of Daily Operation

Michigan State College, Service Radio

Day ________ Date MAY 3 192_

FILAMENTS On	FILAMENTS Off	FILAMENTS Time	CARRIER On	CARRIER Off	CARRIER Time	CURRENT Osc. Pl.	CURRENT Mod. Pl.	CURRENT Sp. Amp.	CURRENT Fil.	VOLTAGE Plate	VOLTAGE Fil.	VOLTAGE Ampl.	VOLTAGE Ex	GRID CURRENT Oscil.	GRID CURRENT Modl.	GRID CURRENT Sp. Am.	RADIO FREQUENCY Tank	RADIO FREQUENCY Feeder	RADIO FREQUENCY Antenna	Frequency		O S
10:28			10:30			1700			24	1670	15.2			290			21	4	10.8	1080		E
			10:32.5			1650			"	1640	"			280			20.4	3.9	10.6	"		
			10:35			1590			"	1590	"			270			20	3.8	10.4	"		
			10:37.5			1540			"	1570	"			268			19.8	3.8	10.3	"		
			10:38			1520			"	1510	"			255			19.2	3.5	10	"		
			10:42.5			1450			"	1450	"			245			18.3	3.4	9.5	"		
			10:45			1380			"	1360	"			230			17.5	3.2	8.9	"		
			10:47.5			1300			"	1290	"			218			16.2	3	8.4	"		
			10:50			1200			"	1210	"			205			15.3	2.8	7.8	"		
			10:52.5			1100			"	1110	"			185			14	2.6	7.2	"		
			10:55			1000			"	1030	"			170			13	2.4	6.5	"		

RUNNING LOG

DATA FOR VARYING POWER TEST

ITEM	Checked by. Time	REMARKS
Studio Lines		
Union Lines		
Lansing Lines		
Church Lines		
Gymnasium Lines		
Demonstration Lines		
Stadium		
Reo Lines 1		
Reo Lines 2		
Special Lines		
Lines		
Lines		
Lines		
Piezo Crystals		

ITEM	Checked by. Time	REMARKS
Studio Batteries 1		
Studio Batteries 2		
Studio Amplifier Studio Monitor		
Local Amplifier Station Amplifier		
Relay Battery Station Amp. Battery		
14 Volt Battery		
Exciter Battery		
Exciter		
Filament Generators 1		
Filament Generators 2		
High Voltage Gen. 1		
High Voltage Gen. 2		
Eliminator		
Receiver Batteries 1		
Receiver Batteries 2		
Public Address Batteries		
Transmitter Bias Batteries		

Form 243-G
Report of Daily Operation

Michigan State College, Service Radio

Day ______ Date MAY 3 92_

FILAMENTS On	FILAMENTS Off	FILAMENTS Time	CARRIER On	CARRIER Off	CARRIER Time	CURRENT Osc. Pl.	CURRENT Mod. Pl.	CURRENT Sp. Amp.	CURRENT Fil.	VOLTAGE Plate	VOLTAGE Fil.	VOLTAGE Ampl.	VOLTAGE Ex	GRID CURRENT Oscil.	GRID CURRENT Modl.	GRID CURRENT Sp. Am.	RADIO FREQUENCY Tank	RADIO FREQUENCY Feeder	RADIO FREQUENCY Antenna	Frequency	Ope Sin
			10:57.5			940			24	950				155			12	2.2	6	1080	Bo
			11:00			850			''	860				140			11	2	5.5	''	
			11:02.5			750			''	770				125			10	1.8	5	''	
			11:05			680			''	700				115			9.3	1.6	4.6	''	
			11:07.5			550			''	550				95			8	1.2	4	''	
			11:10			420			''	420				72			7	1	3.5	''	
	11:50		11:12.5	11:50		1625			''	1630				275			20.5	3.8	10.6	''	
11.52	12:24	2:45	11:52	12:29	2:54	1650	420		77	1680	15.2	130	106	280			20.6	3.8	10.6	''	

RUNNING LOG

DATA FOR VARYING POWER TEST

ITEM	Checked by. Time	REMARKS
Studio Lines		
Union Lines		
Lansing Lines		
Church Lines		
Gymnasium Lines		
Demonstration Lines		
Stadium		
Reo Lines 1		
Reo Lines 2		
Special Lines		
Lines		
Lines		
Lines		
Piezo Crystals		

ITEM	Checked by. Time	REMARKS
Studio Batteries 1		
Studio Batteries 2		
Studio Amplifier		
Studio Monitor		
Local Amplifier		
Station Amplifier		
Relay Battery		
Station Amp. Battery		
14 Volt Battery		
Exciter Battery		
Exciter		
Filament Generators 1		
Filament Generators 2		
High Voltage Gen. 1		
High Voltage Gen. 2		
Eliminator		
Receiver Batteries 1		
Receiver Batteries 2		
Public Address Batteries		
Transmitter Bias Batteries		

Form 243-G
Report of Daily Operation

Michigan State College, Service Radio

SEE COLUMN AT LEFT (Day) (Date) 192 8

DATE	FILAMENTS On	FILAMENTS Off	FILAMENTS Time	CARRIER On	CARRIER Off	CARRIER Time	CURRENT Osc. Pl.	CURRENT Mod. Pl.	CURRENT Sp. Amp.	CURRENT Fil.	VOLTAGE Plate	VOLTAGE Fil.	VOLTAGE Ampl.	VOLTAGE Ex	GRID CURRENT Oscil.	GRID CURRENT Modl.	GRID CURRENT Sp. Am.	RADIO FREQUENCY Tank	RADIO FREQUENCY Feeder	RADIO FREQUENCY Antenna	Frequency		Ope Sin
5/4	3:18			3:20			1675			24	1630	15		118	275			20.3	3.7	10.5	1080		Bo
5/4	3:45																	20		10.4	"		
5/4	3:50	5:06	1:48		5:06	1:46	1660				1660				280			20.6	3.8	10.6	"		
5/5	3:30	4:58	1:28	3:35	4:58	1:23	1580			24	1620	15.4		114	285			20.7	3.8	10.6	"		Bo
5/7	3:00	5:02	2:02	3:05	5:02	1:57	1600	475		78	1680	15.2		118	290			20.7	3.8	10.6	"		Bo
5/11	3:05	3:35		3:10	3:35		1560			24	1620	14		116	285			20.6	3.8	10.6	"		Bo
5/15	3:10	5:20	2:10	3:10	5:20	2:10	1560			24	1630	14.8		105	285			20.6	3.8	10.6	"		Bo

RUNNING LOG

ITEM		Checked by. Time	REMARKS
Studio Lines			
Union Lines			
Lansing Lines			
Church Lines			
Gymnasium Lines			
Demonstration Lines			
Stadium			
Reo Lines	1		
	2		
Special Lines			
Lines			
Lines			
Lines			
Piezo Crystals			

ITEM		Checked by. Time	REMARKS
Studio Batteries	1		
	2		
Studio Amplifier			
Studio Monitor			
Local Amplifier			
Station Amplifier			
Relay Battery			
Station Amp. Battery			
14 Volt Battery			
Exciter Battery			
Exciter			
Filament Generators	1		
	2		
High Voltage Gen.	1		
	2		
Eliminator			
Receiver Batteries	1		
	2		
Public Address Batteries			
Transmitter Bias Batteries			

Form 243-G
Report of Daily Operation

Michigan State College, Service Radio

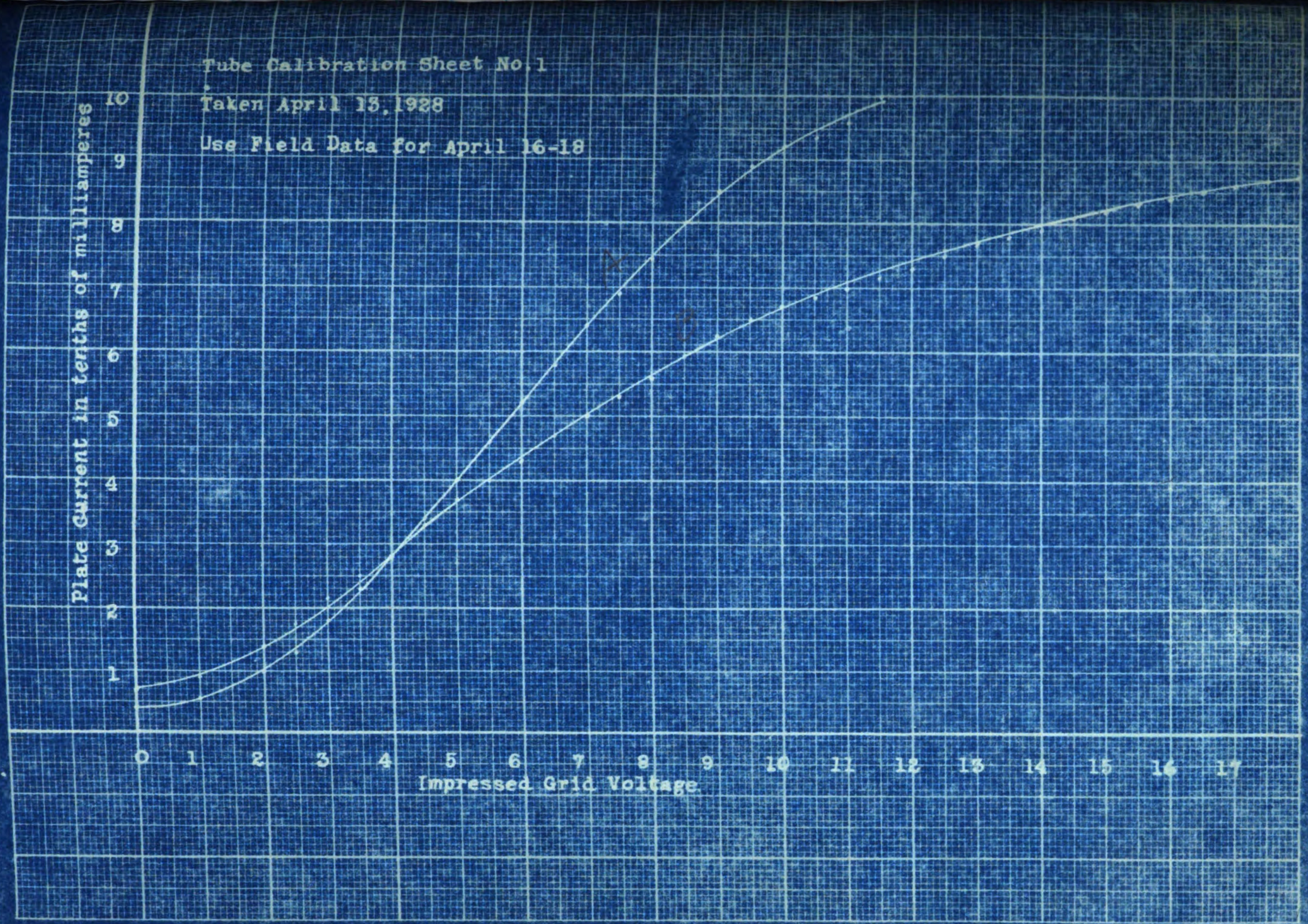
SEE COLUMN AT LEFT (Day) (Date) 192 8

DATE	FILAMENTS On	FILAMENTS Off	FILAMENTS Time	CARRIER On	CARRIER Off	CARRIER Time	CURRENT Osc. Pl.	CURRENT Mod. Pl.	CURRENT Sp. Amp.	CURRENT Fil.	VOLTAGE Plate	VOLTAGE Fil.	VOLTAGE Ampl.	VOLTAGE Ex	GRID CURRENT Oscil.	GRID CURRENT Modl.	GRID CURRENT Sp. Am.	RADIO FREQUENCY Tank	RADIO FREQUENCY Feeder	RADIO FREQUENCY Antenna	Frequency		Gp… Sir…
5/29	9:40			9:45			1525			24	1610	14.7		107	285			20.9	3.8	10.6	1080		Bo
5/29	11:45	12:20		12:00	12:20		1525	550		78	1650	15.4		107	290			20.8	3.9	10.5	1080		Ba
5/28	3:05	4:12		3:10	4:12		1550			24	1630	14.5		105	290			—	3.8	10.6	1080		Bo

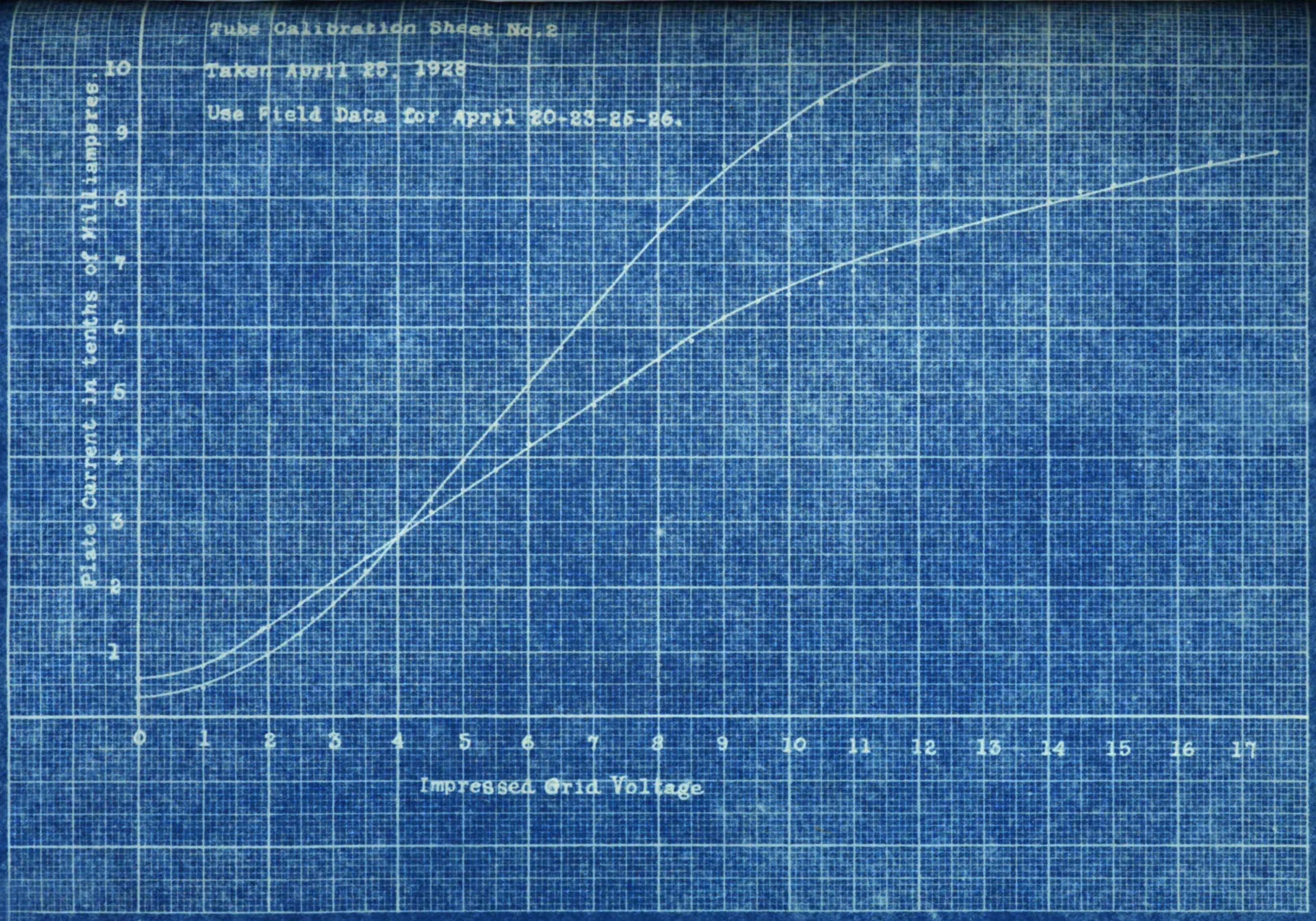
RUNNING LOG

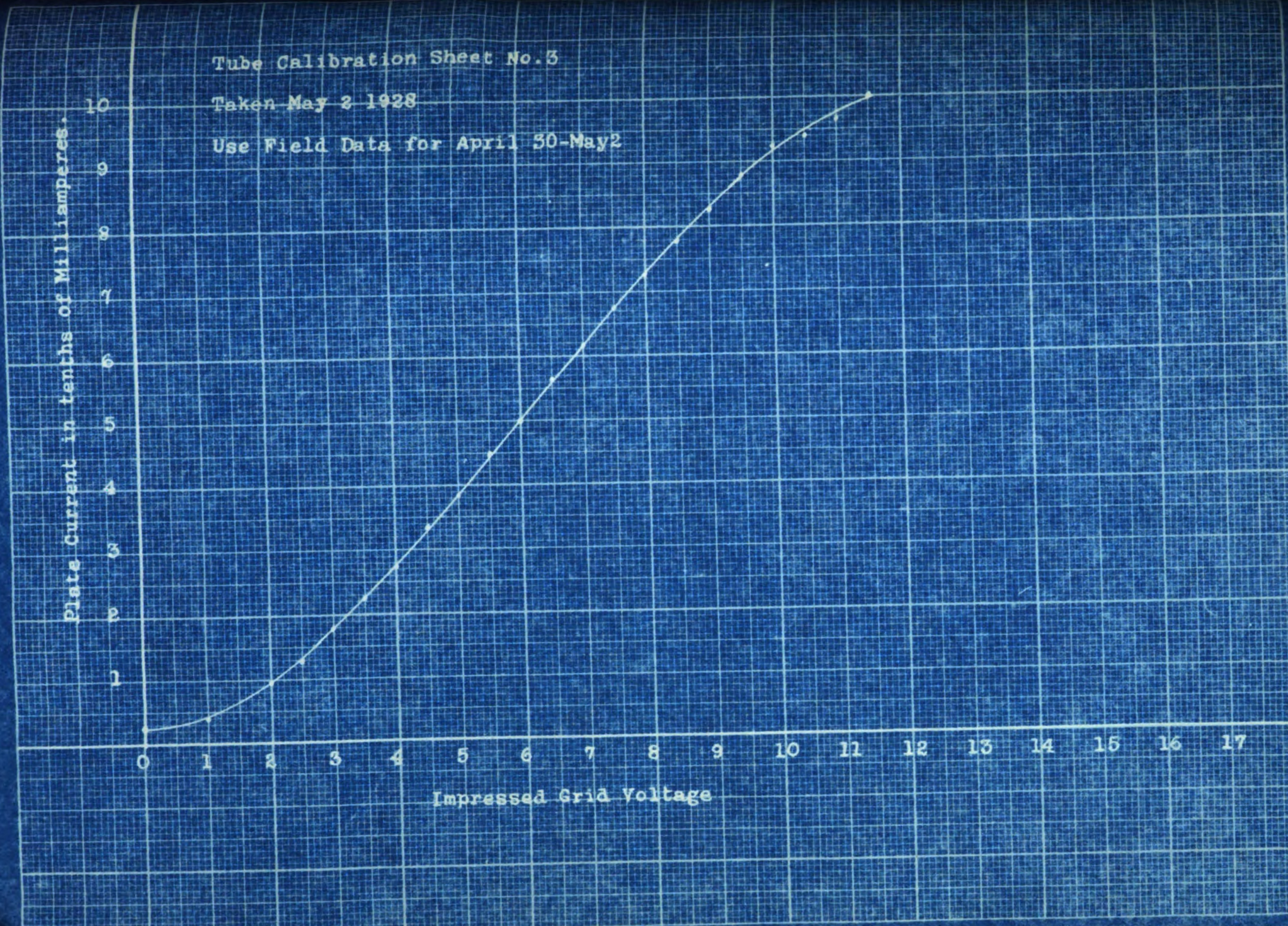
ITEM		Checked by. Time	REMARKS
Studio Lines			
Union Lines			
Lansing Lines			
Church Lines			
Gymnasium Lines			
Demonstration Lines			
Stadium			
Reo Lines	1		
	2		
Special Lines			
Lines			
Lines			
Lines			
Piezo Crystals			

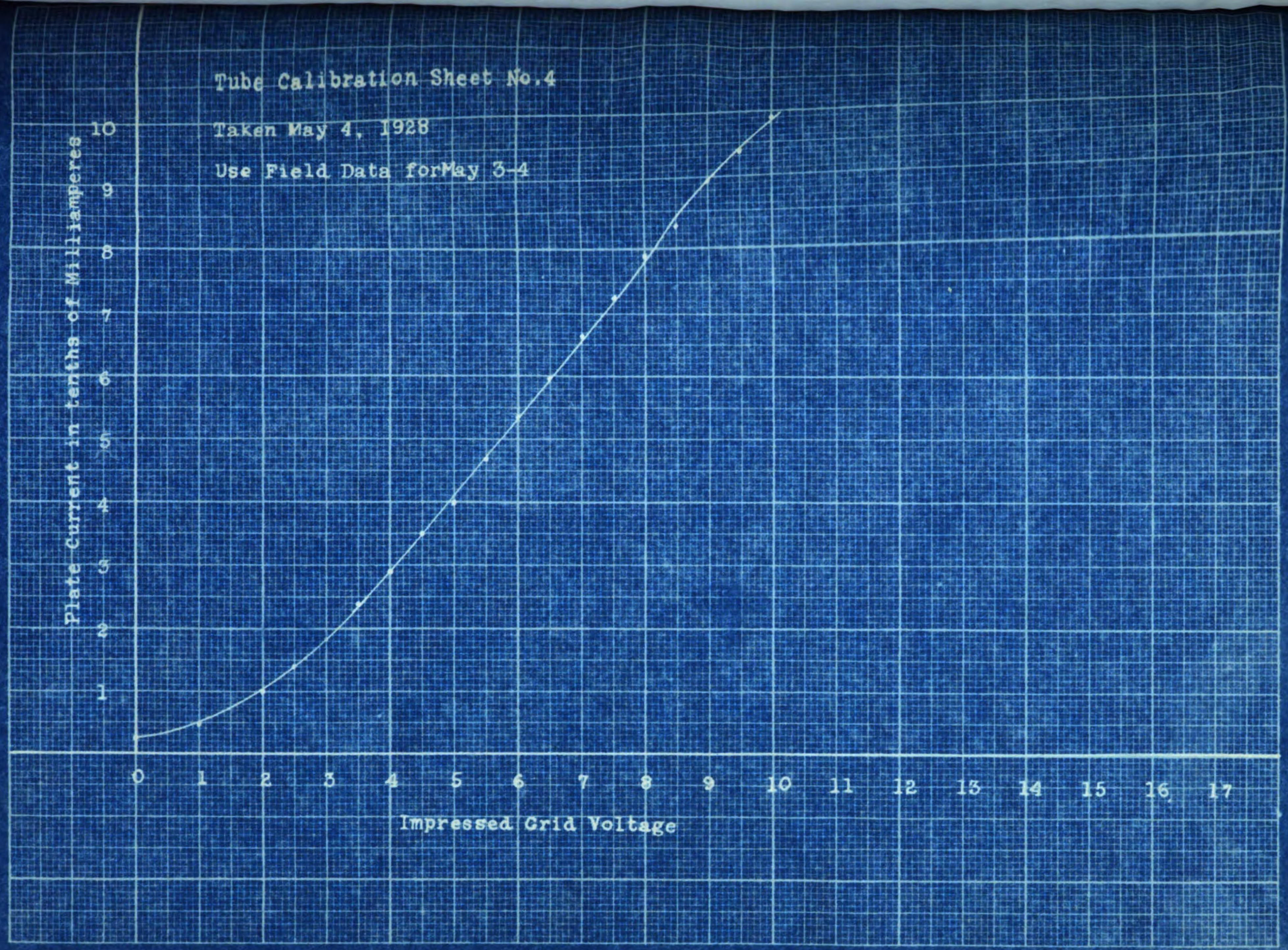
ITEM		Checked by. Time	REMARKS
Studio Batteries	1		
	2		
Studio Amplifier			
Studio Monitor			
Local Amplifier			
Station Amplifier			
Relay Battery			
Station Amp. Battery			
14 Volt Battery			
Exciter Battery			
Exciter			
Filament Generators	1		
	2		
High Voltage Gen.	1		
	2		
Eliminator			
Receiver Batteries	1		
	2		
Public Address Batteries			
Transmitter Bias Batteries			

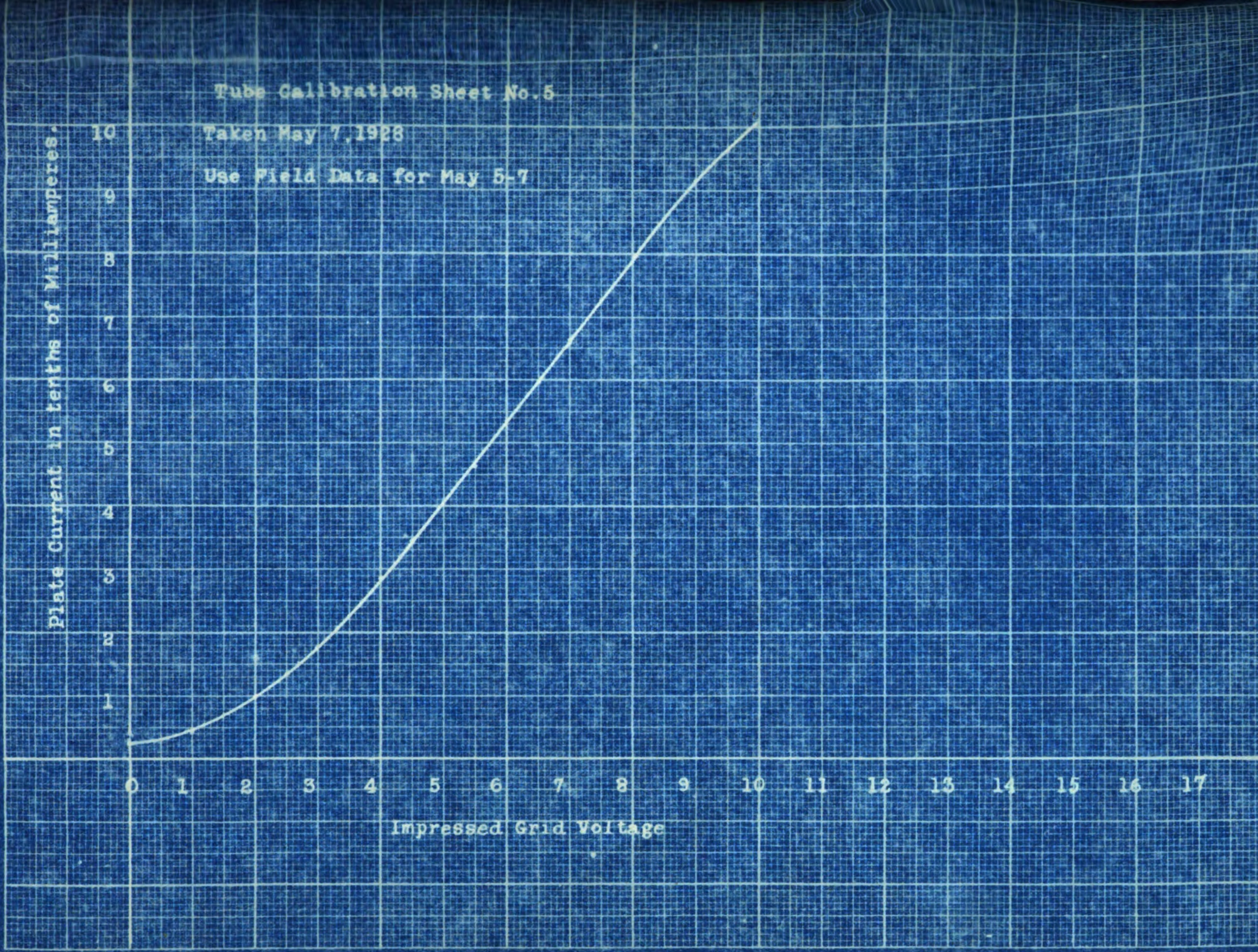


Tube Calibration Sheet No.1
Taken April 13,1928
Use Field Data for April 16-18
Plate Current in tenths of milliamperes
10
9
8
7
6
5
4
3
2
1
X
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Impressed Grid Voltage

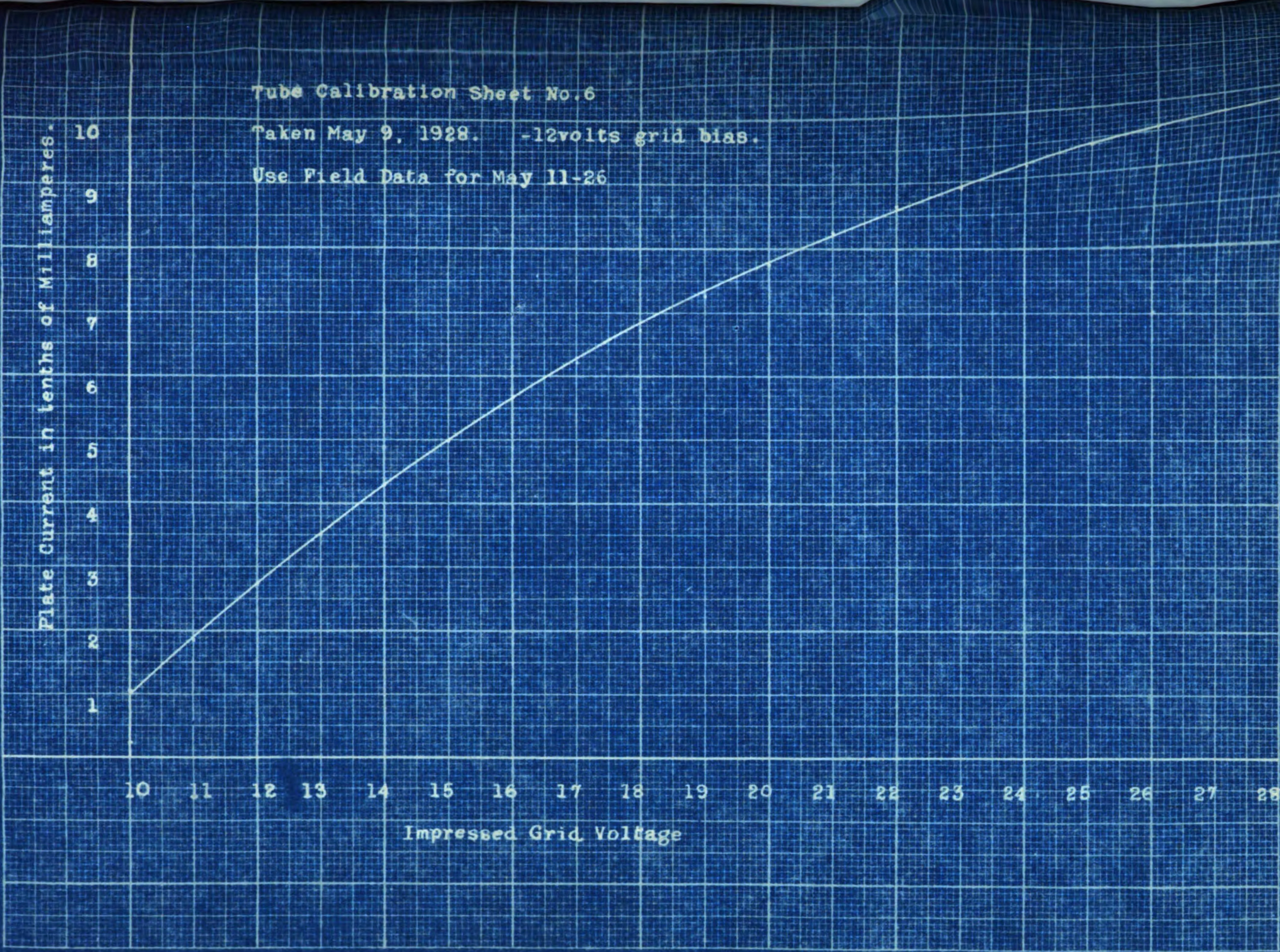

Tube Calibration Sheet No.2.
Taken April 25, 1928
Use Field Data for April 20-23-25-26.
Plate Current in tenths of Milliamperes.
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Impressed Grid Voltage


Tube Calibration Sheet No.3
Taken May 2 1928
Use Field Data for April 30-May2
Plate Current in tenths of Milliamperes.
1 2 3 4 5 6 7 8 9 10
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Impressed Grid Voltage

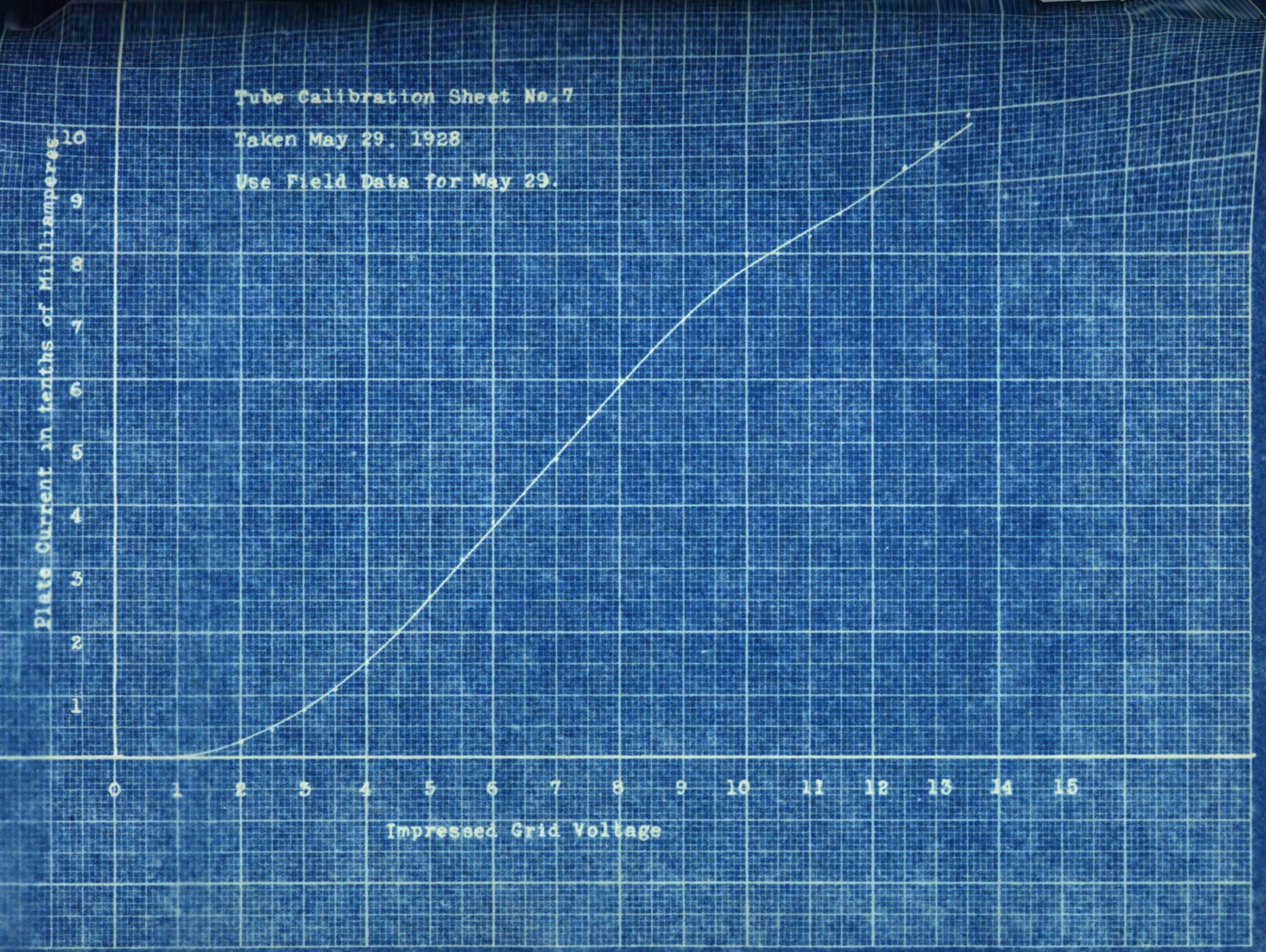

Tube Calibration Sheet No.4
Taken May 4, 1928
Use Field Data forMay 3-4
Plate Current in tenths of Milliamperes
1
2
3
4
5
6
7
8
9
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Impressed Grid Voltage



Tube Calibration Sheet No.5
Taken May 7,1928
Use Field Data for May 5-7
Plate Current in tenths of Milliamperes.
0
1
2
3
4
5
6
7
8
9
10
Impressed Grid Voltage
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17



Tube Calibration Sheet No.6
Taken May 9, 1928. -12volts grid bias.
Use Field Data for May 11-26
Plate Current in tenths of Milliamperes.
1
2
3
4
5
6
7
8
9
10
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
Impressed Grid Voltage


Tube Calibration Sheet No.7
Taken May 29, 1928
Use Field Data for May 29.
Plate Current in tenths of Milliamperes
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Impressed Grid Voltage

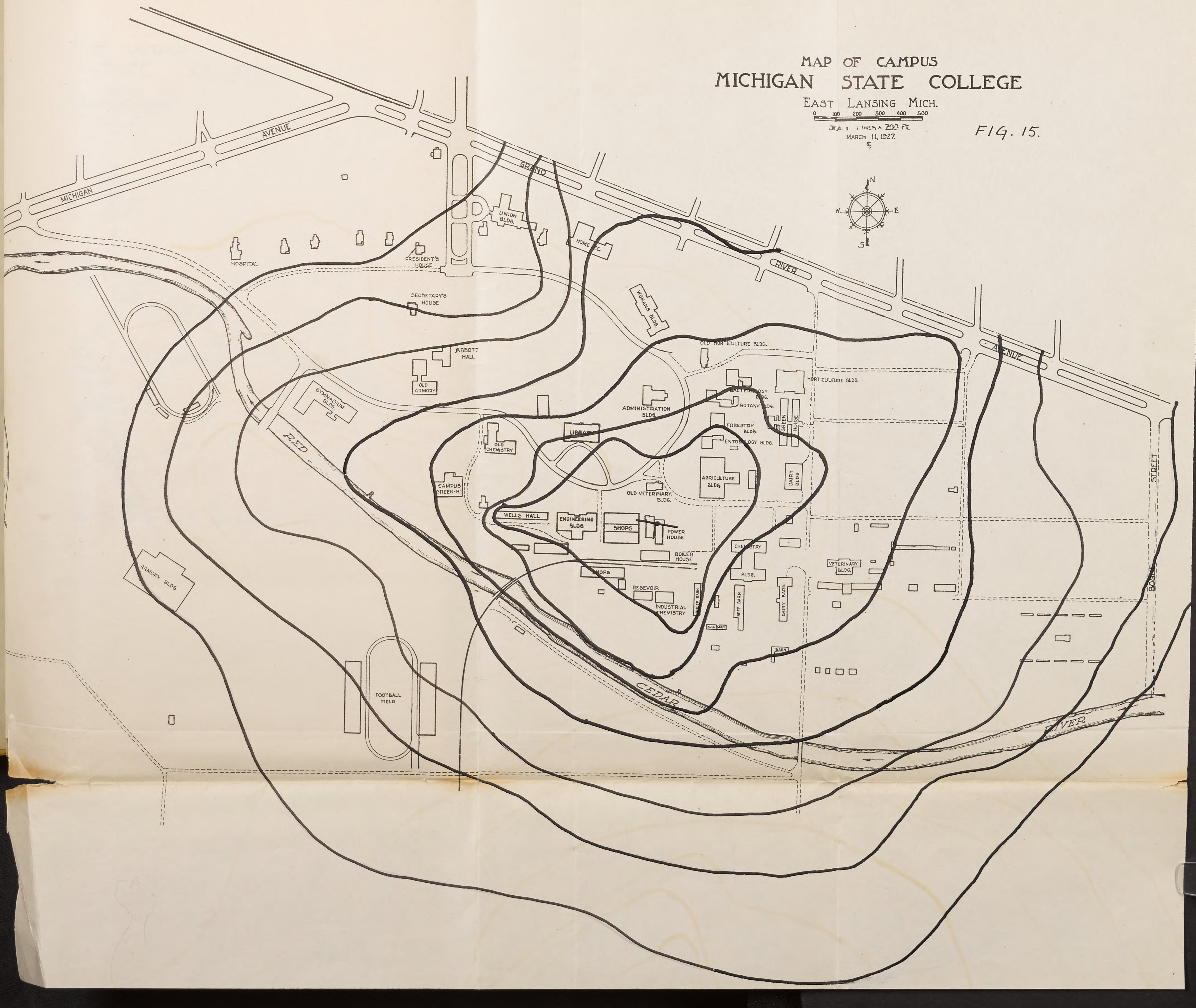

MAP OF CAMPUS
MICHIGAN STATE COLLEGE
EAST LANSING MICH.
0 100 200 300 400 500
MARCH 11, 1927.
N
W
E
S
MICHIGAN
AVENUE
GRAND
RIVER
AVENUE
HOSPITAL
PRESIDENT'S HOUSE
UNION BLDG.
HOME EC.
SECRETARY'S HOUSE
WOMANS BLDG.
ABBOTT HALL
OLD ARMORY
GYMNASIUM BLDG.
OLD HORTICULTURE BLDG.
HORTICULTURE BLDG.
BACTERIOLOGY BLDG.
BOTANY BLDG.
GREEN HOUSE
ADMINISTRATION BLDG.
LIBRARY
FORESTRY BLDG.
ENTOMOLOGY BLDG.
OLD CHEMISTRY
AGRICULTURE BLDG.
DAIRY BLDG.
CAMPUS GREEN-H.
OLD VETERINARY BLDG.
WELLS HALL
ENGINEERING BLDG.
SHOPS
POWER HOUSE
BOILER HOUSE
CHEMISTRY BLDG.
VETERINARY BLDG.
SHOPS
RESEVOIR
INDUSTRIAL CHEMISTRY
SHEEP BARN
BEEF BARN
DAIRY BARN
BULL BARN
BARN
RED
CEDAR
RIVER
ARMORY BLDG
FOOTBALL FIELD
STREET

FIG. 15.

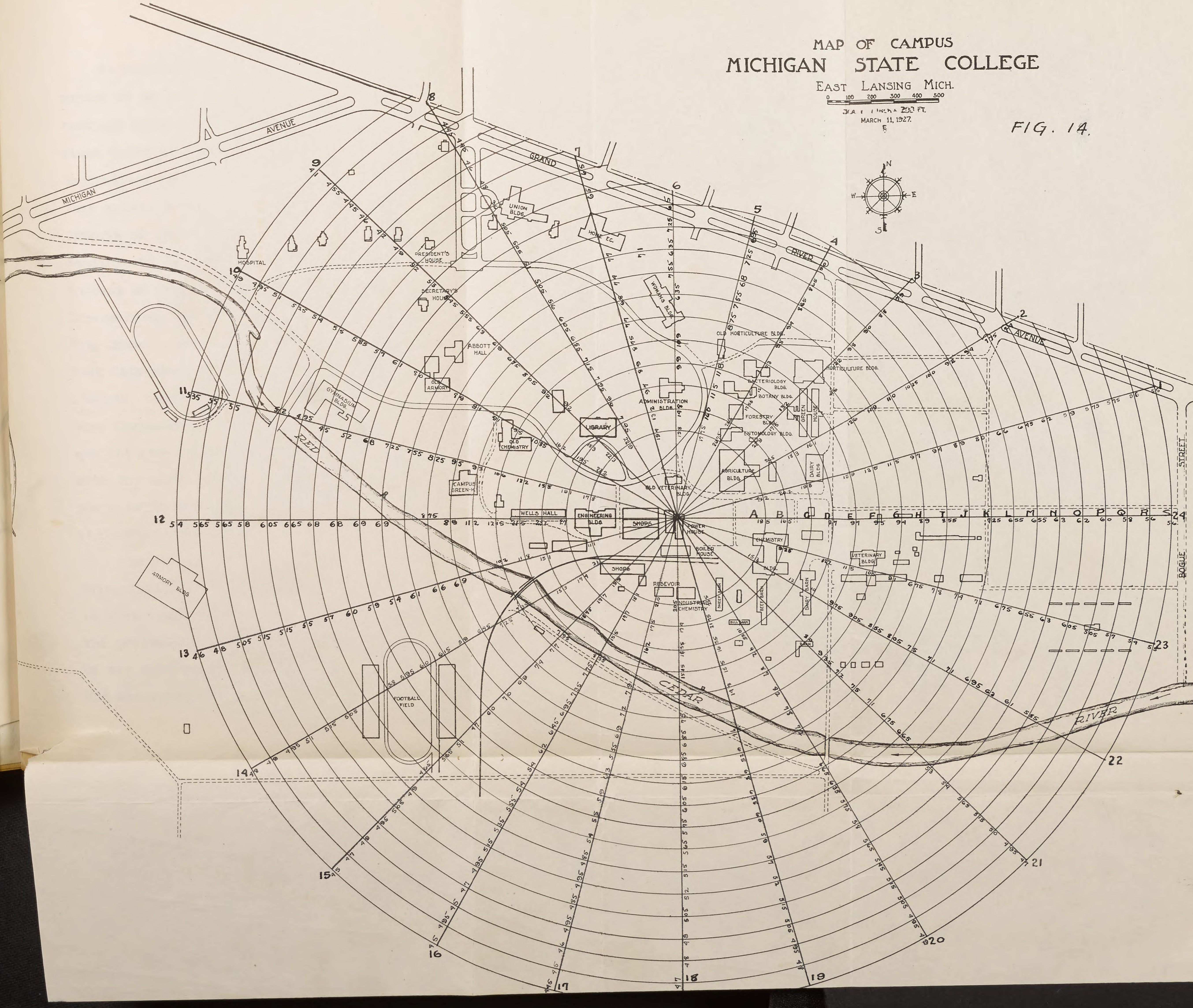

MAP OF CAMPUS
MICHIGAN STATE COLLEGE
EAST LANSING MICH.
0 100 200 300 400 500
MARCH 11, 1927.
N
S
E
W
MICHIGAN AVENUE
GRAND RIVER AVENUE
BOGUE STREET
RED CEDAR RIVER
HOSPITAL
PRESIDENT'S HOUSE
SECRETARY'S HOUSE
UNION BLDG.
HOME EC.
WOMAN'S BLDG.
ABBOTT HALL
OLD ARMORY
GYMNASIUM BLDG.
OLD CHEMISTRY
LIBRARY
ADMINISTRATION BLDG.
OLD HORTICULTURE BLDG.
HORTICULTURE BLDG.
BACTERIOLOGY BLDG.
BOTANY BLDG.
FORESTRY BLDG.
ENTOMOLOGY BLDG.
GREEN HOUSE
AGRICULTURE BLDG.
DAIRY BLDG.
OLD VETERINARY BLDG.
CAMPUS GREEN-H.
WELLS HALL
ENGINEERING BLDG.
SHOPS
POWER HOUSE
BOILER HOUSE
CHEMISTRY
VETERINARY BLDG.
RESEVOIR
INDUSTRIAL CHEMISTRY
ARMORY BLDG.
FOOTBALL FIELD
A B C D E F G H I J K L M N O P Q R S

FIG. 14.

CONCLUSIONS

Directional Effects

In considering the results obtained in this field survey it is well to keep in mind that some of the field readings were probably in error in spite of the precautions taken to keep the operating conditions of the transmitter and receiver constant. These errors, if they exist, are mainly due to reflection and absorption effects of trees, wire fences, etc., and cause certain readings to be representative of purely local conditions instead of general conditions of the area in question. Espenschied, in his report on "Broadcast Coverage of City Areas", states that field survey readings in New York City were taken at one mile intervals on concentric circles, whose radii differed by five miles. The relative distances between points where readings were taken and the area covered in this survey compare favorably with the above mentioned test and the authors believe the results obtained are as accurate as the results of similar commercial tests.

The curves shown in Fig. 15 contain many small irregularities, but the general projection to the west is what would be expected from the T-shaped antenna. The projection that would be expected from the east end of the antenna is apparently destroyed due to shielding and absorption effects of the water tower and chemistry building. In fact, a slight shadow effect persists between the station and chemistry building caused probably by the water tower which is used as a support for this end of the antenna. The steel tower supporting the other end of the antenna exhibits a slight shadow effect near the antenna also.

Assuming that the shape of the counterpoise has the same effect on directional characteristics of a radiating system as the shape of the antenna, Fig. 8 would indicate that a directional effect would be obtained in a north and slightly easterly direction. The curves show this to be true except for slight shadows caused by the agricultural and old veterinary buildings.

A strong shadow or shielding effect is noticed on the far side of the library building. This is the only shadow effect that persisted for any great distance. Although the outer curve seems to show that this shadow is starting to heal, it is a noteworthy fact that this shadow is in the general direction of Grand Rapids and reception in that direction is reported to be very poor.

Reception of WKAR in a southwest direction is also very poor, but the results and curves obtained in this survey indicate that the poor results are due to conditions outside the immediate vicinity of the transmitter.

It is noted that the strength of signals on the far side of the river are much less than the signal strengths obtained on the near side. That such a large drop should be obtained in such a short distance is peculiar and inconsistent with the results obtained on other parts of the campus. A satisfactory explanation of this phenomenon has not been obtained, inasmuch as the absorption over water is much less than that over land and trees.

Varying Power Test

In the discussion on "Theory of Wave Propagation" it was shown that various authors differed as to the manner in which the radiation field varied with the distance from the antenna.

A test was made to discover, if possible, whether the radiation field varies inversely as the first power of the distance or as the inverse square of the distance. In Fig. 6 it will be noticed that Espenschied varied the radiated power in order to keep a constant field at points of varying distance from the antenna. In the varying power test made in this survey the distance was kept constant and the variation in radiated and received power noted.

According to Dellinger the induction field becomes negligible at a distance of one wave length. The wave length of WKAR is 277.6 meters or 907 feet. For this reason the receiver was set up near points I-17 somewhat further away than one wave length. The watches of the

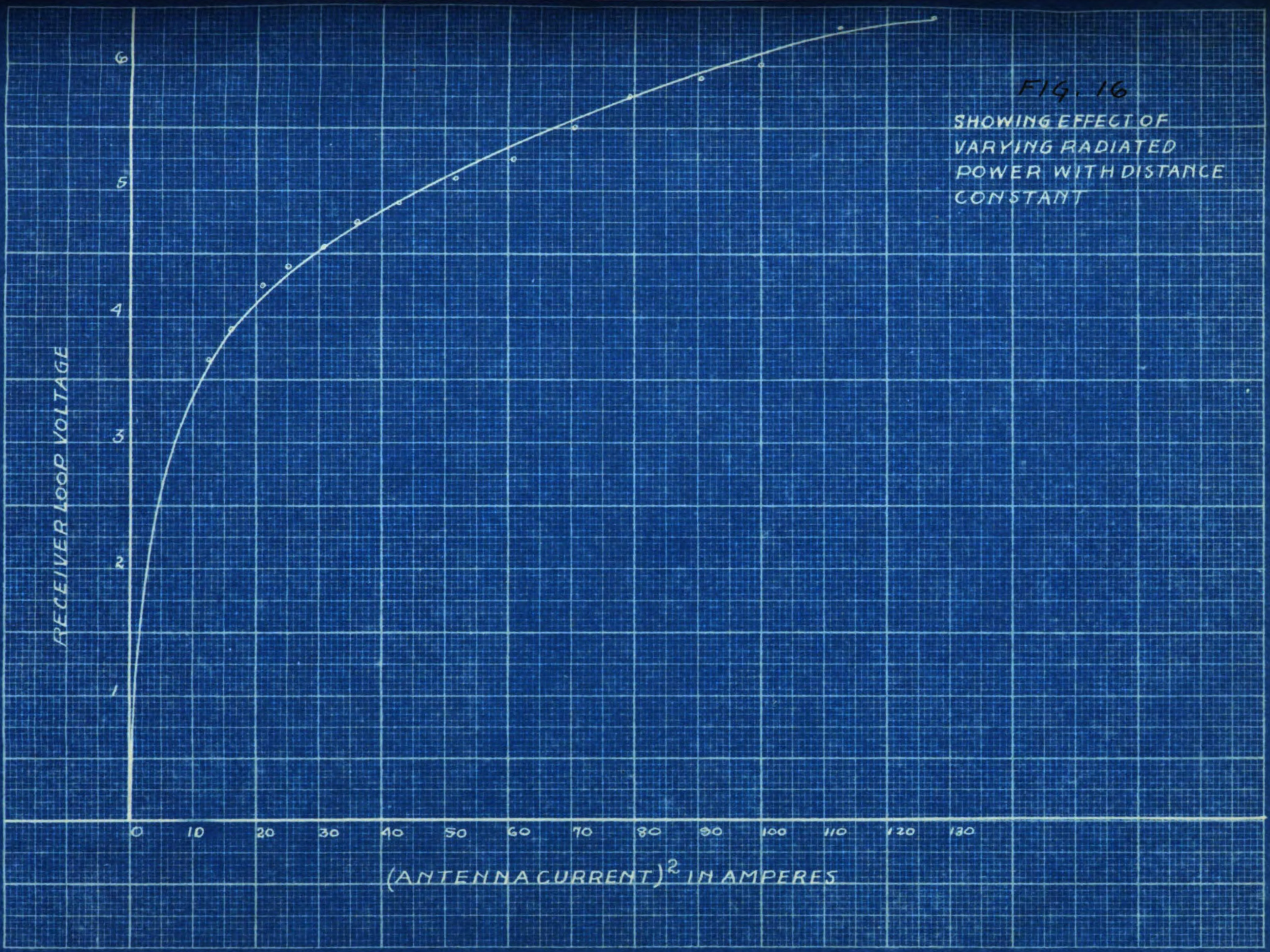


FIG. 16

SHOWING EFFECT OF VARYING RADIATED POWER WITH DISTANCE CONSTANT

Station operator and field operator were synchronized before the test and certain times arranged for decreasing power and making readings. The power was left constant at each point for 2-1/2 minutes to give the field operator time to observe readings. Inability to reduce the plate voltage of the oscillators below 420 volts prevented readings lower than 3.5 amperes antenna current. For this reason the lower part of the curve in Fig. 16 is theoretical. However, it is evident that such a curve must pass through the origin so the lower part must be approximately correct.

The resulting data was plotted with antenna current squared as abscissa and receiver loop voltage as ordinates. As radiated power equals I^2R and the radiation resistance is constant with constant frequency it is correct to use I^2 as the abscissa as it is proportional to the power output. As the loop voltage is proportional to the field intensity it may be used as the ordinate.

From this curve it can be seen that the effect at the receiver varies about as the square root of the radiated power. Varying the received power with constant distance is the same as varying the distance with constant received power, so it would appear correct to state that according to this experiment the radiation field varies approximately as the inverse square of the distance.

ACKNOWLEDGMENT

We are indebted to the Service Department of the Michigan State College for the use of the College Radio Station, WKAR, and for maps of the campus, to the Electrical Engineering Department and especially Mr. B. K. Osborn of this Department for many helpful suggestions. We are also thankful to the Technical Staff of WKAR for their cooperation and help in standing station watches during the tests.

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