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This paper describes a new ultra-high frequency radio oscillator by means of which it was possible to obtain wavelengths as short as 4.9 mm.

The wavelengths were measured with a diffraction grating, a radio frequency thermocouple, and a high sensitivity D'Arsonval galvanometer.

The effect of changes in grid voltage, plate voltage, and filament emission were studied. It was found that by varying the grid voltage alone from 15 volts negative to 45 volts positive the wavelength changed from 7.0 cm to 0.5 cm. The plate voltage exerted an influence upon the wavelength but not to such a marked degree. The filament emission not only affected the wavelength but also the power output as well.

All these effects support the premise that the thermionic tube in the case discussed is acting as an electronic oscillator of the Barkhausen-Kurz type.

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A NEW MICRO-WAVE GENERATOR

by

William Alphonso Miller

A THESIS

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The author wishes to take this opportunity to express his gratitude to Dr. Weniger and Dr. Boynton for their kind and helpful criticisms and to Professor Yunker under whose direction this work was done.

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A NEW MICRO-WAVE GENERATOR

INTRODUCTION

Since the ultra-high frequency portion of the radio spectrum has been found to be of use, not only for communication (10) but also for spectroscopic analysis (2), considerable attention has been concentrated upon the means of producing continuous wave oscillations at these frequencies. See Bibliography (1-12).

There exist at present but two types of oscillators capable of producing these continuous ultra-high frequencies, now (ca. 1934) known as microwaves, namely Barkhausen-Kurz oscillators (1) and magnetron oscillators (12).

In the first mentioned type of oscillator the grid of a triode having concentric cylindrical elements is made positive while the cathode is kept at zero potential and the plate at either zero or a slightly negative voltage. This type of oscillator has been made to produce weak oscillations in the 5 cm region.

In the magnetron oscillator a diode (usually with the anode split in two or more segments) is mounted in a magnetic field in such a way that the magnetic field is applied parallel to the longitudinal axis of the tube elements. Thus far this oscillator has proved to be the best both as to efficiency and shortness of wavelength. However it is generally recognized, as indicated by the following quotation, that the limiting dimensions of a tube for this purpose have been nearly reached. "One of the smaller tubes, which had an anode radius of 0.027 cm and a Lecher wire system about 4 mm long produced waves 1.13 cm long, with 870 volts on the anode and a magnetic field of 11,000 gauss." (2)

A thorough search of all the available literature revealed that at the time this investigation was started the shortest continuous wave that had been produced with thermionic tubes was 1.13 cm.

Some thought was given to the possibility of combining these two types of oscillators by using a triode thermionic tube in a magnetic field. Such an experiment was attempted and the results obtained were far better than anticipated, the minimum wavelength produced being 0.49 cm with a power output comparable to that of a Type 45 thermionic tube in a regenerative oscillator on 5 meters.

By using the circuit shown in this report and a tube especially designed and built for this purpose there is no reason why it should not be possible to attain wavelengths in the region usually referred to as the far infra-red.

Although the author has made no attempt to use the oscillator herein described, either as a means of communication or in the field of infra-red spectroscopy, it is his belief that the oscillator mentioned will provide a useful and versatile tool for research in these fields.

APPARATUS, PROCEDURE, AND DATA

The apparatus used consisted of the tube, the magnet, and the device for measuring the wavelength. The thermionic tube was an old French tube, pre-war model, type number unknown. The electromagnet was one which was capable of producing a field strength of 3.5 kilogausses across an air-gap of 5.5 cm between pole pieces 1.5 cm in diameter with a direct current of 6 amperes. The wavelengths of the several frequencies were measured by means of a grating spectrometer. The oscillating doublet was placed at the focus of a cylindrical parabolic reflector. Two diffraction gratings were used at different times. Both were made of strips of transformer iron with an air-gap equal in width to that of the strip in order to eliminate spectra of even order. In one the strips were 5.5 cm wide in the other 2.5 cm. Spectral energies were measured by means of a radio frequency thermocouple and high sensitivity D'Arsonval galvanometer.

The oscillator and detector together with the necessary auxiliary apparatus are shown on page 5 with the parts being labelled as follows:

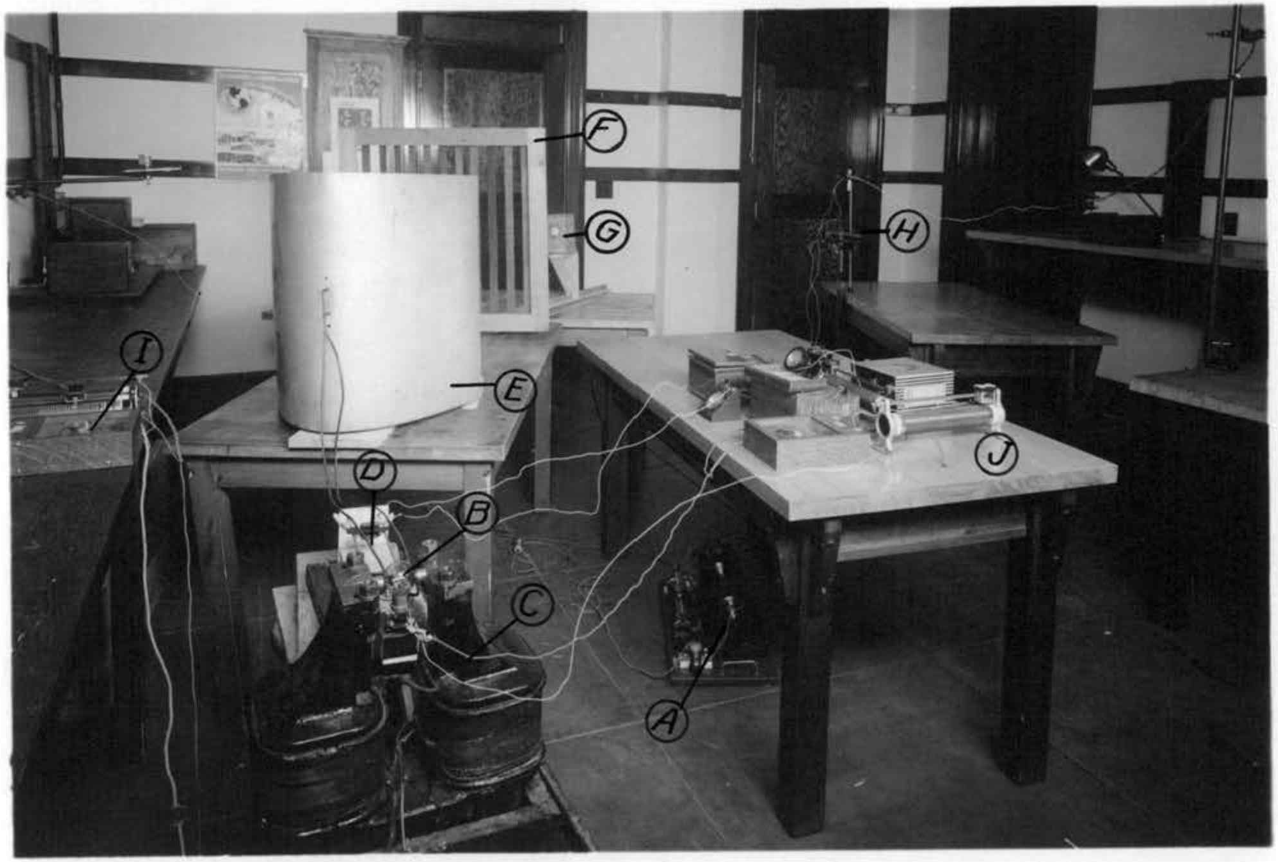
A--Motor-generator set for anode potential

B--Thermionic-Tube (French, pre-war, type unknown)

C--Electromagnet

D--Lecher wire system and pick-up loop

E--Parabolic reflector


F
G
H
I
E
D
B
C
A
J

F--Diffraction grating

G--Thermocouple shield, grounded by wire

H--Telescope

I--Ammeter in the electromagnet circuit with rheostats in the rear of it for varying the current in the electromagnet

J--Table, holding the following instruments, in background--from left to right--plate milliammeter and plate circuit voltmeter, in the middle also from left to right, grid circuit galvanometer, grid potential voltmeter, voltage divider, and "B" battery for supplying the grid bias; and in the foreground, from left to right the filament circuit ammeter and rheostat.

The grating spectrometer is shown on pages 7 and 8. The various parts are labelled on the photograph (page 8) as follows:

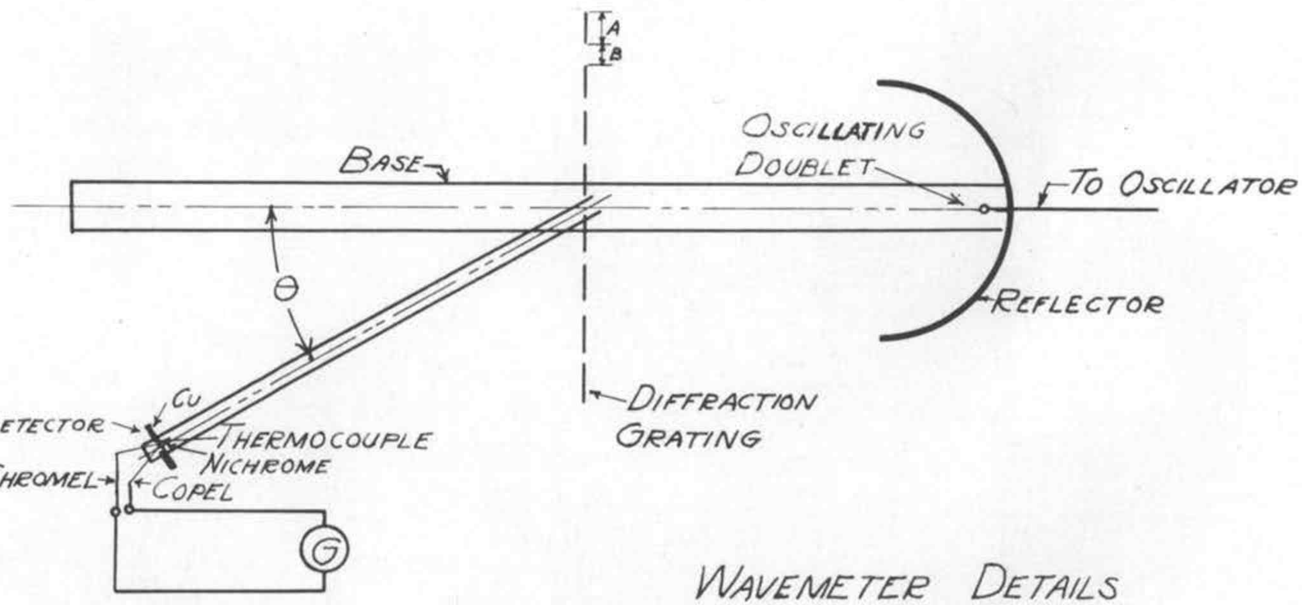
A--Parabolic reflector

B--Grating

C--Grounded thermocouple shield

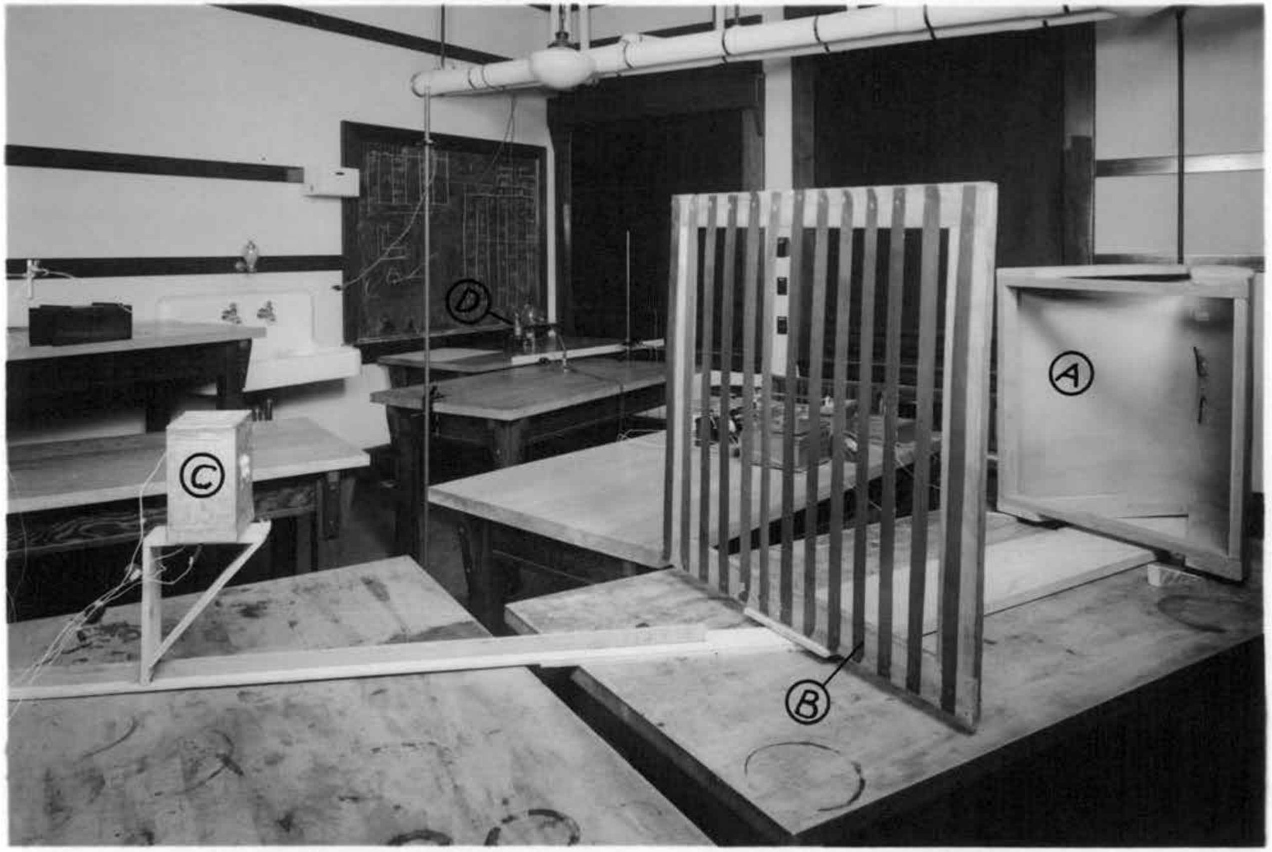
D--High sensitivity galvanometer

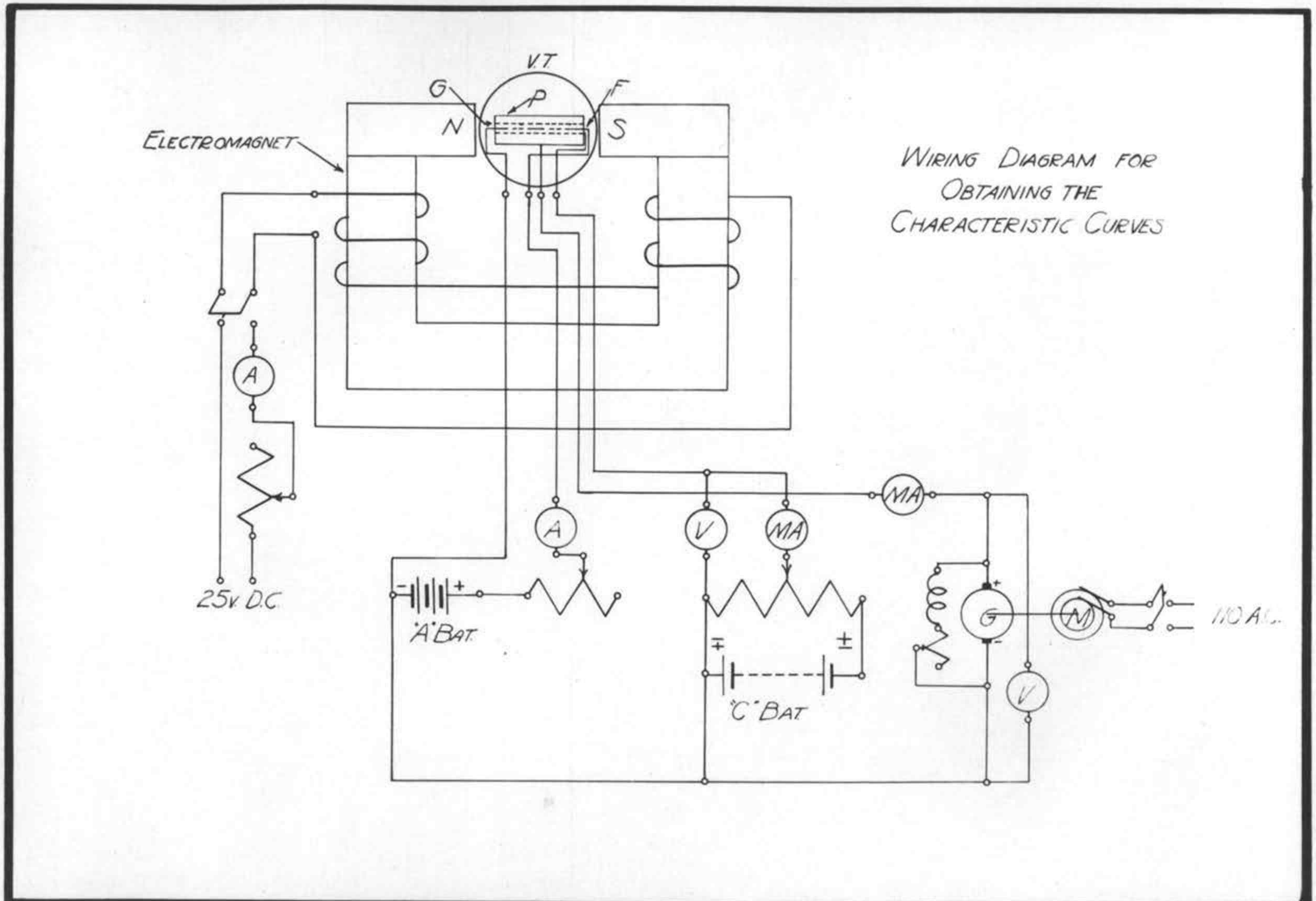
Page 9 shows the apparatus connected for taking data for the static characteristic of the triode in a magnetic field. These curves shown on pages 10, 11, 12, and 13 were taken with the plate voltage, grid bias voltage, and filament current constant while the magnetic field strength was varied

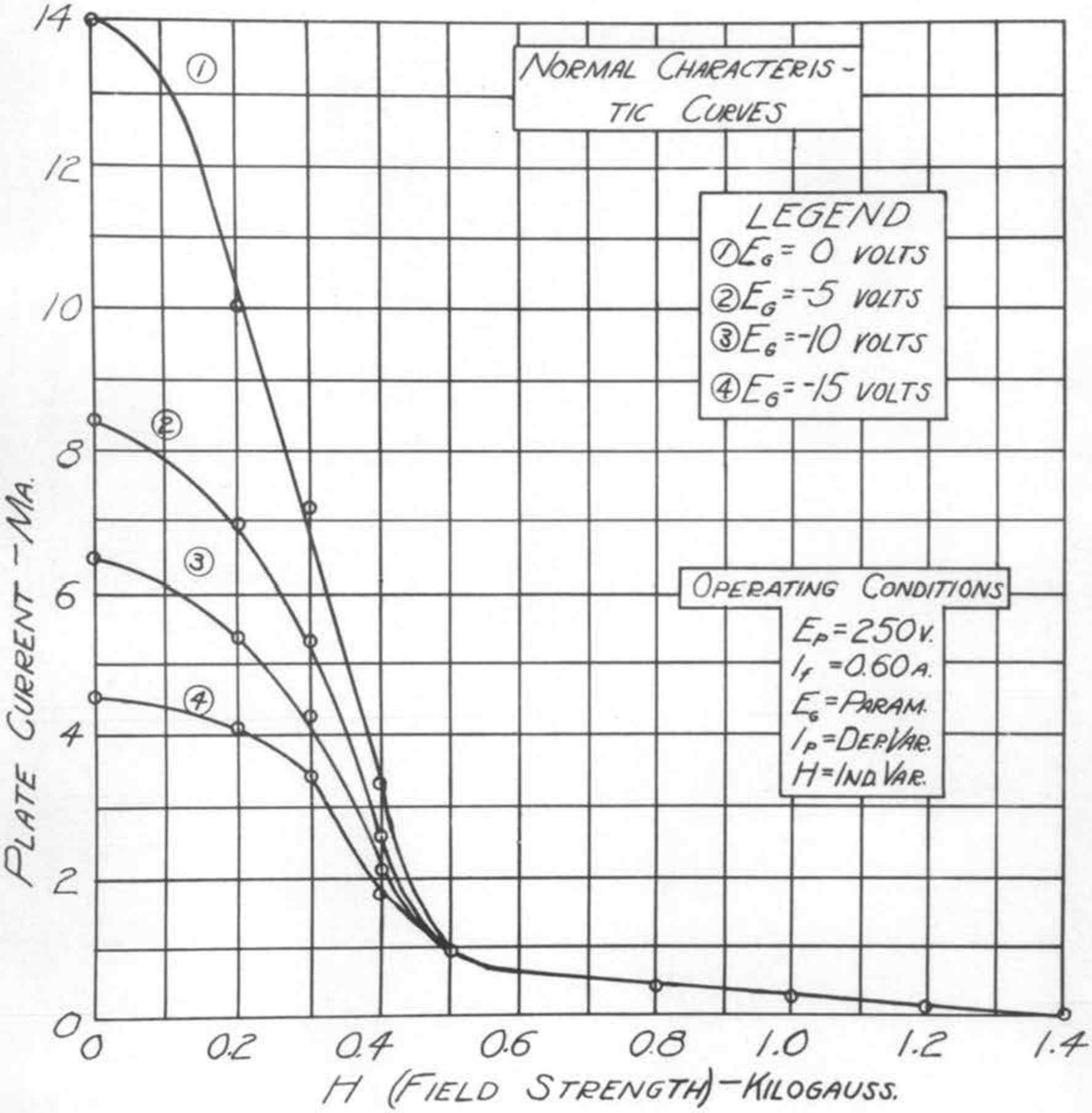


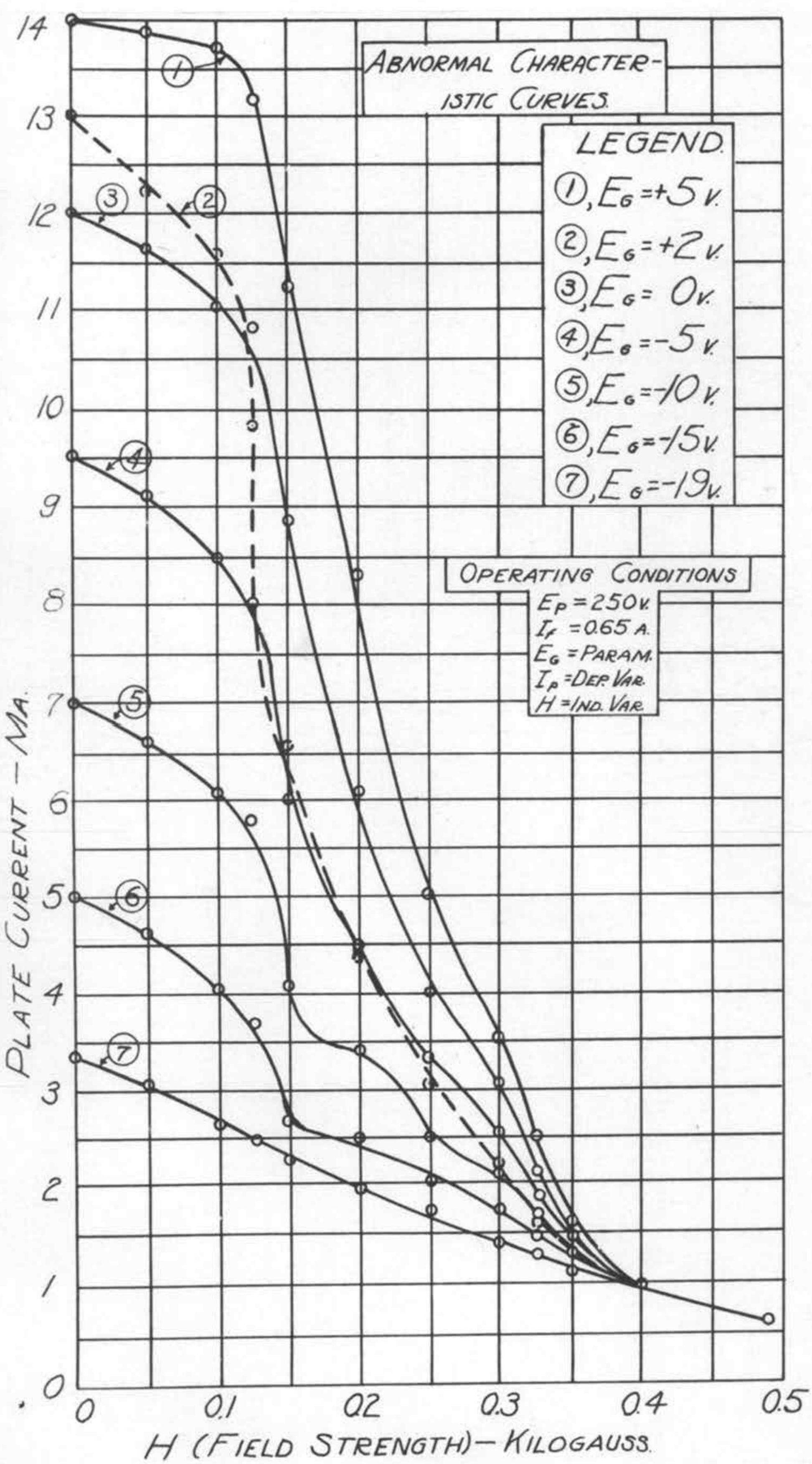
WAVEMETER DETAILS

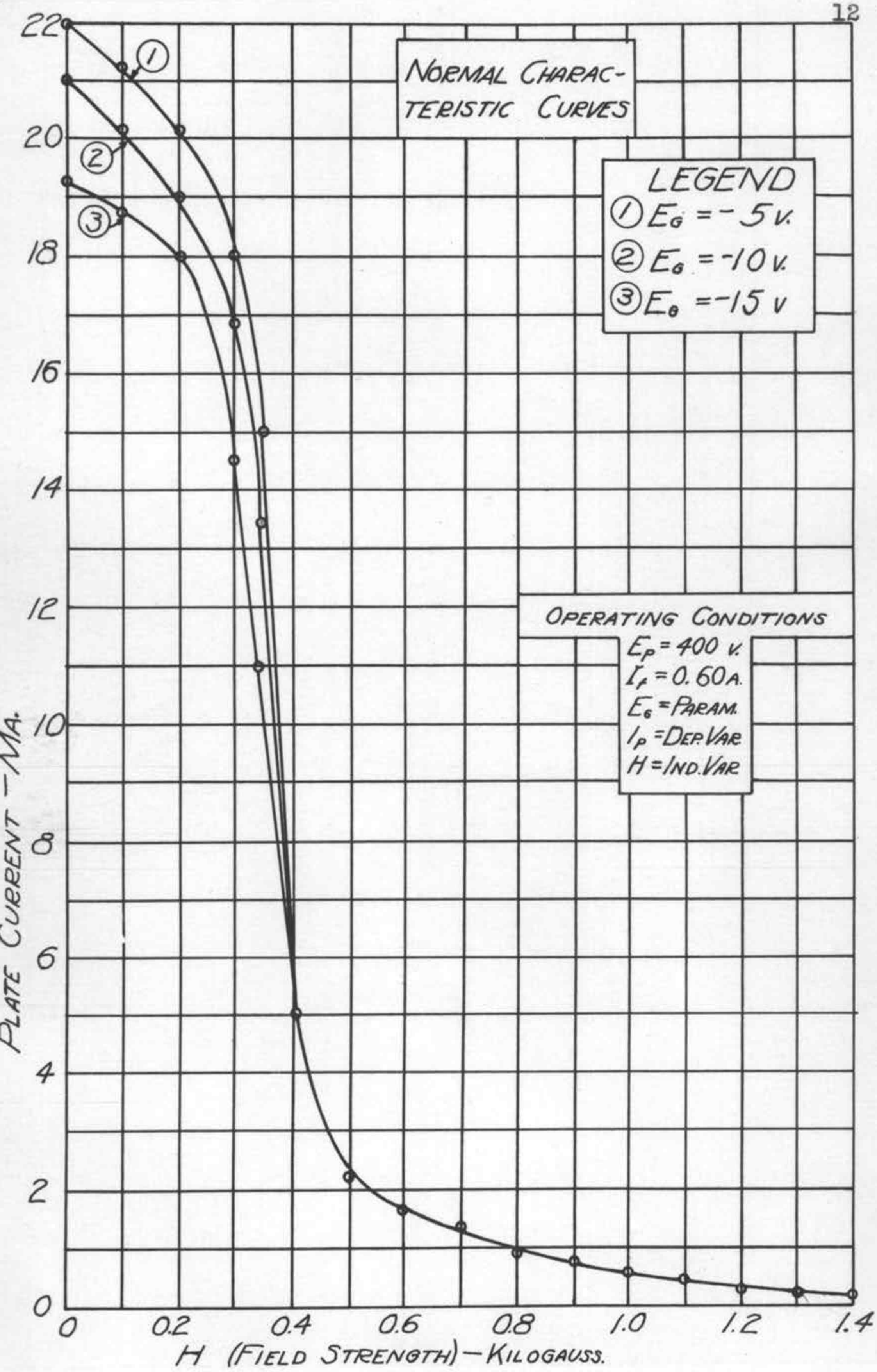
$$N\lambda = (A+B)\sin\theta$$

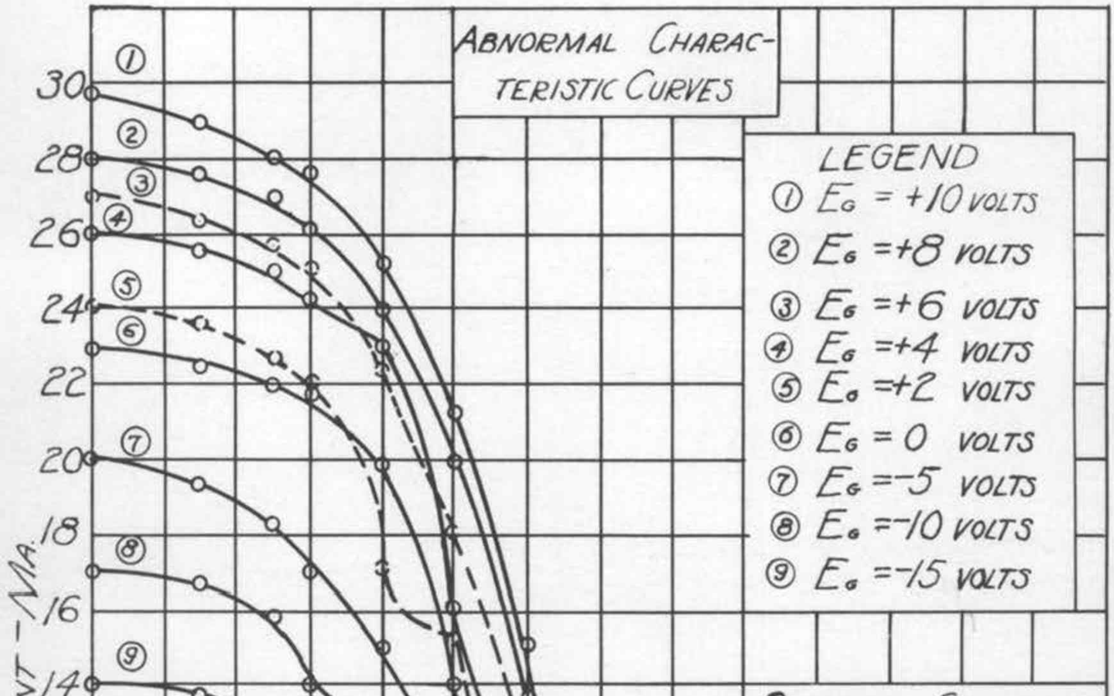

A
B
C
D


WIRING DIAGRAM FOR
OBTAINING THE
CHARACTERISTIC CURVES
V.T
G
P
F
N
S
ELECTROMAGNET
A
25V D.C.
"A" BAT.
A
V
MA
MA
"C" BAT.
G
M
V
110 A.C.


NORMAL CHARACTERISTIC CURVES
LEGEND
① E_G = 0 VOLTS
② E_G = -5 VOLTS
③ E_G = -10 VOLTS
④ E_G = -15 VOLTS
OPERATING CONDITIONS
E_P = 250 V.
I_f = 0.60 A.
E_G = PARAM.
I_P = DEP. VAR.
H = IND. VAR.
PLATE CURRENT - MA.
H (FIELD STRENGTH) - KILOGAUSS.
0
2
4
6
8
10
12
14
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4


ABNORMAL CHARACTERISTIC CURVES.
LEGEND.
①, E_G = +5 V.
②, E_G = +2 V.
③, E_G = 0 V.
④, E_G = -5 V.
⑤, E_G = -10 V.
⑥, E_G = -15 V.
⑦, E_G = -19 V.
OPERATING CONDITIONS
E_P = 250 V.
I_f = 0.65 A.
E_G = PARAM.
I_p = DEP. VAR.
H = IND. VAR.
PLATE CURRENT - MA.
H (FIELD STRENGTH) - KILOGAUSS.
0
0.1
0.2
0.3
0.4
0.5
1
2
3
4
5
6
7
8
9
10
11
12
13
14


NORMAL CHARACTERISTIC CURVES
LEGEND
① E_G = -5 v.
② E_G = -10 v.
③ E_G = -15 v
OPERATING CONDITIONS
E_P = 400 v.
I_f = 0.60 A.
E_G = PARAM.
I_P = DEP. VAR.
H = IND. VAR.
PLATE CURRENT – MA.
H (FIELD STRENGTH) – KILOGAUSS.
0
2
4
6
8
10
12
14
16
18
20
22
0.2
0.4
0.6
0.8
1.0
1.2
1.4

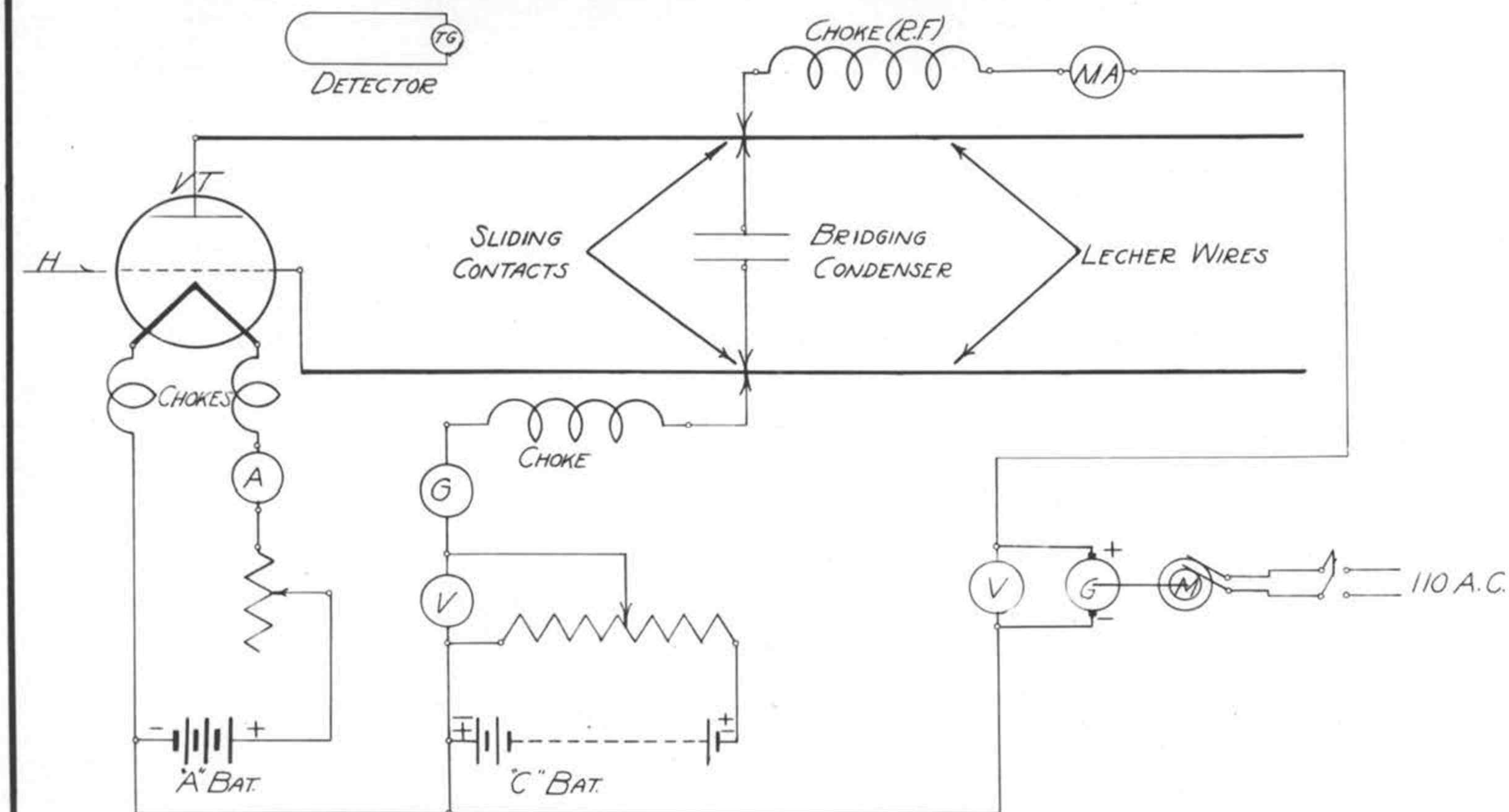

ABNORMAL CHARACTERISTIC CURVES
LEGEND
① E_G = +10 VOLTS
② E_G = +8 VOLTS
③ E_G = +6 VOLTS
④ E_G = +4 VOLTS
⑤ E_G = +2 VOLTS
⑥ E_G = 0 VOLTS
⑦ E_G = −5 VOLTS
⑧ E_G = −10 VOLTS
⑨ E_G = −15 VOLTS
OPERATING CONDITIONS
E_P = 400 V.
I_f = 0.65 A.
E_G = PARAM.
I_P = DEP. VAR.
H = IND. VAR.
PLATE CURRENT - MA.
H (FIELD STRENGTH) - KILOGAUSS.
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

from zero to the point at which it prevented electrons from reaching the plate (cut-off).

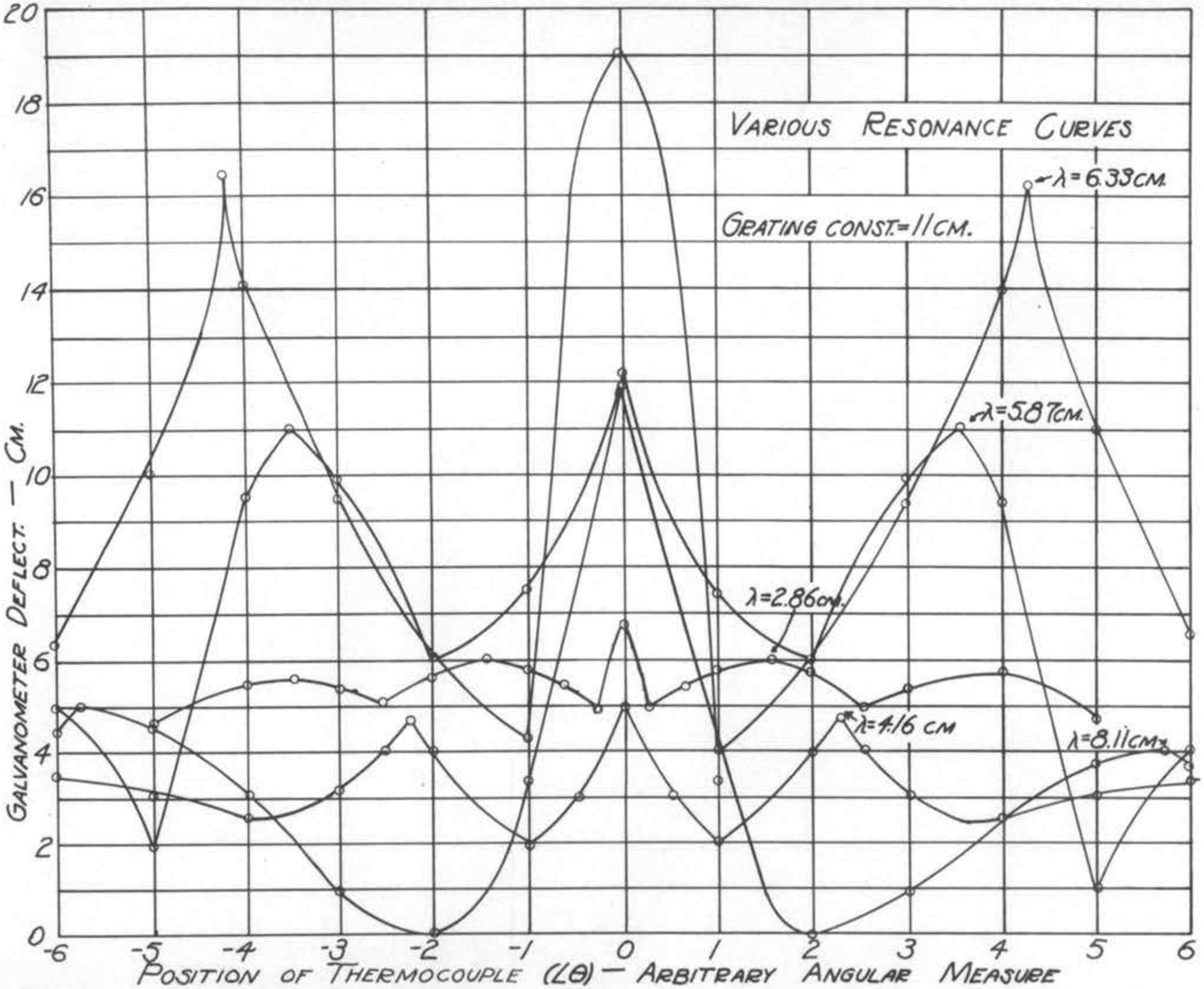
The apparatus was then connected as shown on page 15 where the following procedure was found necessary for successful operation as an ultra-high frequency oscillator. First the filament was heated and the grid bias applied, then the plate voltage was applied and brought up to the value desired, and, finally the magnetic field strength was slowly increased from zero to the point where the plate current stopped decreasing and suddenly increased. At this point there is a noticeable change in the deflection of the galvanometer in the grid circuit, and a deflection of the thermogalvanometer in the detector circuit (page 15). The latter deflection was made a maximum by carefully varying the current flowing through the electromagnet.

When this had been done the oscillator was operating in its most stable state, giving maximum output at the best efficiency.

A measurement of wavelength was made in the following manner: first, angle θ (page 16) was made equal to zero; then the arm was moved in a clockwise direction in equal arbitrary steps, until the third order spectrum energy peak was passed, (see page 16), then the arm was rotated in a counter clockwise direction back through the position $\theta = 0$ (position of central maximum); then the thermocouple arm was



OSCILLATOR WIRING DIAGRAM



VARIOUS RESONANCE CURVES
GRATING CONST.=11CM.
λ=6.33CM.
λ=5.87CM.
λ=2.86CM.
λ=4.16 CM
λ=8.11CM.
GALVANOMETER DEFLECT. — CM.
POSITION OF THERMOCOUPLE (∠θ) — ARBITRARY ANGULAR MEASURE
0 2 4 6 8 10 12 14 16 18 20
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6

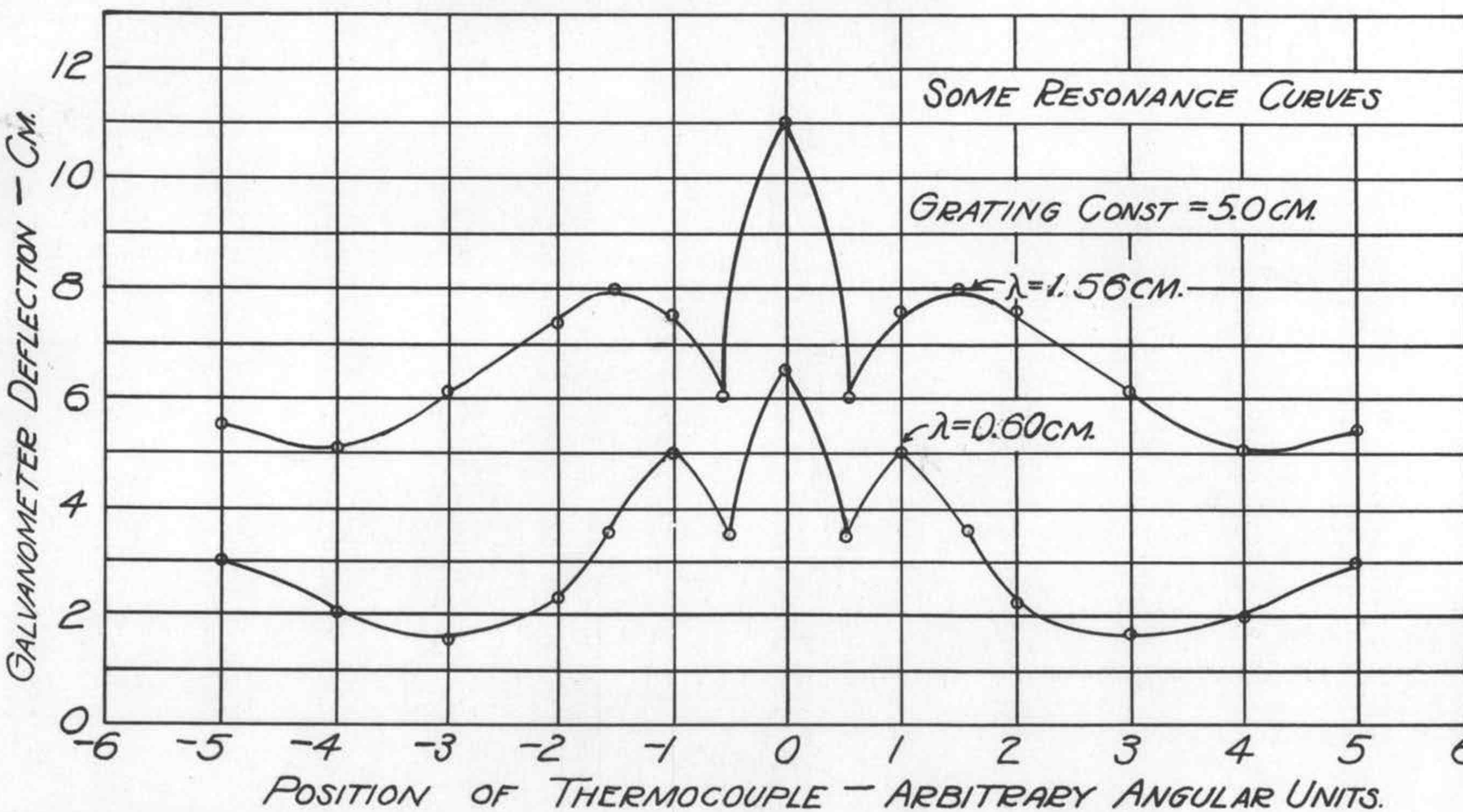
moved further in the same direction (counter clockwise) until the third order spectrum peak was passed, after which the thermocouple arm was moved back in a clockwise direction to the position of central maximum. Galvanometer readings were taken at each step. This procedure allowed every point to be checked twice during a run and each run was duplicated at some other time to check the results.

These data were then plotted as shown on pages 16, 18, and 19. From these curves the position of the first order peak was carefully determined and the angle θ carefully measured with an accurate protractor. The wavelength of the oscillations was then computed by means of the equation, (see 11),

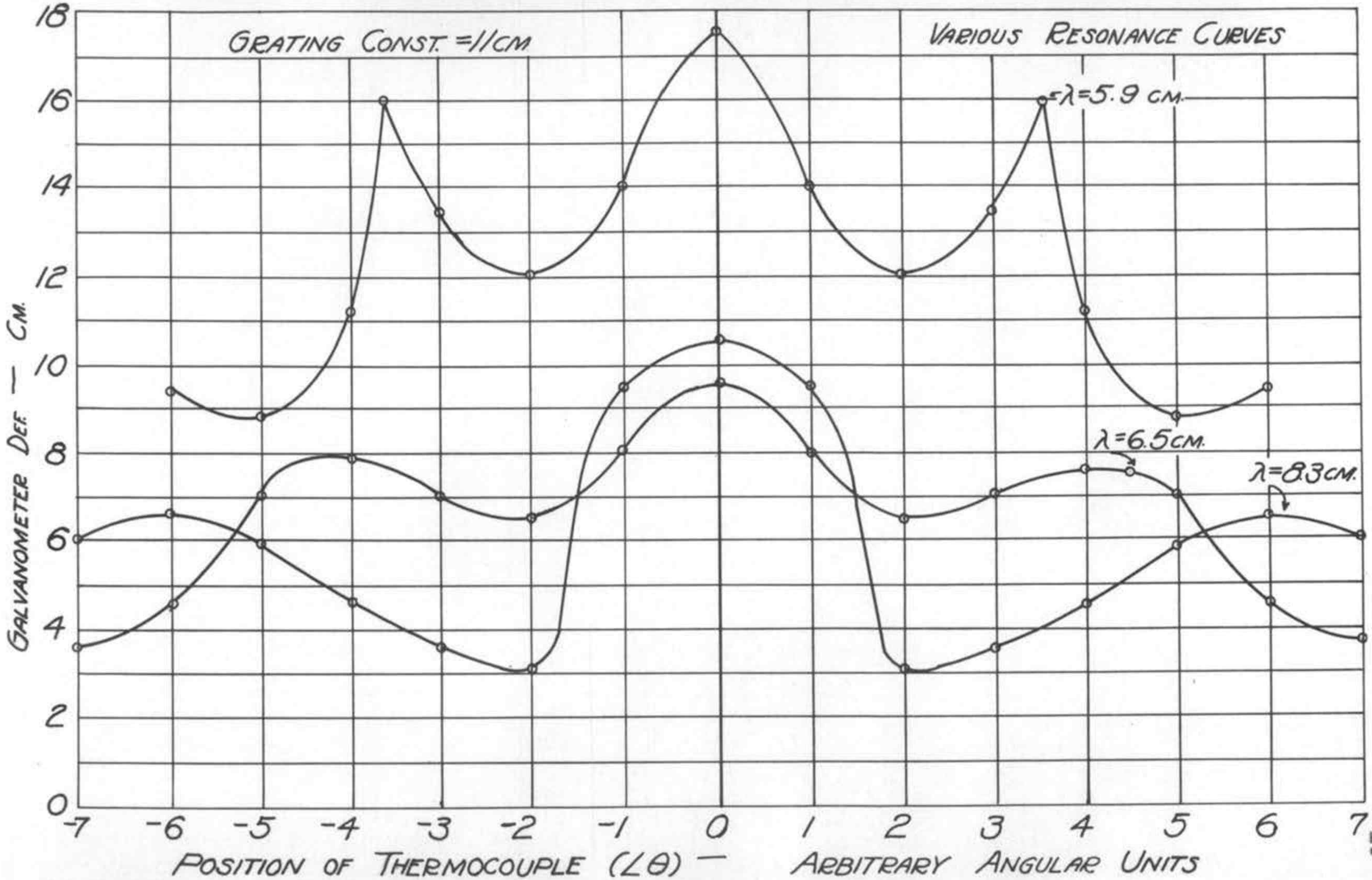
$$n\lambda = (A + B) \sin \theta$$

where n, the order of the spectrum, is unity (in this case), and A + B is the grating constant, and is equal to 11 cm for the grating used in determining the longer wavelengths and 5 cm for that used with the shorter wavelengths.

The author realized that there should be some attempt made at collimation of the energy impinging on the thermocouple. This was to be accomplished by mounting the thermocouple at the focus of another cylindrical parabolic reflector, however, unfortunately, the tube in use at the time was burnt out due to the necessity for large over-voltages on the elements for the production of the shortest wavelengths obtained, thus bringing the investigation to a close, since



SOME RESONANCE CURVES
GRATING CONST = 5.0 CM.
λ=1.56 CM.
λ=0.60 CM.
GALVANOMETER DEFLECTION - CM.
0
2
4
6
8
10
12
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
POSITION OF THERMOCOUPLE - ARBITRARY ANGULAR UNITS.



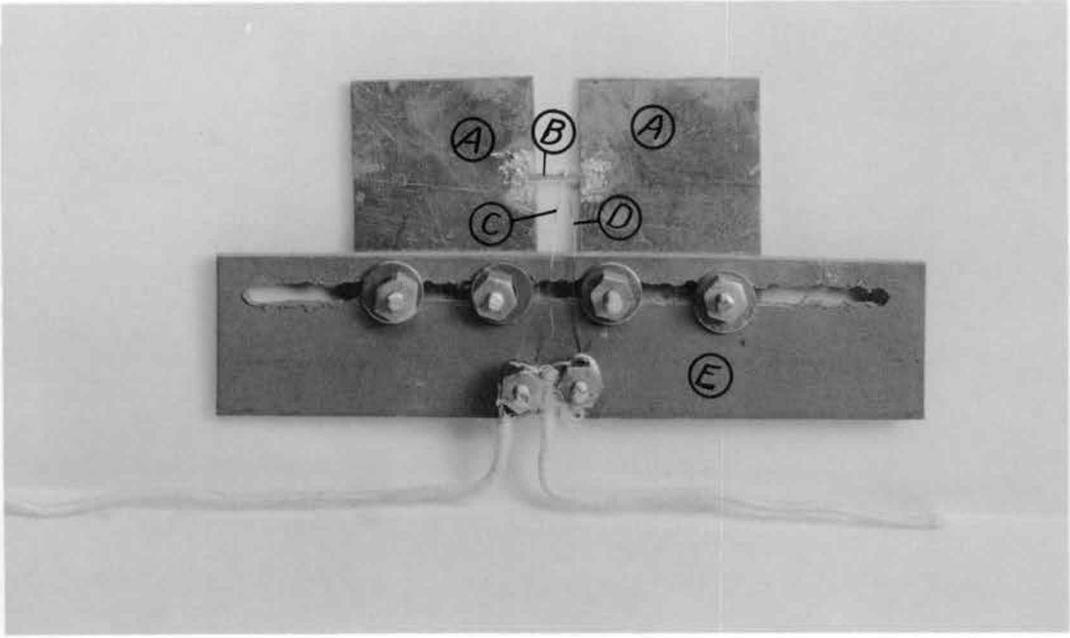
GRATING CONST. =11CM
VARIOUS RESONANCE CURVES
λ=5.9 CM.
λ=6.5CM.
λ=8.3CM.
GALVANOMETER DEF. — CM.
POSITION OF THERMOCOUPLE (∠θ) — ARBITRARY ANGULAR UNITS
18
16
14
12
10
8
6
4
2
0
-7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7

it was impossible to replace the triode used.

The thermocouple used was one of the hot-wire type, shown on page 21. It consisted of two copper sheets, A, which were connected with a nichrome ribbon, B, to which was soldered a small chromel wire, C, and a small copel wire, D. The couple was mounted on a piece of fiber board, E. The thermocouple was then swathed in cotton and put into the box, C, page 8, which was grounded. The thermocouple was connected to the galvanometer, D, page 8.

Since these experiments were conducted almost directly beneath the antenna of broadcasting station KOAC, 550 kc, 1000 watts, particular attention was given to shielding. No difference in operation or measurement could be detected whether KOAC was in operation or not.

Before the grating spectrometer was constructed, attempts were made to detect the presence of any oscillations between 2500 meters and 1 meter by means of a General Radio wavemeter, and from 1 meter to 10 cm by means of a Lecher wire wavemeter. Both attempts were unsuccessful.


A
B
A
C
D
E

THEORY

The theory of the Barkhausen oscillator has been very completely studied by F. B. Llewellyn, (5) (6) (7), of The Bell Laboratories.

The Barkhausen oscillator consists of a filamentary cathode, surrounded by a cylindrical grid which in turn is surrounded by a cylindrical plate. The grid is operated at a high positive potential while the plate is operated at the same potential or a slightly lower one than the cathode. Generally, although not necessarily, the plate and grid are connected by an external tuned circuit, consisting of inductance and capacitance. This tuned circuit need not be external to the tube but may consist of the internal capacitance and inductance of the tube elements and leads.

Suppose that a transient is started in the tuned circuit by some external means, say the application of a voltage. Then if the forces produced on the moving electrons by this transient deliver energy to the electrons, it will die out, whereas if the moving electrons supply energy to the transient it will be built up. The necessary energy is furnished by the grid battery in increasing the kinetic energy of moving electrons; the transient exists as a continuous oscillation of the period of the moving electrons.

In the absence of a transient an electron emitted from the cathode will be attracted to the grid, and in so doing will draw energy from the grid battery. After passing through the grid mesh the electron travels on, but gradually slows down until it comes to a stop before reaching the plate; during the flight through the grid-anode space the electron has been delivering energy back to the grid supply. Then as the electron retraces its path through the grid-anode space it again draws energy from the grid voltage supply, and on passing through the grid mesh delivers energy back to the grid battery until it has stopped its motion toward the cathode. The same process is then repeated. However, oscillations, in the sense of electromagnetic vibrations, do not take place, because the energy transfer from grid battery to the electron is exactly balanced by the energy transfer from the electron back to the grid battery, resulting in a system in perfect dynamical equilibrium.

However, when the transient is introduced into the tuned circuit, conditions are considerably changed. For the reasons described above, the grid potential alternates with the swinging of the electrons back and forth through the grid mesh. Therefore, the resulting forces acting on electrons that start from the cathode at different times in the alternating-current cycle, will be quite different. For example, let us suppose that an electron starts out just at the time when the alternating force is acting in the same direction as the steady potential of the grid battery. The alternating force increases in intensity as the electron moves along, then decreases to zero, reverses direction and opposes the motion, and finally completes the cycle by becoming positive again. At the instant the electron passes through the grid there is a reversal of force on the electron due to the fact that the grid is now behind the electron instead of in front of it. As the electron moves toward the plate the alternating force decreases to zero and then reverses. Therefore, it is seen, the force due to the alternating current supplies energy to the electron through both halves of the cycle and since this energy must be supplied from the transient the transient will soon die out and oscillations cease.

Let us examine an electron which leaves the cathode a half-cycle after the one just discussed. It is easily seen that in this case the alternating force opposes the motion of the electron, but cannot stop it since the alternating force is never as great as the force due to the constant grid potential. Therefore, the electron is actually doing work against the alternating force, delivering energy to the transient in the external circuit. Due to the fact that this delivery of power to the transient slows down the electron, the electron will pass through the grid after the reversal of direction of the alternating force. When passage through the grid mesh again reverses the direction of the steady force, the electron will continue to supply energy to the transient. This electron will return to the grid-cathode space at such a time that it will start back on its journey through the grid mesh at the same time that other favorable electrons are leaving the cathode. This results in a concentration of electrons in the tube-spaces; these feed energy to the transient, the energy being supplied by the grid battery, and resulting in oscillations of the Barkhausen type.

In practice the operating conditions modify this process somewhat. For example, space charge around the cathode results in the production of more harmful electrons than beneficial ones. Therefore cathode space-charge saturation is to be avoided. Space-charge concentration around the plate results in a phase shift between the grid potential and the alternating potential which in general tends to raise the oscillation frequency.

In the case of the oscillator with which this report deals, it is fairly safe to say, for reasons which will appear later, that the oscillator is in effect a Barkhausen oscillator, and that the theory as stated fits the case at least qualitatively.

In order to check the assumption that the oscillator described is an electronic oscillator, computations were made by means of equation (2) below.

Hollman (3) gives an equation for wavelength of the oscillations of a Barkhausen-Kurz oscillator, which is as follows;

$$\lambda = \frac{1000}{\sqrt{E_g}} \cdot \frac{d_a E_g - d_g E_a}{E_g - E_a} \text{ cm} \qquad \text{-----(1)}$$

Where λ is the wavelength,

E_g is the grid voltage,

E_a is the plate voltage,

d_a is the diameter of the anode,

and d_g is the diameter of the grid.

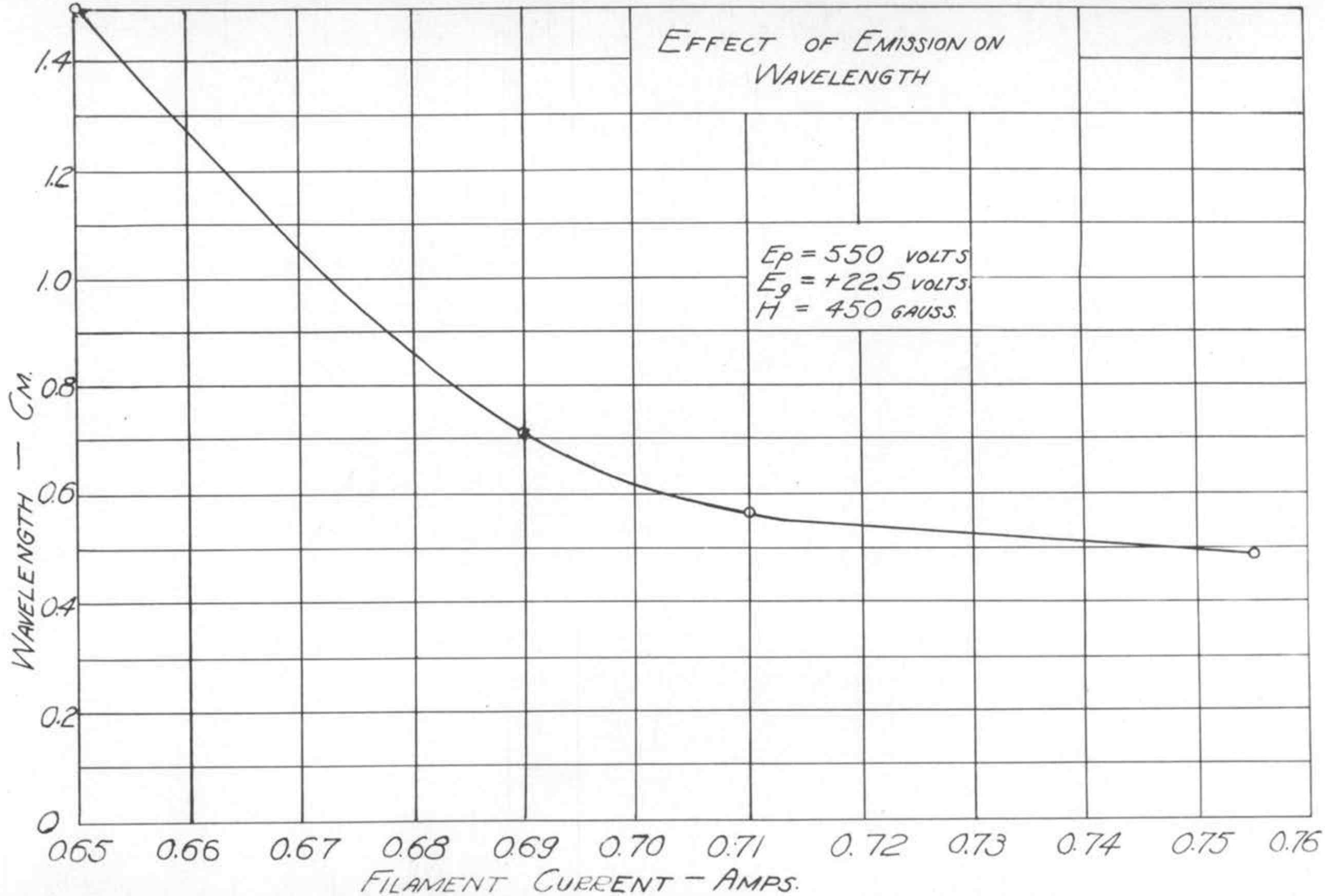
This equation is not directly applicable to the present oscillator on account of the difference in the circuits. Instead of using a high positive potential on the grid of the triode to provide power for the transient by means of the motion of electrons, the power is supplied by a high positive potential on the anode, while the to and fro movement of the electrons is caused by the magnetic field. The latter part of the above assumption is true, since Hull (4) has shown that at the cut-off condition the electrons leaving the cathode describe paths which are approximately cardiodal in shape, returning to the cathode at approximately the same place from which they left. Equation (1) becomes;

$$\lambda = \frac{1000}{\sqrt{E_a}} \cdot \frac{d_g E_a - d_a E_g}{E_a - E_g} \text{ cm} \qquad \text{-----(2)}$$

Computations with Equation (2) yield a set of values which when plotted to the same scale lie parallel to and in excess of the values of wavelength determined experimentally. This apparent non-fitting of experimental data and computed values is to be expected however, for Equation (1) is an empirical equation somewhat modified by the assumption that the alternating current is very small, which is not true for the oscillator being described. A correction factor is needed to take account of the large magnitude of the alternating current, (8) (9).

From the above discussion it seems logical to assume that the oscillations are due to the action of a moving cloud of electrons, in which the electron transit time is proportional to the period of the oscillations, rather than due to some feed-back or regenerative condition.

There are several advantages in using a high positive plate potential and a magnetic field rather than a high positive grid potential to produce the oscillations. The plate is capable of dissipating more energy than is the grid. Higher potentials can be used. Space charge around the cathode is prevented; with the magnetic field space-charge saturation in the cathode space is not attained except for extremely high values of filament current because the magnetic field keeps the electron clouds in rotation about the cathode at such speeds that the electrons are thrown out of the cloud by centrifugal force. However, for high cathode emission the electrons are supplied much faster than the field strength requisite for oscillations can remove them. This accounts for the flattening out of the curve on page 29.


EFFECT OF EMISSION ON
WAVELENGTH
Ep = 550 VOLTS
Eg = +22.5 VOLTS.
H = 450 GAUSS.
WAVELENGTH — CM.
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0.65 0.66 0.67 0.68 0.69 0.70 0.71 0.72 0.73 0.74 0.75 0.76
FILAMENT CURRENT — AMPS.

DISCUSSION

On pages 10 and 12 are shown some curves of plate current plotted against magnetic field strength, at various values of grid bias voltage. These curves are identical in shape to those obtained from the two-element tube used as a magnetron. It is interesting to note that the value of grid bias, although it changes the maximum value of plate current and the slope of the curves, does not affect in any way the value of the magnetic field strength at cut-off. However, this is to be expected, since, according to Hull (4), space-charge has no effect upon the cut-off value of the magnetic field. Therefore, since both the space-charge field and the field due to the grid potential are electrostatic in nature, naturally if one has no effect upon the cut-off value of the magnetic field, neither will the other. Thus the experimental curves shown on pages 10 and 12 substantiate Hull's reasoning. These curves will be referred to as "normal" characteristic curves.

The curves on pages 11 and 13 will be called "abnormal" characteristic curves. At every irregularity, either in the trend of a single curve or in the crossing of one curve by another, oscillation is taking place. The irregularities in the abnormal curves are accounted for by the fact that oscillations take place, not at a definite single value of magnetic field strength, but over a small range of values.

Naturally there is some optimum point in this band at which the oscillation energy will be a maximum. This will give rise to a curve of the same shape and character as a resonance curve. In fact, because the magnetic field strength is an integral part of the oscillatory circuit, this curve may be called a resonance curve.

Let us take for discussion curve 5 on page 11. At zero value of field strength the plate current has a value of 7 ma determined by the grid bias alone. As the magnetic field strength is gradually increased, the plate current decreases in a normal manner until a field strength of 150 gauss is reached, when, due to the circuit conditions being right for oscillations, the tube starts oscillating and there is an abrupt change in curvature; the plate current no longer follows the normal curve, but, due to the interlocking effect present in all oscillators, follows the resonance curve, mentioned previously. This results in a secondary maximum causing the curve to become irregular; but as discussed above this irregularity is not inherent in the characteristic curves themselves but is due to the superposition of two curves, namely, the normal characteristic curve and the oscillation resonance curve.

The same reasoning may be applied to the crossing of two or more curves, for if at one value of the grid bias no oscillations occur, and if at another value close to that for the non-oscillatory case, the tube does oscillate, it is perfectly possible that due to the resonance curve the plate current may be raised to such a value that the two curves may cross once or, depending upon the descending slope of the resonance curve, twice or even three or four times.

The presence of these oscillations is easily detected by use of the detector shown on page 15.

The curves shown on pages 16, 18, and 19 were obtained by plotting galvanometer deflection against angular position of the thermocouple. Each curve shows, very definitely (a) the central maximum of energy which is present in all transmission diffraction gratings, (b) the maximum of energy present in the first order spectrum, and (c) the general upward trend of the curve as the galvanometer approaches the third order peak of energy.

The differences in the position of the first order peaks shown on pages 16 and 18 is due to the fact that the grid biasing potential was different for each run.

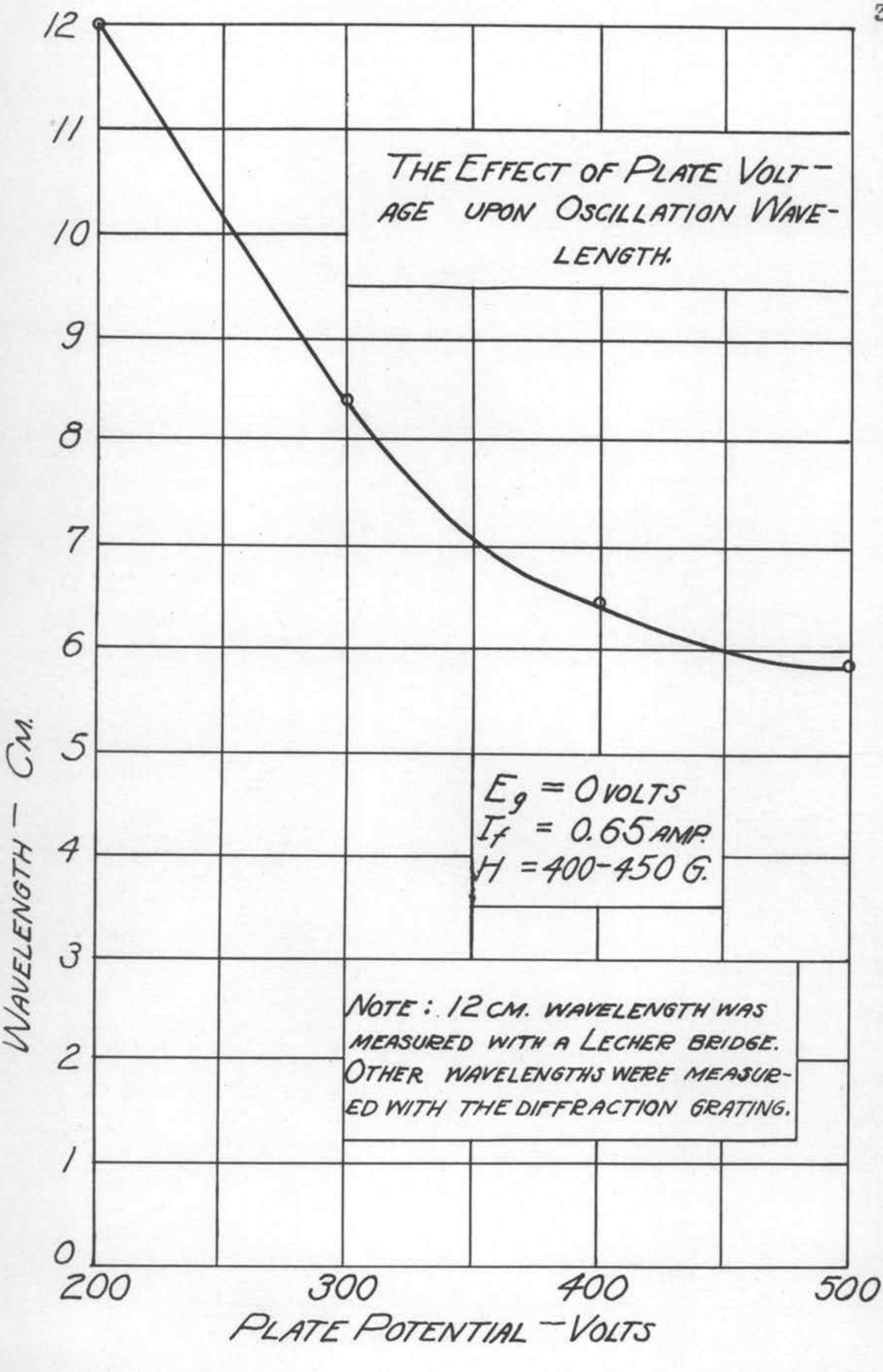
Attention is particularly called to the symmetry of these curves about the central axis. This symmetry, while not absolutely necessary for accurate wavelength measurement, is convenient for it adds to the ease of determining the angles to be measured. If the resonance curves are not symmetrical about the central axis, one or both of two things may be wrong. Either the grating is not perpendicular to the incident beam, in which case it is necessary to measure the angle of incidence and use the value determined for the computation of the wavelength, or, during the construction of the wavemeter, the grating has been mounted in such a position that a large absorbing space is presented to the beam at the center or zero position. The former case was found to be the more prevalent of the two and called for careful adjustment of the grating until it was normal to the incident beam. The latter source of error was recognized early in the work and easily avoided thereafter.

The resonance curves on page 19 are curves obtained from the diffraction grating wavemeter when the tube was oscillating with different values of plate voltage.

These curves have been called resonance curves because they are similar in shape to those that would be obtained by the use of a conventional resonant circuit.

The resonance curves for change in wavelength with change in filament current are not shown in this report because the curves are of the same form as those shown on pages 16, 18, and 19. The curves on the above pages are included in the belief that they supply sufficient evidence that oscillation is taking place and that continuous waves are being emitted.

The curve, page 34, shows the effect of plate voltage

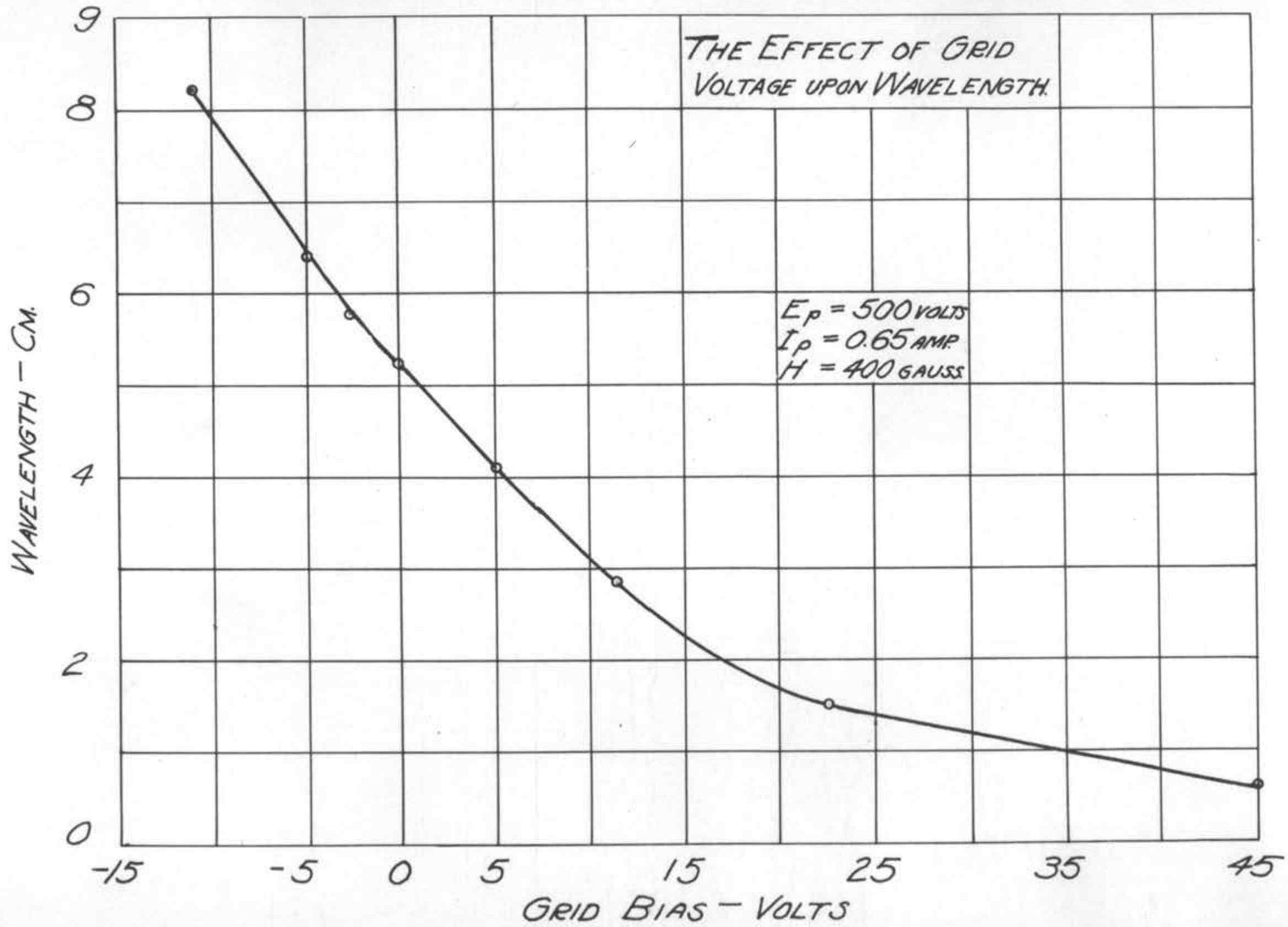

THE EFFECT OF PLATE VOLTAGE UPON OSCILLATION WAVELENGTH.
E_g = 0 VOLTS
I_f = 0.65 AMP.
H = 400-450 G.
NOTE: 12 CM. WAVELENGTH WAS MEASURED WITH A LECHER BRIDGE. OTHER WAVELENGTHS WERE MEASURED WITH THE DIFFRACTION GRATING.
WAVELENGTH - CM.
0
1
2
3
4
5
6
7
8
9
10
11
12
200
300
400
500
PLATE POTENTIAL - VOLTS

on the wavelength of the oscillations produced by the tube. There is a very striking similarity between this curve and a curve showing the effect of grid voltage on the wavelength of a Barkhausen-Kurz oscillator. This similarity is due to the similarity of mechanism of oscillation between the two different types of oscillator.

As shown in the notation on the curve, it is also necessary to change the field strength of the electromagnet a slight amount for each change in plate voltage. This must be done to apply the proper torque to the electrons so that a considerable portion of those emitted may never reach the anode at all but be returned to the cathode.

The curve, page 36, is a curve obtained by plotting wavelength against grid voltage with constant plate voltage and filament current. This curve also has the same shape as the grid voltage-wavelength curve of a Barkhausen-Kurz oscillator. However, a glance at the scales of the curve will show that there is a vast difference between the two, for the curve on page 36 shows a much larger control over the wavelength of the oscillations than does a similar curve for the Barkhausen-Kurz oscillator. This is probably due to the fact that in the oscillator shown on page 15 the grid potential functions in much the same way that it does ordinarily, as a controlling potential.

It was also necessary in this case to increase the


THE EFFECT OF GRID
VOLTAGE UPON WAVELENGTH.
E_p = 500 VOLTS
I_p = 0.65 AMP.
H = 400 GAUSS
WAVELENGTH - CM.
9
8
6
4
2
0
-15
-5
0
5
15
25
35
45
GRID BIAS - VOLTS

magnetic field strength with each increase of grid potential in the positive direction. The reason for this may be easily seen from the curves of either page 11 or page 13. As the grid voltage is changed the tube operates upon a different abnormal characteristic curve and in so doing requires a change in the field strength to again make the plate current a maximum. The change in field strength is very slight, however, amounting only to between 25 and 50 gauss.

The curve shown on page 29 gives the relation between filament current and wavelength. Since the space-charge saturation in the cathode space is dependent upon the filament emission, this curve shows the relation between space-charge and wavelength.

It would appear at first sight that this curve shows a relation contrary to the accepted idea that space-charge saturation in an electronic oscillator is harmful, but this is not the case; because, with the high positive potential on the anode and with the magnetic field which keeps the electron clouds in motion throughout their existence, the building up of a large space-charge near the cathode does not occur. Thus, as the filament current is increased, up to a certain limit, the power output will increase and the wavelength will decrease. However, as the filament current is increased beyond this limit the magnetic field can no longer keep all the electrons in motion resulting in the building up of space-charge near the filament with a consequent slowing down of the action described above and the flattening out of the filament current-wavelength curve as shown on page 29.

That the power output does increase with increased filament current and the corresponding decrease in wavelength, is shown by the fact that with the filament current at 0.65 amp the deflection of the thermogalvanometer, page 15, was equivalent to 30 milliamperes, whereas when the filament current was increased to 0.755 amp the current in the thermogalvanometer was over 115 milliamperes. This increase cannot be due to resonance as the loop short-circuiting the galvanometer was 30 centimeters long.

SUBJECTS FOR FURTHER INVESTIGATION

A glance at the curve on page 11 suggests several applications. One of these, and perhaps the most interesting, is the possibility of using a triode to measure the strength of the earth's magnetic field. Another is the use of this property of the triode to measure the magnetic field of magneto-striction and thus analyse internal stresses in steel I-beams, channel-iron, etc. A third is that of using this oscillator in a transceiver for secret communication between two points when there is an unobstructed path between them. In connection with this suggestion it may be remarked that since the grid voltage controls the wavelength to such a marked degree, it should be possible to obtain pure frequency modulation of the output by applying the modulating voltage to the grid of the oscillator.

Further work on this oscillator with a different triode leads the author to believe that for maximum efficiency the anode should either be made from some non-magnetic material or operated above the Curie point.

Investigations with a type 10 tube (with tantalum anode) in this circuit, show that it is possible to produce wavelengths so short that there is considerable difficulty in the measurement of wavelength and power.

CONCLUSIONS

The results attained in the work reported show that:

1. The oscillator described in this report is an electronic oscillator, closely related to the Barkhausen-Kurz oscillator.

2. It has a much higher power output than any other electronic oscillator operating at these frequencies.

3. The general theory of electronic oscillators may be extended to fit the case herein described, at least qualitatively.

4. A strong magnetic field applied along the longitudinal axis of a vacuum tube will reduce space-charge saturation around the cathode.

5. Much shorter wavelengths than those reported in this thesis can easily be obtained by decreasing the size of the elements; work along this line has been started.

6. For wavelengths below 10 cm Lecher wires no longer form an adequate means of measuring wavelength.

7. The diffraction grating spectrometer is an admirable instrument for measuring these oscillations as it is easily constructed, highly accurate, and rapid in manipulation.

8. Owing to the near linearity of some of the characteristic curves, the tube can probably be used as an instrument for measuring field strengths.

8. (a) It should be possible to make a triode which would measure the anomalies in the earth's magnetic field.

8. (b) In all probability a special tube could be constructed in such a manner that it would be sensitive enough to give a qualitative measure of the internal strain of a steel member under stress.

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BIBLIOGRAPHY

(1)--Barkhausen, H. and Kurz, K., Phys. Zeit. Vol. 21, No. 1, p. 1, Jan. 1920

(2)--Cleeton, C. E. and Williams, N. H., "Electromagnetic Waves of 1.1 Cm. Wavelength and the Absorption Spectrum of Ammonia", Phys. Rev. Vol. 45, No. 4, p. 234, Feb. 15, 1934

(3)--Hollman, H. E., "Electronic Oscillations", Proc. I.R.E., Vol. 17, No. 3, p. 229, Mar. 1929

(4)--Hull, A. W., "The Magnetron", Phys. Rev., Vol. 18, No. 1, p. 31, July 1921

(5)--Llewellyn, F. B., "Vacuum Tube Electronics at Ultra-High Frequencies". B.S.T.J., Vol. XIII, No. 1, p. 59, Jan. 1934

(6)--Llewellyn, F. B., "Note on Vacuum Tube Electronics at Ultra-High Frequencies", Proc. I.R.E., Vol. 23, No. 2, p. 112, Feb. 1935

(7)--Llewellyn, F. B., "The Barkhausen Oscillator", Bell Lab. Rec., Vol. XIII, No. 12, p. 354, August, 1935

(8)--Megaw, E. C. S., "Electronic Oscillations", Jl. I.E.E., (London) Vol. 72, No. 4, p. 313, Apr. 1933

(9)--Schiebe, A., Ann. d. Phys., Vol. 73, No. 1, p. 54, Jan. 1934

(10)--Wolff, I., Lindner, E. G., and Broden, R. A., "Transmission and Reception of Centimeter Waves", Proc. I.R.E., Vol. 23, No. 1, p. 11, Jan. 1935

(11)--Wood, R. W., "Physical Optics", Macmillan Co., New York, 1934, p. 240-253

(12)--Yagi, H., "The Magnetron Oscillator", Proc. I.R.E., Vol. 16, No. 10, p. 715, Oct. 1928

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