E. L. Crump

RELIABILITY OF RESONANCE INDICATORS ON WAVEMETERS.

BY

EDWARD LEE CRUMP

A THESIS SUBMITTED FOR
THE DEGREE OF BACHELOR OF SCIENCE
ELECTRICAL ENGINEERING COURSE

University of Tennessee

1923

CONTENTS.

Page.

PREFACE iv

INTRODUCTION 1

Letter from Bureau of Standards 2

The Local Generating Set 5

Schedule of Transmits 6

Trial of Resonance Click Method 6

Trial of Zero Beat Method 8

Results from Standard Wave Transmits 9

Resonance Circuits using Detector and Galvanometer 11

Method of Comparing Different Resonance Indicators 12

Results Obtained 13

Characteristic Curves of WD 11 Vacuum Tube 18

Other Results Obtained 21

COMPARATIVE TEST using all methods on 600 meters 26

Explanations and Comparisons of Results Obtained 31

Broadcasting Station Wave Lengths and Difficulties 38

List of Some Stations Tested and Their Wave Lengths ... 41

Near Future Schedule of Bureau of Standards 41

Conclusions 42

APPENDIX—
Data for Characteristic Curves of WD 11 Tube 44

APPROVAL 51

PREFACE

This thesis deals with the accuracy of matching incoming radio frequencies and the reliability of resonance indicators on wavemeters. Dr.Perkins received a letter from the Bureau of Standards in regard to a series of standard wave lengths that they were going to transmit for the purpose of testing and calibration of wavemeters. He recommended that I take the matter up as a thesis, which he had already started to work on. Since the tests were conducted by the Bureau of Standards, I have obtained considerable information from there in connection with the best methods to measure the standard frequencies. I have received information from the following circulars from the Bureau of Standards :

"Memorandum on Procedure for Reception of Signals and Wave Frequency Measurement"

"Radio Signals of Standard Frequency and Their Utilization" or Letter Circular LC 92.

"The Secondary Standardization of Radio Wavemeters " or Letter Circular LC 75.

"Radio Instruments and Measurements" or Circular of the Bureau of Standards No. 74.

"Methods of Measuring Voltage Amplification of Amplifiers" or Letter Circular LC 86.

"Methods of Measuring Properties of Electron Tubes" or Letter Circular LC 87.

"A Low-Power Electron Tube Generating Set for Laboratory Use."

Frequent reference has also been made to and considerable information obtained from Morecroft's "Principles of Radio Communication".

The conditions under which the tests were made and the methods of checking the calibration of a wavemeter with the standard frequencies are herein described, and this thesis may be read by anyone interested in these measurements and the results obtained.

Edward Lee Crump.

RELIABILITY OF RESONANCE INDICATORS ON WAVEMETERS.

Radio Communication has grown very rapidly in the last few years and has become not only exceedingly popular as as entertainment feature but also for a commercial use. Commercial Radio broadcasting has frequently been offered considerable interference by entertainment programs sent out on about the same wave length. Hence it has been necessary for some measures to be taken to assign each broadcasting station a certain definite wave length. Now that these measures have been taken and the definite wave lengths have been assigned to some of the stations, especially the new ones, another difficulty has been met. This is that the wavemeters by which the broadcasting stations check their wave lengths are not standardized and some have even varied as much as seven percent. To solve this problem and to give anyone a chance to calibrate his wavemeter or receiving set, the Bureau of Standards, Station WWV has sent out five transmits of Standard Radio Wave Signals covering a range of wave lengths of from 300 to 1500 meters.

The following letter has been received:

DEPARTMENT OF COMMERCE

BUREAU OF STANDARDS

WASHINGTON

January 20, 1923.

University of Tennessee,
(Attention: Dr.C.A.Perkins),
Knoxville, Tennessee.

Subject: Standard wave transmission.

Gentlemen:

1. The Bureau of Standards expects, within the next few months, to begin the regular transmission of radio waves of known frequency, the value of wave length or frequency to be announced during the transmission. This will be useful to persons who desire to standardize their wavemeters and in the adjustment of radio transmitting and receiving apparatus.

2. In order to obtain information from interested persons and institutions as to the best schedule to be followed, what frequencies(wave lengths) are most desired, and to test the methods proposed for standardizing wavemeters, we are planning preliminary transmissions on January 29, 1923. We are asking a few laboratories to assist us by taking observations. Knowing that you are interested in frequency measurements, we ask you to cooperate with us by setting up the necessary apparatus to receive and measure the wave frequency of the signals transmitted, as explained further in the memorandum we are sending herewith.

3. If you can make these measurements, we should be glad to have you write us after the completion of the test, stating the values of wave length or frequency as measured by your wavemeter, and sending also the enclosed questionnaire duly filled out. This will give us data on the degree of agreement between wavemeters at present in use, as well as information that will assist us in arranging the definite schedules of regular standard wave transmission. A franked envelope is enclosed for your convenience in transmitting this material.

4. It is our desire that no publicity be given this project. These tests are for the purpose of determining the practicability of a system to be begun later. If the preliminary tests are successful, the project will presumably be given wide publicity when the regular transmissions are begun later.

5. We should be glad to hear from you immediately, stating whether you can participate. If you should not be able to, we should still be glad to have you fill out the questionnaire and return it to us. Any criticisms or suggestions on the method or on the project in general will be welcome.

Respectfully,

F. C. BROWN

Acting Director

Enclosure:
Memo on Procedure.
Questionnaire
"A Low-Power Electron Tube..."
Franked envelope.

The Bureau of Standards requested in the "MEMORANDUM ON PROCEDURE FOR RECEPTION OF SIGNALS AND WAVE FREQUENCY MEASUREMENT" that the measurements be made by two methods if possible. The two methods recommended were the resonance click and the zero beat methods, and were explained therein as follows:

"In measuring the wave frequency (wave length) of a signal by the resonance click method, it is necessary to use a regenerative receiving set in a generating ("oscillating") condition, tuned to produce zero beat with the signal. The wavemeter is brought up close to the inductor of the receiving set and its setting varied until a click is heard in the telephone receivers. This click is produced by the stopping of the locally generated current when the wavemeter is tuned to resonance, due to the absorption of power from the oscillatory circuit by the wavemeter. If the coupling of the wavemeter to the receiving set is too close the click will probably be heard with different settings of the wavemeter, depending upon whether the capacity is being increased or decreased. These clicks will approach each other as the coupling is loosened and a coupling will be found where only one click will be heard. This coupling should be used for the measurements.

"In measuring the wave frequency of the signals by the zero beat method it is necessary to have, in addition to receiving set and wavemeter, a small radio-frequency generating set or separate heterodyne that will produce about 0.2 ampere of radio-frequency current. It would be well to locate the generating set as far away from the receiving set as possible as the strong signals produced by it would be likely to block

the tube of the receiving set and render it inoperative. This generating set must produce sufficient radio-freq. current to satisfactorily operate the resonance indicating device of the wavemeter.

"If a non-regenerative receiving set is used it will be necessary to use the local generating set as a heterodyne when tuning in the telegraph and standard frequency signals from WWV. If a regenerative receiving set is available best results will probably be obtained if it is used in a generating (oscillating) condition when tuning in the signals of WWV. After picking up the signals, the receiving set should be adjusted for maximum regeneration without generation in order to obtain high sensitivity and selectivity and the local generating set should be used as a heterodyne.

"When the test signal is transmitted the frequency of the local generating set is varied until the beat frequency is zero. When this condition is obtained the frequency of the local generating set is then exactly the same as that of the test signal. The wavemeter is then brought up near the inductor of the local generating set and the wave frequency measured.

"If the reaction of the wavemeter on the local generating set is sufficiently great to change its frequency, this will be evidenced by the production of beats and it will be necessary to loosen the coupling of the wavemeter with the generating set. Very little reaction by the wavemeter on the local generating set is to be expected if a sensitive device is used on the wavemeter as a resonance indicator".

The experimenting performed and data taken, recorded herein, was chiefly done for the purpose of comparing different

kinds of resonance indicators on wavemeters with regard to their sensitivity , accuracy , and reliability.

THE LOCAL GENERATING SET

The Bureau of Standards in Letter Circular 92 (4/25/23) on "RADIO SIGNALS OF STANDARD FREQUENCY AND THEIR UTILIZATION" give a description of a low-power electron tube generating set for laboratory use, with a frequency range of from 100 to 2000 kilocycles per second, as follows:

"Sufficient power can be obtained from a five-watt tube in a Hartley circuit, as shown in Fig.1. Inductor 'A' is a 3 $\frac{1}{2}$ inch tube of suitable insulating material about 4 $\frac{1}{2}$ inches long, wound with 55 turns of No. 16 B & S gauge double cotton covered copper wire with taps taken out from every fifth turn. This coil is used for frequencies (wave lengths) from 500 to 2000 kilocycles (600 to 150 meters). Inductor 'B' consists of 200 turns of No.22 B & S gauge double cotton covered copper wire on a tube about 5 $\frac{3}{4}$ inches in diameter and about 9 inches long. Taps are made on turns as shown in the diagram. This coil is used for wave lengths from 300 to 3000 meters. The plate voltage may be secured from several 22 $\frac{1}{2}$ volt 'B' batteries connected in series. Satisfactory operation can be obtained on voltages from about 100 to 400 volts. It is desirable to completely shield the generating set by placing it in a box lined with copper window screening which should be grounded. A long handle may be attached to the variable condenser control to obtain fine adjustment and reduce body capacity effects".

A schematic drawing of this local generating set is shown in Fig.1 . The Bureau of Standards recommends it for the

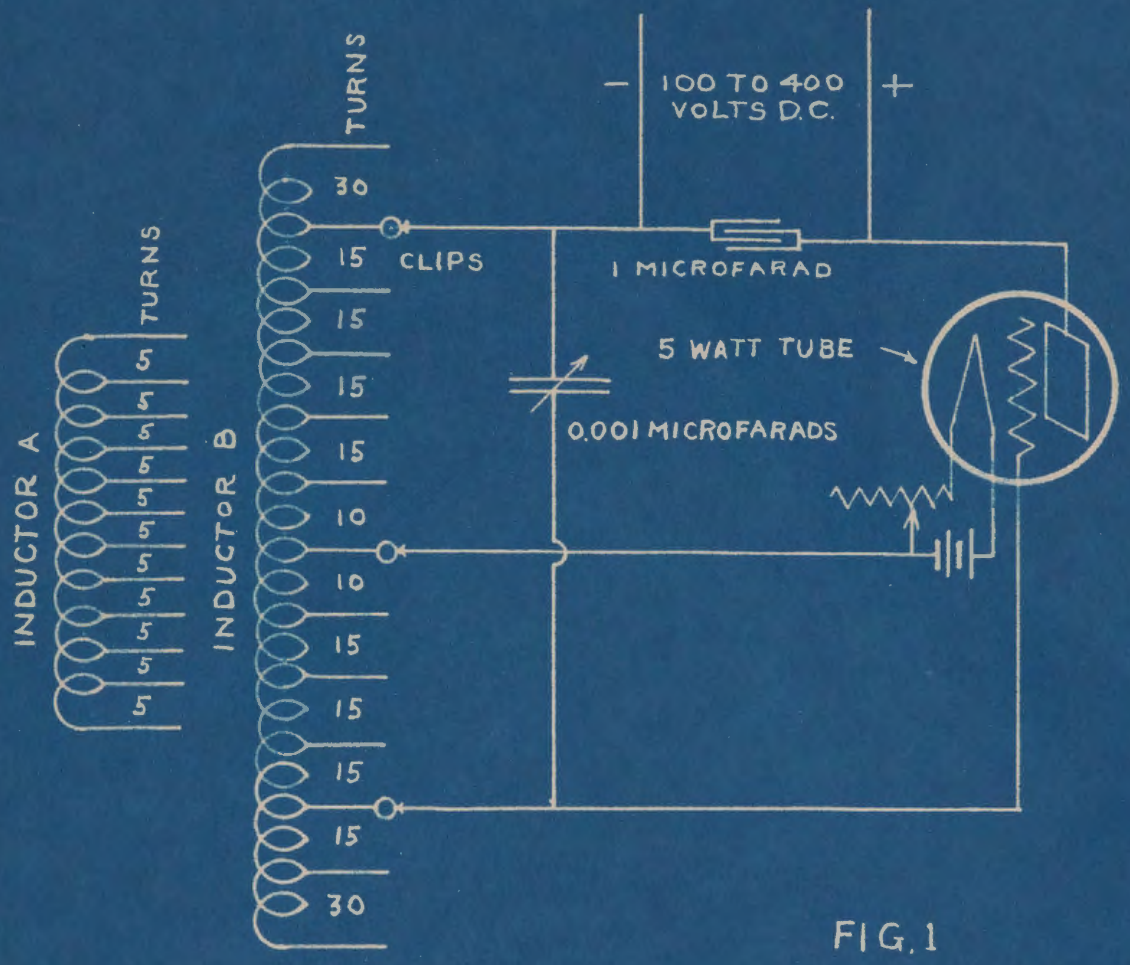


FIG. 1

ELECTRON TUBE GENERATING SET.

WAVE METER

measurement of the standard waves. They much prefer the zero beat method for it is more accurate and satisfactory than the resonance click method.

SCHEDULE OF TRANSMITS.

There have been five series of Standard Waves transmitted from the Bureau of Standards (Station WWV) since this plan was begun, the dates and ranges of which are given here.

Date	Wave length range.	Eastern Standard Time.
January 29	300 to 600 meters ...	9:00 to 10:30 p.m.
January 30	300 to 600 meters ...	9:00 to 10:30 p.m.
March 6	550 to 1500 meters..	11 p.m. to 1:15 a.m.
May 1	750 to 300 meters...	11 p.m.to 12:41 a.m.
May 7	750 to 300 meters...	11 p.m.to 12:41 a.m.

The first two series of these wave lengths were broadcast before the necessary apparatus had been obtained to receive them. The last three series have been received very successfully.

TRIAL OF RESONANCE CLICK METHOD

The resonance click method was tried on the night of March the 6th but it was impossible to obtain any results. It has been learned since then that to obtain accurate results with this method it is necessary to use closer coupling than was possible with the receiving set used. The receiving set used in the reception of these signals was the Grebe CR-9 Type with a wave length range of from 150 to 3000 meters and as the large inductance was in a box the effect of the regenerative circuit on the wavemeter was much stronger than the inductance in the antenna circuit, hence no click would be heard when the

wavemeter was adjusted to the frequency of the incoming signal. To avoid this difficulty a small coil of about 25 turns was put in the antenna circuit and the coupling with the wavemeter was made through this coil. This coil was evidently too small for still no click was produced with the setting of the wavemeter. If the size of the coil and number of turns are increased to a point where the resonance click would be heard the inductance in the coil of the receiving set will have to be lessened so much as to make the signals inaudible.

Some of the variations of the resonance click method have been used with much more satisfaction. A buzzer directly across the wavemeter was turned on and it of course modulated the wave in the wavemeter circuit. Now when the wavemeter was set to the frequency of the incoming wave the pitch of the buzz would be heard very sharp in the telephone receivers. If the coupling of the wavemeter to the coil in the antenna circuit was too close there would seem to be quite a range on the wavemeter dial in which the pitch of the buzz could be heard. However as the coupling is loosened the range over which the buzz was heard is lessened and at the same time the loudness of the buzz is decreased, until a point is reached where there is a very sharp change of pitch in the telephone receivers for a certain place on the wavemeter dial. This is the point at which the wavemeter is in resonance with the incoming frequency.

Still another variation of this resonance click method has proved satisfactory. The frequency of telephone broadcasting stations may be measured by noting the sudden decrease of signal intensity as the wavemeter is tuned to the frequency of the incoming signal. To obtain accurate results with this method it

is necessary to use very loose coupling.

TRIAL OF ZERO BEAT METHOD

The zero beat method as previously explained was given a trial in matching the incoming frequencies on the night of March 6th but it could not be checked with the results obtained with the resonance click method until later as we had no device for indicating resonance on the wavemeter. To compare this the setting of the local generating set was carefully recorded and when a resonance indicator was obtained, each recorded setting was checked by the wavemeter and found to check within one percent of the frequency obtained by the resonance change of pitch method. The zero beat method checked exactly with the rating of the waves. It was therefore concluded that the wavemeter was correctly calibrated for the range of frequencies given and that the zero beat method was the best to use for the checking of the calibration.

On the nights of May 1st and May 7th this method was tried again with good results is so far as the incoming waves could be received. There was so much static in the air and so much interference from broadcasting stations that some of the frequencies could not be received.

The results obtained from the standard wave transmits are given below. The standard frequency signals consisted of the call letters WWV (.-- .-- ...-) repeated with very long dashes intervening and were transmitted by unmodulated continuous waves. Announcements were made in regard to the length of the wave both by voice and by telegraphy and were made on the same frequency as the Standard frequency signals, which continued for five minutes.

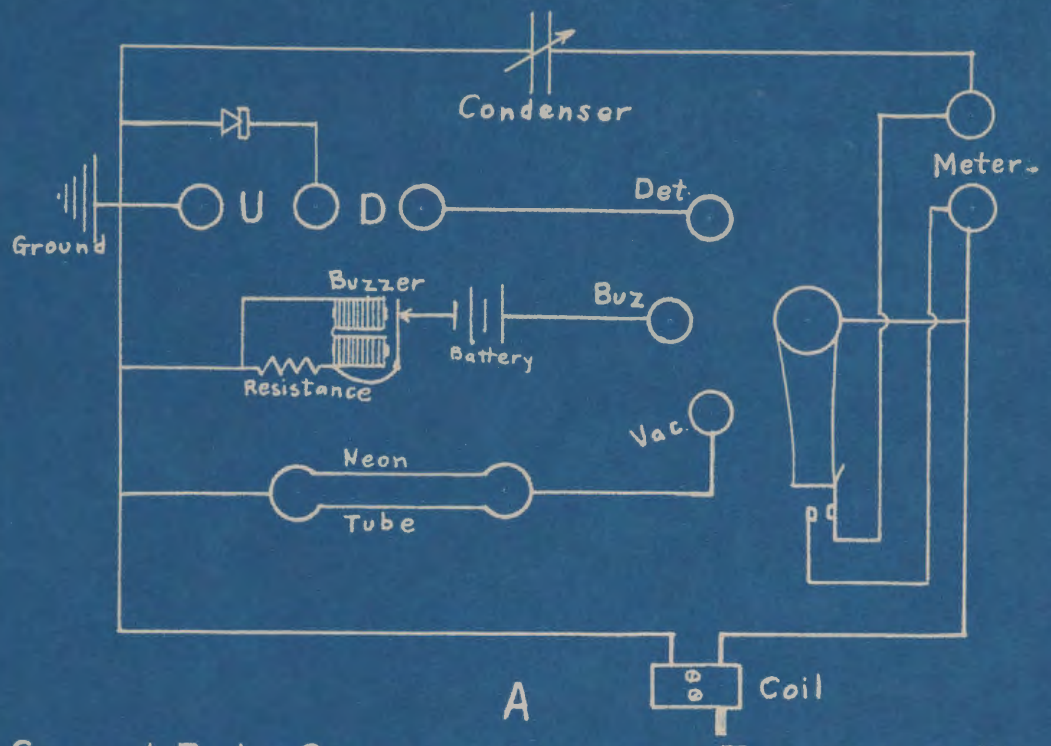
RESULTS FROM STANDARD WAVE TRANSMITS

Date in 1923	Eastern Standard Time	Wave length by Resonance Pitch in meters	Wave length by Zero Beat in meters	Standard Wave meters	Percent of Error.
Mar.6	11:05 pm	545	550	550	0.00
"	11:25 "	Too many ship signals		600	——
"	11:50 "	685	680	680	0.00
Mar.7	12:07 am	800	790	790	0.00
"	12:28 "	960 ?	940	940	0.00
"	12:49 "	1145	1150	1150	0.00
"	1:07 "	1495	1500	1500	0.00
		The resonance pitch method was not used for the two transmits in May.			
May 1	11:06 pm	Schedule was changed		750	——
"	11:20 "	——	600	600	0.00
"	11:35 "	Too much static		500	——
"	11:50 "	——	432	428	0.93
May 2	12:05 am	Interference from broadcasting		375	——
"	12:20 "	——	331	333	0.60
"	12:35 "	——	300	300	0.00
May 7	11:05 pm	Schedule was changed		750	——
"	11:20 "	Ship stations and static		600	——
"	11:35 "	——	500	500	0.00
"	11:50 "	——	428	428	0.00
May 8	12:05 am	Interference from broadcasting		375	——
"	12:20 "	——	333	333	0.00
"	12:35 "	——	300	300	0.00

It will be noticed by reference to the above that the 600 meter wave was not received during the first series but that

it was received during the second series and found to check with the wavemeter calibration . On the third series the same difficulty resulted,as in the first series but the wavemeter checked with the one that was received so it may be considered correct at the point corresponding to 600 meters. It is also seen that static prevented the reception of the 500 meter wave of the second series but that conditions were more favorable and it was picked up the next time and found to check fine. The waves of lengths 428 and 333 as measured the second series differed by a fraction of one percent from the rated Standard Wave length and it might have been supposed that the calibration curve of wavemeter was a little off at these points, but the next series showed them correctly measured, so the reason for the small error must have been due to inaccuracy in setting. The 375 meter wave was caught in neither series on account of the numerous broadcasting stations operating on wave lengths from 360 to 400 meters at that time of night, and offering too much interference.

When the local generating set is tuned to produce zero beat with the incoming wave signal it is then, as stated before, oscillating at a frequency equal to that of the incoming wave. The problem then is to measure this frequency by means of a wavemeter with a resonance indicator which is sensitive enough to allow the wavemeter to be so loosely coupled to the local generating set that it will not change the frequency as it is coming into resonance. This resonance indicator must not only be sensitive but must be of such a type that connecting it to the wavemeter will not change the capacity of the wavemeter and so



A

General Radio Company Wavemeter Type 105 D No. 152.

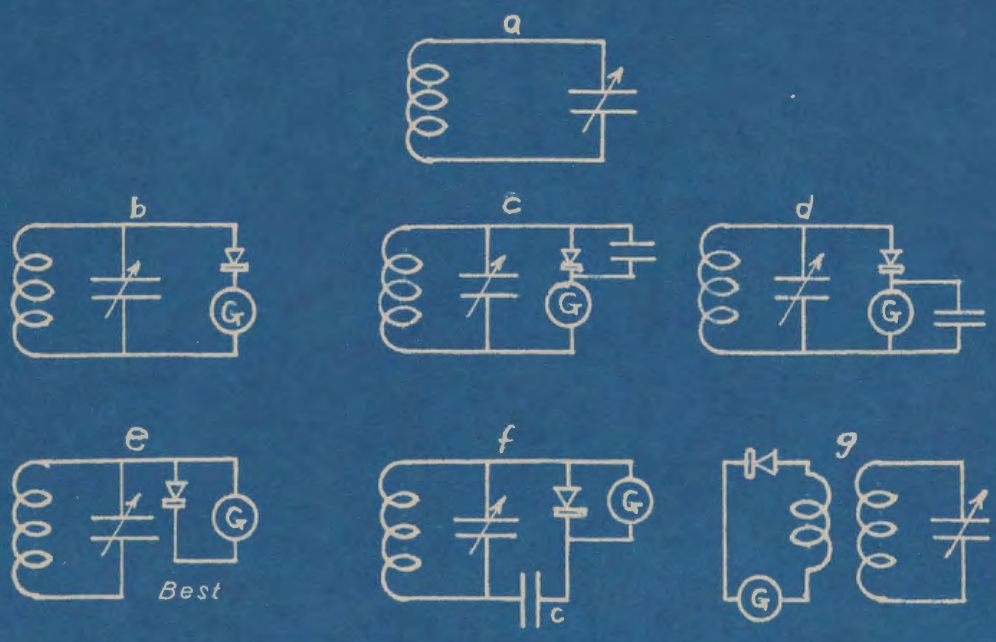


FIG. 2 VARIOUS WAVE-METER CIRCUITS
using detector and galvanometer

render its calibration useless. Many different types of resonance indicators have been experimented with and compared in order to find the one most suited for the above conditions. The schematic diagrams of the resonance indicating circuits used are shown in Figs. 2, 4, and 5.

Curve Sheet I is a reproduction of the calibration curves of coils A, B, and C of the wavemeter used which was a General Radio Company Wavemeter Type 105 D , Serial No. 152. The settings of the wavemeter dial as given herein may be checked with a fair degree of accuracy by referring to this Sheet. Fig.2A shows a schematic diagram of the wavemeter used.

RESONANCE CIRCUITS USING DETECTOR AND GALVANOMETER.

The various wavemeter circuits with resonance indicators using a crystal detector and a sensitive galvanometer are shown in Fig.2, diagrams b, c, d, e, f, and g. All six of these circuits are given in both Morecroft's "Principles of Radio Communication" page 786 , and Circular of the Bureau of Standards No.74 "Radio Instruments and Measurements" page 105 with a pair of phones in place of the galvanometer; and a table of relative audibility is the same given by both as follows:

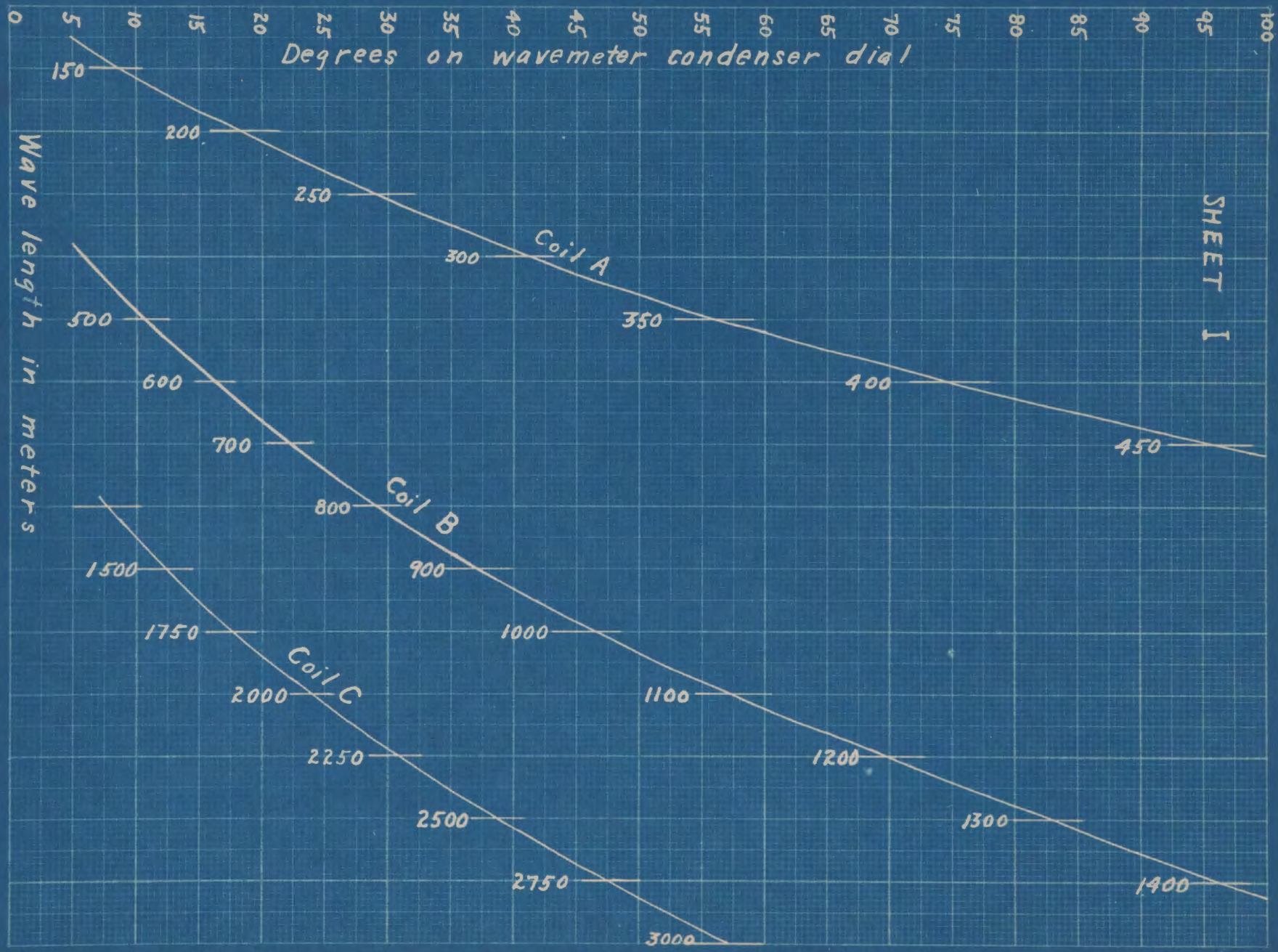
Circuit Letter	b	c	d	e	f	g
Relative Audibility	55	85	45	10	40	15 .

A sensitive galvanometer has an advantage over phones because it does not take as large a current to deflect it as to produce a click in the phones. Another advantage is that a maximum can be obtained with the galvanometer which cannot be heard in the phones on account of the slow change of current in the circuit. The galvanometer being thus more sensitive than

the phones makes possible by its use a much looser coupling. In many of the tests the phones and galvanometer were both put in series in the circuit in order to check one against the other. It was generally found that for a close enough coupling to cause the phones to click that the galvanometer would have already gone off the scale. The galvanometer scale was in about thirty divisions and its sensitivity was such that one volt through a million ohms would produce one division deflection.

METHOD OF COMPARING DIFFERENT RESONANCE INDICATING CIRCUITS.

It has been previously stated that when the local generating set was tuned to produce zero beat with an incoming standard wave signal that the setting of the generating set was carefully recorded for future use. Now when the local generating set is again adjusted to this recorded setting it is oscillating at the frequency of that particular standard wave. The coil of the wavemeter may be coupled with the inductance of this generating set and the condenser of the wavemeter varied until resonance is obtained. The different resonance indicating circuits are connected to the wavemeter and the wavemeter setting varied until resonance is indicated. As the generating set continues to oscillate at the same frequency the accuracy of the different resonance circuits may be compared by comparing the different settings of the wavemeter with the correct setting. The method used primarily in matching the two last series of standard waves was that shown in diagram "e" of figure 2, the crystal and galvanometer unilaterally connected to indicate resonance. As this method checked the calibration of the wavemeter with the standard waves it was considered correct and


Degrees on wavemeter condenser dial
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Wave length in meters
150
200
250
300
350
400
450
Coil A
500
600
700
800
900
1000
1100
1200
1300
1400
Coil B
1500
1750
2000
2250
2500
2750
3000
Coil C
SHEET I

the results obtained from the other methods may be compared with this .

RESULTS OBTAINED.

Generating set adjusted to produce zero beat with frequency of 550 meter wave.

Correct wavemeter setting as calibrated = 13.6

Settings by different resonance indicators.

Galvanometer and crystal direct connected (Fig. 2b)

Maximum deflection at 11.7, 11.5, 11.6, 11.5, 11.7

Mean 11.6

Phones put in series with the galvanometer in Fig. 2b.

Much larger maximum than before at 11.3, 11.3, 11.3

Mean 11.3

This shows that the capacity and inductance of the galvanometer across the circuit affected the calibration of the wavemeter. The phones in series with the galvanometer changed this calibration still more.

Galvanometer and crystal unilaterally connected (Fig.2e)

Maximum deflection at 13.5, 13.6, 13.7, 13.6

Mean 13.6

Phones connected in series with galvanometer in Fig. 2e.

Maximum deflection of galvanometer is the same.

Two clicks in phones approach each other as coupling is decreased.

Wavemeter coil beside generating set inductance

Coupling 0" two clicks at 11.2 and 20.5

Coupling $\frac{1}{2}$" two clicks at 12.5 and 19.0

Coupling 1" two clicks at 13 and 15.5

Coupling $1\frac{1}{4}$" two clicks at 13.5 and 13.8

In all the above couplings the galvanometer was off scale, but with a coupling of 24" the maximum deflection of the gal. was at 13.5, 13.6, 13.6, 13.7 the mean being 13.6 .

It is seen here that the two phone clicks vary inversely, in their distance apart, as the coupling. It might also be well stated here that the intensity of the click varies inversely as the coupling and at a point where it would be expected that the two clicks had approached to one click, the one is so faint as to be inaudible. It will also be noticed that the correct setting of the wavemeter is always between the two clicks for any coupling, but this does not necessarily mean that the correct setting of the wavemeter is the arithmetical mean of the points of the two clicks. There are two frequencies at which closely coupled circuits will be in resonance. These two frequencies mark the points at which the clicks are heard. The disadvantage of this method is that very close coupling is necessary.

BOLOMETER method as shown in Fig. 5d.

In using the bolometer method it is necessary to have very close coupling. With the close coupling there are as before two frequencies of resonance and there are two maximums deflections of the galvanometer in the bolometer. The principle of the bolometer is that of a balanced Wheatstone's Bridge one arm of which is a small high resistance light globe or something similar. As the wavemeter comes into resonance with the generating set a current flows through the wavemeter circuit. As

the small light globe is in the wavemeter circuit it becomes heated which changes its resistance and unbalances the bridge which in turn causes the galvanometer to be deflected. But as it takes quite a current to change the resistance of the light appreciably, close coupling is necessary.

Two maximum deflections of gal. by bolometer at 13.8 and 14.1

It is also seen that the bolometer which contains the battery, bridge, galvanometer, and globe changes the capacity of the wavemeter circuit and gives a slightly different setting for the mean maximum deflection at about 13.9.

THERMOCOUPLE and galvanometer method as shown in Fig. 5a.

Another method tried was that of having a crossed wire thermoelement in the wavemeter circuit and a sensitive galvanometer to measure the current generated at the junction due to the heat of the high frequency current flowing. Several thermocouples were made useing nichrome and copper, nichrome and constantan, tungsten and copper and tungsten and nichrome. The one giving the best results was that made nichrome and copper. But this did not prove satisfactory. The nichrome wire was 0.0014 in. in diameter and the copper wire about 0.0025 in. At some instants the deflection would be great and it would seem to work fine but then in the next instant the current would seem to be cut off and it looked as if something was wrong. The large current was due possibly to some oxide which was a poor conductor getting between the wires and then when the oxide burned away the current had nothing to heat. The wires were soldered together with a tiny bit of solder but the current in the wavemeter was so small as not to heat up the joint enough to

to get a deflection. The wires getting hot would take some time to heat the joint and such a thermocouple was considered unsatisfactory. A thermocouple was received from the General Radio Company and it proved more satisfactory than any of the home made ones for it had much smaller wire in it. But it was slow to reach a maximum. If the correct point of resonance could be found the thermocouple would gradually rise in temperature and the galvanometer would gradually increase its deflection. This gradual increase soon burnt out the wires of the thermocouple and rendered it useless. This method is satisfactory for large currents for it does give the correct setting of the wavemeter but for small currents it is too hard to find the maximum point and after it is found the wires which necessarily have to be small so the point can be found are likely to become so hot as to be burned out.

Maximum gal. deflection at 13.5, 13.6, 13.7, Mean = 13.6

NEON TUBE, shown in Fig.5c.

The principle of the Neon Tube is to glow when the wavemeter comes into resonance due to the ionization of the gas it contains by the electric potential impressed on it. This scheme is good only for testing high power sets and is not strictly accurate then, although it is a simple quick method of determination. The accuracy obtainable depends on the ability of the observer to judge the maximum brightness. The accuracy of this sort of measurement is still further decreased in that close coupling is required. No results could be obtained with the Neon tube in this test on account of the use of such low power.

Phones unilateral with crystal and buzzer.(See Fig.5d).

After the coupling of the wavemeter has been decreased until the phone clicks are inaudible the point of resonance may be obtained by putting a buzzer across the wavemeter circuit and modulating its frequency thereby. At the point of maximum resonance there will be a sharp sensitive point at which the pitch of the buzzer will be heard. It has been found that this point differs very slightly from the correct value. The difference is due perhaps to the inductance and capacity of the buzzer across the circuit. The inductance of the buzzer is eliminated to a certain extent by putting a small high resistance non-inductive shunt across the coils of the buzzer as shown in the figure.

Settings with this connection at 12.9, 13.0, and 13.1

Mean = 13.0

Phones direct with crystal and buzzer as in Fig.5e.

In using this method there is a larger current flowing through the phones and the pitch of the buzzer is heard over a considerable range of the wavemeter dial. Since no sharp point can be determined this method is considered useless. The reason there is no sharp point is that the buzzer is of itself setting up a pulsating current in the phones and this pulsating current continues whether the wavemeter is in resonance or not .

Phones direct with crystal and buzzer in series as in Fig.5f

By changing the connections of the method mentioned

above and putting the buzzer in series so that it only serves to make and break the circuit of the phones the pitch of the buzz will be heard loudest at the maximum point of resonance. The accuracy of this method depends upon the ear and the judgement of the loudest point. The loudest point is not by any means at the point of the correct calibration for the wavemeter constants are changed by putting the phones directly across the circuit.

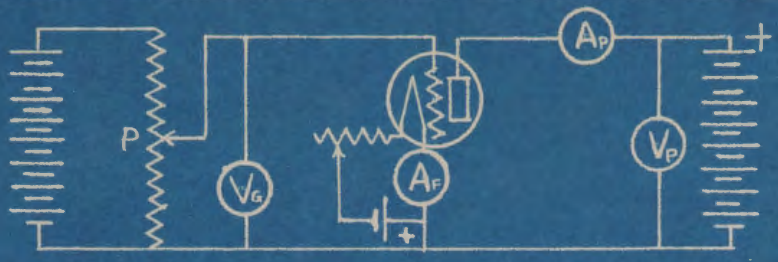
Mean wavemeter settings with this connection at 8.0

The crystal and galvanometer unilaterally connected has been the best method so far discussed. It was thought that a vacuum tube would be useful to take the place of the crystal, so a WD11 1½ volt tube was obtained and tried in a number of different methods of connection. Before using the tube, in order to become thoroughly familiar with its actions as many direct current characteristic curves were plotted for it as was thought necessary.

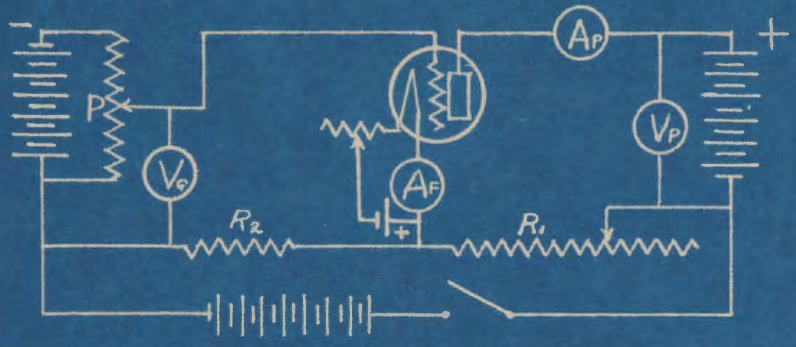
CHARACTERISTIC CURVES OF WD11 VACUUM TUBE

The data for these curves, as it was not directly a part of the thesis, are given in the Appendix.

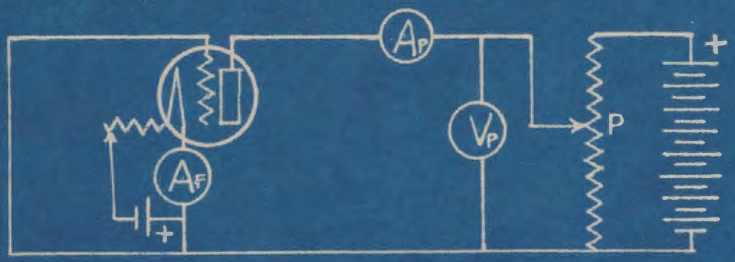
The first curves plotted were the so called "static" characteristiccurves which show how the plate current varies as the grid potential is varied, the plate potential being constant while the series of points for the curve is being obtained. The same curves are taken for several values of plate potential and filament current. These "static"



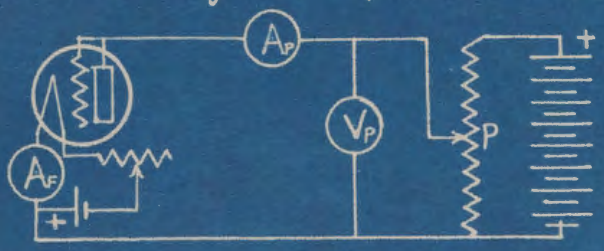
A = Plate current against grid potential.



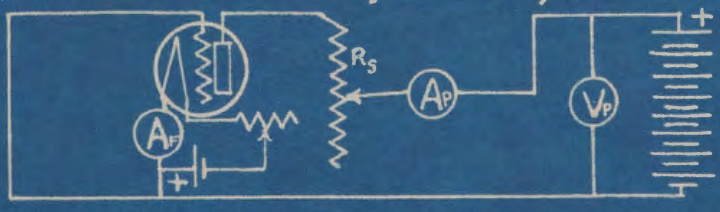
B = Voltage Amplification Factor.



C = Plate current against plate voltage.

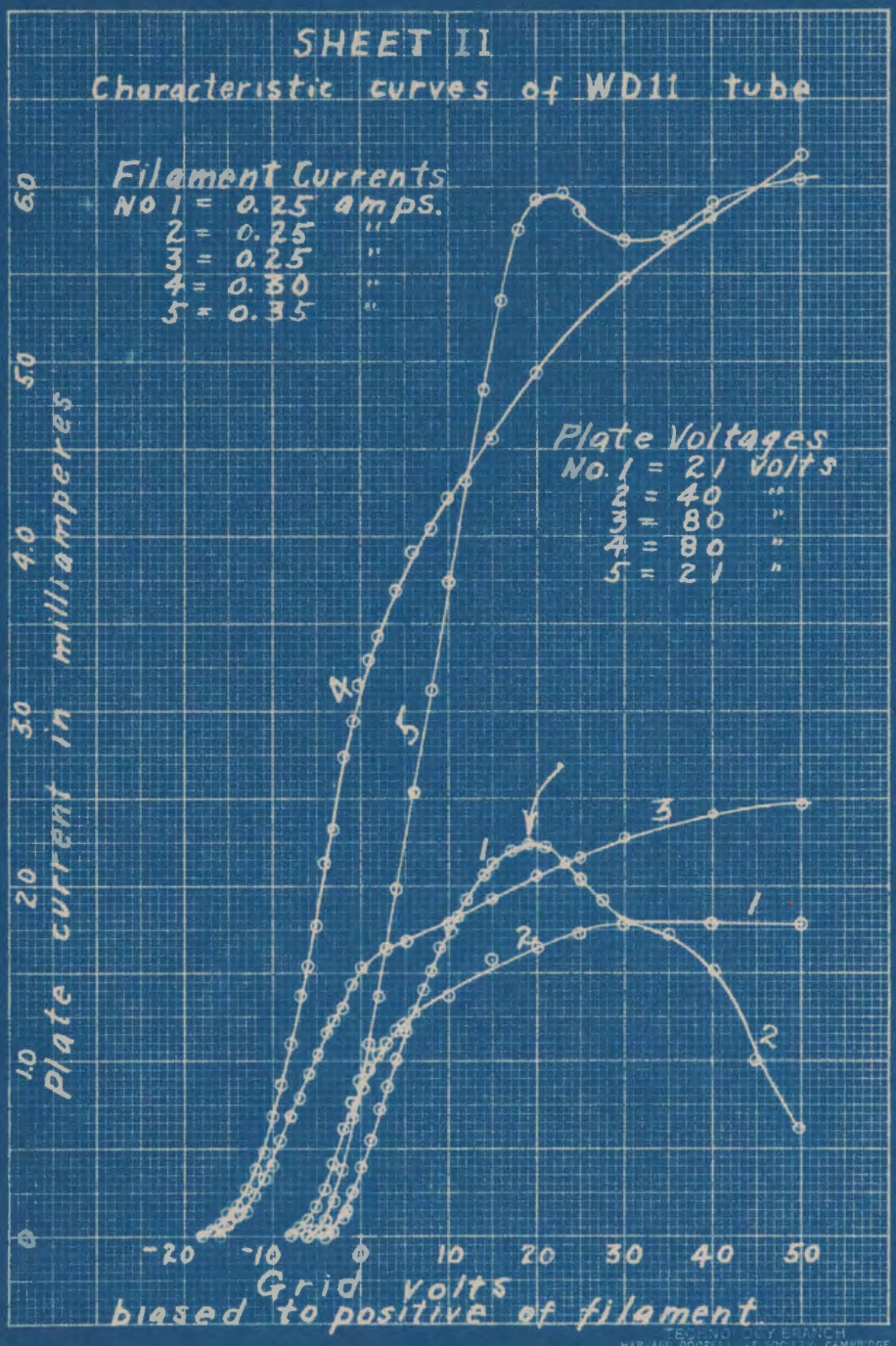


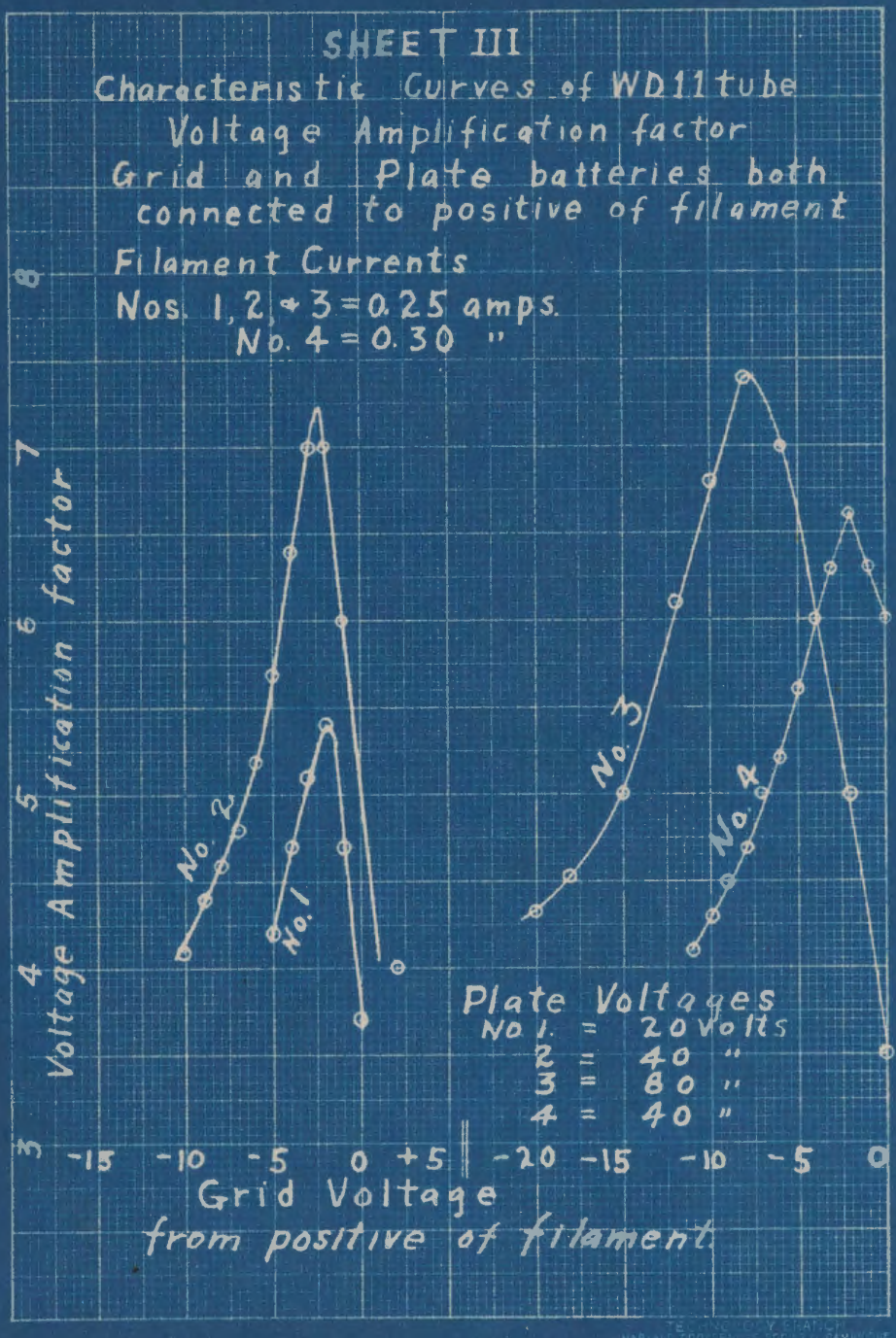
D = Plate current against plate voltage.



E = Resistance of plate circuit.

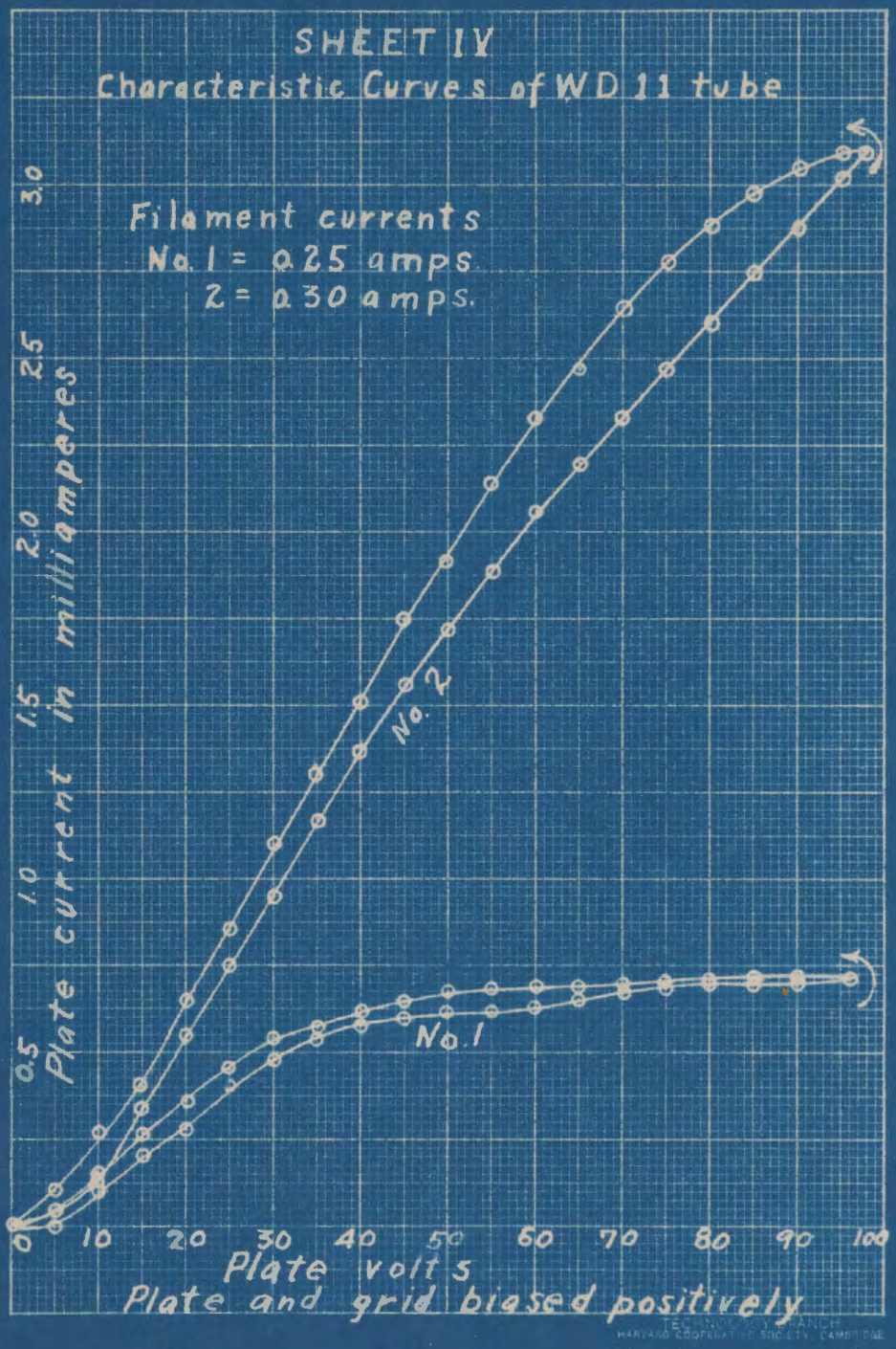
FIG. 3 CHARACTERISTIC CURVE CONNECTIONS.

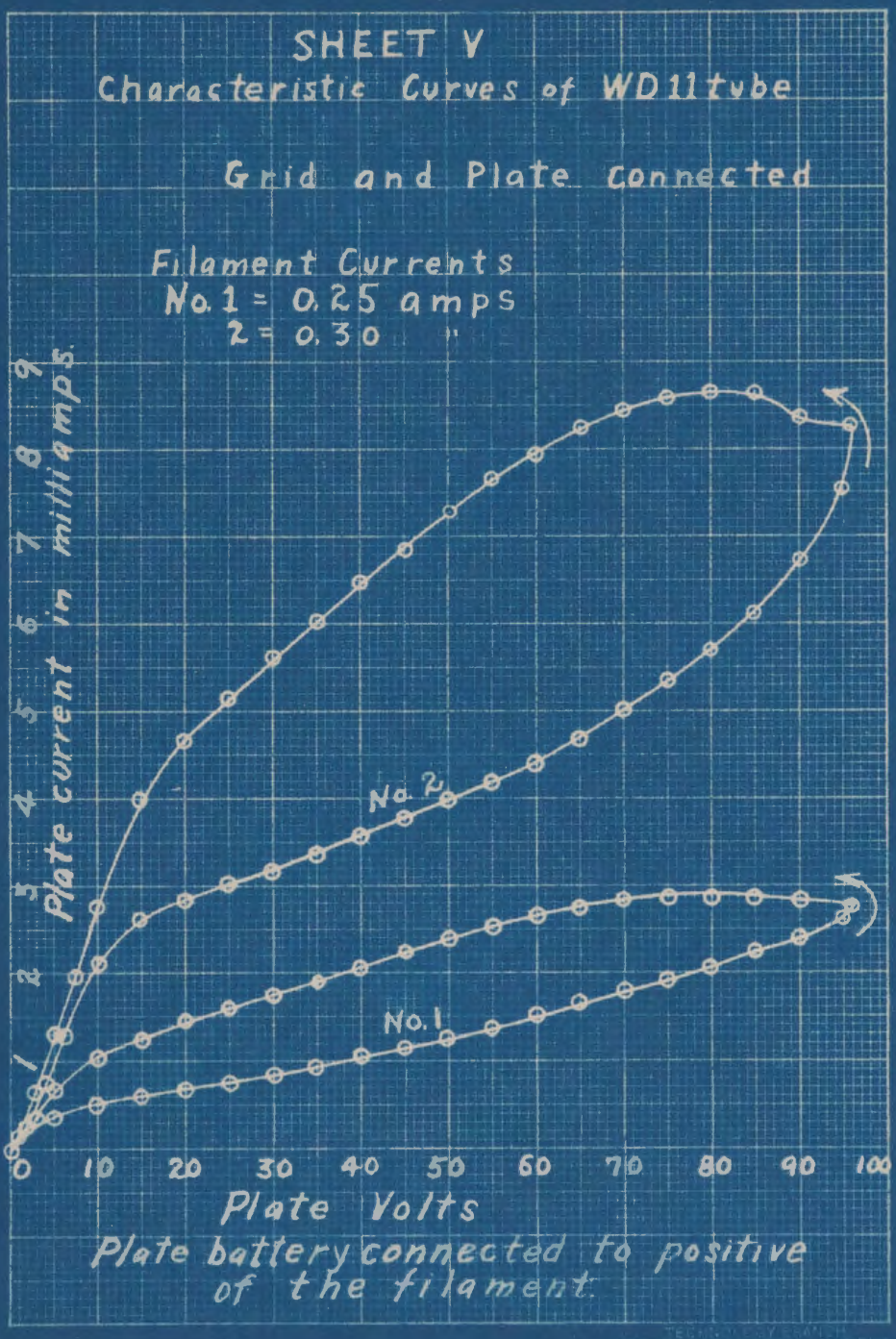

SHEET II
Characteristic curves of WD11 tube
Filament Currents
No 1 = 0.25 amps.
2 = 0.25 "
3 = 0.25 "
4 = 0.30 "
5 = 0.35 "
Plate Voltages
No. 1 = 21 Volts
2 = 40 "
3 = 80 "
4 = 80 "
5 = 21 "
Plate current in milliamperes
0
10
20
30
40
50
60
-20
-10
0
10
20
30
40
50
Grid volts
biased to positive of filament.
4
5
3
1
1
2
2


SHEET III
Characteristic Curves of WD11 tube
Voltage Amplification factor
Grid and Plate batteries both connected to positive of filament
Filament Currents
Nos. 1, 2 & 3 = 0.25 amps.
No. 4 = 0.30 "
Voltage Amplification factor
3
4
5
6
7
8
No. 1
No. 2
No. 3
No. 4
Plate Voltages
No 1. = 20 Volts
2 = 40 "
3 = 80 "
4 = 40 "
-15 -10 -5 0 +5
-20 -15 -10 -5 0
Grid Voltage
from positive of filament

characteristic curves are shown on SHEET II, the connections of the apparatus for obtaining these curves being given in Fig.3A. The rapid curvature of Curve 1 at about -3 volts grid potential marks the best point for the rectifying and detecting action of the tube. The straight part of the curve shows the best conditions under which the tube will amplify. The amplification factor depends upon the slope of the straight part of this curve. The arrow points out a well defined hump in curve one which is due to the presence of gas in the tube. It will be noticed that this hump appears again in Curve 5.

The voltage amplification factor is plotted on SHEET III. The connections for obtaining this factor are shown in Fig.3B. This diagram of connections was obtained from Morecroft's "Principles of Radio Communication" page 417 in which the formula is given, Voltage Amplification Factor = $\frac{R_1}{R_2}$, where R_1 and R_2 are the resistances as shown in the figure. Careful observation will show that this method of obtaining the voltage amplification factor is a Wheatstone's Bridge in which one arm is from the grid to the filament, another from the plate to the filament and the two other arms the resistances R_1 and R_2. R_2 is kept constant at 10 ohms and for the different grid potentials R_1 is adjusted so that on closing the switch there is no change in deflection of the ammeter or galvanometer A_p. The Plate potential and filament current are kept constant while the series of points for any one curve is being taken. The same curves are taken for several values of plate potential and filament current. It will be noticed that in each case the peak or maximum amplification factor corresponds to the steepest


SHEET IV
Characteristic Curves of WD 11 tube
Filament currents
No. 1 = 0.25 amps.
2 = 0.30 amps.
Plate current in milliamperes
0.5
1.0
1.5
2.0
2.5
3.0
No. 2
No. 1
0
10
20
30
40
50
60
70
80
90
100
Plate volts
Plate and grid biased positively

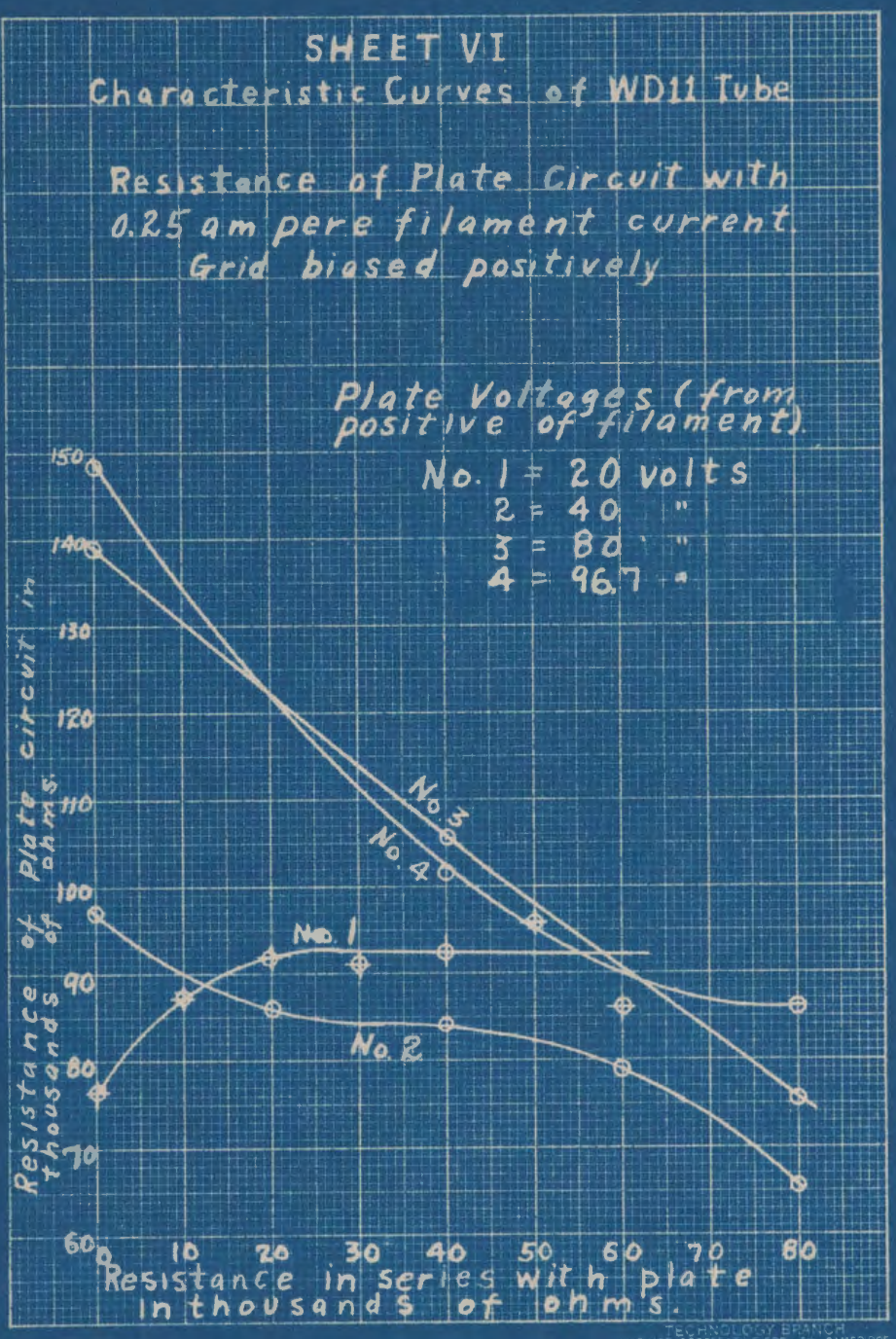

SHEET V
Characteristic Curves of WD11 tube
Grid and Plate connected
Filament Currents
No. 1 = 0.25 amps
2 = 0.30 "
Plate current in milliamps.
1 2 3 4 5 6 7 8 9
No. 2
No. 1
0 10 20 30 40 50 60 70 80 90 100
Plate Volts
Plate battery connected to positive of the filament.

straight part of the "static" curve.

SHEET IV shows the plate current characteristics in which the grid potential is kept constant at the same potential as the positive of the filament while the plate voltage is varied. The connections for obtaining such curves are shown in Fig. 3C. It will be noticed that there is an increase in the plate current on coming down to what there was going up. This makes the curve form a loop which is known as the hysteresis loop. These curves were plotted for two different filament currents.

This hysteresis loop is much better defined in the curves on SHEET V in which the grid and plate are connected together as shown in Fig.3D. The effect of the gas present so altered the emitting properties of the filament that the saturation current was appreciably different with increasing and decreasing plate voltages. This probably shows a change in the number of electrons emitted from the filament due to the ionization of the gas present. The filament current was kept constant for the series of points of each curve. The curve was plotted for two different filament currents.

The resistance of the Plate circuit is shown to vary as other resistance R_s is added to the plate circuit. These variations are shown on curve SHEETS VI and VII. The connections used in obtaining data for these curves are shown in Fig.3E. It will be noticed that in some cases the resistance of the plate circuit increases with added resistance is series while in other cases it decreases. This is probably due to the fact that as resistance is added there is a certain drop of potential in



TECHNOLOGY BRANCH
HARVARD COOPERATIVE SOCIETY, CAMBRIDGE

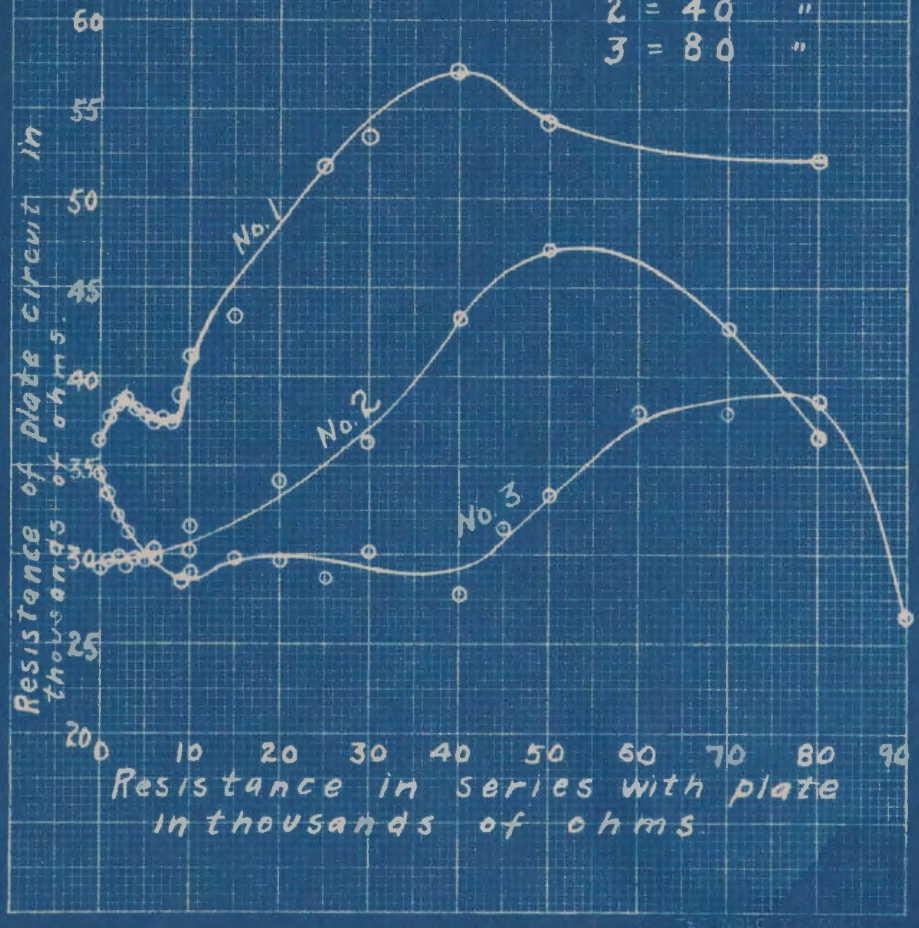
SHEET VII

Characteristic Curves of WD11 tube

Resistance of Plate Circuit with 0.30 ampere filament current. Grid biased positively

Plate Voltages (from positive of filament)

No. 1 = 20 volts.
2 = 40 "
3 = 80 "



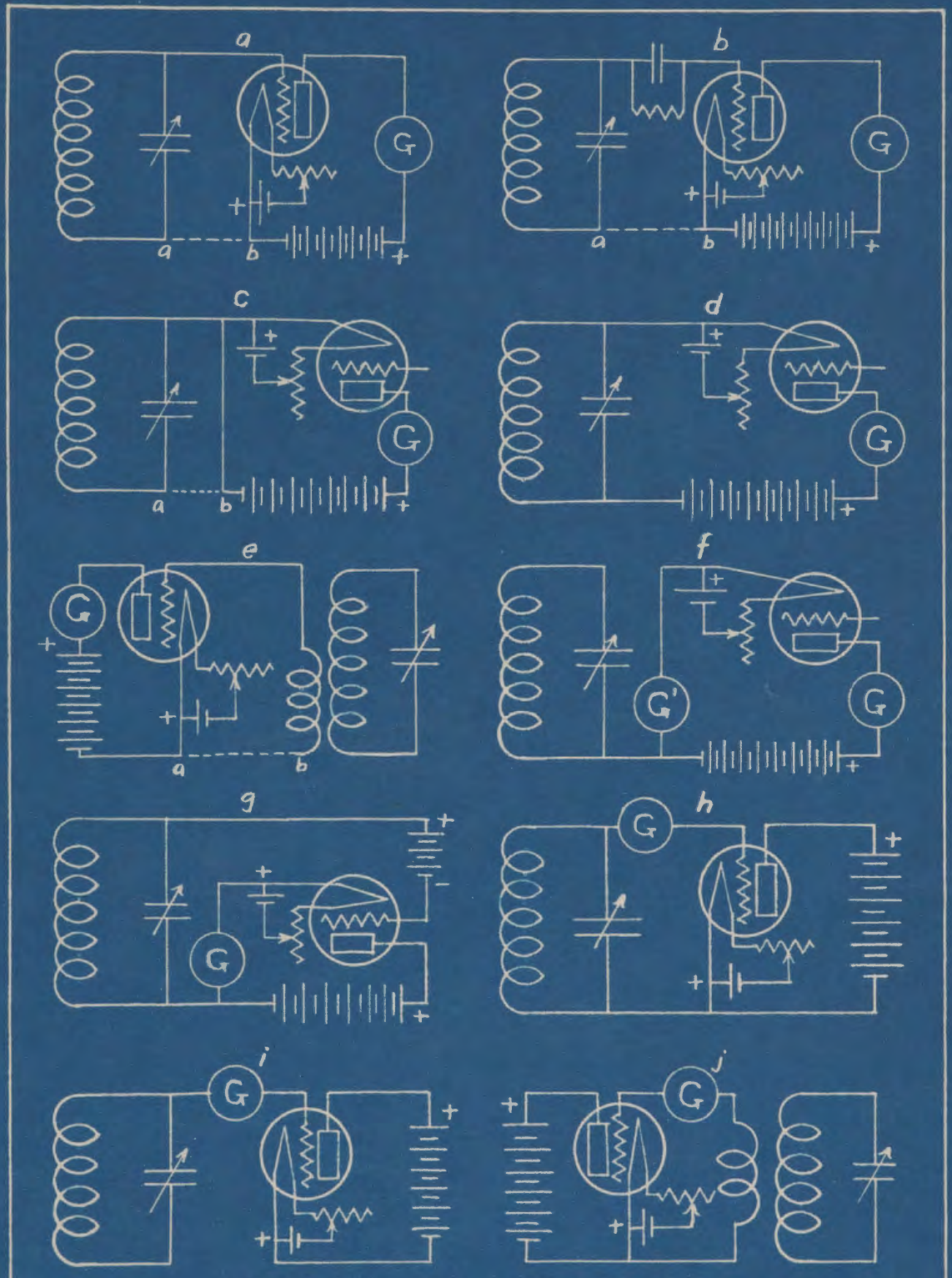


FIG. 4 VARIOUS WAVEMETER CIRCUITS
using vacuum tube and galvanometer

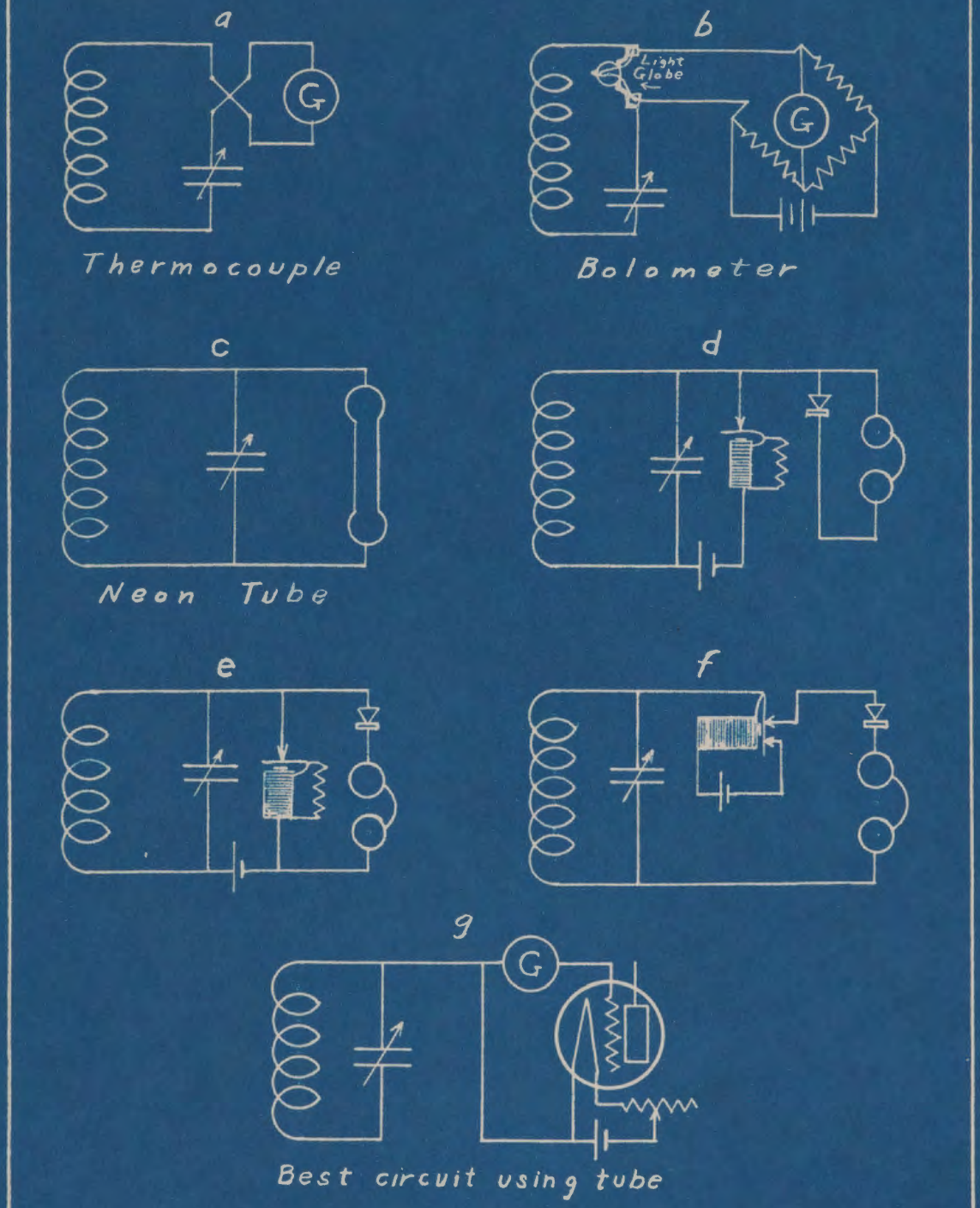


FIG. 5 VARIOUS WAVEMETER CIRCUITS

the added resistance and this is subtracted from the plate potential; but as the plate circuit does not follow Ohm's law and the current does not vary directly as the voltage, but varies as shown by the curves on SHEET IV, the resistance will also vary as a function of these curves on SHEET IV.

Now that the characteristic curves were available so that any desirable or critical point of the tube's action could be readily obtained the next thing done was to try different methods of connecting the tube to the wavemeter to indicate resonance. The principal methods tried are shown in Fig.4 (a, b, c, d, e, f, g, h, i, and j) and Fig. 5g. Only a few of these methods were tried on the particular frequency now being measured which is the frequency of the 550 meter wave at which frequency the generating set is oscillating.

Resonance circuit as shown in Fig.4a without "ab" connected.

There was a slight decrease in current, the maximum of which was hard to locate at 13.4 . This decrease in current in the galvanometer in the plate circuit showed that the grid was getting a negative charge.

When "ab" was connected it changed the charge of the grid and there was no point at which the galvanometer indicated resonance.

Circuit as shown in Fig.4b without "ab" connected.

This connection only differs from that shown in Fig.4a in that a grid leak of one megohm and a condenser of 0.00025 microfarad capacity is put in the grid circuit. As the wavemeter

dial was rotated there was a point very sharp and sensitive, at which point the galvanometer almost went back to zero. This point was at 13.6 on the wavemeter dial. This is the correct setting for the frequency produced but it is unsatisfactory in that the galvanometer has to be read at a minimum point and not at a maximum. This makes it very difficult to read.

When "ab" is connected there is no change in the deflection of the galvanometer for any point of the wavemeter dial. However if a crystal is put in "ab" the galvanometer will go to a mimimum point at 13.3. This is nothing but the direct crystal and galvanometer scheme as shown previously in Fig.2b except that the capacity of the circuit is changed by the capacity of the condenser on the grid, and the capacity of the tube itself. There is no advantage in using this method for the crystal can be used without the tube.

Circuit as shown in Fig.4c without "ab" connected.

Small mimimum deflection hard to locate at 13.3
With "ab" connected it would seem that the shunting of the condenser would prevent the wavemeter from coming into to resonance but this is not the case. The wavemeter comes into resonance as shown by a small deflection, miniumn at 13.2.

No other methods were tried for this 550 meter wave. The oscillating set was next adjusted to oscillate at the frequency of a 680 meter wave, several methods of resonance indication tried again.

Generating set adjusted to produce zero beat
with frequency of 680 meter wave.

For 680 M. Correct wavemeter setting as calibrated = 21.2

Settings by different resonance indicators.

Galvanometer and crystal unilaterally connected (Fig. 2e)

Maximum deflection at 21.2, 21.1, 21.3 . Mean = 21.2

Phones connected in series with galvanometer in Fig. 2e.

For close coupling two clicks at 20.6 and 21.9

For looser coupling two clicks at 21.0 and 21.4

Galvanometer and crystal direct connected (Fig. 2b)

Maximum deflection at 19.5, 19.2, 19.1, 19.8, 19.5

Mean = 19.4

Phones connected in series with the galvanometer in Fig. 2b

For close coupling two clicks at 18.7 and 19.5

Bolometer method (Fig.5d).

For close coupling mean maximum deflection at 21.9

Phones direct with crystal and buzzer in series as in Fig. 5f.

Loudest pitch of buzz heard at setting of 14.0

Phones unilateral with crystal and buzzer. (See Fig.5d).

Sensitive and sharp change of pitch at 20.9

Thermocouple and galvanometer method as shown in Fig. 5a.

Mean maximum deflection of galvanometer at 21.2

It will be observed that the results obtained by different methods for the 680 meter wave agree comparitively with those results for the 550 meter wave.

The two above waves were measured with the use of Coil B of the wavemeter. In order to try out the different methods with the other coils wavelengths of 400 and 1500 meters were measured.

Generating set adjusted to produce zero beat
with frequency of 1500 meter wave.
Correct wavemeter setting as calibrated = 12.5 with Coil C.
Settings by different resonance indicators.

Galvanometer and crystal unilaterally connected (Fig. 2e)
Mean maximum deflection at 12.5 using coil C.
Phones connected in series with galvanometer in Fig.2e.
For close coupling two clicks at 12.0 and 13.8
For looser coupling two clicks at 12.4 and 12.5
Galvanometer and crystal direct connected (Fig.2b).
Mean maximum deflection at 21.0
Bolometer method (Fig.5d)
For close coupling two maximums at 12.5 and 14.5
For looser coupling two maximums at 12.9 and 13.2
Circuit as shown in Fig.4a without "ab" connected.
Largest decrease in current at 12.2, 12.5, 12.7, 12.6
Mean = 12.5

This is the correct setting of the wavemeter but it is very difficult to obtain, due to the fact that the dial must be turned so slowly. If the dial is turned rapidly the varying charges on the grid give deflections first positive and then negative. However with very careful slow setting the largest decrease may be obtained. One other disadvantage of this method is that body capacity has a considerable effect and this is disagreeable. If the connection "ab" is added to this circuit the deflection is cut out due to a negative charge on the grid and no results can be obtained.

Generating set adjusted to produce zero beat
with frequency of 400 meter wave.
Correct wavemeter setting as calibrated = 75.0 with coil A.
Settings by different resonance indicators.

Galvanometer and crystal unilaterally connected (Fig.2e)

Large maximum deflection at 75.0 using coil A.

Galvanometer and crystal directly connected (Fig.2b)

Much larger maximum deflection at 74.3

For closer coupling maximum deflection is at 76.7

Circuit as shown in Fig.4a without "ab".

With 0.25 amp.filament current

Maximum deflection at 73.5, 73.4, 73.3. Mean = 73.4

Minimum deflection at 75.8, 75.9, 76.0. Mean = 75.9

With 0.30 amp. filament current

Maximum deflection at 72.6, 72.5, 72.7. Mean = 72.6

Minimum deflection at 76.0, 76.6, 76.3. Mean = 76.3

With 0.20 amp. filament current

Maximum deflection at 73.4, 73.2, 73.6. Mean = 73.4

Minimum deflection at 76.5, 76.4, 76.6. Mean = 76.5

These maximum and minimum deflections are apparently at the points which correspond to the two resonance frequencies of the closely coupled circuits, since in each case the correct setting is between the maximum and minimum points. One point is maximum and the other minimum since they correspond to the points of increasing and decreasing capacity of the wavemeter circuit for resonance.

Circuit as shown in Fig.4e without "ab" connected

For close coupling small minimum deflection at 75.0

Circuit of Fig. 4e with "ab" connected

Small increase in plate current due to positive charge on grid, but no change of deflection at point of resonance.

COMPARATIVE TEST

Since there were so many methods tried of resonance indicators and such different results obtained with them, it was thought advisable to make a comparative test by locating the point of resonance of the same wave frequency using all the methods. The wave frequency chosen for this particular comparative test was that of a 600 meter wave, since the calibration of the wavemeter at this point had been successfully checked, and found correct.

Generating set adjusted to produce zero beat with frequency of 600 meter wave.

Correct wavemeter setting as checked = 16.4 with coil B.

Settings by the different resonance indicators.

Galvanometer and crystal directly connected as in Fig. 2b

Very large deflection with very loose coupling at 15.0

Phones put in series with galvanometer in circuit of Fig. 2b

No clicks in phones but for very loose coupling the maximum deflection is at 14.7.

Condenser across crystal directly connected as in Fig. 2c

Small maximum deflection at 14.0

Galvanometer replaced by phones in circuit of Fig. 2c

Loudest clicks by breaking the detector circuit at 11.0

Phones put in series with Gal. in circuit of Fig. 2c

Small deflection at 14.0 . Not sensitive.

Condenser across galvanometer directly connected as in Fig. 2d

Large maximum at 12.5 for loose coupling. A little slow.

Galvanometer replaced by phones in circuit of Fig. 2d

No click nor any signs of a maximum apparent.

Phones in series with galvanometer in circuit of Fig. 2d.

Very large maximum for very loose coupling at 10.5.

Galvanometer and crystal unilaterally connected as in Fig. 2e.

Very sensitive maximum deflection at 16.4 . Best method.

Galvanometer replaced by phones in circuit of Fig. 2e

For close coupling two clicks at 16.5 and 18.1

Phones in series with galvanometer in circuit of Fig. 2e

For loose coupling maximum deflection at 16.4

For close coupling two clicks at 16.5 and 18.1

Condenser in series with crystal, connected as in Fig. 2f.

For loose coupling maximum deflection at 16.4 . Correct method but not as sensitive as unilateral connection .

Galvanometer replaced by phones in circuit of Fig. 2f.

For close coupling two clicks at 16.3 and 18.0 the one at 16.3 being much louder.

Phones in series with galvanometer in circuit of Fig. 2f.

For loose coupling maximum deflection at 16.4

For close coupling two clicks at 16.5 and 19.0 the click at 16.5 being much louder.

Inductively coupled resonance circuit as shown in Fig. 2g.

Wavemeter coil between oscillating coil and resonance coil

Maximum deflection sensitive at 16.4. Good.

Resonance coil between oscillating coil and wavemeter coil

Minimum deflection sensitive at 16.5

Galvanometer replaced by phones in circuit of Fig. 2g.

For close coupling two clicks at 16.8 and 17.4

the click at 17.4 being much louder than the other.

Phones in series with galvanometer in circuit of Fig. 2g.

For loose coupling maximum deflection of gal. at 16.4

For close coupling two clicks at 16.7 and 16.8

For closer coupling two clicks at 16.8 and 17.4

For loose coupling again

Maximum deflection of galvanometer at 16.5

Minimum deflection of galvanometer at 16.6

Thermocouple and galvanometer as in Fig. 5a

For medium close coupling maximum deflection at 16.4

Bolometer method as shown in Fig. 5b

For close coupling mean maximum deflection at 16.8

Neon Tube as in Fig. 5c

No results on account of low power.

Phones unilat. with crystal, buzz and battery direct as in Fig.5d.

Maximum resonance by pitch of buzz at 15.7

Phones direct with crystal, buzz and battery direct as in Fig.5e.

Pitch of buzz over entire scale but no maximum obtainable.

Phones direct with crystal and buzzer in series as in Fig. 5f.

Loudest pitch of breaking circuit at 11.0

Circuit using tube as in Fig. 4a without "ab" connected.

Small deflection minimum at 16.5 for close coupling.

Same circuit of Fig. 4a with "ab" connected

No results for all deflections are eliminated.

Circuit using tube as in Fig. 4b without "ab" connected.

For close coupling small minimum deflection at 16.5

Same circuit as in Fig. 4b with "ab" connected

No deflections could be obtained.

Circuit using tube as in Fig. 4c without "ab" connected.

For close coupling small minimum deflection at 16.3

No results obtained when grid is biased either + or − .

Same circuit as in Fig. 4c with "ab" connected.

For close coupling very weak minimum deflection at 16.0

Circuit using tube as in Fig. 4d.

For close coupling weak minimum deflection at 16.2

No results obtained by biasing grid either way.

Circuit using tube as in Fig. 4e without "ab" connected

For close coupling two minimums as 15.8 and 17.5 the one at 17.5 being so weak as to be almost unnoticeable.

Same circuit as in Fig. 4e with "ab" connected

Increased plate current due to positive charge on grid but no results from change of wavemeter setting.

No results obtained with coil connected to filament and free grid.

Circuit using tube as in Fig. 4f with two galvanometers.

Small minimum on galvanometer "G" at 16.1

Good large minimum of 4 divisions at 16.1 on galvanometer " G' ".

Circuit using tube as in Fig. 4g.(Fil.Current = 0.28 amp.)

Grid Volts by C bat.	Galvanometer "G"(See Fig.)	Galvanometer between plate and "B" bat.	At Point
-8	No deflection	No.deflection	——
-6	20 divs. maximum	No results	16.4
-4	5 divs. maximum	No results	16.4
-2	No results	No results	——
0	Weak minimum	Weak minimum	16.4
2	No results	No results	——

Best results obtained with galvanometer "G" and a "C" battery putting a charge of -6 volts on the grid for here a large maximum instead of a minimum deflection is obtained.

Circuit using tube as in Fig. 4h

For loose coupling maximum deflection of 15 divisions at 16.4 . Very sensitive and correct.

Circuit using tube as in Fig. 4i

No deflection unless filament is connected to side of galvanometer opposite the grid, then a maximum deflection of about 15 divisions of galvanometer at 16.4

Circuit using tube and coupling coil as in Fig. 4j

Maximum deflection of 5 divisions at 16.4

Circuit using tube without "B" battery as in Fig. 5g

Maximum deflection of 25 divisions at 16.4

About same results for direct connection at 16.5

B battery connected and deflection lessened to 15 divisions.

Circuit shown in Fig.5g without the B battery is the best resonance indicating circuit tried in which the vacuum tube is used. This however is not near as sensitive as the crystal connections.

EXPLANATIONS.

The crystal and galvanometer directly connected as shown in Fig. 2b is the most sensitive and probably the most generally used method of all but the leads going to the detector and galvanometer may possess considerable capacity, and as this capacity is parallel to the wavemeter condenser the calibration of the wavemeter will no longer apply. The wavemeter may be calibrated for any leads and phones etc. but if these are changed the calibration is useless. That the calibration is changed by different indicators in this resonance circuit is shown by the fact that the galvanometer did not read the same when the phones were in series with it that it did without the phones.

With the "unilateral" connection shown in Fig. 2e the wavemeter constants are unaltered. This is shown by the fact that the galvanometer gave the maximum point for the same setting of the wavemeter either with or without the phones in series. The action of this connection is one of magnetic induction, in which the high frequency magnetic field links also the closed loop of the detector circuit. The coupling being so loose prevents this circuit from having any effect on the wavemeter's calibration. Since this method is fairly sensitive (although not near so much as the direct connection) and does not have any

effect on the wavemeter calibration it was considered the best method for the present use.

The action of the circuits shown in Figs. 2c, 2d, and 2f is that of trapping a charge on one condenser plate during the passage of a wave train (by means of the crystal rectifier). When the condenser discharges the sudden current either causes a click in the phones or a deflection of the galvanometer depending on which is used.

Morecroft's "Principles of Radio Communication " page 787 explains the action of circuits 2c and 2f as follows :

In circuit of Fig.2c "if we assume that the detector will permit current to flow downward, but not upward, it is evident that a positive charge will accumulate on the lower condenser plate during the passage of a wavetrain. After the group has passed the condenser discharges downward through the phones (it cannot discharge upward through the detector) and up through the inductance of the wavemeter circuit until the charges on its plates are neutralized." If a galvanometer is used in stead of phones as mentioned the point of maximum discharge will produce maximum deflection of the galvanometer.

"In circuit No.(Fig.2f) the charge is trapped on one plate of the condenser C in the phone detector circuit. If we again assume the detector to be conducting for downward flowing current then the right hand plate of the condenser will accumulate a positive charge. Current will also flow through it in the opposite direction through the phones, but with difficulty due to greater impedance of the phones. The condenser charge, caused

by the asymmetrical flow of current, is discharged upward through the phones (it cannot pass through the detector) and causes the phones to click once per wave train as in previous circuits."

The action of circuit 2d is very similar to that of 2b.

It will be noticed by referring to the results obtained with methods of Figs. 2c and 2d that they effected to a considerable extent the calibration of the wavemeter by putting a capacity in parallel with the wavemeter condenser.

Circuit 2f gave almost as good results as the unilateral circuit 2e since its effect on the calibration was so small as to be negligible, but it was not quite as sensitive.

The inductively coupled circuit of Fig.2g is fairly sensitive and since it has no direct connection with the wavemeter does not affect its calibration. This circuit however is better suited to large currents. It will be noticed that from the results obtained this method may be used to get either a maximum or a minimum deflection of the galvanometer. The maximum deflection occurs when the wavemeter coil is placed between the oscillating coil and the resonance coil, and the maximum is due to the current induced in the resonance coil by the current in the wavemeter coil at the point of resonance with the generating set. The minimum deflection occurs when the resonance coil is placed between the oscillating coil and the wavemeter coil and is due to the fact that the current which is induced in the resonance coil by the generating set is decreased on account of the absorption of energy by the wavemeter as it comes into resonance.

The thermocouple has the chief disadvantage that it must be closely coupled in order to cause a deflection. For small currents it is too slow in action on account of the time it requires to heat the crossed wires.

The bolometer has about the same disadvantages as the thermocouple and would not be recommended for small currents.

The Neon tube cannot be used for small currents as before stated and explained.

The phones unilaterally connected with crystal and buzzer proves a very satisfactory method for indicating resonance but it has the disadvantage that the inductance and capacity of the buzzer across the wavemeter effect its calibration slightly. This is a good method and might be recommended for finding the approximate point of resonance. (See connections in Fig. 5d).

The phones connected directly across the wavemeter with the crystal and buzzer cannot be used as a resonance indicator for the buzzer produces a current in the phones giving the pitch of the buzz audible over the whole wavemeter scale with very little change of intensity at the correct point. This change of intensity is distributed over so many divisions of the scale that no correct judgement can be made as to the correct point.(Fig.5e).

The phones connected directly with the crystal and buzzer in series as in Fig.5f produce a loud pitch of the buzz in the phones due to the making and breaking of the rectified high frequency current in the phones. The point of maximum intensity is also rather hard to locate here, and on account of the added

capacity of the phones and buzzer to the wavemeter circuit this point of maximum intensity is incorrect for the wavemeter as calibrated.

It will be observed that the circuits using the vacuum tube are not as sensitive as the crystal circuits, but they have less effect on the wavemeter calibration. The chief disadvantage of the circuits shown in Figs. 4a, 4b, 4c, 4d and 4e is that the galvanometer is deflected to a minimum point at resonance instead of a maximum. This is due to the fact that the grid accumulates a negative charge, the greatest negative charge being of course accumulated at the point of resonance. It is very difficult to adjust the wavemeter to a minimum deflection of the galvanometer, especially when the minimum is so near to the original plate current deflection. The above mentioned methods are so little sensitive that they would not be recommended for use.

Some interesting results were obtained from the circuit shown in Fig. 4f in that the galvanometer in the plate circuit "G" went to minimum at the point of resonance (which was due to a negative charge accumulated by the grid), while the galvanometer " G' " went much lower at the point of resonance. This shows that even though the current in the plate circuit is decreased that there is still some other current flowing into the filament which as it decreases the plate current decreases. This current probably flows from the grid to the filament accumulating a negative charge on the grid and so decreasing the plate current. This method proves very satisfactory for locating

the point of resonance but since such close coupling with the generating set is required it changes the frequency of the generating set.

The use of a C battery as in Fig.4g gave some other interesting results. It will be observed that for a large negative charge on the grid no deflection occurred in the galvanometer G . This was probably due to the fact that the grid was so negatively biased that no current would flow either from the plate to the filament or from the filament to the grid. As this negative charge is decreased however there is maximum deflection of the galvanometer which is due to the current flowing in the grid circuit from the filament to the grid. When the C battery is reduced to zero, instead of getting a maximum deflection as before the current in the galvanometer is decreased at the point of resonance and a minimum deflection is obtained. This minimum deflection is the same as the results of the methods of Figs.4a, 4b, 4c etc. in that in this case it is a decrease in the plate current measured. It will be noticed that the galvanometer is so placed as to measure both the grid and plate currents, and that as the grid current increases due to larger negative charge (to a certain point), the plate current decreases. This shows that there is a current flowing from the filament to the grid in the grid circuit which is opposed in the direction to the current in the plate circuit which flows from the plate to the filament. This method proved very satisfactory and sensitive with a filament current of 0.28 amperes and a charge on grid of -6 volts (biased positively). It might also be noted that it does not change the calibration

of the wavemeter.

The circuit of Fig.4h is the same circuit using a tube for the rectifier as the direct connected crystal circuit of Fig.2b. In this case however the capacity of the tube is so much less than the capacity of the leads, crystal, phones or galvanometer, etc. in the crystal circuit that it does not affect the calibration of the wavemeter appreciably.

The circuit of Fig.4i is the same as that of Fig.4h except that the return for the grid current has been removed. No deflection with this arrangement proves that the current flowing through the galvanometer in circuit of Fig. 4h had been rectified by the grid and filament.

The circuit of Fig.4j gives the correct point on the calibration curve of the wavemeter for resonance but it has no advantage over the other methods. The deflection may be varied in magnitude by varying the coupling.

The circuit of Fig. 5g was first tried with a $22\frac{1}{2}$ volt B battery in the plate circuit. The deflection of the galvanometer went to a maximum at the correct point. It has been stated above that there is a current in the grid circuit which is opposed by the current in the plate circuit. This was proved by taking out the plate battery. The deflection of the galvanometer was increased by about 10 divisions at the maximum point of resonance. This is a unilateral circuit and works on the same principle of the unilat. crystal circuit of Fig. 2e. This was considered the best of the tube circuits because it gave a <u>maximum</u> deflection at the correct point on the calibration

curve, and less connections were required than with any of the other circuits using the tube.

BROADCASTING STATION WAVE-LENGTHS

The wavelengths of a number of broadcasting stations were measured in order to become familiar with the method of measuring. It was found that if while the generating set is oscillating at a certain frequency the filament current of the oscillating tube be increased the frequency of oscillation may be so changed as to change the wave length by from one to ten meters. This is due to the change in capacity of the circuit by changing the capacity of the tube. It was also found that if the wavemeter is set to resonance with the oscillating set and the B battery of the oscillating set is increased the wavemeter goes out of resonance and it must be set back to a point corresponding to one or two meters less wavelength than the original. This shows that care should be taken to keep the filament current and plate voltage of the generating set constant during any one measurement.

Another difficulty found in the measurement of the wavelengths of broadcasting stations was that often a multiple of the true wave length was measured. A multiple of the wave length is a sub-multiple of the frequency. In overcoming this difficulty it was observed that the higher the multiple the less was the signal strength of the incoming signal decreased by the production of zero beat with it by means of the generating set. When zero beat was produced on the correct frequency the

signal strength was lowered to zero.

Another difficulty in this measurement was that since there were so many broadcasting stations operating on approximately the same wave length at the same time that it was almost impossible to select any certain one and measure it. When the local generating set was adjusted to a certain wave length it would act as a heterodyne and if the receiving set was oscillating at a near frequency the heterodyne would produce oscillations of its frequency in the receiving set. If there happened to be any signals on that wavelength they would be heard at that time, but as soon as the heterodyne or local generating set was turned off, the signal would disappear and the receiving set would assume an oscillation determined by its own adjustment. Hence if there were several broadcasting stations on the same wave length (approximately) operating at the time of a measurement and only one was being received with the receiving set, as the local generating set was adjusted to produce zero beat with this it would cause the receiving set to change its frequency of oscillation and pick up the signals of some other station. There were two methods used in avoiding this difficulty. The first method is to set the generating set as near as possible to the wave length of the incoming signal before turning it on. Then as soon as it is turned on and before it has time to produce an oscillation of a different frequency in the receiving set (aided by another incoming signal) it is adjusted to produce beat with the wave frequency of the receiving set. This method proves very satisfactory and as before stated the signal strength of the incoming signal is

reduced to zero. After the generating set has been oscillating at this frequency for a short time there will be several points of zero beat produced by varying the frequency of the oscillating circuit.

The other method of distinguishing between a certain wave length at which the receiving set is oscillating and several others in the near neighborhood of it is to set the generating set to oscillating so that it produces zero beat on half the frequency of the incoming signal (or twice the wavelength), It so happens that this frequency being only half as fast as that of the receiving set and also of the incoming wave will not tend as much as before to set up an oscillation of a different frequency in the receiving set. It may be necessary sometimes to go to the third and fourth multiples of the wave length being tested before the accompanying wave lengths can be eliminated enough to distinguish them for the one being tested. It is to be understood that the receiving set will oscillate at such a frequency as to eliminate all the signals except the one being tested (unless the generating set is oscillating at a very near frequency). Having found out some multiple of the wave under test, the multiple found can be determined by the method given under the previous difficulty (on multiples).

It was learned that some stations which are supposed to broadcast on a certain frequency, do so on a different frequency because they have no standardized wavemeter by which to check their wave length. One station tested was supposed to broadcast on 353 meters, but it was found several times that it broadcasted on 385 meters. Such a condition should be remedied.

Below is a LIST OF STATIONS AND THEIR WAVE LENGTHS as tested on the nights of April 24, 25, and 27, 1923.

Station Call letters.	Location.	Wave length as tested. Meters.
WNAV	Knoxville, Tenn.	387
WMC	Memphis, Tenn.	407
WGM	Atlanta, Ga.	408
WOS	Jefferson City, Mo.	399
KDKA	Pittsburgh, Pa.	333
NAA	Radio, Va.	2650
WLW	Cincinnati, O.	361
WDAP	Chicago, Ill	356
WDAF	Kansas City, Mo.	405

The Bureau of Standards has arranged a schedule to send out six more series of standard wave lengths, as follows:

Date	Wave Length Range	Eastern Standard Time.
May 11	333 to 200 meters	11:00 p.m. to 12:41 a.m.
May 17	1500 to 600 meters	" " " " "
May 23	4000 to 1200 meters	" " " " "
May 29	214 to 150 meters	" " " " "
June 4	333 to 200 meters	" " " " "
June 11	750 to 300 meters	" " " " "

CONCLUSIONS

From the results obtained the following conclusions may be drawn:

The best resonance indicator from all view points is the galvanometer and crystal unilaterally connected, since it gives a fairly large and sensitive deflection and does not change the calibration of the wavemeter.(See Fig. 2e).

The most sensitive indicator is that using the crystal and galvanometer directly connected, but its chief disadvantage is that it must have a special calibration to be used.(Fig. 2b).

The best circuit using a tube is that shown in Fig. 5g. It is not as sensitive as the crystal and galvanometer connected unilaterally but works on the same principle and does not affect the calibration of the wavemeter.

For measuring large currents the thermocouple or bolometer shown in Figs. 5a and 5b respectively may be used. Both of these methods prove satisfactory where the current is large enough that close coupling is unnecessary.

The tube circuits in which the galvanometer is in the plate circuit are all unsatisfactory in that they give only a small deflection, and this deflection is a decrease in deflection or minimum which is hard to locate.

If a quick measurement is desired and it does not have to be strictly accurate the phones and crystal connected unilaterally with a buzzer in the wavemeter circuit as shown in Fig. 5d prove very satisfactory and give correct settings within about one division.

In all cases close coupling of the wavemeter to the

generating set, and direct connections of any kind across the wavemeter circuit should be avoided.

APPENDIX

The data obtained and used in plotting the direct current characteristic curves of the WD11 vacuum tube, as shown on Curve Sheets II, III, IV, V, VI, and VII, is given here.

SHEET II

Connections as shown in Fig. 3A.

In all cases the grid and plate were biased positively.

Curve 1

Plate Potential = 21 volts
Filament current = 0.25 amps.

Grid Potential Volts	Plate Current* Milliamps.
50	1.78
40	1.78
30	1.78
27.5	1.92
25	2.03
23	2.13
21	2.23
19	2.23
17	2.20
15	2.13
14	2.06
12	1.92
11	1.82
10	1.75
9	1.65
8	1.51
7	1.41
6	1.28
5	1.17
4	1.00
3	0.86
2	0.73
1	0.55
0	0.40
-1	0.26
-2	0.12
-3	0.02
-4	0.00

Curve 2

Plate Potential = 40 volts
Filament Current = 0.25 amps.

Grid Potential Volts	Plate Current* Milliamps.
50	0.62
45	1.00
40	1.51
35	1.72
30	1.78
25	1.72
20	1.65
15	1.58
10	1.37
5	1.20
4	1.17
3	1.10
2	1.03
1	0.96
0	0.86
-1	0.76
-2	0.62
-3	0.41
-4	0.27
-5	0.17
-6	0.10
-7	0.05
-8	0.01
-9	0.00

*The plate current was measured by a millivoltmeter taking into account its resistance.

Data for SHEET II (Cont.)

Curve 3

Plate Potential = 80 volts
Filament current = 0.25 amps.

Grid Potential Volts	Plate Current Milliamps.
50	2.47
40	2.40
30	2.27
25	2.16
20	2.06
15	1.92
10	1.78
5	1.65
3	1.65
0	1.53
-1	1.44
-2	1.30
-3	1.23
-4	1.17
-5	1.03
-6	0.93
-7	0.79
-8	0.69
-9	0.55
-10	0.41
-11	0.34
-12	0.24
-13	0.15
-14	0.14
-15	0.07
-16	0.01
-17	0.00

Curve 4

Plate Potential = 80 volts
Filament current = 0.30 amps.

Grid Potential Volts	Plate Current Milliamps.
50	6.17
40	5.83
30	5.48
20	4.94
15	4.56
10	4.22
8	4.05
6	3.91
4	3.70
2	3.43
1	3.20
0	3.16
-1	2.95
-2	2.74
-3	2.33
-4	2.13
-5	1.78
-6	1.54
-7	1.37
-8	1.10
-9	0.82
-10	0.69
-11	0.48
-12	0.38
-13	0.27
-14	0.17
-15	0.14
-16	0.07
-17	0.03
-18	0.00

Curve 5

Plate Potential = 21 volts.
Filament current = 0.35 amps.

50	6.04	6	2.54
40	5.90	4	1.99
35	5.70	3	1.65
30	5.70	2	1.37
25	5.86	1	1.10
23	5.97	0	0.87
20	5.93	-1	0.69
18	5.76	-2	0.38
16	5.35	-3	0.21
14	4.84	-4	0.10
12	4.32	-5	0.03
10	3.74	-6	0.00
8	3.12		

Data for SHEET III.

Connections as shown in Fig.3B

Voltage amplification factor = $\frac{R_1}{R_2}$

R_2 is a constant resistance of 10 ohms.

Curve 1

Plate Potential = 20 volts
Filament Current = 0.25 amps.

Grid Potential Volts	Amplification Factor
0	3.7
-1	4.7
-2	5.4
-3	5.1
-4	7.7
-5	4.2
-6	Not sensitive

Curve 1 was repeated with a different auxiliary battery and with the same battery with polarity reversed. The same results as the above were obtained.

Curve 2

Plate Potential = 40 volts
Filament Current = 0.25 amps.

Grid Potential Volts	Amplification Factor
5	Not sensitive
2	4.0 ?
0	5.0
-1	6.0
-2	7.0
-3	7.0
-4	6.4
-5	5.7
-6	5.2
-7	4.8
-8	4.6
-9	4.4
-10	4.1

Curve 3

Plate Potential = 80 volts
Filament Current = 0.25 amps.

Grid Potential Volts	Amplification Factor
0	3.5
-2	5.0
-4	6.0
-6	7.0
-8	7.4
-10	6.8
-12	6.1
-15	5.0
-18	4.5
-20	4.3

Curve 4

Plate Potential = 40 volts
Filament Current = 0.30 amps.

Grid Potential Volts	Amplification Factor
0	6.0
-1	6.3
-2	6.6
-3	6.3
-4	6.0
-5	5.6
-6	5.2
-7	5.0
-8	4.7
-9	4.5
-10	4.3
-11	4.1

Data for SHEET IV.

Connections as shown in Fig. 3C.

Plate Current plotted against Plate Potential.

Curve 1

Filament Current = 0.25 amps.

Plate Potential Volts	Plate Current Milliamps.
0	0.00
5	0.00
10	0.10
15	0.20
20	0.28
25	0.41
30	0.48
35	0.55
40	0.58
45	0.60
50	0.62
55	0.62
60	0.63
65	0.65
70	0.67
75	0.68
80	0.69
85	0.69
90	0.70
96	0.71
90	0.71
85	0.71
80	0.71
75	0.70
70	0.69
65	0.69
60	0.69
55	0.68
50	0.67
45	0.64
40	0.62
35	0.57
30	0.54
25	0.45
20	0.36
15	0.27
10	0.14
5	0.05
0	0.00

Curve 2

Filament Current = 0.30 amps.

Plate Potential Volts	Plate Current Milliamps.
0	0.00
5	0.05
10	0.10
15	0.34
20	0.55
25	0.75
30	0.95
35	1.17
40	1.37
45	1.56
50	1.72
55	1.88
60	2.06
65	2.20
70	2.33
75	2.47
80	2.61
85	2.74
90	2.88
95	3.02
97.5	3.09
95	3.09
90	3.05
85	2.98
80	2.88
75	2.78
70	2.64
65	2.47
60	2.33
55	2.13
50	1.92
45	1.75
40	1.51
35	1.30
30	1.10
25	0.86
20	0.65
15	0.41
10	0.27
5	0.10
0	0.00

Data for SHEET V

Grid and Plate connected as shown in Fig. 3D.

Curve 1

Filament Current 0.25 amps.

Plate Potential Volts	Plate Current Milliamps.
0	0.00
5	0.38
10	0.51
15	0.60
20	0.69
25	0.76
30	0.86
35	0.93
40	1.03
45	1.13
50	1.23
55	1.34
60	1.51
65	1.65
70	1.78
75	1.92
80	2.06
85	2.26
90	2.40
95	2.61
96	2.75
90	2.82
85	2.88
80	2.88
75	2.88
70	2.81
65	2.75
60	2.65
55	2.52
50	2.40
45	2.23
40	2.06
35	1.88
30	1.75
25	1.58
20	1.44
15	1.23
10	1.06
5	0.69
3	0.30
0	0.00

Curve 2

Filament Current 0.30 amps.

Plate Potential Volts	Plate Current Milliamps.
0	0.00
2	0.27
4	0.75
6	1.30
10	2.13
15	2.61
20	2.81
25	3.02
30	3.16
35	3.36
40	3.57
45	3.77
50	3.98
55	4.18
60	4.39
65	4.67
70	5.01
75	5.35
80	5.69
85	6.11
90	6.72
95	7.50
96	8.25
90	8.38
85	8.65
80	8.65
75	8.58
70	8.45
65	8.25
60	7.96
55	7.65
50	7.29
45	6.86
40	6.48
35	6.04
30	5.63
25	5.15
20	4.67
15	3.98
10	2.75
7.5	1.92
5	1.30
3	0.62
1	0.14
0	0.00

Data for Sheet VI

Connections shown in Fig. 3E.

Plate Resistance plotted against resistance in series with plate.

Filament current = 0.25 amps.

Curve 1. Plate Potential = 20 volts.

Resistance in series with plate Ohms	Plate resistance Ohms
0	76600
10000	87200
20000	92000
30000	99200
40000	92500
50000	96000
60000	86000

Curve 2. Plate Potential = 40 volts.

0	97000
20000	86000
40000	84000
60000	79000
80000	65300

Curve 3. Plate Potential = 80 volts.

0	139000
40000	105800
80000	75500

Curve 4. Plate Potential = 96.7 volts.

0	148300
40000	101500
80000	86000

Data for SHEET VII

Connections shown in Fig. 3E.

Plate resistance plotted against resistance in series with plate.

Filament current = 0.30 amps.

Curve 1

Plate Potential = 20 volts

R in series ohms	Plate R ohms
0	36400
1000	37800
2000	38500
3000	38700
4000	38200
5000	37800
6000	37500
7000	37700
8000	37500
9000	39000
10000	41200
15000	43400
20000	52800
30000	53400
40000	57200
50000	54200
80000	52200

Curve 2

Plate Potential = 40 volts

R in series ohms	Plate R ohms
0	29160
1000	29650
2000	30000
3000	29400
4000	29850
5000	29700
6000	29900
10000	31700
20000	34100
30000	36400
40000	43200
50000	47100
70000	42700
80000	36700

Curve 3

Plate Potential = 80 volts

R in series ohms	Plate R ohms
0	34350
1000	33350
2000	32350
4000	31250
6000	30400
9000	28550
10000	28850
15000	29800
20000	29600
25000	28700
30000	30100
40000	27800
45000	31500
50000	33400
60000	36000
70000	36000
80000	36700
90000	26500