

**EXPERIMENTS ON AN ARTIFICIAL TELEPHONE TRANSMISSION LINE,
AND THE DESIGN OF A MILLIAMMETER-VOLTMETER-AMPLIFIER**

BY

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Foreword

Through the generosity of the Western Electric Company and the American Telephone and Telegraph Company of New York, scientific equipment was given to the Virginia Polytechnic Institute in 1927 and subsequent years.

The articles were:

A variable frequency oscillator - 8-A

An impedance bridge including a telephone receiver

A milliammeter-voltmeter-amplifier measuring set -

D-79017

All equipment necessary for the construction of a 200 mile, artificial telephone transmission line, open wire type.

The necessary instruction and description booklets were also sent.

The variable frequency, oscillator is of the vacuum tube type, covering a range of frequencies from 100 cycles to 50,000 cycles per second. The circuit consists of a vacuum tube oscillating circuit and two stages of amplification. The first stage consists of one vacuum tube and the second of two tubes in parallel. The output frequency of the oscillator is controlled by varying the constants of the oscillating circuit. A calibration chart is furnished with the oscillator to facilitate the tuning of the circuit to any desired frequency.

The impedance bridge, type 1-B, consists of a fixed inductance of 100 millihenries; a Brooke's type inductometer; and a "14-B"

rheostat. The Brooke's type inductometer is a variable inductance, which may be varied by turning a rotating element. This element reads the inductance directly in millihenries, having a range from 50 to 560, both positive and negative. The "14-B" rheostat contains a variable resistance (0-11-110 ohms), the ratio arms of the bridge circuit, and two keys for switching the inductometer and fixed inductance to different bridge arms. In addition to these parts a telephone receiver is required for the operation of the impedance bridge.

The milliammeter-voltmeter-amplifier consists of four tubes. Three stages of amplification are used with a detector. Through a potentiometer arrangement and a thermocouple, measurements are made by the comparison method, in which the unknown currents and voltages are compared with known values of current and voltage.

The artificial line, approximates the constants of 200 miles of open wire telephone transmission line. But by proper manipulation of the switches, the characteristics can be changed to those of a #00 NBS line.

The line consists of 24 full sections and four half sections. Each section represents 7.88 miles of non-loaded, open wire, transmission line.

This line was assembled by students of the Virginia Polytechnic Institute previous to 1932.

One piece of apparatus, namely, the Milliammeter-Voltmeter-Amplifier has given poor service in previous years. Unstable and

non-constant readings were obtained. For this reason its readings were of no practical value.

The author's project was to investigate the behavior of this instrument, and to try to correct it. This instrument is rather complicated to operate, so a simpler, laboratory model was designed by the author, to be constructed by students, if the above milliammeter-voltmeter-amplifier is decided to be too complicated to be used by undergraduate students.

This report will be divided into three parts:

Part 1 - Experiments with the oscillator and impedance bridge.

Part 2 - Investigation of the faults of the milliammeter-voltmeter-amplifier. Experiments with this instrument and the oscillator.

Part 3 - The design of a laboratory milliammeter-voltmeter-amplifier.

If the reader wishes further information on the constructional details and operation of the above apparatus, he is referred to the following booklets:

1-B- IMPEDANCE BRIDGE

8-A- OSCILLATOR

"D- 79017 VOLTMETER MILLIAMMETER"

LABORATORY EQUIPMENT FOR TECHNICAL SCHOOLS , - ARTIFICIAL
LINE

The experiments have been numbered, not from any particular manual, but for cross indexing.

Part I

The first thing to see was if the frequencies obtained from the variable frequency oscillator were correct. A table of calibrated values are given in the booklet - "8-A - Oscillator". The oscillator was connected to the impedance bridge as shown in Figure 1. The resonance method of calibration was used. Across the line terminals of the impedance bridge, a variable condenser was connected. From the table in the booklet, a frequency was selected, the condenser set at the capacity given, and the inductometer varied. This was done for about ten different frequencies. If the inductometer read the values (corrected of course) given in the booklet, the oscillator was said to be operating satisfactorily. This was found to be the case.

Perhaps a description of the method of making a measurement with the oscillator and impedance bridge will be beneficial to the reader.

The procedure is as follows:

Connect the proper batteries to the oscillator. These values are marked on the oscillator.

Adjust the filament current to 2.3 amperes.

Connect the impedance to the measures across the line terminals of the impedance bridge.

Set the knobs on the oscillator corresponding to the frequency wanted. This information may be obtained from the calibration chart.

Vary the knobs on the "14-B" rheostat, the toggle switches on

same, and the inductometer until minimum signal is heard in the telephone receiver.

The resistance of the impedance will be indicated value on the "14-B" Rheostat. The inductance, positive or negative will be the indicated value on the inductometer, plus a correction factor, as to which way the toggle switches on the "14-B" rheostat are turned. These correction factors may be obtained from the booklet "1-B- IMPEDANCE BRIDGE". A simple concise tabulated form of these correction factors is given below.

If the toggle switches read "Add", "+", add 100 millihenries to the indicated reading. The range is 150 to 560 millihenries, all positive values.

If the toggle switches read "Subtract", "+", subtract 100 millihenries from the indicated reading. The range is -50 to +360 millihenries.

If the toggle switches read "Add", "-", add 100 millihenries to the indicated reading. Range is -150 to -560 millihenries.

If the toggle switches read "Subtract", "-", subtract 100 millihenries from the indicated value. Range is -360 to +50 millihenries.

It is to be understood that negative inductance is capacitance.

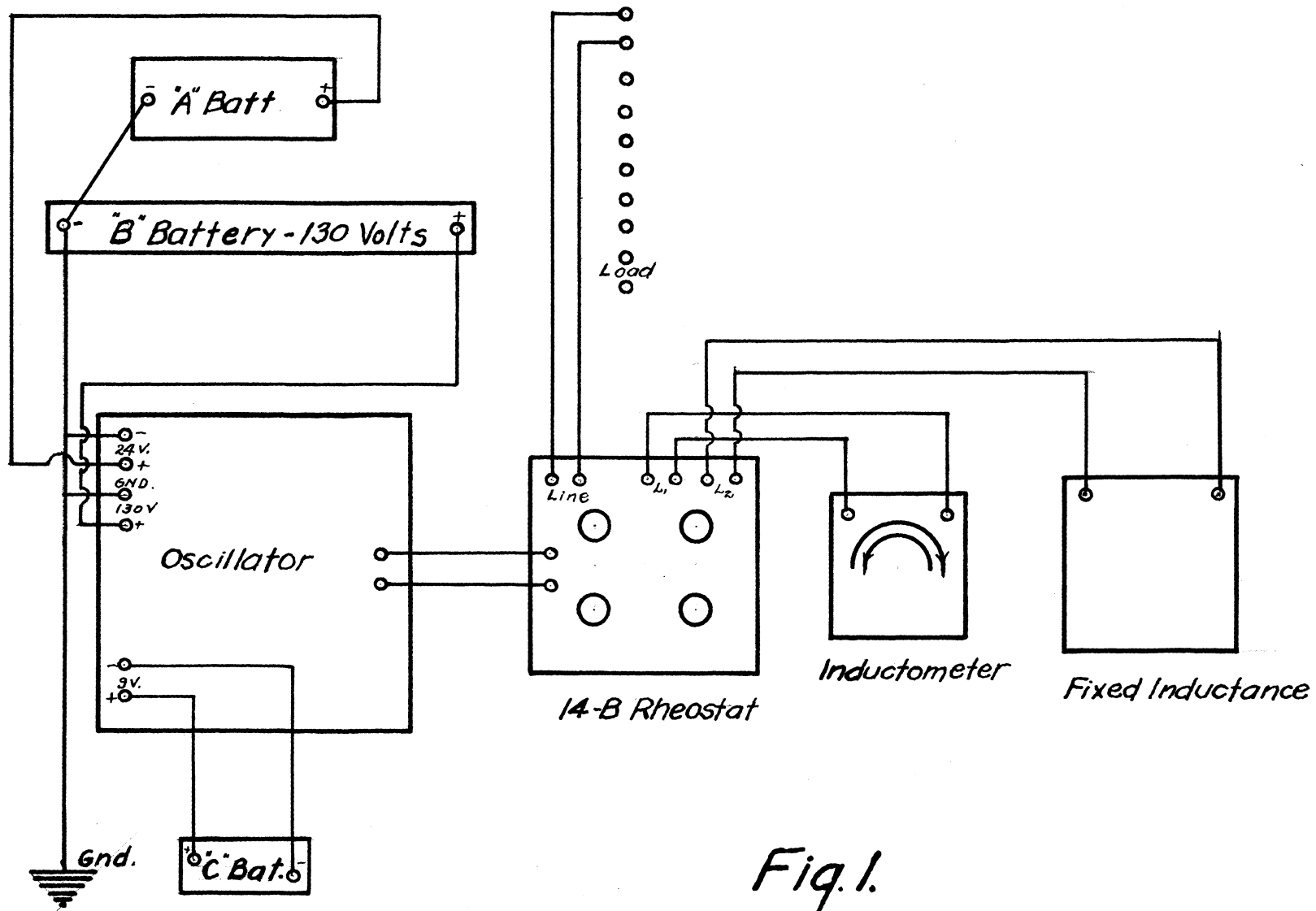


Fig. 1.

Experiment 1

Object:

To illustrate the method of making an impedance measurement with an impedance bridge and to illustrate the variations of impedance with frequency of different types of circuits.

Apparatus Required:

- 1 - Impedance Bridge
- 1 - Oscillator, variable frequency
- 1 - Artificial non-loaded open wire line
- 3 - No. 18 AD resistance, 240 ohms
- 1 - No. 25-A repeating coil
- 1 - 1 mf. condenser
- 1 - 130-volt battery
- 1 - 24-volt battery
- 1 - 9-volt battery

Procedure:

The apparatus was hooked up as in Fig. 1.

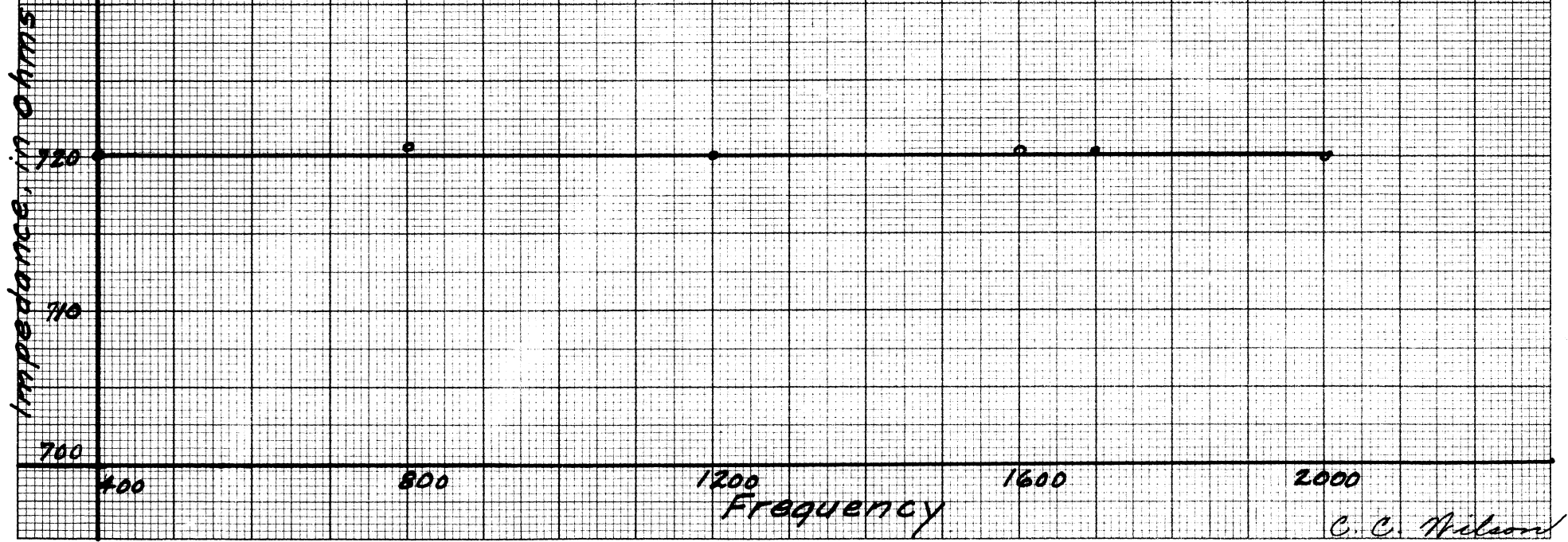
Part I - Impedance of a Resistance. The 18 AD resistances were connected in series. The impedance was measured at frequencies of 200, 800, 1500, and 2000 cycles per second.

Part II - Impedance of a Condenser. The impedance of a 1 mf. condenser was measured from 400 to 200 cycles per second, in steps of 400 cycles.

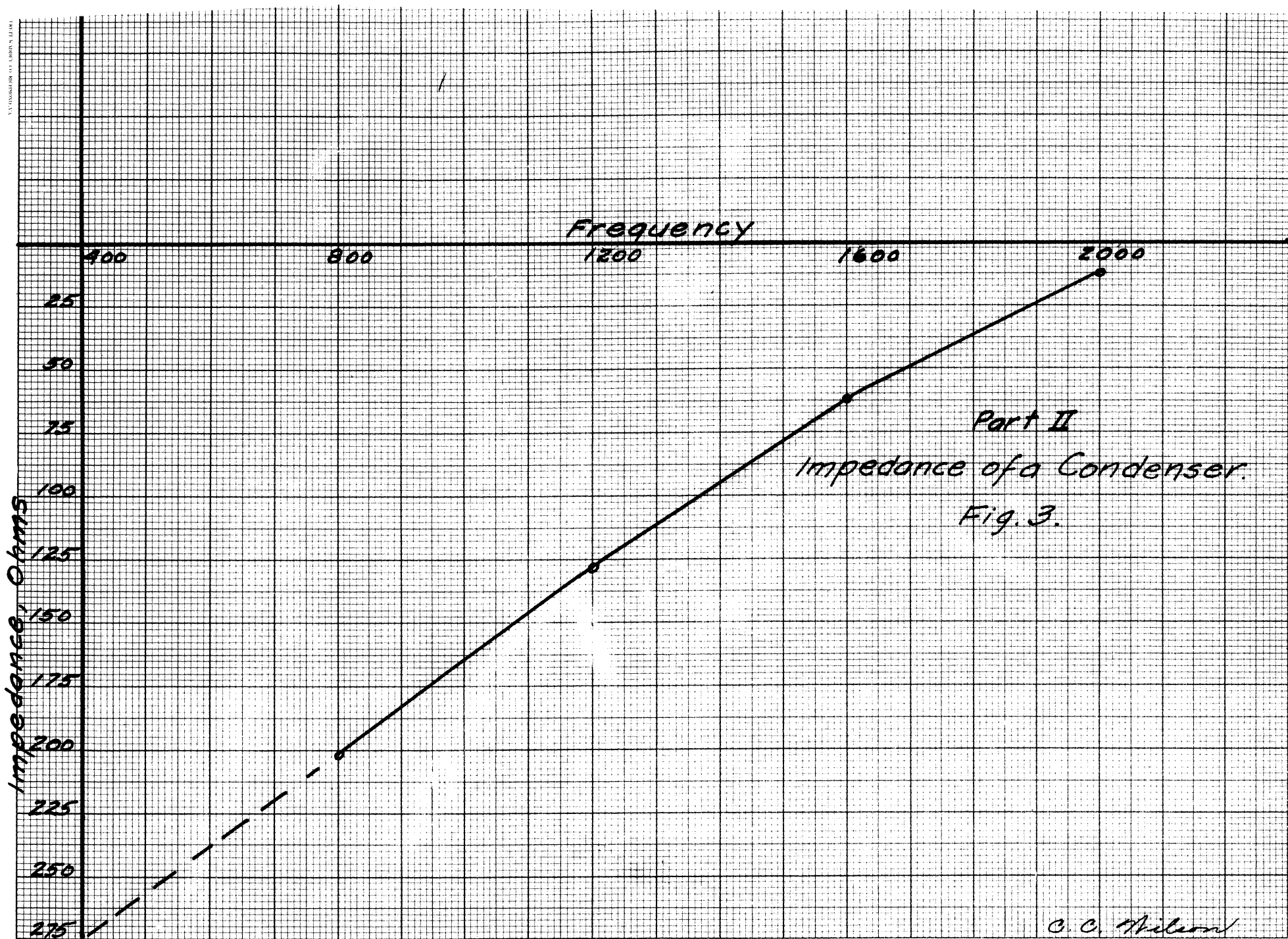
Part III - Impedance of an Inductance. All the coils of a No. 25-A repeating coil were connected in parallel. The impedance was

Part. I.
Impedance curve for an non inductive
Resistance

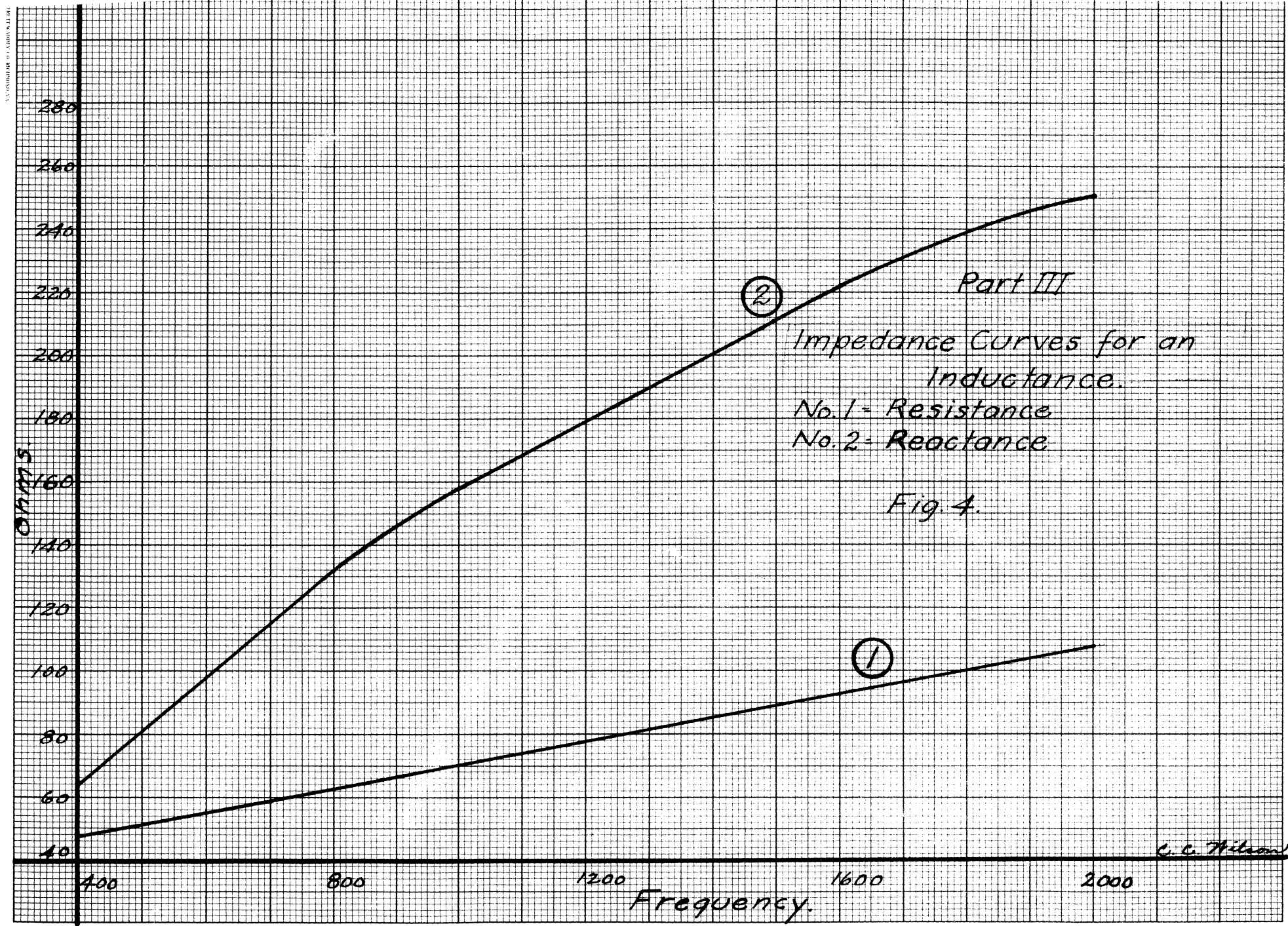
Fig. 2



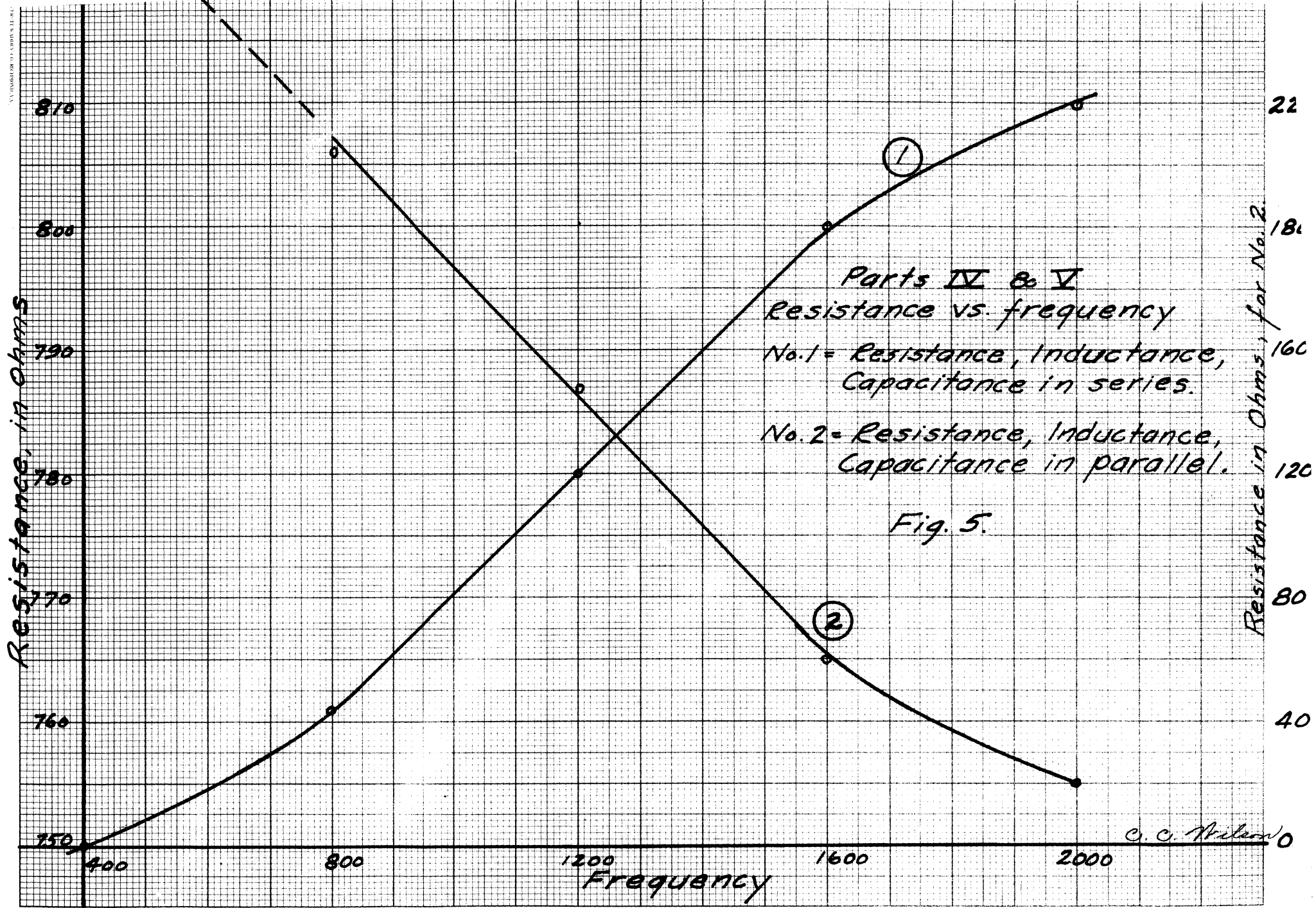
C. C. Wilson

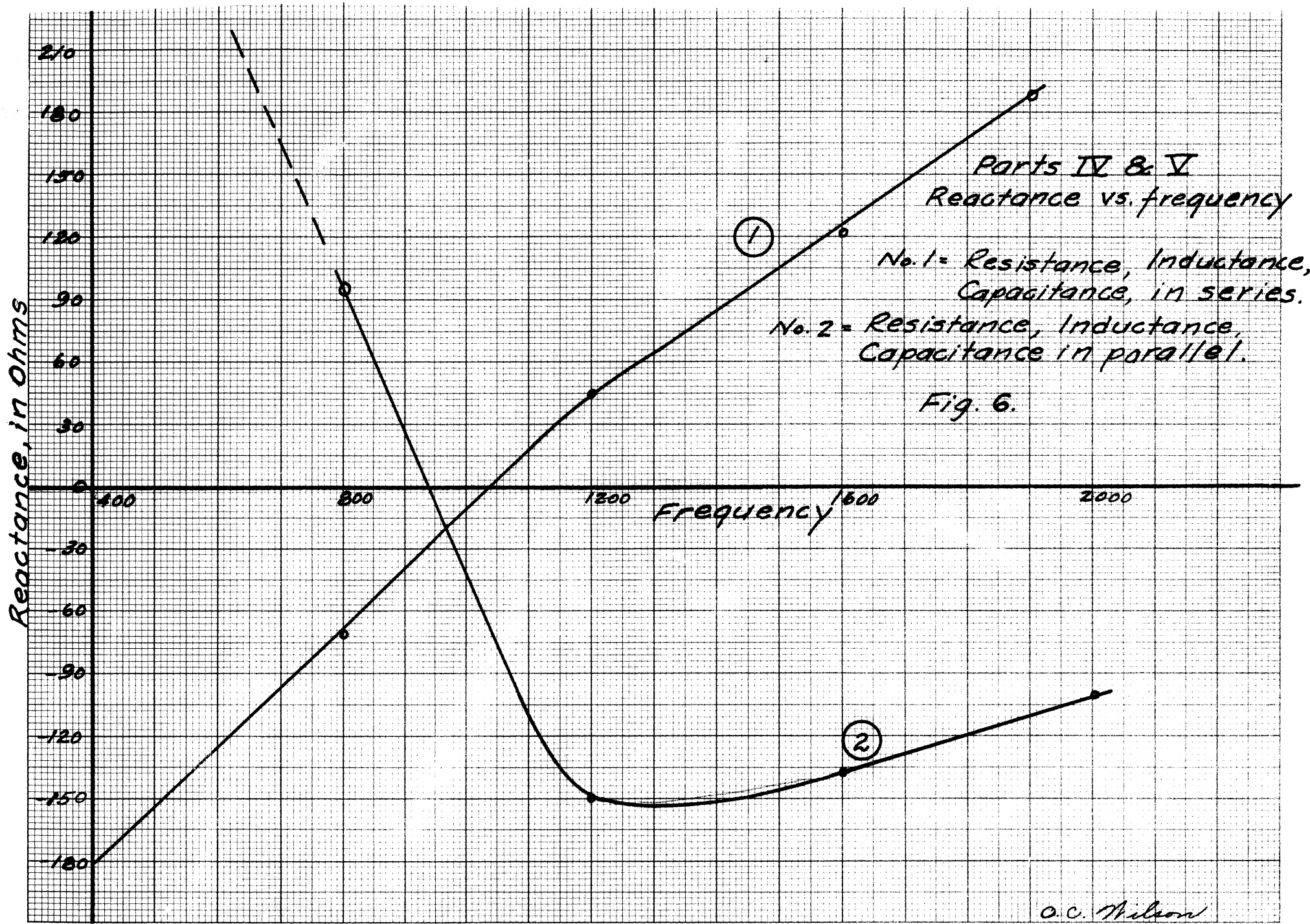


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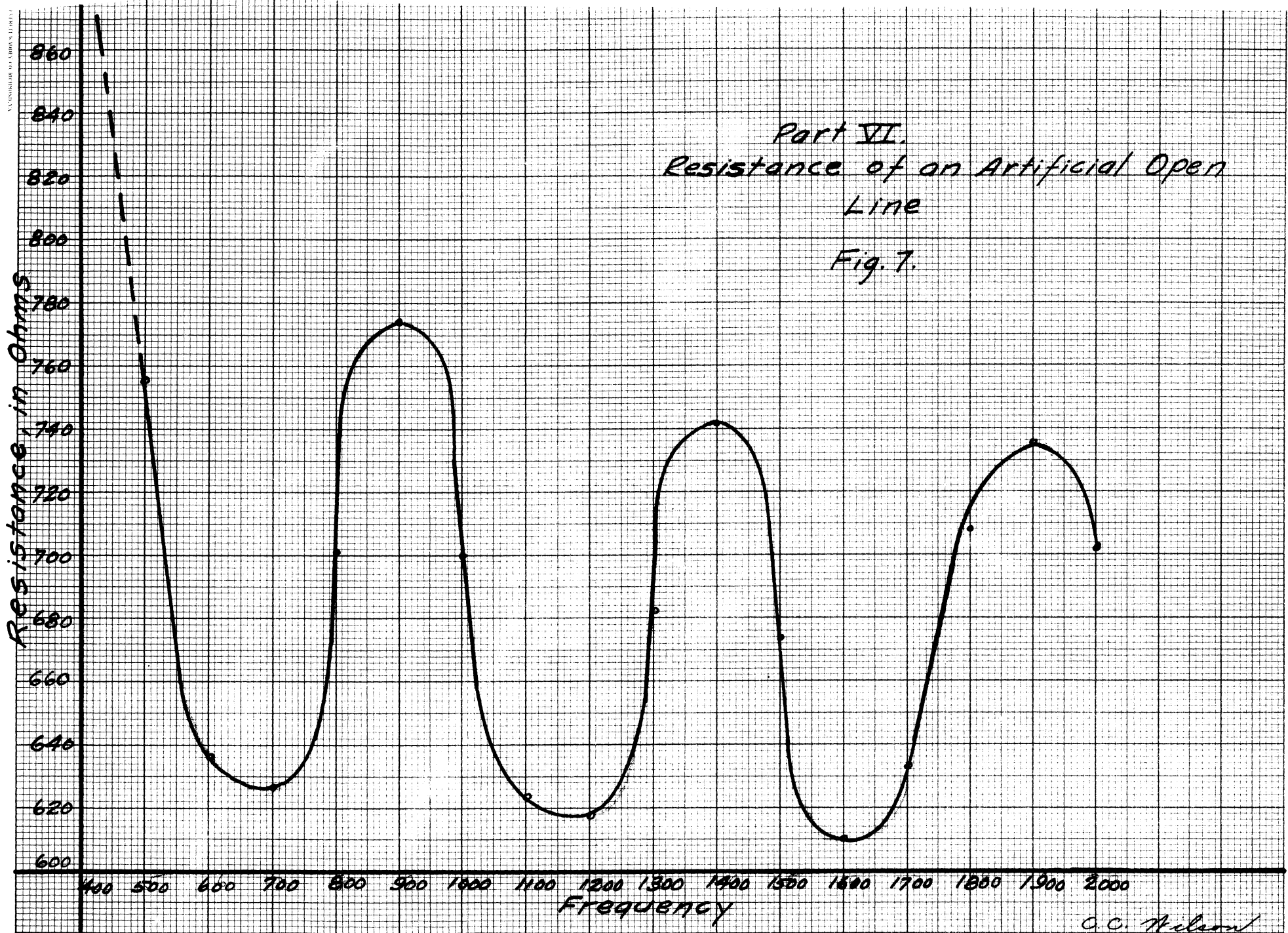


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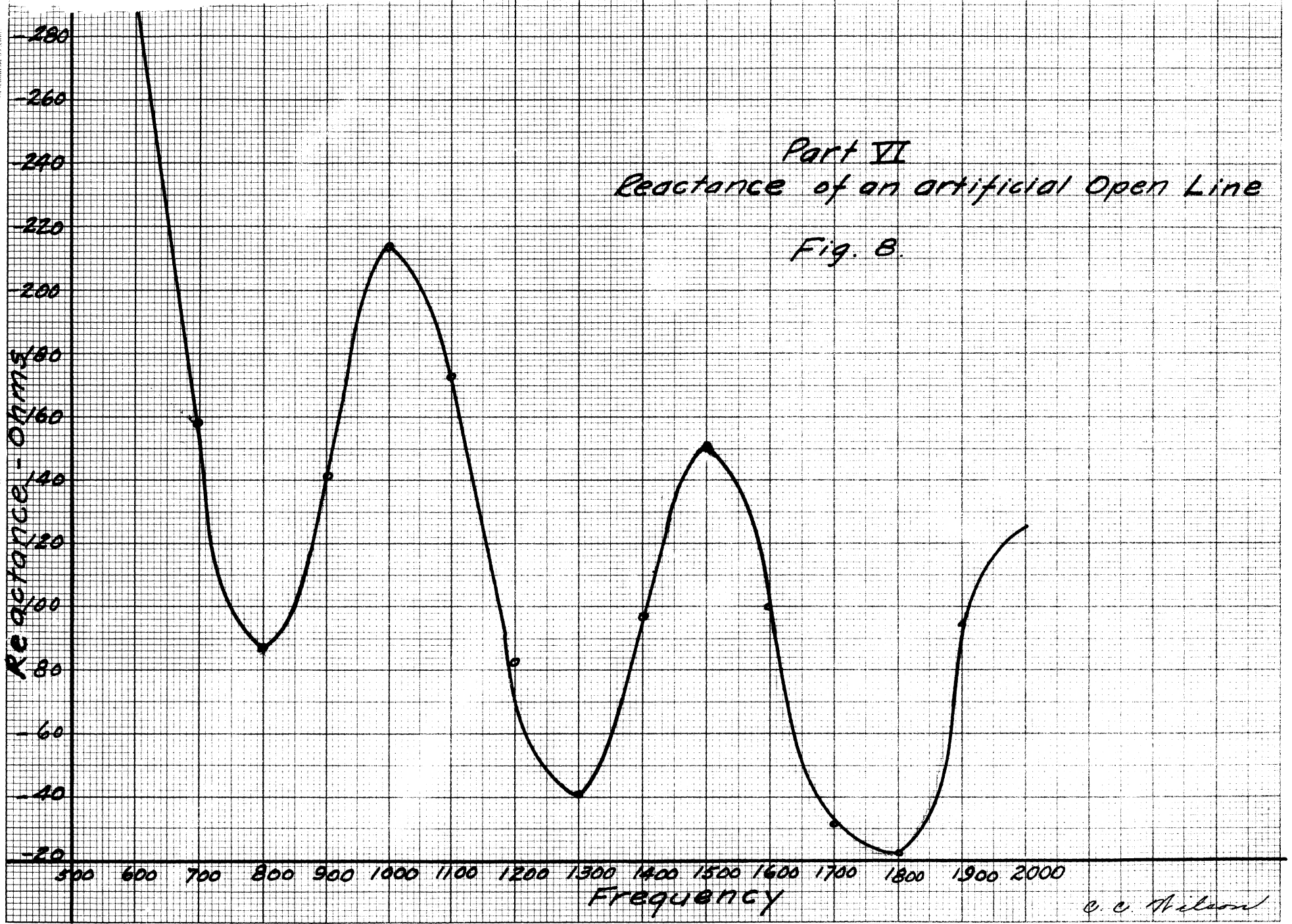
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Part VI.
Resistance of an Artificial Open
Line
Fig. 7.

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Experiment II

Object:

The purpose of this experiment is to illustrate the determination, by means of impedance measurements, the location of a departure from uniformity in the construction of a long telephone circuit.

Apparatus Required:

- 1 Artificial non-loaded open-wire line
- 1 Oscillator, variable frequency
- 1 Impedance bridge
- 1 No. 18 DH resistance, 700 ohms
- 1 130-volt battery
- 1 24-volt battery
- 1 9-volt battery

Procedure:

Part I - Impedance Measurement of a Circuit Containing an

Irregularity.

(a) A section of the artificial line near to the distant end was selected and its inductance coils were short-circuited.

(b) The line was terminated with a 700-ohm resistance and the impedance was measured at frequencies from 400 to 2500 cycles at sufficient intervals to obtain a sharply defined curve.

(c) The above procedure was repeated with a condenser unsoldered somewhere near the middle of the line.

Part II - Computation of Speed of Propagation. The speed of propagation of a telephone circuit may be computed if the wavelength and frequency are known from the formula $W = \frac{2 \pi f}{B}$. In the above formula B is expressed in radians and is termed the "wave length constant" of the telephone circuit. It may be determined from the formula.

$$Y = A + jB = \frac{1}{(R + j\omega L)(G + j\omega c)}$$

In employing the above formula, one section of the line, which is 7.88 miles, will be used as the unit. The constants of each section of the artificial circuit are as follows:

$$R = 82 \text{ ohms}$$

$$L = .0292 \text{ henrys}$$

$$c = .0645 \text{ mf.}$$

$$G = 0$$

Discussion:

(1) From the impedance measurements obtained in Part I, (b) and (c), curves were plotted showing the resistance and reactance components of the impedance of the circuit versus frequency. These are shown in Figs. 9, 10, 11, and 12.

(2) From the above curves, the average frequency difference between adjacent humps or peaks was obtained. Using this figure and the speed of propagation to be obtained from Part II, the location of the irregularity in terms of sections from the sending end will be computed. This will be obtained from the following formula:

$$D = \frac{\text{speed of propagation}}{2(f_2 - f_1)}$$

where D = the distance to the irregularity and, $f_2 - f_1$, the average frequency difference between adjacent peaks on the curve.

(3) If a line has no irregularity, the impedance-frequency curve is a smooth curve. If the impedance-frequency curve is wavy in shape, some irregularity exists at some point along the line, though the nature of the irregularity is not at all disclosed by the shape of the curve. The reason why the curve is wavy is because the telephone currents are reflected back to the sending end. These reflected currents vary in phase relation with the sending current as the frequency is changed, some being in phase, in which case they add and give the effect of a smaller impedance; in the other cases they will be 180 degrees out of phase and will subtract, giving the effect of a larger impedance. The wave obtained in this experiment is similar to a sinusoidal one. The closer the irregularity to the sending end, the greater will be the frequency difference between adjacent peaks. The word impedance was used above. The resistance-frequency curves are very similar to impedance-frequency curves. Resistance-frequency curves were plotted.

Calculations on Experiment No. II.

$$R = 82 \text{ ohms}$$

$$L = .0292 \text{ henrys}$$

$$c = .0645 \times 10^{-6} \text{ farads}$$

$$G = 0$$

$$w = 2 \pi f, f = 800$$

$$W = 2 \pi f/B$$

$$Y = A + jB = \frac{1}{(R + jwL)(G + jwc)}$$

$$D = W/2 (f_2 - f_1)$$

$$\text{when } f = 800, w = 5025$$

$$Y = A + jB = \frac{1}{(82 + j(5025 \times .0292)) (j(5025 \times .0645 \times 10^{-6}))}$$

$$= \frac{1}{(82 + j147)(j.324 \times 10^{-3})}$$

$$= \frac{1}{-.0475 + j.0268}$$

$$= \frac{.0545}{150.5^\circ}$$

$$= .234 \angle 75.25^\circ$$

$$= .0597 + j.226$$

$$B = .226$$

$$W = \frac{5025}{.226} = 22,200$$

From (a) of Part I, $f_2 - f_1 = 500$

$D = 22,200/2 (500) = 22.2 =$ no. of sections from sending end at which the irregularity occurred. The irregularity actually was between the 22d and the 23d sections.

From (c) of Part I, $f_2 - f_1 = 650$ avg.

$D = 22,200 / 2 (650) = 17.1 =$ no. of sections from sending end at
which the irregularity occurred.

The irregularity actually occurred between the 17th and 18th
sections.

Data for Curves - Part I(a) - Inductances short-circuited

Frequency	Resistance	Reactance	Impedance
500	741	-266.5	789
600	717	-241.0	756
700	690	-206.5	720
800	681	-166.0	712
900	686	-147.0	701
1000	687	-138.1	700
1100	676	-131.1	689
1200	666	-113.0	676
1300	668	-90.0	673
1400	675	-88.0	680
1500	671	-89.5	677
1600	661	-85.5	667
1700	653	-74.8	657
1800	657	-67.9	660
1900	661	-65.6	665
2000	656	-62.8	660
2100	648	-52.8	650
2200	646	-48.4	648
2300	649	-43.3	650
2400	646	-45.2	647.5
2500	640	-47.1	641.5

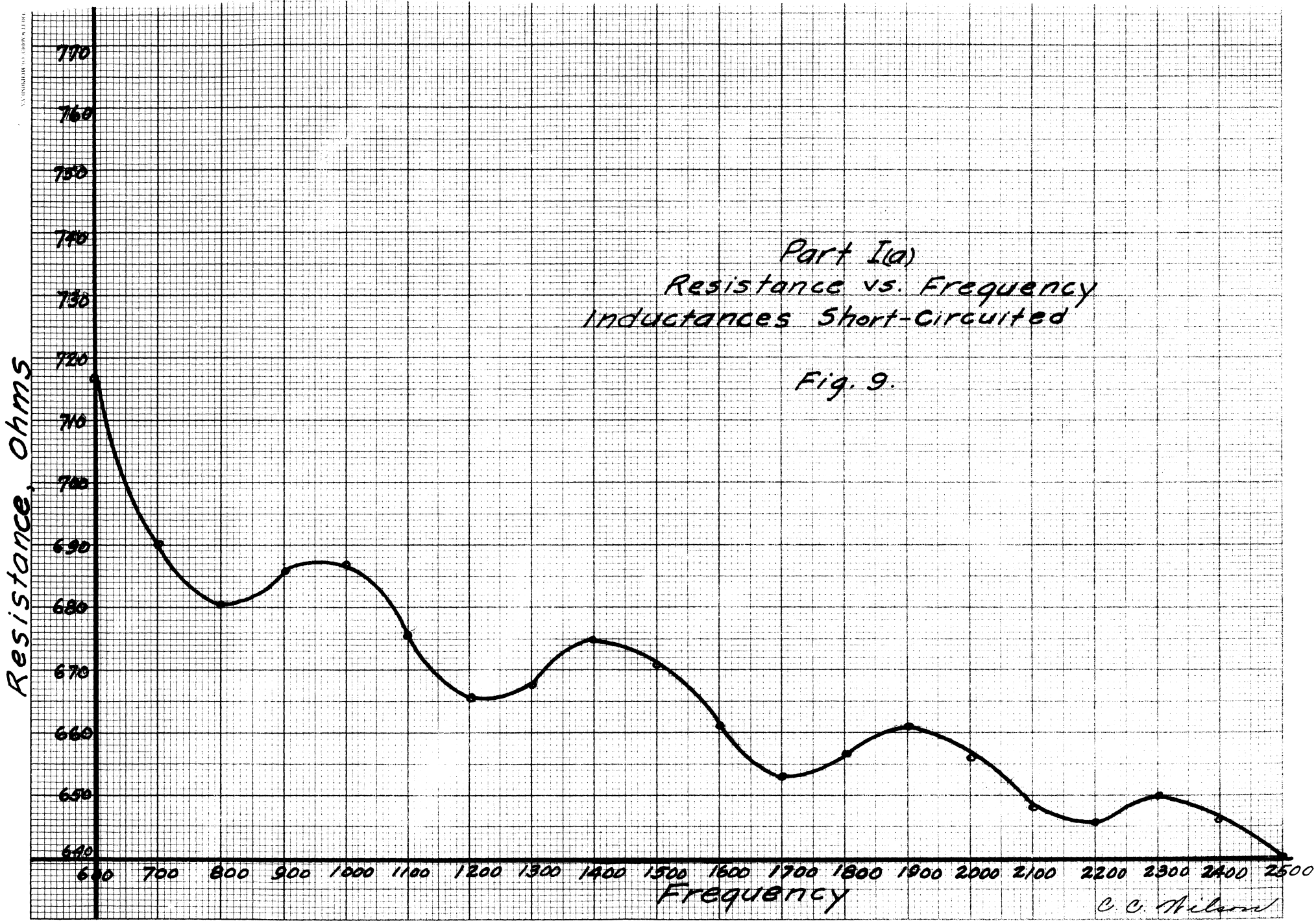
Frequency is in cycles/second. Resistance, Reactance, and Impedance are in ohms.

Part I(c) - Condenser unsoldered

Frequency	Resistance	Reactance	Impedance
500	730	-245.0	771.0
600	724	-222.5	764.0
700	705	-200.0	733.0
800	700	-171.0	720.0
900	698	-155.5	716.0
1000	689	-157.0	705.0
1100	658	-152.0	675.0
1200	633	-113.0	642.0
1300	642	-65.4	643.0
1400	685	-44.0	687.0
1500	720	-75.5	725.0
1600	701	-120.8	710.0
1700	644	-128.0	657.0
1800	612	-84.8	619.0
1900	620	-35.8	621.0
2000	651	-25.2	651.5
2100	673	-33.0	674.5
2200	677	-48.4	680.0
2300	672	-65.0	675.0
2400	650	-90.5	657.0
2500	614	-78.5	619.0

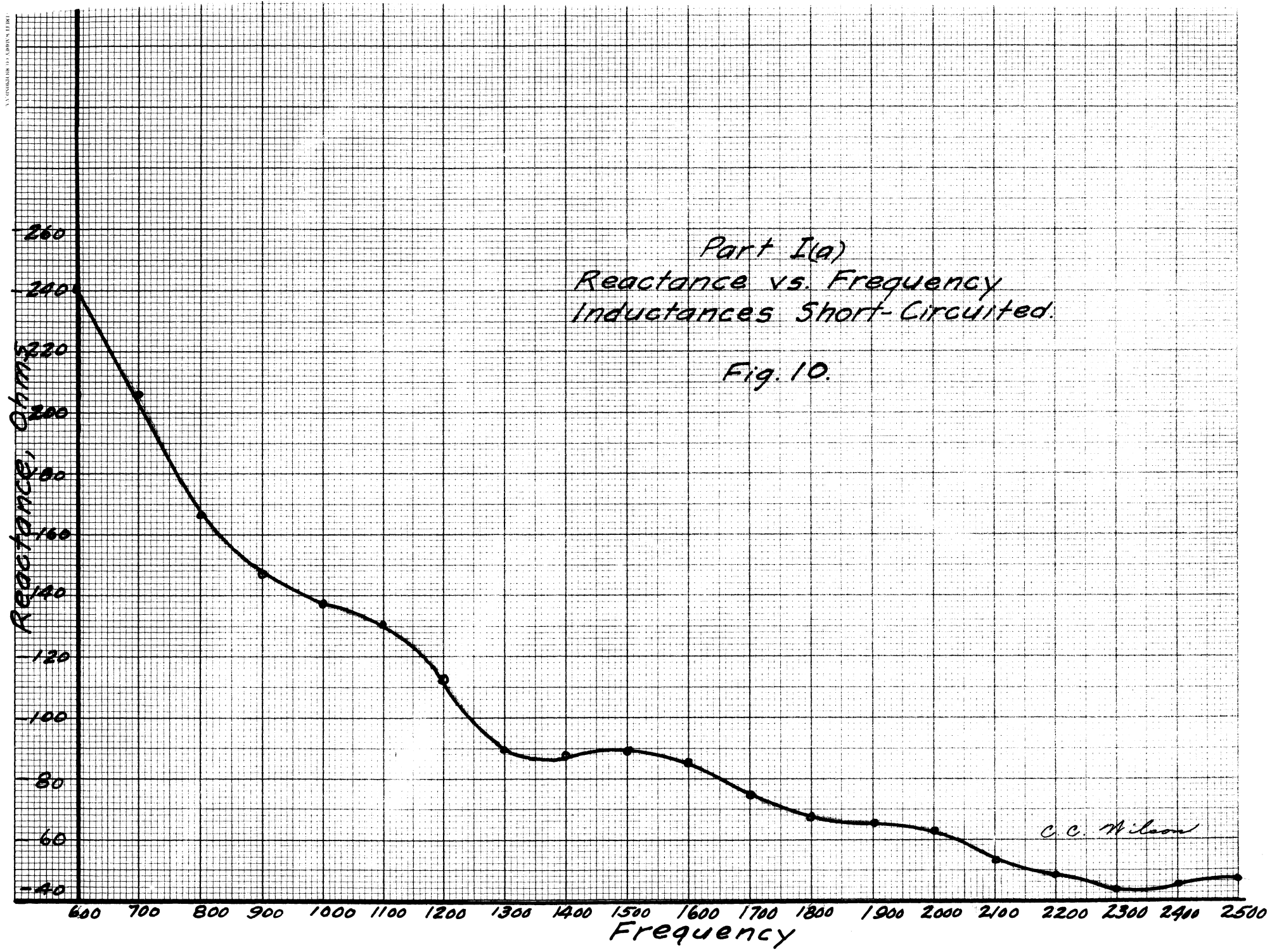
The frequency is in cycles/second, and the Resistances, Reactances, and Impedances are in ohms.

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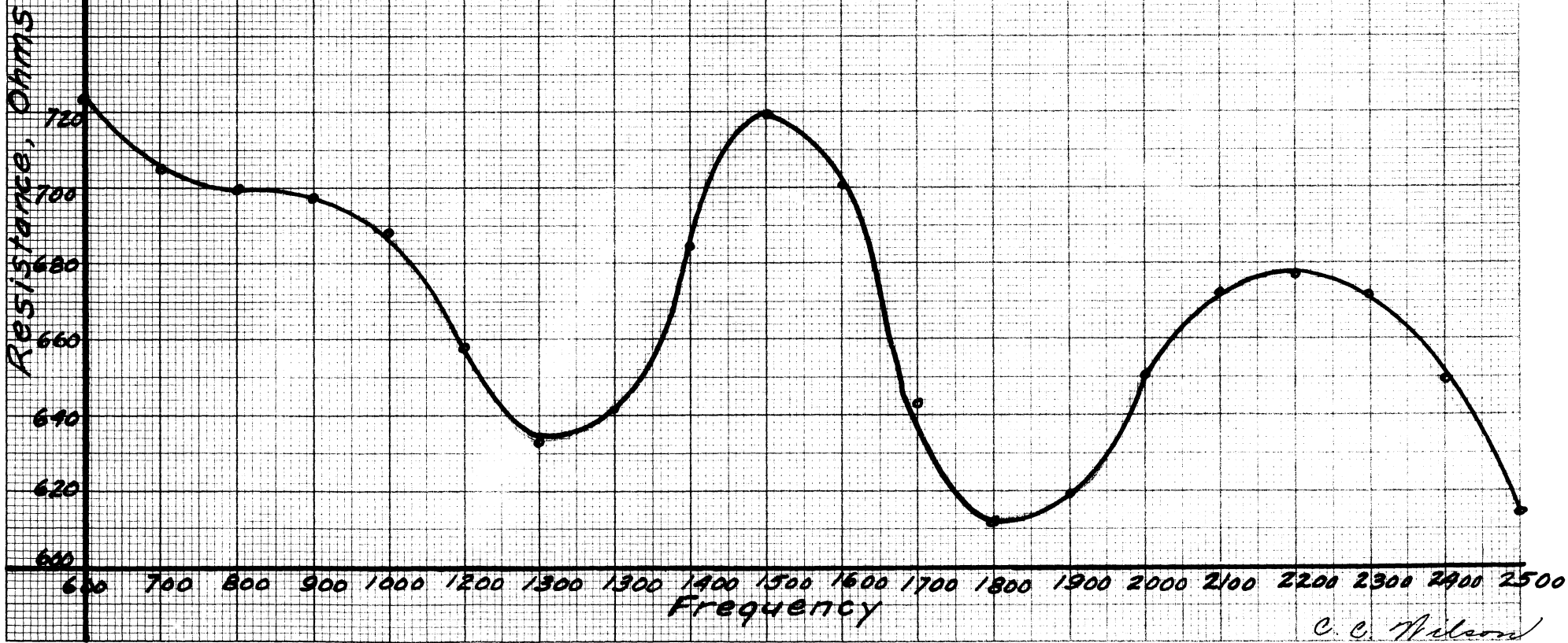
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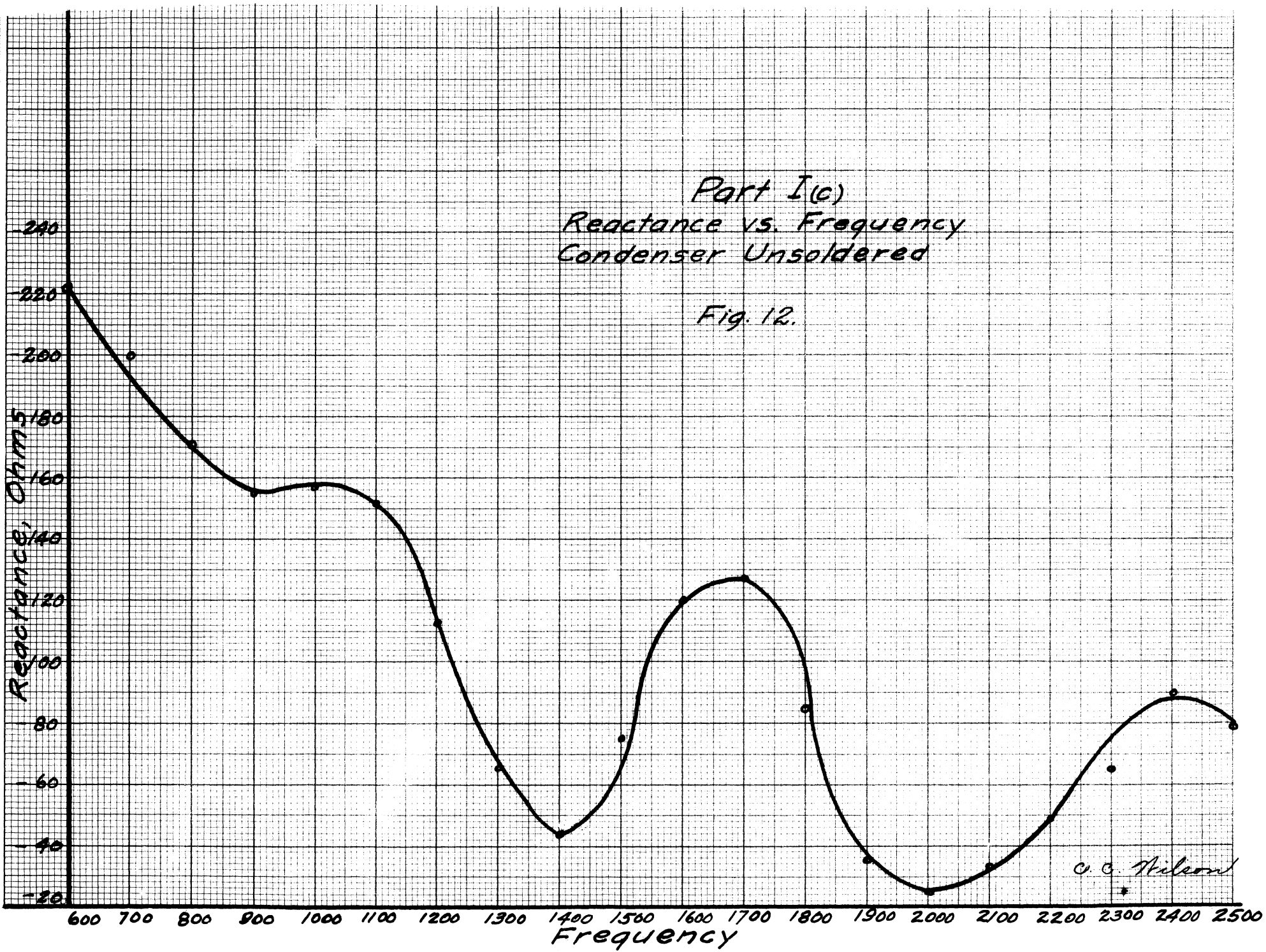
SAUNDERS & BARNES CO. NEW YORK, N. Y.

Part I(c)
Resistance vs. Frequency
Condenser Unsoldered.

Fig. 11.



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Part I(c)
Reactance vs. Frequency
Condenser Unsoldered

Fig. 12.

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Experiment III

Object:

To determine the characteristic line impedance by open and short-circuited tests.

Apparatus:

- 1 Artificial non-loaded open line
- 1 Variable frequency oscillator
- 1 Impedance bridge
- 1 130-volt battery
- 1 24-volt battery
- 1 9-volt battery

Procedure:

The apparatus was hooked up as in Fig. 1. By means of the impedance bridge, the resistance, R , and the inductance, L , components of the sending-end impedance were measured at the desired frequency:

- (1) with the line open-circuited at its end, and
- (2) with the line short-circuited at its end.

This procedure was repeated for a range of frequencies between 500 and 2500 in steps of 100 cycles.

Discussion:

- (1) From the measured values of R , L and the test frequency,
 - (a₁) the sending-end impedance Z_1 and its phase angle θ_1 of the line open-circuited, was calculated and
 - (a₂) the sending-end impedance Z_2 and its phase angle θ_2 of the line short-circuited, was calculated.

(2) From the values of Z_1 and Z_2 obtained in (a₁) and (a₂) the characteristic line impedance Z_0 was calculated from the equation

$$Z_0 e^{j\phi} = \sqrt{Z_1 e^{j\theta_1} \times Z_2 e^{j\theta_2}}$$

The phase angle ϕ in each case was computed.

Curves of R_1 , R_2 , Z_1 , Z_2 , Z_0 , and ϕ , are shown in Fig. 13 as functions of frequency. The curve between the intersections of Z_1 and Z_2 which is Z_0 shows the characteristic impedance for each frequency. Similarly, if curves were drawn between the intersections of R_1 and R_2 , they would show the resistance component of the characteristic impedance for each frequency. Likewise, a curve through the intersections of L_1 and L_2 would show the inductance component of the characteristic frequency for each frequency.

(3) General Theory: Suppose that an impedance test is made at one desired frequency, first with the line open-circuited at the distant terminal, and then with the line short-circuited. Then let us set

Z_1 = bridge impedance balancing the line impedance when the line is open-circuited;

r_1 = adjusted resistance of the balancing impedance Z_1 ;

x_1 = adjusted reactance component of the balancing impedance Z_1 ;

Z_2 = bridge impedance balancing line impedance when the line is short-circuited;

r_2 = adjusted resistance component of balancing impedance Z_2 ;

x_2 = adjusted reactance component of balancing impedance Z_2 .

Then we have, for the balanced condition in the two cases,

$$Z_1 e^{j\theta_1} = \sqrt{r_1^2 + x_1^2} e^{j\theta_1}$$

and
$$Z_2 e^{j\theta_2} = \sqrt{r_2^2 + x_2^2} e^{j\theta_2}$$

where $\theta_1 = \tan^{-1} \frac{x_1}{r_1}$

and $\theta_2 = \tan^{-1} \frac{x_2}{r_2}$

θ_1 being the line phase angle when the line is open-circuited, and

θ_2 the line phase angle when the line is short-circuited. The

impedance of an open-circuited line is, however,

$$Z_1 = \frac{Z_0}{\tan hYL} \quad (1)$$

where Y = propagation constant, and L is the length of line in

miles, and that for a short-circuited line is

$$Z_2 = Z_0 \tanh BD \quad (2)$$

If we solve (1) and (2) for $\tanh BD$ and equate the two values,

we have
$$\frac{Z_0}{Z_1} = \frac{Z_2}{Z_0}$$

or $Z_0 = \sqrt{Z_1 Z_2}$, substituting our values of Z_1 and Z_2 , we have

$$Z_0 e^{j\theta} = \sqrt{(r_1^2 + x_1^2)(r_2^2 + x_2^2)} \cdot e^{j \frac{\theta_1 + \theta_2}{2}}$$

which gives the characteristic line impedance and its phase angle.

Data for Curves - Experiment III. Open Circuit Test.

Frequency	Resistance	Inductance	Impedance	Angle
500	756	-120	845	.
600	637	-76	698	24.2
700	624	-36	644	14.26
800	702	-18	707	7.38
900	769	-25	780	10.40
1000	713	- 33.5	743	16.40
1100	623	-24.0	644	14.90
1200	619	-10.0	623	6.94
1300	692	-5.0	693	3.40
1400	742	-12.0	749	8.10
1500	678	-16.5	696	12.90
1600	611	- 11.0	621	10.24
1700	624	-3.0	625	2.94
1800	697	-2.0	698	1.86
1900	719	-8.0	725	7.60
2000	646	-9.5	657	10.50
2100	600	-4.0	602	5.06
2200	636	- .5	636	.64
2300	702	-2.0	702	2.30
2400	683	-6.0	689	7.56
2500	607	-4.5	611	6.66

The frequency is in cycles/second. The Resistance (R_1) and Impedance (Z_1) are in ohms. The Inductance (L_1) is in millihenries. The angle θ_1 is in degrees.

Data for curves - Experiment III - Short-circuit test.

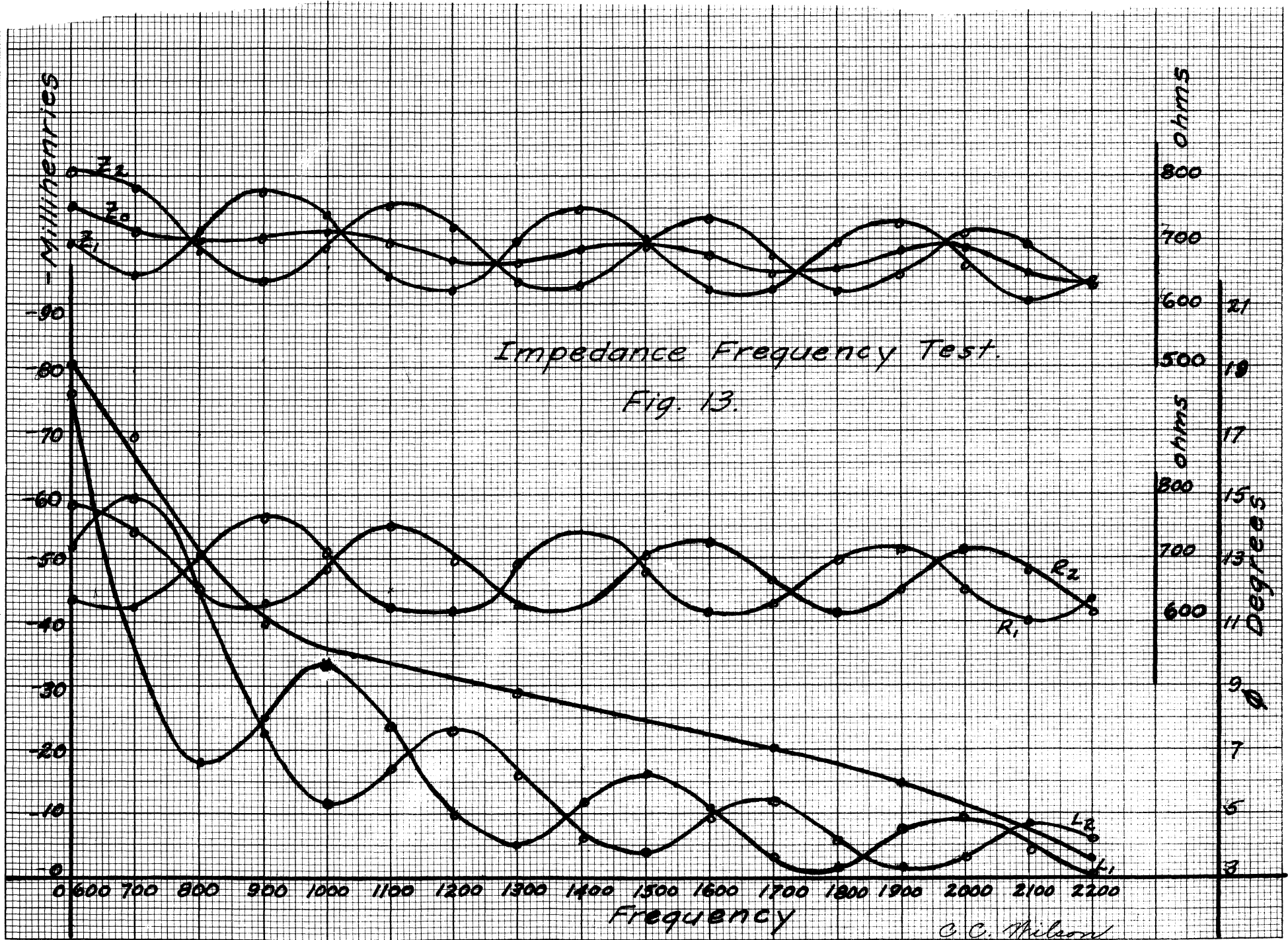
Frequency	Resistance	Inductance	Impedance	Angle
500	700	-30.0		
600	786	-52.0	810	14.00
700	745	-60.0	790	19.50
800	646	-45.5	685	19.40
900	624	-22.5	637	11.54
1000	689	-11.0	692	5.64
1100	748	-17.5	758	9.20
1200	694	-23.5	716	14.32
1300	621	-16.5	635	12.28
1400	629	-6.0	631	4.80
1500	702	-4.0	702.5	3.06
1600	723	-10.0	730	7.90
1700	652	-12.0	664	11.10
1800	611	-6.0	615	6.30
1900	647	-1.5	648	1.60
2000	708	-3.5	710	3.56
2100	679	-8.0	687	8.84
2200	617	-6.0	623	7.70
2300	615	-2.0	616	2.70
2400	671	-.5	671	.66
2500	684	-4.5	689	7.00

The frequency is in cycles/second. The Resistance (R_2) and Impedance (Z_2) are in ohms. The inductance (L_2) is in millihenries. The angle (θ_2) is in degrees.

Data for Curves in Experiment III

Frequency	Impedance	Angle, - ϕ
600	752	19.10
700	713	16.88
800	697	13.39
900	705	10.97
1000	718	11.02
1100	699	12.05
1200	668	10.63
1300	664	7.84
1400	687	6.45
1500	700	8.98
1600	674	9.07
1700	644	7.02
1800	656	3.98
1900	686	4.60
2000	683	7.03
2100	644	6.95
2200	629	4.17
2300	657	2.50
2400	679	4.11
2500	649	6.83

The frequency is in cycles/second. The impedance (Z_0)
the characteristic impedance is in ohms. The angle ϕ is in degrees.



Impedance Frequency Test.

Fig. 13.

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Part 2

This part of the report will deal with the inspection and experimentation of the Milliammeter-Voltmeter-Amplifier. Its operation and description will be given. After these experiments that were run in conjunction with it, perhaps it would be feasible to give the operation and test of

THE ARTIFICIAL LINE

The plan of the present board is a combination of circuits as recommended by the American Telephone and Telegraph Company and a plan published by The University of Missouri. The lay-out includes a bus line in conjunction with double-pole-double throw switches, enabling the operator to switch the half-sections which include the measuring instruments into the line between any two sections by throwing four of the switches. If one wishes not to have any current enter the measuring instrument i.e., the milliammeter-ammeter-amplifier, he may disconnect the leads leading to the instrument which are labeled "milliamperes", or he may leave these leads connected and close only the voltmeter switch leading to the measuring instrument. This kind of measurement is for an experiment to show the Ferranti effect.

A two color system is used which enables the operator to determine the circuit represented by each wire or bus. The double-pole-single throw switches that are mounted toward the center of the board connect in the half sections to the measuring instrument. The double-pole-single-throw switches that are mounted at the edge of the board are for shorting out the resistors when it is desired to eliminate practically all the pure resistance in the circuit.

This makes the line equivalent to No. 00 N.B.S. wire.

Suppose that we wish to measure a potential difference and current at the end of the first section. It is assumed that the instruments are properly connected to the binding posts at the left end facing the panel. The double-pole-double-throw switches at this section are both opened, and the two double-pole-single-throw switches toward the center of the board at this point are closed. All the other corresponding double-pole-single-throw switches should be opened and then the measurements are made with the Milliammeter-Voltmeter-Amplifier. The same procedure may be used to make a similar measurement elsewhere. If all the elements of the line (all section) are to be in the circuit, all the double-pole-double-throw switches except those where a measurement is to be made, should be thrown to the outside edge of the panel. If we reverse these switches, i.e., throw them to the center of the panel, we short out the section or sections of the line by an amount nearly equal to sixteen miles per section. If we wish to convert the line into a power transmission line, we close the double-pole-single-throw switches that are mounted at the edge of the panel, and make measurements like the procedure given above.

Impedance measurements are obtained by connecting the "Line" terminals of the impedance bridge to the sending end of the line (terminals No. 1 and 2). The line may be terminated in a characteristic impedance of the line, or another impedance, or in an open-circuit or in a short-circuit, depending upon the measurement desired.

If we wish to measure the impedance at the beginning of any section, the "Line" terminals of the impedance bridge may be connected to line terminals 4 and 8 and the impedance of any portion may be measured by closing the second double-pole-single-throw switch mounted toward the center of the board at the beginning of the section and the first corresponding double-pole-single-throw switch should be opened. The second double-pole-double-throw switch at this section should be opened.

If it is desired to terminate the line in its characteristic impedance or other type of load, the load may be connected to line terminals 3 and 7 and thence connected across the line at the end of any section by closing the first double-pole-single-throw switch mounted toward the center of the board at the end of that section. The corresponding double-pole-double-throw switch at the end of this section should be opened.

GENERAL THEORY OF VACUUM TUBE MEASURING INSTRUMENTS

In order to get away from the defects of current-actuated meters in the measurement of small currents and voltages in a network, a voltage-operated device is desirable. The vacuum tube is such a device. Furthermore, if the voltage is too small to give a good indication, it may be amplified with vacuum tubes until such an indication can be obtained with a device whose input resistance may be of the order of several megohms. Since the sensitivity to small voltages may be made very great, it is possible to read the drop produced by a small current in flowing thru a small resistance, and so ammeters whose resistance is of the order of 1 ohm may be constructed to read currents of the order of a microampere.

As in the case of the thermocouple and rectifier types of alternating current meters, the vacuum-tube voltmeter converts the alternating current voltage into a direct current voltage which can be read on a direct current meter.

One of the simplest uses to which a voltmeter may be put is to compare two voltages in different parts of a network. As far as the network is concerned, measurements of relative voltage will give all the information which is useful. If the input voltage is "n" times the output voltage, the latter will be known for any applied voltage at the sending end.

The basic components needed to construct a comparison voltmeter are shown in Fig. 14. A vacuum tube amplifier is required to increase the sensitivity and to isolate the input from the detector so that a calibrated gain control may be inserted. In its simplest

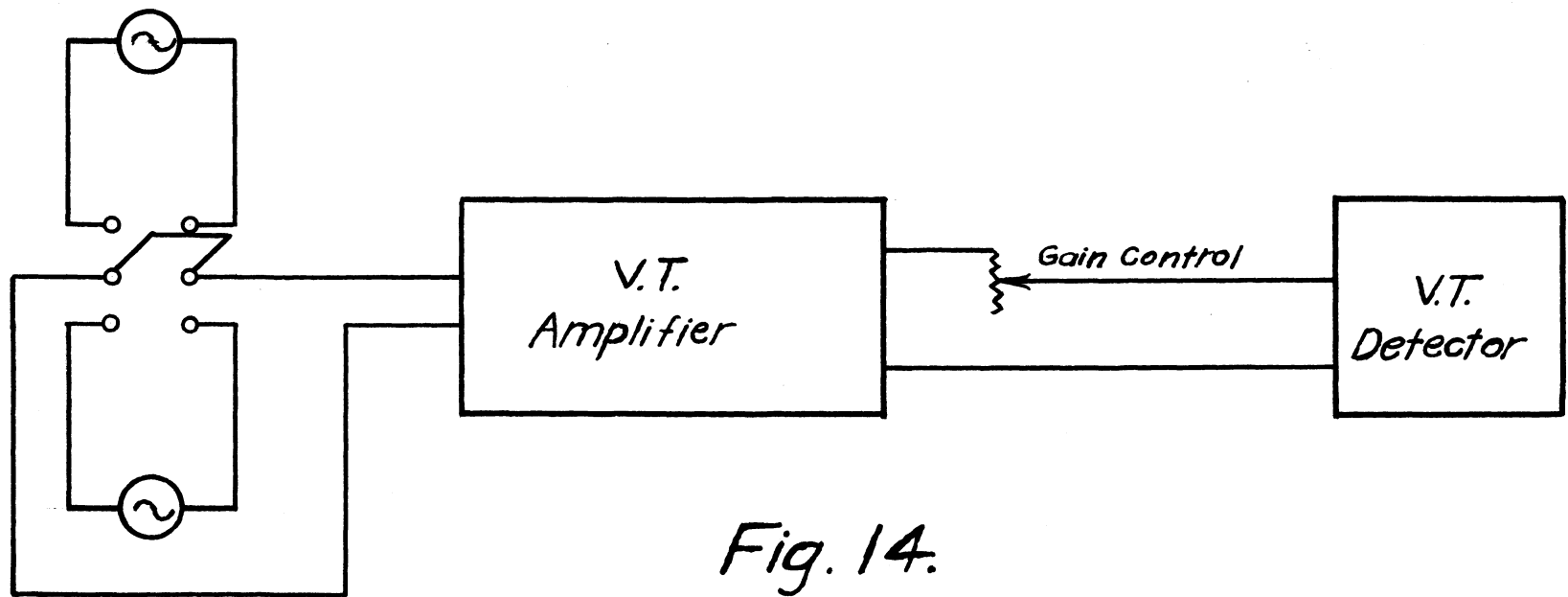


Fig. 14.
Comparison Vacuum Tube Voltmeter.

form, this gain control may consist of a slide wire potentiometer with a calibrated slider. The potentiometer is arranged so that a known portion of the total voltage available may be obtained from the output of one of the amplifier stages. The voltage is applied to a succeeding stage or to the grid of the detector. If the impedance to which the slider is connected is very high in comparison with the impedance of the potentiometer, the voltage selected will be proportional to the position of the slider along the wire.

To compare two voltages, the input of the amplifier is first connected in the network where one of the voltages occurs. An adjustment of the gain is made until any convenient indication is obtained with the detector. This setting of the potentiometer is recorded. The input terminals of the voltmeter are then connected to the part of the network whose voltage is to be compared with the first, and a readjustment of the potentiometer is made until the same indication is obtained on the detector.

The voltage on the detector must be the same in both cases, since identical indications were obtained. Assume that the first setting was .2 of the maximum while in the 2d case it was .6 of the maximum. Then in the first case, only .2 of the available voltage was needed in order to secure the convenient reading. In the 2d case, .6 of the available voltage was needed to secure the same indication, and so, in this case, the available voltage must be $\frac{1}{3}$ of the available voltage of the first reading. The larger the reading on the potentiometer, the less is the voltage applied to the input terminals. Therefore, in such a device,

$$\frac{E_1}{E_2} = \frac{\text{reading on potentiometer for } E_2}{\text{reading on potentiometer for } E_1}$$

It is essential for accurate readings that there be no stray coupling between the circuit preceding the gain control and that following it, since the setting of the potentiometer should completely determine the voltage impressed on the detector. This imposes shielding and filter requirements more severe than are required for an ordinary amplifier. The higher the gain, or the greater the range of voltages to be compared, the greater will be the error introduced by stray coupling.

Since a voltmeter can be used to compare absolute values of two voltages, if the comparison of an unknown voltage E_x is made with a known voltage, then the magnitude of E_x will be determined. A known voltage may easily be obtained by measuring, with a thermocouple, the current thru a standard resistance, and using the drop in this resistance as a voltage standard. The resistance of the thermocouple does not interfere in the least with its use in such a circuit. When used in this way as a comparison voltmeter, it is not necessary to make the comparison with the standard at every reading, but a number of voltages may be compared after one measurement of the standard. If an auxiliary control is put on either the amplifier gain or detector bias, the full scale setting of the potentiometer can be adjusted to give any convenient reading for a given standard voltage. It is then possible to calibrate the dial of the potentiometer so that it will give voltage readings directly, provided the adjustment for the standard reading is made first.

To expand the range of the voltmeter, another gain control may be introduced. This need not be continuously adjustable, a requirement of the first control, but may be made in decade steps or any other ratio desired. The continuously variable control will then cover the range between steps of the second control.

We will now take up the theory of a "Vacuum Tube Meter Having a Calibrated Sending Circuit".

For transmission measurements on telephone lines, since geographical separation of different points in the network may be large, a comparison voltmeter cannot be used even though information on relative voltages is desired. To overcome this difficulty, a sending circuit is used to introduce a standard power at one point in the line, and the absolute value of voltage at the other points on the line is then measured. A transmission measuring set provides such a standard network to be used in introducing the known power. One milliwatt is used for most standard tests. The transmission measuring set is capable of measuring absolute voltages at any point along the line or its terminals. In the latter case, it should provide a terminating impedance. The testing current is usually obtained from a vacuum tube oscillator. The input circuit is expected to simulate the standard termination. This is 600 ohms for an unloaded line.

We will now describe a "Comparison Voltmeter with Calibration in the Standard".

The vacuum-tube voltmeter which has been described may be said to have a calibrated gain with a fixed standard. An alternate method

would be to have an adjustable but uncalibrated gain and a variable and calibrated standard. It is somewhat easier to make this latter method operate over a wide range in voltages. The set up is shown in Fig. 15.

The voltage to be measured is first connected by the double-pole double-throw switch to the amplifier, and the gain adjusted until a convenient reading is obtained on the detector. The switch is then thrown to the calibrating network. The oscillator is adjusted until a standard voltage, as measured by the thermocouple voltmeter, is impressed across the network. This network is arranged so as to reduce the voltage by any power of ten. A potentiometer is connected to the terminals of the network. It will give a continuous variation so that any desired voltage within the range of the instrument, can be obtained. After throwing the switch to connect the amplifier to the calibrating network, the standard voltage is varied until the same reading is obtained as was given by the unknown voltage. If, when the switch is thrown, the indication is unaltered, the unknown voltage must be the same as that obtained from the calibrating network. Since the latter is known, the absolute value of E_x has been determined.

As the gain of an amplifier varies somewhat with frequency, it is desirable where possible to compare voltages of the same frequency. The oscillator of Fig. 15 can usually be used at the same time as the supply of the network under investigation and in that way the frequency characteristic of the amplifier is eliminated. Furthermore,

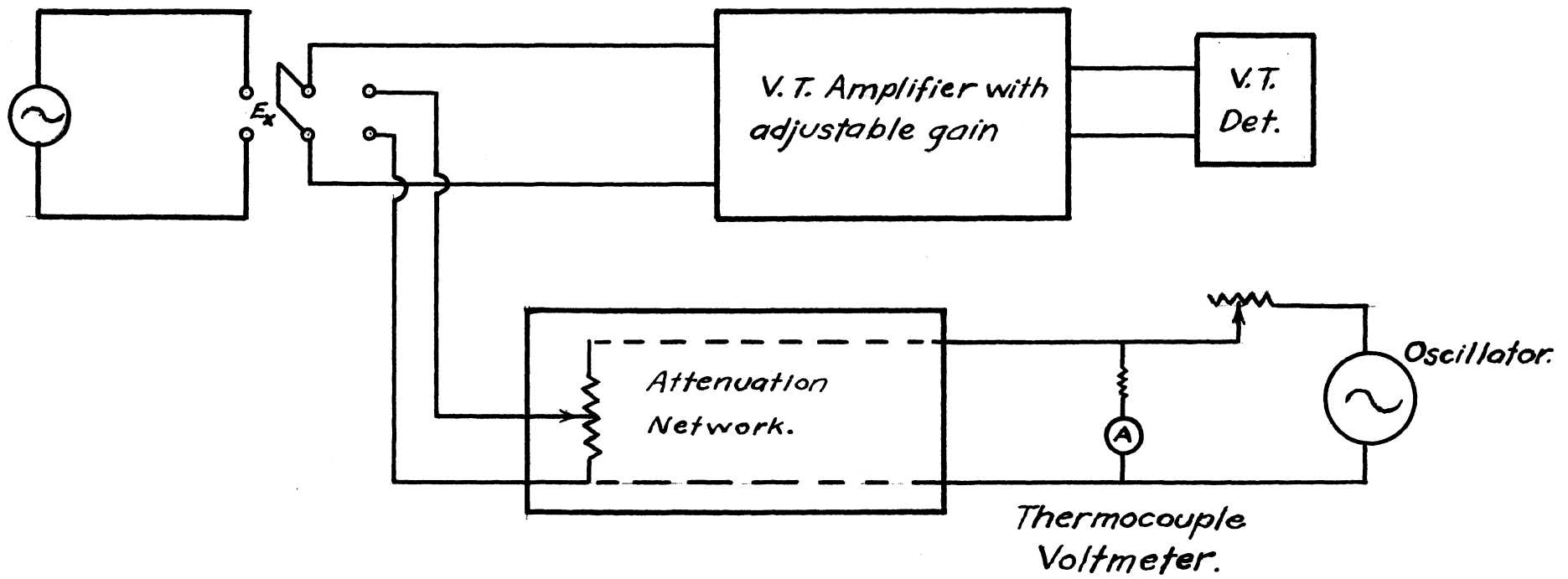


Fig. 15.

the shielding requirements are not so severe as in the type shown in Fig. 14, and so it is easier to construct the circuit of Fig. 15 to have a wide range.

Either type of vacuum-tube-voltmeter may be used to read current by measuring the voltage drop in a resistance. When measuring the drop across a small resistance, a transformer of high turns ratio may be connected between the resistance and the grid of the amplifier tube. By making this calibration convenient, so that it can be made with each reading, the accuracy of the vacuum-tube-voltmeter may be made as great as any other type of meter.

A Description of the "D-79017 Voltmeter-Milliammeter-Amplifier

The principle of the circuit of the D-79017 Milliammeter-Voltmeter-Amplifier is the same as the vacuum-tube voltmeter previously described.

The D-79017 has a sending circuit, calibration circuit, input circuit, and an amplifier circuit.

The sending circuit consists of an arrangement of apparatus which enables the following to be done.

(1) Send a testing power of about 1 milliwatt into a circuit of 600 ohms impedance. One milliwatt is the standard testing power used with transmission measuring apparatus in the Bell System.

(2) Establish a definite voltage (E_0) across a potentiometer, (P_2). When a potentiometer (P_1) in the sending circuit is adjusted to establish a voltage (E_0) on the potentiometer (P_2) in the calibrated circuit. This potentiometer (P_2) and a meter form the calibrated circuit, and will be described later. The voltage E_0 is measured by a voltmeter consisting of a thermocouple and a d.c. meter. The thermocouple is of the conventional vacuum type consisting of a heater and thermojunction which when heated generates a small d.c. voltage across its terminals. This voltage is sufficient to give a reading on a sensitive d.c. meter.

The calibrated circuit with which the known adjustable voltage is obtained consists of a potentiometer (P_2) and a number of multiplier networks across which a voltage of 3.16 volts is maintained. This potentiometer has a resistance of 600 ohms which corresponds to a dial setting of 3.16 volts. Thus the dial setting corresponding to

300 ohms is one half of the total or 1.58 volts and for 60 ohms is .316 volt. The multiplier networks are designed to alternate the voltages across the potentiometer by factors of ten, their use being taken in account when fixing the decimal point in the scale readings of this potentiometer.

An additional multiplier network is connected when measurements of milliamperes are to be made. This provides a correction so that the scale reading also gives a direct indication of currents in milliamperes. With the above arrangement any voltage or current within the range of the milliammeter-voltmeter-amplifier may be obtained.

The input circuit is applied to that part of the circuit which is between the unknown voltage or current and the amplifier proper. As a voltmeter the input circuit consists chiefly of a high-impedance input transformer which may be bridged across telephone circuits without appreciably affecting the current and voltage relations in the circuit. By means of a switch the transformer may be connected either to the circuit to be measured or to the calibrated circuit.

When used as a milliammeter the input circuit consists of a suitable input transformer which may be connected to either of two current shunts or to the calibrated potentiometer.

When measurements are being made on telephone lines it is important that the series unbalance between the two sides of the line be kept as low as possible. For this reason extra resistances are provided to be placed in series with the opposite side of the line as balancing resistances for the current shunts.

The amplifier consists of four tubes, impedance coupled, the last one operating as a detector. By this arrangement of the fourth tube the alternating current is converted to direct current, thus making it possible to use a quick, rugged d.c. meter.

By means of switches the amplification may be decreased by cutting out one or two tubes.

A general description of the apparatus follows.

The milliammeter-voltmeter-amplifier has a voltage range of 3.16 to .001 r.m.s. volts and a current range of 31.6 to .02 r.m.s. milliamperes for frequencies between 100 and 5,000 cycles. Between 200 and 3,000 cycles the accuracy of measurement is about 2 per cent. For frequencies above 3,000 the accuracy is within 5 per cent.

The magnitude of an unknown voltage which causes a deflection on the meter can be determined by connecting the amplifier to an adjustable known voltage, varying this voltage until the same meter deflection is obtained as before. This constitutes a measurement.

The potentiometers (P_1) and (P_2) listed above are named (P_1) and (P_2) for the sake of clearness. They are not the potentiometers (P_1) and (P_2) listed on any particular diagram.

Investigation

The Milliammeter-Voltmeter-Amplifier was taken out of its case and its circuit diagram studied. It was checked by the diagram given in the bulletin "D-79017 Voltmeter-Milliammeter". The check revealed that transformers D-81221 and D-81222 were incorrectly connected in the circuit. The primaries of these transformers consist of two windings in series. Instead of these transformers being connected additive they were connected subtractive. On transformers D-81221 the terminals 5 and 2 were connected together and terminals 6 and 1 were connected as the outside terminals of the transformer. The diagram called for them to be vice versa. In transformers D-81222, terminals 4 and 7 were connected together and terminals 3 and 8 were connected as outside terminals. The diagram called for these connections to be vice versa.

Further investigation led to the fact that transformers D-81224 and D-81229 were not grounded as the diagram called for.

The connections to these transformers were connected as the diagram called for. Then preliminary adjustments were made to see if the internal circuits were operating correctly. By this^{is} meant to see if a space charge voltage of the detector registered on the meter after the batteries were connected. The batteries were connected and the first two tubes failed to burn. Investigation carried on further led to the fact that the WL"A" resistance which is in the filament circuit was not making good contact. This was tightened and the internal circuit seemed to work all right.

During the investigation it was found that all the contacts in the tube sockets, the other contact points and the variable resistors

had corroded slightly or were dirty. They were all cleaned with vaseline before the preliminary adjustments were made.

After the internal circuit was found to be working satisfactorily, the thermocouple was calibrated. When this was done, the instrument was hooked up in conjunction with the oscillator to make measurements.

Calibration of Thermocouple

Before the instrument is ready for measuring the thermocouple must be calibrated. A method follows.

Remove the straps from the terminals marked "A" and "B" on the panel of the milliammeter-voltmeter-amplifier and connect the external circuit as shown in Fig. 16. Operate Key 12 to the position marked "INPUT" and adjust the variable resistance until the external d.c. meter used in calibrating indicates 3.16 volts. The reading on the meter located on the voltmeter-milliammeter should then be approximately mid-scale. Adjust Dial 6 by means of a screwdriver until the meter indicates exactly mid-scale (100). Reverse the direction of current thru the thermocouple by operating the reversing switch, making sure that the voltage is still 3.16 volts. If this reading is not 100, Dial 6 should be adjusted until the average of the readings thus obtained for both polarities of current in the thermocouple is exactly 100.

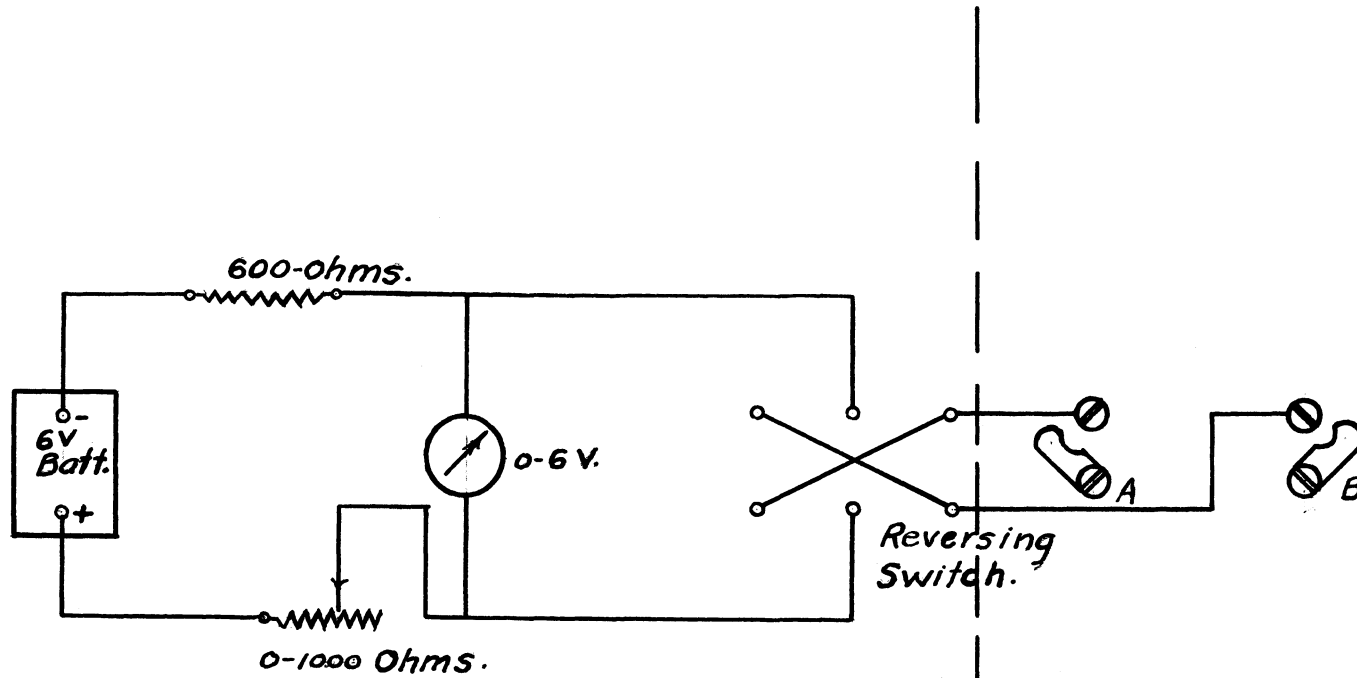


Fig.16.

Measuring Procedure

Insert the tubes - (4Western Electric 102-D) in the instrument. Connect the proper batteries and then connect the output of the oscillator to be used to the terminals marked "OSC". Adjust the frequency output to approximately 1,000 cycles per second. A schematic diagram of connections is in Fig. 17.

(1) With all keys in their normal i.e., vertical position, operate Key 12 to "INPUT".

(2) Adjust Dial 5 until the meter deflection is 100. In this condition the standard voltage, 3.16, is applied to the calibrated circuit.

The instrument is now ready for measuring. Choose some section of the Artificial Line that where a measurement is desired, and to obtain its voltage,

(1) Adjust: Dial 1 to Step 1

Dial 2 to Step 10

Dial 3 to middle setting, and

Dial 4 to approximately .3

(2) Operate: Key 1 to "Volts"

Key 2 to "Out"

Key 3 to "Out"

Key 4 to X - 1.0

Keys 5, 6 and 7 to "VOLTS"

Key 8 to "UNKNOWN"

Keys 9, 10, and 11 to X - .1, and

Key 12 to measure.

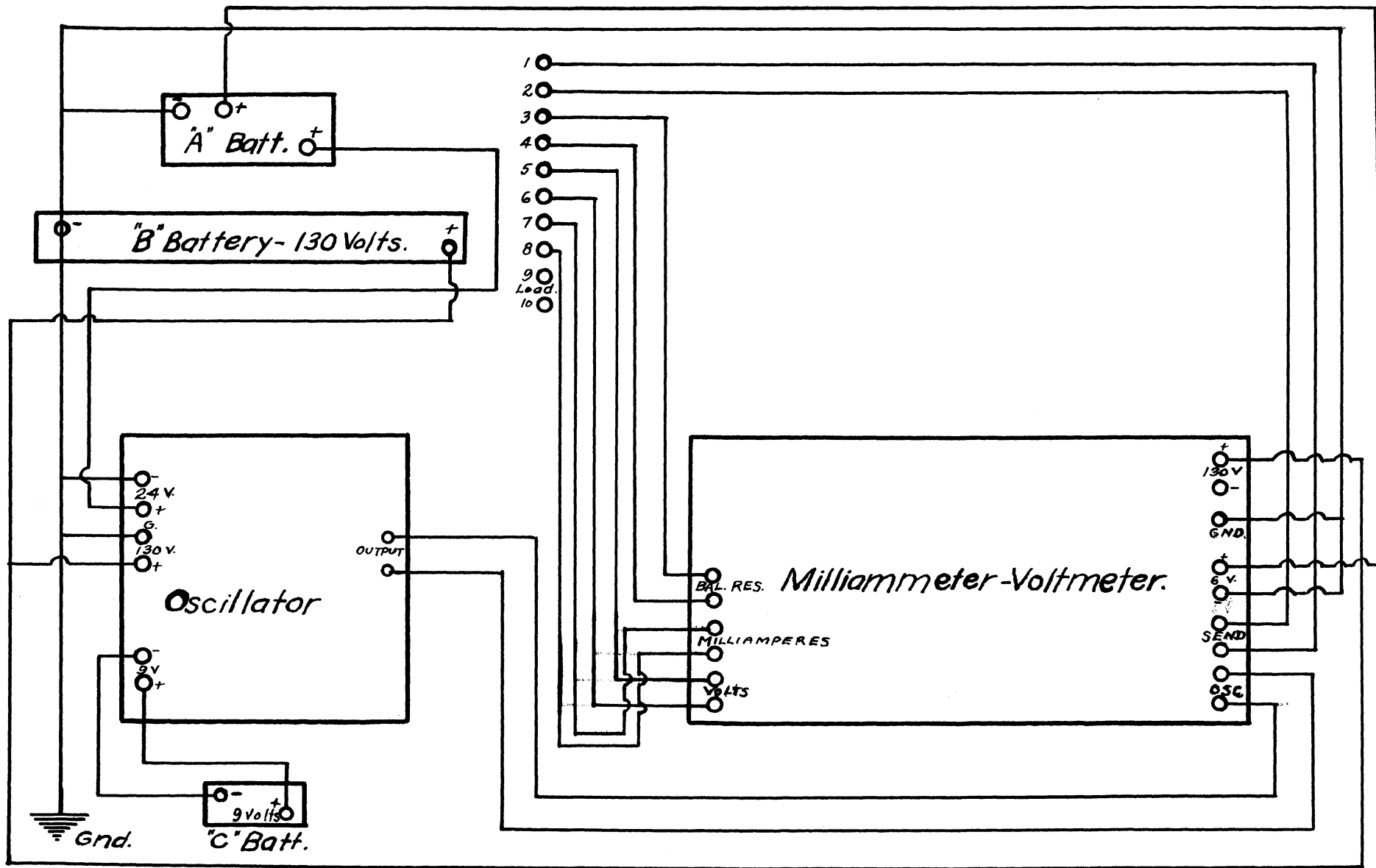


Fig. 17.

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(3) Readjust Dials 1, 2, and 3 and operate Keys 1 and 2 as necessary to obtain a mid-scale deflection on the meter. The settings first described above presumed a voltage near the maximum in the range of the voltmeter, and the dials and keys would have to be readjusted to increase the amplifier gain should the unknown voltage be less. It should be noted that all the dials are arranged to increase the meter deflection for a clockwise turn.

(4) Operate Key 8 to "STANDARD", thereby connecting the amplifier circuit to the voltage of the calibrated circuit.

(5) Adjust Dial 4, and operate Keys 9, 10, and 11 to X -1.0 as necessary to obtain the same deflection as was obtained for the unknown voltage.

(6) Note the reading on the scale of Dial 4 and apply the correction factors for the settings of Keys 9, 10, and 11. This reading as corrected is the measure of the unknown voltage.

(7) Check the deflection obtained with the unknown voltage by operating Key 8 to "UNKNOWN". If this deflection has changed due to a variation in the amplifier gain, readjust Dial 3 and repeat operations 4, 5, and 6. In this way errors due to the use of an amplifier are reduced to a minimum.

(8) Check the adjustment of Dial 5 by operating 12 to "INPUT" and noting the meter reading. Every time this is done the meter should read 100.

If we wish to measure a current we go thru the same procedure above except Keys 1, 5, 6, and 7 are operated to "MILLIAMPERES" instead of "VOLTS", and Key 4 may be used as a multiplier to increase the range of Dial 4. The scale readings as corrected by the multiplier keys are

in milliamperes.

The filament voltage should be kept between 5.8 and 6.1 volts at all times. The plate voltage should be maintained between 120 and 140 volts, but never below 120.

Experimentation

The Milliammeter-Voltmeter-Amplifier was hooked up in conjunction with the Oscillator using the small Edison cells that belong to the laboratory for both filament and plate supply voltage. The Oscillator draws 2.3 amperes filament current and 280 milliamperes plate current. The Milliammeter-Voltmeter-Amplifier draws 2 amperes filament current and 4 milliamperes plate current. Thus there was about 4.6 amperes drain on these batteries. They would not hold up under this discharge over an hour, and during this hour the voltage was varying considerably. Realizing that these cells would not do, 24 G-7 Edison cells were borrowed from the Physics Department. These were then used for the filament supplies, and the small Edison cells were used then only for the plate supplies.

Some time was consumed in installing the G-7's as when we received them they were dry and discharged.

These had to be refilled and recharged. This called for another charging circuit, and so one was installed in the immediate vicinity of these batteries. This charging circuit had to be arranged so that the G-7's and the small cells could be charged at the same time.

The connections from the batteries to the instruments had to be remade. This took more time.

After everything was decided to be all right, the instruments were hooked up so as to make measurements. This will be taken up under "Experiments". It might be added here that before any tests were decided upon that the readings of the Milliammeter-Voltmeter-Amplifier seemed to be stable.

Experiments

Using Milliammeter-Voltmeter-Amplifier in Conjunction with Oscillator

Experiment No. IV

Object:

To illustrate the principles of voltage and current attenuation in telephone and power circuits. Measurements of current and voltage attenuation will also be made at various frequencies to determine the attenuation frequency characteristics of these types of circuits:

Apparatus Required:

- 1 Oscillator, variable frequency
- 1 Milliammeter-Voltmeter-Amplifier
- 1 Artificial open-wire line
- 2 Half sections of artificial open-wire line
- 1 700-ohm resistance
- 1 24-volt battery
- 1 130-volt battery
- 1 9-volt battery

Procedure:

The apparatus was connected as shown in Fig. 17.

(a) The sending terminals of the Milliammeter-Voltmeter-Amplifier were connected to the artificial line with the far end terminated by a resistance of 700 ohms.

(b) Using the Milliammeter-Voltmeter-Amplifier with a 800-cycle supply the current and voltage were measured at the sending and receiving ends of the line.

(c) The current and voltage were measured at several other points along the line. The spare half-sections mentioned in the apparatus are an integral part of the artificial line here, so when a current and voltage measurement is made, they are automatically cut in.

Part II - Voltage and Current Distribution in a Power Line.

The resistance of the artificial line were short-circuited, and the measurements made in Part I were repeated using a 100-cycle source of supply. The line with the resistances short-circuited simulates a No. 00 N.B.S. power circuit. For information as to how to short-circuit the resistances read the portion on the Artificial Line in the first part of this part of the report.

Part III - Attenuation Versus Frequency

Using the artificial line as arranged in Part I, the sending end receiving currents and voltages were measured at frequencies within the range from 500 to 5,000 cycles at 500 cycle intervals.

Discussion:

1. From the data taken in Parts I and II, the following curves were plotted.

(a) Ratio of current at distances X from the sending end to current at the sending versus distances X from the sending end. The distance X is expressed as sections, but each section is equivalent to 7.88 miles of open wire line.

(b) Ratio of voltage at section X from the sending ending to the voltage at the sending ending versus the sections X from the sending end.

These curves are shown in Fig. 18. Had the termination been the characteristic impedance, the ratio of voltage to current at any point of the line would have been unity. From an inspection of the curves drawn, it is seen that the ratio of voltage to current does not vary a great deal, so the 700 ohm resistance was approximately close to the characteristic impedance.

2. From the data taken in Part III, a curve was plotted showing the ratio of receiving end currents and voltages to sending end currents and voltages versus frequency. These curves are shown in Fig. 19.

3. From data taken in Parts I and II, the percentage of power lost in the telephone line was 93, per mile of circuit = .404. The percentage of power lost in the power line was .31, per mile of circuit = .155.

Data for Experiment No. IV

Part I - Frequency = 800

Section	E	I	$\frac{E}{E_s}$	$\frac{I}{I_s}$
0	.496	1.12	1.0	1.0
6	.335	.750	.675	.670
12	.264	.547	.532	.488
18	.210	.360	.423	.321
24	.157	.250	.318	.223

Part II - Frequency = 100, Power line

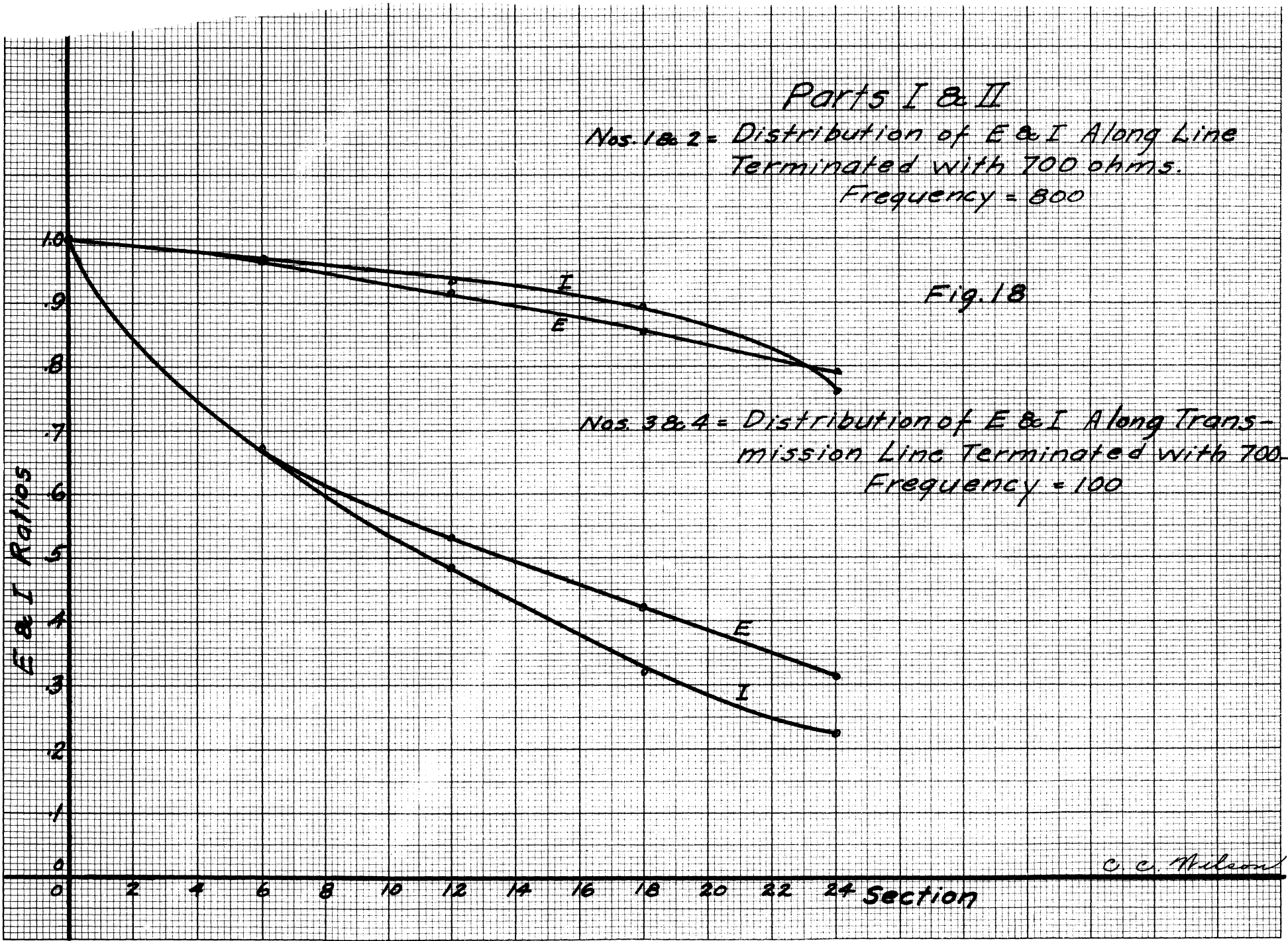
Section	E	I	$\frac{E}{E_S}$	$\frac{I}{I_S}$
0	1.14	.960	1.0	1.0
6	1.10	.925	.965	.965
12	1.05	.895	.920	.932
18	.972	.862	.852	.898
24	.901	.830	.790	.862

Part III - Attenuation Versus Frequency

Frequency	E_S	E_R	I_S	I_R	$\frac{E_R}{E_S}$	$\frac{I_R}{I_S}$
500	.760	.260	1.05	.277	.342	.264
1000	.410	.138	1.08	.247	.336	.229
1500	.304	.083	1.10	.238	.273	.216
2000	.262	.061	1.10	.215	.233	.194
2500	.220	.0446	1.11	.189	.203	.171
3000	.190	.0347	1.12	.171	.183	.153
3500	.156	.0295	1.12	.143	.189	.128
4000	.133	.0250	1.10	.099	.188	.090
4500	.108	.0196	1.075	.0945	.181	.088
5000	.088	.0147	1.070	.0590	.162	.055

The frequency is in cycles per second. The voltage is in volts and the current is in milliamperes.

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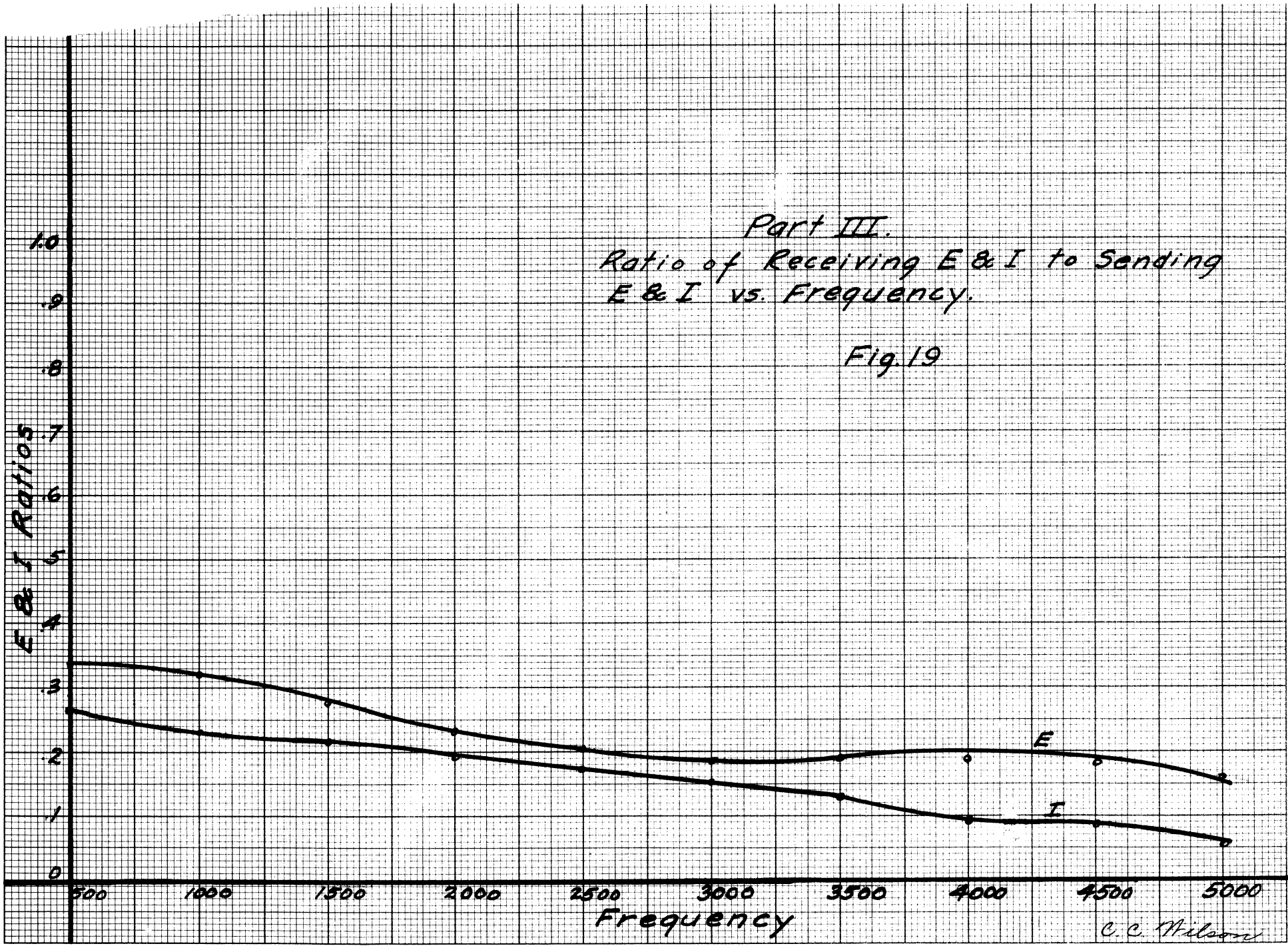


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Part III.
Ratio of Receiving E & I to Sending
E & I vs. Frequency.

Fig. 19



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Calculations for Experiment No. IV.

The line constants of the line are as follows:

<u>Telephone Line</u>	<u>Power Line</u>
R = 10.4 ohms per circuit mile	R = 1 ohm per circuit mile
L = .00367 henrys per circuit mile	L = .00367 henrys per circuit mile
C = .00835 mf. per mile	C = .00835 mf. per mile
G = 0	G = 0

From the following formula the attenuation constants will be computed.

$$A + jB = \sqrt{(R + j\omega L)(G + j\omega C)}$$

For the Telephone line

$$Z = 10.4 + j18.42 = R + j\omega L = 21.2 \angle 60.4^\circ$$

$$Y = (G + j\omega C) = 0 + j42 \times 10^{-6} = 42 \angle 90^\circ \times 10^{-6}$$

Y = Admittance

Z_0 = Characteristic Impedance =

$$\sqrt{\frac{Z}{Y}} = \sqrt{\frac{21.2 \angle 60.4^\circ}{42 \times 10^{-6} \angle 90^\circ}} = \sqrt{\frac{21.2 \times 10^6}{42}} \angle 29.8^\circ$$

$$= 710 \angle -14.9^\circ$$

$$\text{Propagation Constant } P = \sqrt{(21.2) \angle 60.4^\circ \times 42 \times 10^{-6} \angle 90^\circ}$$

$$= \sqrt{(21.2)(42) \times 10^{-6}} \angle \frac{60.4^\circ + 90^\circ}{2}$$

$$= .0297 \angle 75.2^\circ$$

$$\begin{aligned}
 &= .0297 (\cos 75.2^\circ + j \sin 75.2^\circ) \\
 &= .0297 (.2553 + j .9668) \\
 &= .00759 + j .0287 = A + jB
 \end{aligned}$$

The attenuation constant is the real part of P and the wave length constant is the imaginary component.

$$A = \underline{.00759} \text{ nepers / mile}$$

$$B = \underline{.0287} \text{ radians / mile}$$

A neper = $\log e \frac{I_1}{I_2}$. A Standard section would be one which gave

$$\frac{I_1}{I_2} = e = 2.718.$$

For the power line

$$Z = 1 + j 18.42 = R + j\omega L = 18.5 \underline{86.88^\circ}$$

$$Y = 42 \times 10^{-6} \underline{90^\circ}$$

$$\begin{aligned}
 Z_0 &= \sqrt{\frac{Z}{Y}} = \sqrt{\frac{18.5 \times 10^6}{42} \quad \frac{86.88^\circ - 90^\circ}{2}} \\
 &= 665 \underline{-1.56^\circ}
 \end{aligned}$$

$$\begin{aligned}
 P &= \sqrt{ZY} = \sqrt{(18.5)(42) \quad \frac{86.88^\circ + 90^\circ}{2} \cdot 10^{-6}} \\
 &= \sqrt{(18.5)(42) 10^{-6} \quad \frac{86.88 + 90^\circ}{2}} \\
 &= .02785 \underline{88.44^\circ} \\
 &= .000753 + j .02785 = A + jB
 \end{aligned}$$

$$A = \underline{.000753} = \text{Attenuation constant}$$

$$B = \underline{.02785} = \text{Wave length constant}$$

Now we will calculate the attenuation constants from West data.

For the telephone line

$$\frac{I_2}{I_1} = e^{-al}$$

a = the attenuation constant, then

$$-a = \frac{\log(I_2)}{\log(I_1)}$$

$l = 197$ miles

$$\text{then } -a = \frac{\log \left(\frac{.250}{1.12} \right)}{197}$$

$$-a = \frac{-1.501}{197} \quad \underline{.00763} = a$$

The calculated value was .00759. This checks within reason.

For the power line

$$-a = \frac{\log(I_2)}{l(I_1)}$$

$$-a = \frac{\log \left(\frac{.830}{.960} \right)}{197}$$

$$-a = \frac{\log .927}{1}$$

$$-a = \frac{-.1485}{197} \quad \underline{.000755} = a$$

The calculated value was .000753. This checks within reason.

If one refers to the curve shown in Fig. 19, he will see that frequencies higher than 1000 are hardly suitable for telephone work as the power lost for frequencies higher is too high.

Experiment No. V

OBJECT

To find how voltage and current distribute themselves in an Open-circuited Line.

APPARATUS

- 1 Variable Frequency Oscillator
- 1 Artificial Open Wire Line
- 1 Milliammeter-Voltmeter-Amplifier
- 1 24-volt Battery
- 1 130-volt Battery
- 1 9-volt Battery

PROCEDURE

The apparatus was connected up as shown in Fig. 17.

The output of the oscillator was set at a frequency of 800 cycles per second. Measurements of voltage and current were made as like in Experiment No. IV. The far end of the line of course was open-circuited.

This procedure was repeated for a frequency of 2500 cycles.

DISCUSSION

The voltage and current ratios were plotted against sections. These sections were the number of sections from the sending end. The voltage and current ratios are the ratios of section voltage and current to the sending end voltage and current.

The curves are shown in Figs. 20 and 21. The curves are not smooth because of the irregularity in line, i.e., the open circuit at the end of the line. The fact that some of the sections reflect part of their voltage back to the sending end is why the curves vary like they do.

The impedance variation in the line was calculated from data

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numbering

obtained. A curve showing this variation is shown in Fig. 20. The reason for its shape is because it has the same peculiarities as listed in the above paragraph.

A curve was drawn thru the intersections of the voltage and current waves. This curve shows the change in voltage or current along the line hypothetically extended to infinity or terminated at its receiving end thru an impedance equal to the characteristic impedance of the line at test frequency. These curves are shown in Figs. 20 and 21.

CALCULATIONS FOR EXPERIMENT NO. V.

From the curves the attenuation constant will be computed at 800 cycles and 2500 cycles.

For 800 cycles

$$-a = \frac{\log \left(\frac{I_2}{I_1} \right)}{l}$$

This will be computed at the 20th section.

$$I_1 = 1.0, I_2 = .370, l = 157.6 \text{ miles}$$

$$-a = \frac{-.994}{157.6} = \underline{.00625} = \text{attenuation constant}$$

For 2500 cycles

This will be computed at the 20th section.

At the 20th section $I_2 = .27$

$$I_1 = 1, l = .157.6 \text{ miles}$$

$$-a = \frac{-1.309}{157.6} = \underline{.00830} = \text{attenuation constant}$$

For 800 cycles

The wave length = $4D$, when D is the distance between points of intersection. At 800 cycles - $D = 6.7$ sections = 52.9 miles. Then the wave length is $(4)(52.9) = \underline{207}$ miles

The wave length constant is

$$B = \frac{2\pi}{\text{wave length}} = \frac{6.28}{207} = \underline{.0303} \text{ radians}$$

The angle d of the propagation constant vector may be obtained from

$$\tan d = \frac{B}{a}$$

Using our values

$$\tan d = \frac{.0303}{.00625} = 4.85$$

$$d = 78.3^\circ$$

The propagation constant may be calculated from $p = \frac{a}{\cos d}$

$$= \frac{.00625}{.2028} = p = \underline{.0398} = \text{propagation constant}$$

The velocity of propagation is

$$V = \text{wave length} \times \text{frequency}$$

$$V = (207)(800) = 165500 \text{ miles / second}$$

For 2500 cycles.

The wave length = $4D$, $D = 22.8$ miles. Then the wave length is 91.3 miles. The wave length constant is

$$B = \frac{2\pi}{\text{wave length}} = \frac{6.28}{91.3} = \underline{.0688} \text{ radians}$$

The angle d of the propagation constant vector may be obtained from

$$\tan d = \frac{B}{a}$$

substituting our values,

$$\tan d = \frac{.0688}{.00830} = 8.30$$

$$d = 83.1^{\circ}$$

The propagation constant p

$$= \frac{a}{\cos d}$$

$$= \frac{.00830}{.120} = .0692 =$$

$$= (91.3)(2500) = 228000 \text{ miles / second velocity of propagation}$$

The calculations can be no more accurate than the curves. The values given are of course approximately correct.

Data for Curves - Experiment No. V.

800 Cycles

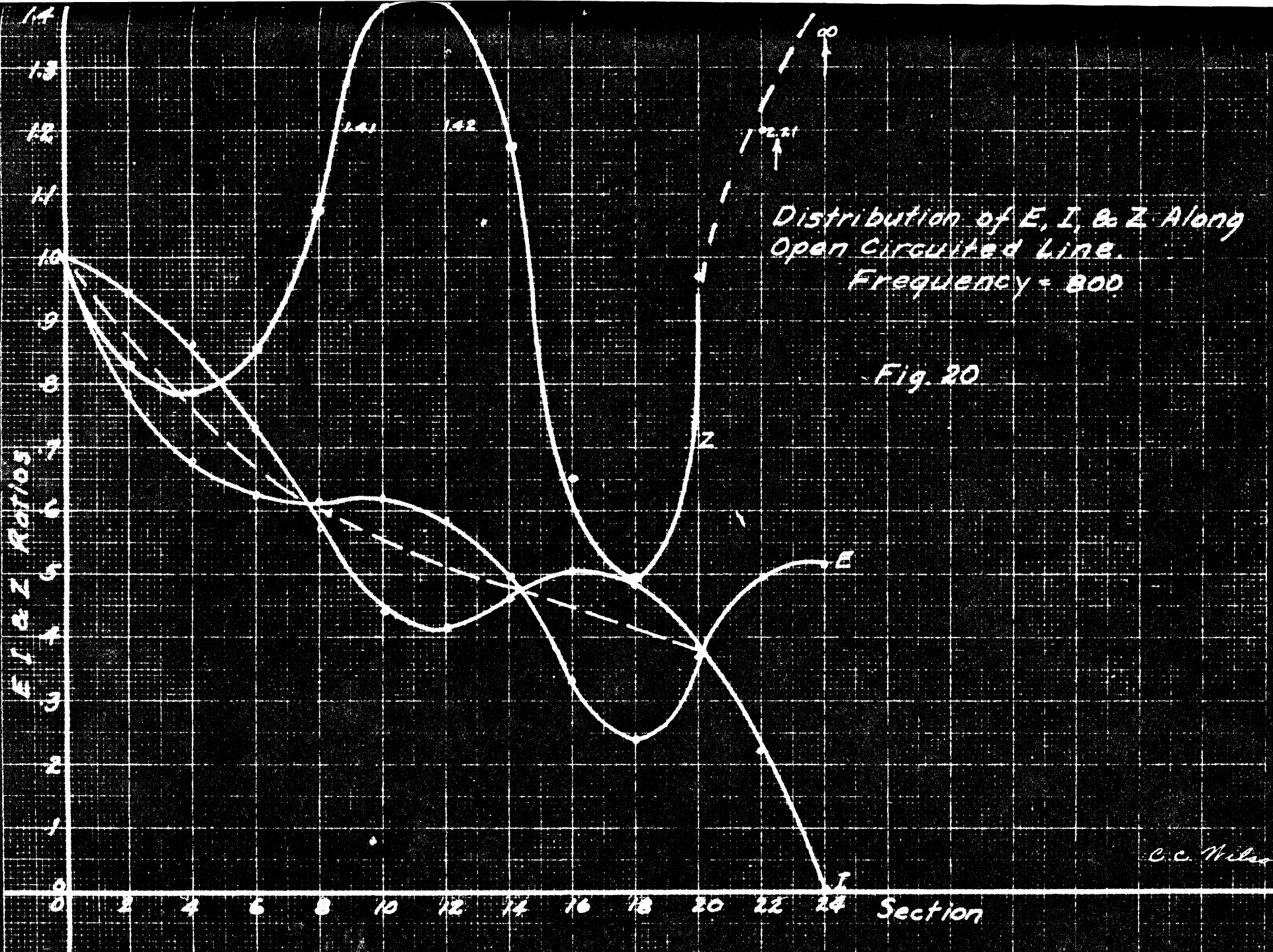
Section	E	I	$\frac{E}{E_s}$	$\frac{I}{I_s}$	$\frac{E}{I}$
0	.497	1.090	1.0	1.0	1.0
2	.395	1.025	.785	.941	.833
4	.335	.940	.675	.862	.783
6	.331	.795	.626	.730	.858
8	.305	.625	.615	.573	1.072
10	.309	.480	.622	.440	1.411
12	.290	.448	.583	.411	1.42
14	.248	.505	.498	.463	1.178
16	.164	.550	.330	.505	.655
18	.118	.530	.238	.486	.490
20	.186	.420	.374	.385	.972
22	.247	.245	.497	.225	.221
24	.255	0	.517	0	Infinity

2500 Cycles

0	.215	1.130	1.0	1.0
2	.203	.910	.945	.805
4	.160	.896	.745	.795
6	.161	.670	.750	.592
8	.113	.700	.525	.620
10	.120	.508	.558	.450
12	.086	.529	.400	.467
14	.083	.433	.386	.383
16	.078	.355	.362	.314
18	.045	.420	.209	.372

20	.078	.187	.362	.165
22	.0196	.421	.091	.373
24	.078	0	.362	0

E is in volts. I is in milliamperes. $\frac{E}{I}$ = voltage ratio divided by current ratio.



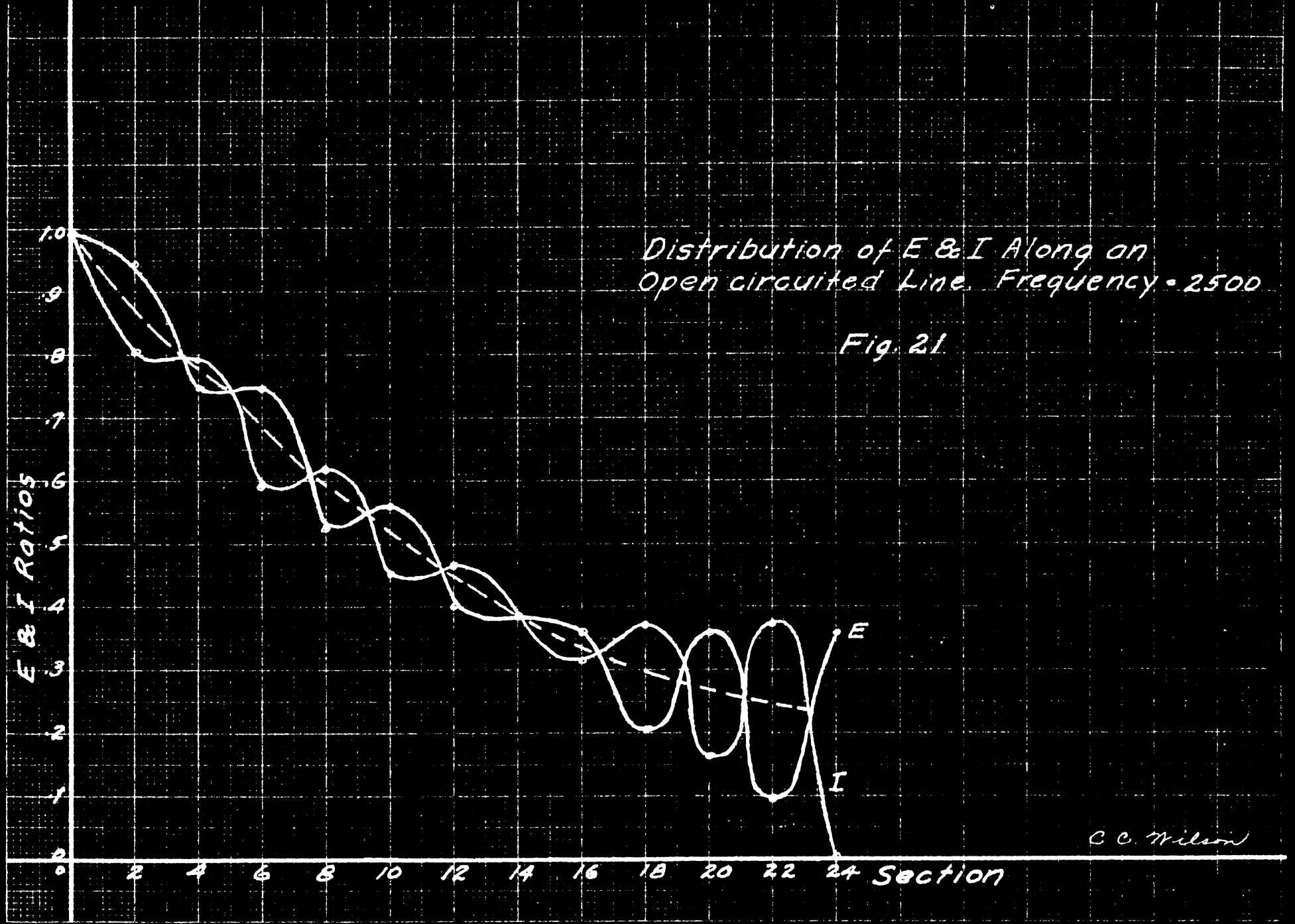
Distribution of E, I, & Z Along
Open Circuited Line.
Frequency = 800

Fig. 20

C. C. Miller

Distribution of E & I Along on
Open circuited Line. Frequency = 2500

Fig. 21



C. C. Wilson

Experiment No. VI

OBJECT:

To find how the current and voltage distribute themselves in a short-circuited line.

APPARATUS:

- 1 Variable Frequency Oscillator
- 1 Artificial Open Wire Line
- 1 24-volt Batter
- 1 130-volt Battery
- 1 9-volt Battery

PROCEDURE:

The apparatus was connected up as shown in Fig. 17.

The output of the oscillator was set at a frequency of 800 cycles per second. The far end of the line was short-circuited. Measurements of voltage and current were made like in Experiment No. IV.

This procedure was repeated for frequencies of 1800 and 2500.

DISCUSSION:

Curves of E and I ratios versus sections from the sending end are shown in Figs. 22, 23, and 24. The E and I ratios are the section E's and I's divided by the sending end E's and I's.

An impedance variation curve is also plotted in Fig. 22. It was calculated from test data.

The curves appearing in Figs. 22, 23, and 24 are not smooth because of the irregularity in the line, i.e., the far end short-circuited.

A curve was drawn between the intersections of E and I at frequencies of 800 and 2500 cycles. This curve shows the change in voltage or current along the line hypothetically extended or terminated

at its receiving end thru an impedance equal to the characteristic impedance at test frequency.

From this curve we shall make our calculations,

For 800 cycles

The attenuation constant a , is

$$-a = \frac{\log \frac{I_2}{I_1}}{l}$$

$I_1 = 1$, $I_2 = .37$, $l = 20$ sections or 157.6 miles

$$-a = \frac{-.994}{157.6}$$

$a = .00625 = \text{attenuation constant}$

The wave length = $4D$,

$$D = 58.9 \text{ miles}$$

The wave length = $(4)(58.9) = 235$ miles

The wave length constant is

$$B = \frac{2\pi}{235} = \frac{6.28}{235} = .0267 \text{ radians}$$

The d of the propagation constant vector may be obtained from

$$\tan d = \frac{B}{a}$$

Using our values

$$\tan d = \frac{.0267}{.00625} = 4.27$$

$$d = 76.8$$

The propagation constant p is

$$p = \frac{a}{\cos d}$$

$$p = \frac{.00625}{.2284} = \underline{.0273}$$

The velocity of propagation is

$$(237)(800) = 187000 \text{ miles / second}$$

For 2500 cycles

$$I_1 = 1, I_2 = .265, l = 20 \text{ sections or } 157.6 \text{ miles}$$

$$-a = \frac{-1.325}{157.6} = \underline{.00840} = \text{the attenuation constant}$$

The wave length is $4D$, D from the curve is 23.2 miles. Then the wave length is 93 miles.

The wave length constant is $B = \frac{2\pi}{93}$

$$= \frac{6.28}{93} = \underline{.0675}$$

The angle d of the propagation constant may be obtained from

$$\tan d = \frac{B}{a}$$

Substituting our values

$$\tan d = \frac{.0675}{.0084} = 82.9^\circ$$

The propagation constant $p =$

$$\frac{a}{\cos d} = \frac{.00840}{.1236} = \underline{.0680}$$

Velocity of propagation = $(93)(2500) = 232,000$ miles per second.

These values check comparatively close to the values found in

Experiment V.

Data for Curves - Experiment No. VI

800 Cycles

Section	E	I	$\frac{E}{E_s}$	$\frac{I}{I_s}$	$\frac{E}{I}$
0	.493	1.12	1.00	1.00	1.000
2	.450	.950	.912	.850	1.075
4	.410	.800	.831	.715	1.165
6	.365	.700	.740	.625	1.185
8	.304	.695	.616	.620	.996
10	.270	.682	.547	.609	.900
12	.235	.638	.486	.570	.855
14	.241	.525	.489	.468	1.042
16	.262	.359	.531	.321	1.655
18	.269	.220	.545	.197	2.760
20	.247	.256	.501	.228	2.200
22	.180	.384	.365	.342	1.070
24	.055	.468	.111	.418	.265

1800 Cycles

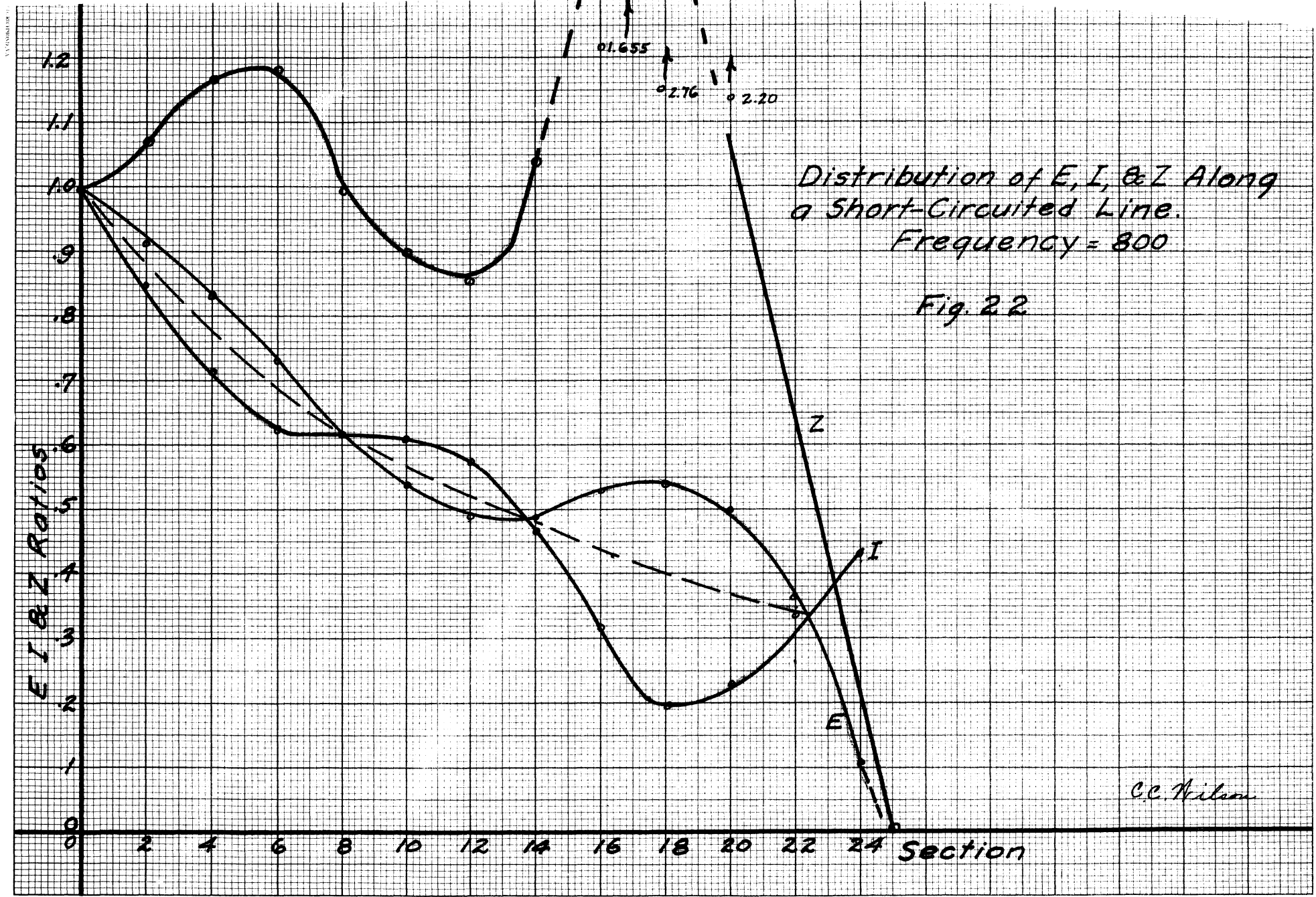
0	.230	1.100	1.00	1.00	
2	.193	1.010	.840	.919	
4	.179	.831	.778	.755	
6	.150	.745	.652	.676	
8	.130	.665	.565	.604	
10	.122	.520	.530	.472	
12	.080	.570	.348	.518	
14	.105	.335	.456	.305	
16	.046	.487	.200	.443	
18	.085	.213	.369	.193	

Section	E	I	$\frac{E}{E_s}$	$\frac{I}{I_s}$
20	.030	.414	.130	.377
22	.067	.210	.290	.191
24	.040	.330	.174	.300

2500 Cycles

0	.225	1.10	1.00	1.00
2	.195	.990	.865	.900
4	.175	.841	.778	.765
6	.140	.740	.623	.673
8	.124	.670	.552	.608
10	.122	.522	.542	.475
12	.078	.570	.348	.518
14	.101	.334	.450	.304
16	.045	.480	.200	.436
18	.084	.215	.374	.195
20	.031	.411	.136	.374
22	.065	.213	.289	.194
24	.039	.330	.175	.300

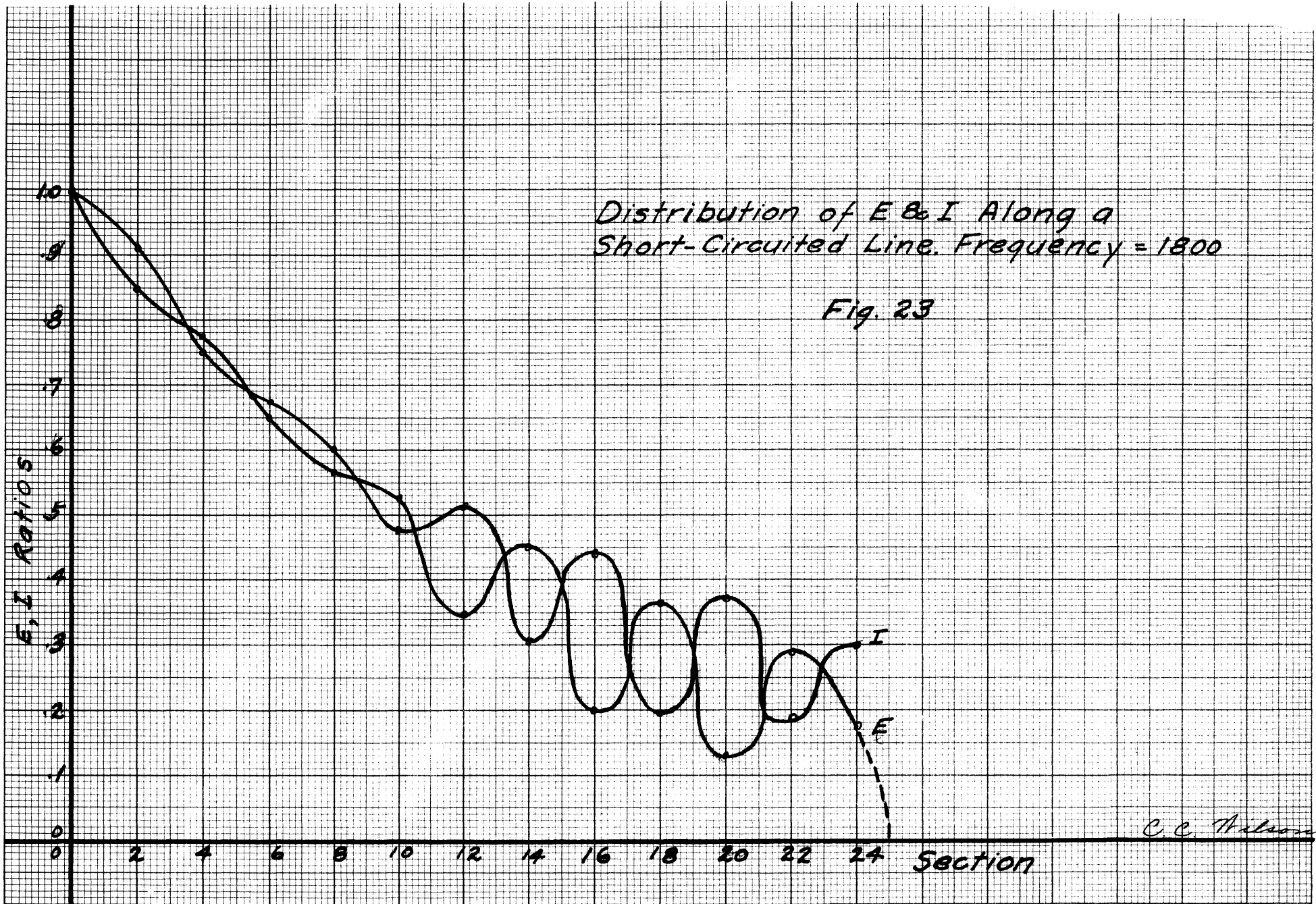
E is in volts, I is in milliamperes. $\frac{E}{E_s}$ is the ratio of the E ratios to the I ratios.

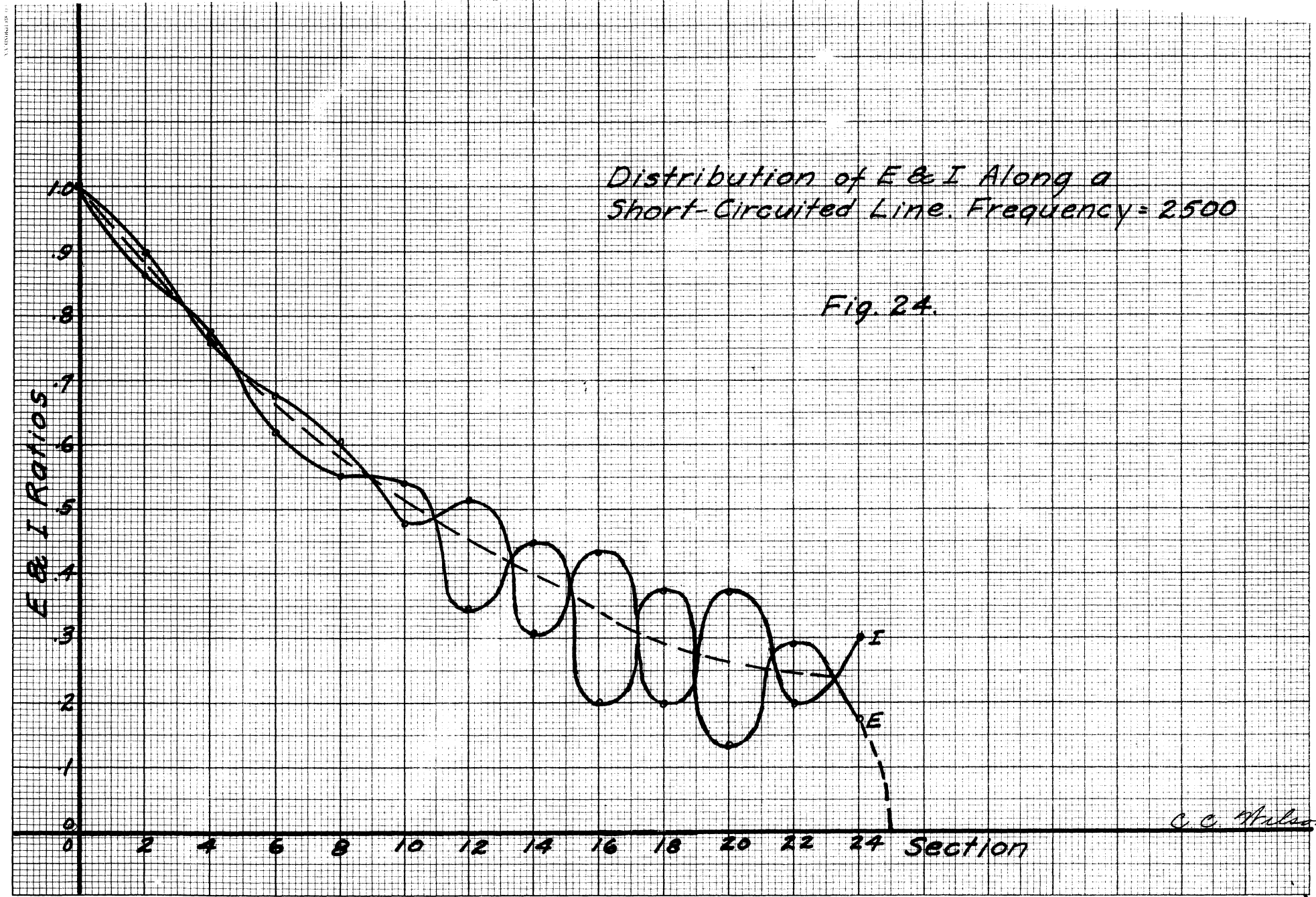


Distribution of E, I, & Z Along
a Short-Circuited Line.
Frequency = 800

Fig. 2.2

C.C. Wilson





Distribution of E & I Along a Short-Circuited Line. Frequency = 2500

Fig. 24.

C. C. Nelson

Experiment No. VII

OBJECT:

To find how voltage and current along a line is distributed when the line is terminated in a receiving impedance.

APPARATUS:

- 1 Variable Frequency Oscillator
- 1 Milliammeter-Voltmeter-Amplifier
- 1 Artificial Open Wire Line
- 1 24-volt Battery
- 1 130-volt Battery
- 1 9-volt Battery
- 1 Commercial Telephone Receiver.

PROCEDURE:

The apparatus was hooked up as in Fig. 17. The output of the oscillator was adjusted to 800 cycles. The artificial line was terminated with the telephone receiver. Voltage and current measurements were made at each section.

DISCUSSION:

The impedance variations of the line were computed from test data. Voltage, Current and Impedance variations are plotted in Fig. 25. These curves are not smooth because of an irregularity in the line. The receiving impedance is far from being the characteristic impedance of the line.

The impedance of the receiver at 800 cycles is 202 ohms.

The sending end impedance of the line as calculated for 800 cycles in Experiment No. IV was 710 ohms.

$$\text{The ratio is } \frac{202}{710} = .284$$

Approximately 8% of the total send-end voltamperes is obtained at the receiver terminals.

Data for Experiment VII

800 Cycles

Section	E	I	$\frac{E}{E_s}$	$\frac{I}{I_s}$	Z
0	.487	1.17	1.00	1.00	1.00
2	.437	.980	.896	.838	1.07
4	.400	.818	.821	.700	1.17
6	.360	.699	.740	.597	1.24
8	.303	.647	.622	.553	1.12
10	.279	.637	.573	.545	1.05
12	.249	.618	.511	.528	.97
14	.223	.550	.458	.470	.975
16	.240	.418	.492	.358	1.37
18	.252	.261	.518	.223	2.32
20	.248	.204	.510	.174	2.93
22	.210	.291	.431	.249	1.73
24	.119	.395	.244	.338	.72

E is in volts, I is in milliamperes. Z = E ratio divided by I ratio.

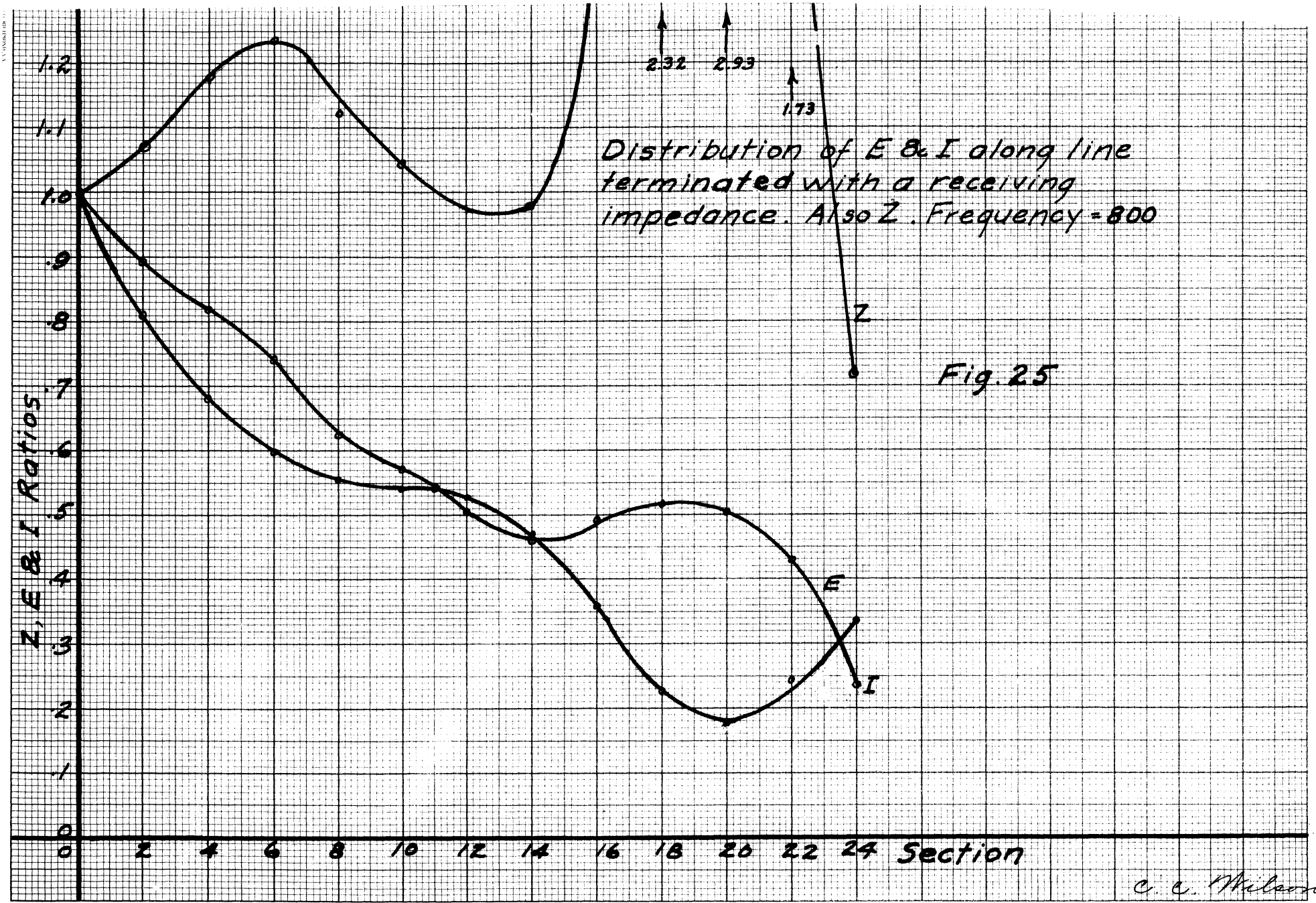


Fig. 25

C. C. Wilson

The Electrical Engineering Department purchased 25 A-6 Edison cells during the early part of April. The Physics Department asked that their G-7 cells be returned. These were returned and the A-6 cells were installed. This consumed some time, but the author is glad that the Department of Electrical Engineering has these cells. They will stand heavy loads. After these were installed work was begun on

Experiment No. VIII

OBJECT:

To observe the variation of open-end voltage with line length.

Experimental Illustration of the Ferranti Effect.

THEORY:

$$E_r = \frac{E_s}{\cosh^2 a l - \sin^2 B l} \cdot e^{-j\theta_1}$$

E_r is the receiving voltage.

E_s is the sending end voltage.

a is the attenuation constant.

B is the wave length constant

θ_1 is the phase angle of the hyperbolic function of the complex numbers.

An analysis of the relation between these terms will lead us to a determination of the conditions favorable for potentials at the open ends of lines in excess of the voltages impressed at the sending end. This discussion furnishes also an explanation of this phenomenon, which is generally called the "Ferranti effect".

Since l is 0 at the sending end of the line the hyperbolic term $\cosh^2 a l = 1$, the trigonometric term $\sin^2 B l = 0$, whence $E_r = E_s$, which is obvious.

As the line-length is increased, the hyperbolic term increases above 1, while the trigonometric term varies between zero and unity, its maximum never exceeding 1. If the value of the attenuation constant, a , and the wave-length, B , are such that for a definite length of line $(\cosh^2 a l - \sin^2 B l)$ is less than 1, then the denominator of the expression for E_r is less than 1, and the voltage at the open-circuited end is larger than that at the sending end. Such a condition evidently obtains when $\cosh^2 a l$ is less than 2, because $\sin^2 B l$ can never be larger than 1. For the limiting condition, when

$$\begin{aligned} \cosh^2 a l &= 2 \\ \text{and} \quad \sin^2 B l &= 1 \end{aligned}$$

The denominator of the equation for E_r is unity, and the end voltage is again equal to the sending-end voltage.

With definite values of the attenuation constant, a , and the wavelength constant, B , for all values of l such that $(\cosh^2 a l - \sin^2 B l)$ is more than 1, the denominator of the equation will be larger than 1, and the open-circuit-end voltage will be smaller than the sending-end voltage.

It follows, from what has been said, that if the Ferranti effect is to occur at the end of the line, the hyperbolic term in the equation must be less than 2. Moreover, if $\cosh^2 a l$ is less than 2,

the denominator will be a minimum when the length of the line is such that

$$\sin^2 B L = 1$$

resulting in a maximum value of E_r , i.e., the maximum Ferranti effect occurs when the line is in resonant condition, with length of line equal to one quarter of the wave length.

To determine whether any line is subject to the above mentioned favorable conditions for the Ferranti effect, consider the limiting conditions, namely when the open-end voltage is equal to the sending-end voltage. We have

$$\cosh^2 a L = 2 \text{ and } \sin^2 B L = 1$$

$$\text{or } \cosh a L = 1.414 \text{ and } \sin B L = +1 \text{ or } -1$$

$$\text{whence } a L = .8814$$

$$\text{and } B L = (2n - 1)\frac{\pi}{2}$$

$$\frac{B}{a} = \frac{(2n - 1)\frac{\pi}{2}}{.8814}$$

If the line is in the one - quarter of a wave length resonant condition, $n = 1$, and the last expression becomes

$$\frac{B}{a} = 1.7828$$

This result indicates that any open-circuited line is subject to the Ferranti effect when the ratio of its wave length constant to its attenuation is more than 1.728, i.e., when the attenuation constant is less than 56.09 per cent of the wave length constant. If this condition is satisfied, the Ferranti effect will occur for all lengths of line between $L = 0$ and the value of L that will make

$$\cosh^2 a l - \sin^2 B l = 1$$

$$\text{or } \sin B l = \sinh a l$$

APPARATUS:

- 1 Variable Frequency Oscillator
- 1 Milliammeter-Voltmeter-Amplifier
- 1 Artificial Open Wire Line
- 1 24-volt Battery
- 1 130-volt Battery
- 1 9-volt Battery

PROCEDURE:

The apparatus was hooked up as in Fig. 17. The open end voltages equivalent to 1, 2, 3, etc. sections were measured. This was done by cutting out the current switch on the panel of artificial line. The voltage switch was closed, and the two double-pole-double-throw switches on the edge of the board for the section in question were opened. The same effect can be obtained by making measurements in the usual manner, but disconnecting the "milliamperes" wires from the measuring set.

DISCUSSION:

If this line is subject to the Ferranti effect, $\frac{a}{B}$ must be less than .5609.

From experiment No. V,

$$a = .00625$$

$$B = .0303$$

then $\frac{a}{B} = \frac{.00625}{.0303} = .206$ which is less than .5609.

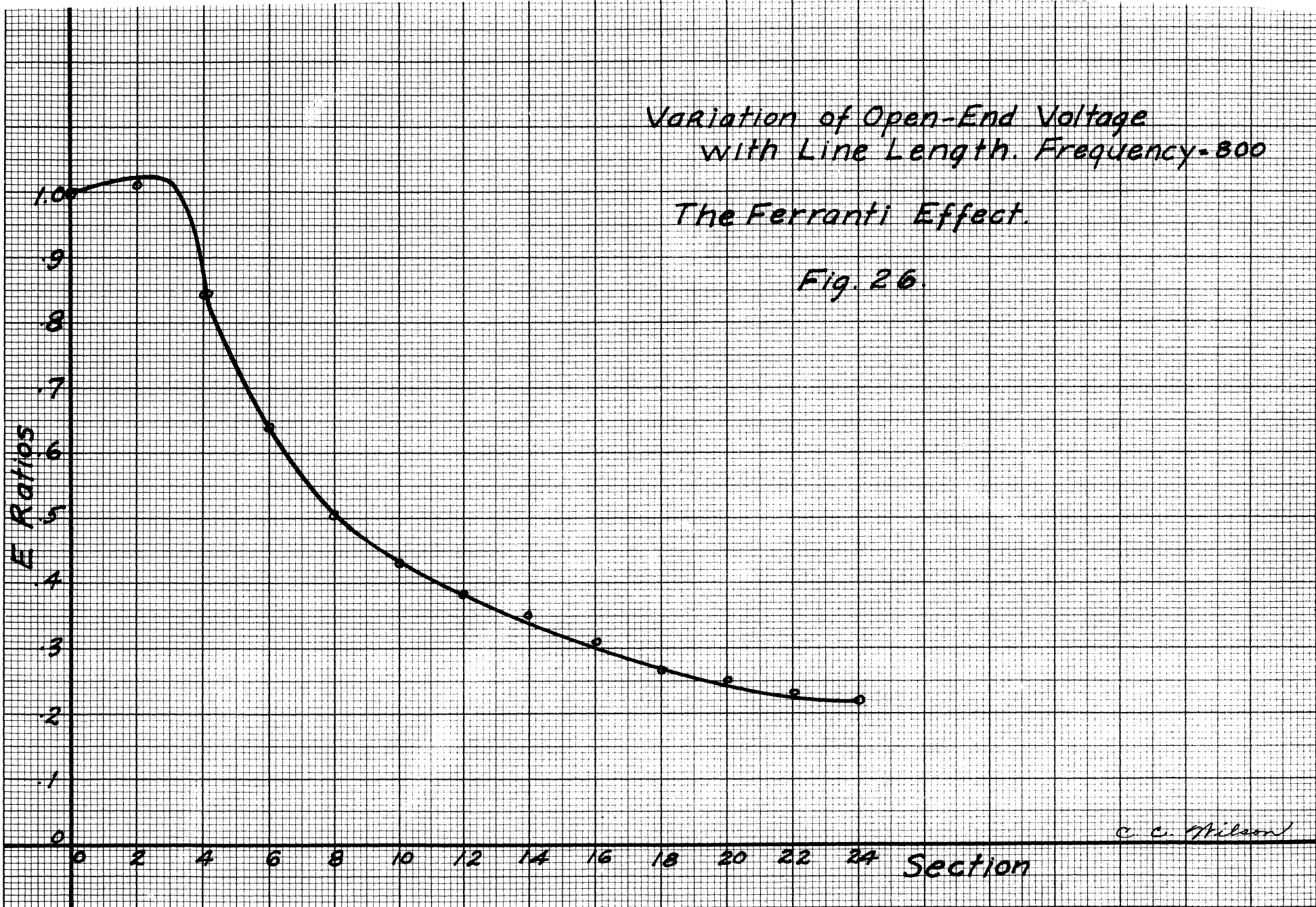
A curve showing open end voltage against corresponding lengths of line is shown in Fig. 26. The Ferranti effect was not very predominant in this line. The curve is not smooth because of the irregularity in the line, i.e., the section ends were open-circuited. The open-end voltage is a maximum at the third section.

Data for the Curve in Experiment No. VIII

Frequency = 800

Section	E	$\frac{E}{E_s}$
0	1.185	1.00
2	1.20	1.01
4	.99	.835
6	.75	.633
8	.60	.505
10	.51	.430
12	.46	.388
14	.42	.354
16	.37	.313
18	.32	.270
20	.30	.253
22	.28	.234
24	.26	.220

E is in volts.



Variation of Open-End Voltage
with Line Length. Frequency-800

The Ferranti Effect.

Fig. 26.

C. C. Milam

EXPOSITION

The writer in general obtained satisfactory results from the "D-79017 Milliammeter-Voltmeter-Amplifier". He believes that connecting the four transformers, namely, D-81221, D-81222, D-81224, and D-81229, like the diagram called for that he eliminated the cause for the unstable meter deflections that were obtained previously. At one time he experienced some small error readings, ie., the meter would not remain constant at a figure when a measurement was being made. He found that the contact points in the oscillator were dirty. He cleaned these and the vacuum tube socket contacts with a rag moistened in vaseline. At the same time he cleaned all moving parts in the Milliammeter-Voltmeter-Amplifier. He connected the apparatus up and obtained very satisfactory readings after that.

The new A-6 Edison cells furnishing a practical constant voltage at all times helped to rid the unstable readings.

The contact points in the oscillator and milliammeter-voltmeter-amplifier are not perfect, but the writer sees no way in which a new type could be installed without materially altering the construction of these instruments. This he does not consider practical. Inasmuch as these instruments are delicate scientific instruments they should be treated with care. Therefore the contacts and slide wires should be cleaned with vaseline occasionally.

The writer experienced a small drop of voltage in the batteries during an afternoon run. He used a voltage slightly higher than 6 for the milliammeter-voltmeter-amplifier and cut this down with a

rheostat, having a voltmeter to observe the voltage at all times.

The writer recommends for satisfactory operation of the Oscillator, impedance bridge, and Milliammeter-Voltmeter-Amplifier that all moving parts be kept clean; that the oscillator filament voltage of the milliammeter-voltmeter-amplifier be kept between 5.8 and 6.1 volts; that the plate supply be kept between 120 and 140 volts.

Part 3

DESIGN OF A MILLIAMMETER-VOLTMETER-AMPLIFIER

As has been previously told, the Milliammeter-Voltmeter-Amplifier is a device for determining the relative magnitude of small alternating currents and voltages at frequencies within the range of the human voice. It consists essentially of the following elements.

1. A vacuum tube amplifier.
2. A vacuum tube detector to rectify the alternating current so that a sensitive direct current meter can be used to indicate the magnitudes of current and voltage.
3. A calibrated potentiometer used to indicate the ratio of the magnitudes of the voltage impressed on the input of the amplifier.

The operation of the device in comparing voltages or currents consists fundamentally of noting the meter deflection caused by the smaller current or voltage and then reducing by means of a potentiometer the larger voltage or current until the same meter deflection is observed. The potentiometer readings being proportional to the applied voltages or currents furnish the basis of comparison. Fig. No. 27 shows the schematic drawing of a laboratory model of a Milliammeter-Voltmeter-Amplifier. This circuit was obtained from one of the Bell System booklets.

The components of this circuit are:

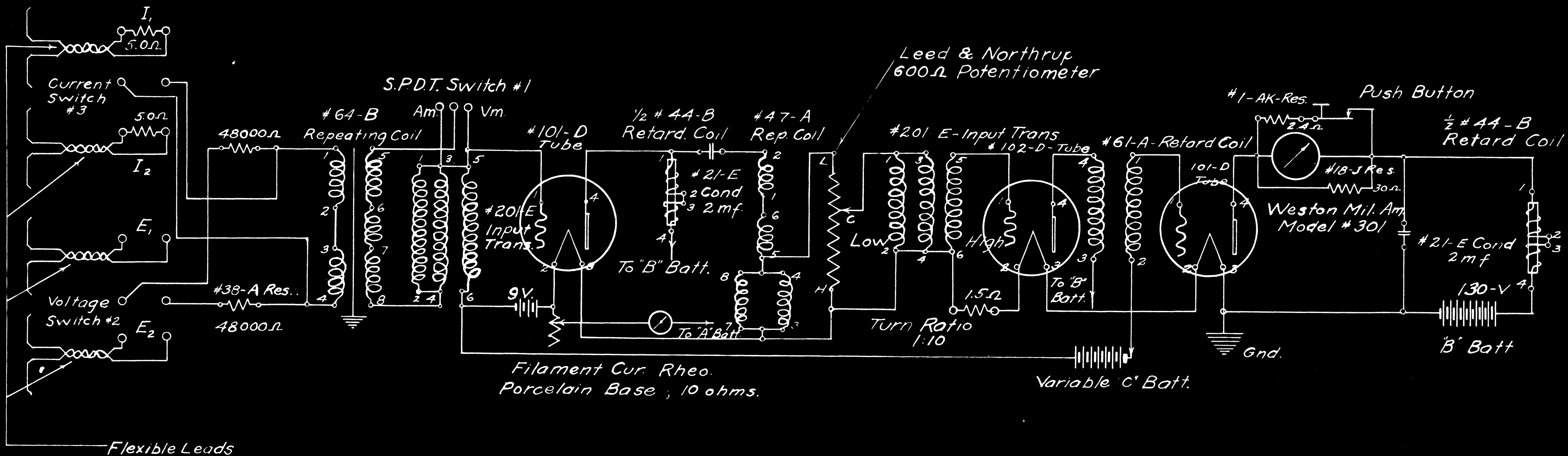


Fig. 27.
MILLIAMMETER-VOLTMETER-AMPLIFIER.
 LABORATORY MODEL.

- 2 - 5 ohm resistors
- 1 - voltage switch, D.P.D.T.
- 1 - current switch, D.P.D.T.
- 2 - No. 38-A-48000 ohm resistors
- 1 - #64-B- repeating coil
- 2 - #201-E - input transformers
- 1 - switch, No. 1, - S.P.D.T.
- 1 - #44B - retarding coil
- 2- No. 21-E, condensers - 2mf.
- 1 - No. 47-A - repeating coil
- 1 - 600 ohm Potentiometer - Leed and Northrup
- 1 - No. 61-A - retarding coil
- 1 - 1.5 ohm resistor
- 1 - No. 1-AK - resistor - 2.4 ohms
- 1 - No. 18-J - resistor - 30 ohms
- 1 - No. 301 - Weston Milliammeter, Weston Electrical Inst. Co.
- 1 - 0-2 amp. ammeter
- 1 - filament current rheostat, 10 ohms with porcelain base
- 1 - push button
- 2 - No. 101-D - vacuum tubes
- 1 - No. 102-D - vacuum tube
- 3 - No. 100-L - vacuum tube sockets
- 1 - board - 3 ft by 2 ft.

necessary hook up wire, screws, spring clips, etc.

Auxiliary equipment needed:

- 1 - 130-volt battery
- 1 - 18-volt battery
- 1 - 9-volt battery
- 1 - 3-6 volt battery

All the apparatus that has a number is of Western Electric Company manufacture unless otherwise mentioned. The other apparatus may be that of any other reliable manufacturer.

If the reader is to understand the changes that will be made in this circuit, perhaps it would be well to give a description and operation of the circuit in Fig. No. 27.

Using currents of approximately the magnitude of telephone currents, the device is capable of measuring voltage and current ratios as high as 1 to 100 with reasonable accuracy. The maximum measurable ratio depends on the magnitude of the current at the input of the circuit under investigation, and also on the turn ratio of the high ratio input coil in the cases where this coil is used.

DESCRIPTION

As may be seen, the amplifier-detector consists of three vacuum tubes and requires 18 volts for the filament circuit, and from 120 to 140 volts for the plate circuit. The first tube requires a 9-volt C battery, the second tube a $1\frac{1}{2}$ -volt C battery, and the third a variable C battery, usually about 3 to 6 volts.

The input to the amplifier detector is composed of:

2 - 48000 ohm resistances

1 - No. 64-B repeating coil

A high ratio input coil which can be cut in or out
by means of a switch, and

A No. 101-D vacuum tube

This combination forms a high impedance which can be connected directly across a circuit whose impedance is of the order commonly found in telephone circuits without appreciable effect upon it. The No. 64-B repeating coil is a shielded transformer used to reduce the effects of unbalance currents. The turn ratio of this transformer is 1:1. In comparing voltages the two high resistances are used in connection with the 64-B repeating coil, but usually without the high ratio input coil. In comparing currents the high resistances are omitted and the high ratio input coil used, thus impressing about the same voltages on the grid of the No. 101-D vacuum tube for both current and voltage measurements. For circuits of average impedance and average frequency of the voice range, about the same range of voltage ratios and current ratios can be measured without changing the voltage applied to the circuit under investigation. In some cases when measuring very small voltages it may become necessary to make use of the high ratio input transformer to get a satisfactory reading on the meter. This coil can be cut in or out as required by means of the knife switch provided for this purpose.

The first tube is used as an amplifier. The output impedance

of this tube is stepped down by using a No. 47-A repeating coil used as an autotransformer with a turn ratio of 3 to 1 or an impedance ratio of 9 to 1. This brings the output impedance of the tube down to approximately match the impedance of the 600 - ohm calibrated potentiometer. The scale of this potentiometer is divided into 200 equal parts and forms a means by which ratios are determined.

The next piece of apparatus in the circuit is the No. 201-E input transformer. This transformer has an impedance ratio of about 1 to 100 when windings 1-2 and 3-4 are connected in parallel. This transformer with the second tube, which is a No. 102-D, introduces a large amplifying factor in the circuit. The grid potential of the 102-D tube is obtained by means of a resistance in series with the filament circuit. In the circuit this is shown to be 1.5 ohms. With one ampere flowing, this gives the required potential of -1.5 volts.

The output of the second tube is connected to the input of the third tube thru a No. 61-A retardation coil arranged as 1:1 transformer. This is made possible by the high output impedance of the No. 102-D vacuum tube.

The third tube, which is a No. 101-D type, is used as the detector and requires a large grid potential. This should be about 20 volts. Part of it is furnished by the filament circuit drop across the first and second tubes and the 9-volt C battery of the first tube. Additional dry cells may be needed to bring the total up to 20 volts

or to give an initial deflection on the milliammeter of about 3 scale divisions.

Be careful that the grid circuit of the last tube is closed, otherwise the meter may be damaged.

The meter in the output circuit of the last tube is used to indicate the magnitude of the voltage impressed on the grid of the second tube. The circuit thru the meter will be increased about ten times when the push button is opened. Therefore, if the meter reads 3 divisions or less, it is safe to operate the push button.

OPERATION

Adjustment of Amplifier Detector Unit:

- (1) Adjust filament current to .97 amperes
 - (2) B battery should be between 120 and 140 volts
 - (3) C battery of first tube should be 8 or 9 volts
- C battery of second tube should be 1.4 to 1.5 volts
- C battery of third tube should be adjusted until a deflection is observed on the milliammeter of 3 scale divisions. The meter shunt should be closed.

Measuring Voltage Ratios:

- (1) Circuit to be investigated should be connected to an oscillator.
- (2) By means of the spring clips on the flexible leads, connect the voltmeter leads across the circuit at two points where the voltages are to be compared.
- (3) Switch No. 1 should be thrown so as to cut out the high ratio input coil unless the smaller of the two voltages is so weak that the coil is required in order to obtain a satisfactory deflection.

- (4) Throw the voltmeter switch (knife switch No. 2) toward the side where the voltage is smaller.
- (5) Set the calibrated potentiometer at 1000.
- (6) Adjust the oscillator output potentiometer until the desired deflection, about 20 scale divisions, is observed on the meter.
- (7) Now throw the voltmeter switch to the opposite side and adjust the calibrated potentiometer until the same deflection is obtained on the meter. The reading of the calibrated potentiometer in the two cases indicates inversely the ratio of the two voltages. When measuring voltage ratios the current switch should be open.

Measuring Current Ratios:

- (1) Insert the spring clips of the ammeter leads in the circuit at the points where currents are to be compared.
- (2) Throw switch No. 1 so as to cut in the high ratio input coil.
- (3) Throw the current switch (knife switch No. 3) toward the shunt, that which will probably be carrying the least current.
- (4) Set the calibrated potentiometer at 1000.
- (5) Adjust oscillator output until desired deflection is observed on the meter.
- (6) Throw the current switch to the other position and adjust the calibrated potentiometer until the previous deflection is again obtained on the meter. The ratio of the two settings of the calibrated slide wire indicates inversely the ratio of the two currents. When measuring current ratios the

voltage switch should be open.

The Western Electric - 101-D and 102-D tubes are rather expensive. They cannot stand much overload as to filament current, i.e., the filaments are easily burned out. The writer wishes to compare these tubes with tubes that have similar characteristics manufactured by the RCA - Radiotron Co. A comparison follows:

Characteristics of 102-D-

If = .94 to 1.00 amps

Ef = 2.5 volts

Ep = 100-150 volts

Ip = .3 to 1.5 m.a.

Rf = 40,000 to 100,000 ohms

u = 26 to 34

Ep max = 160 volts

A similar RCA Tube

If = .25 amps

Ef = 5 volts

Ep = 135-180 volts

Ip = .2 m.a.

Eg = 1.5 to 3 volts

u = 30

Rf = 150,000 ohms

Tube = X-240

<u>Characteristics of 101-D</u>	<u>Similar RCA Tubes</u>	
	112-A	201-A
Ef = 4.4 volts	Ef = 5 volts	Ef = 5 volts
If = 1.0 amps.	If = .25 amps	If = .25 amps.
Ip = 8 m.a.	Ip = 6.2 m.a.	Ip = 3 m.a.
Ep = 100 - 150 volts	Ep = 135 volts	Ep = 135 volts
Rf = 6,000 ohms	Rf = 5,000 ohms	Rf = 10,000 ohms
u = 6	u = 8.5	u = 8
Eg = -9 volts	Eg = -9 volts	Eg = -9 to -13.5 volts

Thus it is seen that the RCA - 240 has practically the same constants as the W.E. - 102-D. Similarly the RCA - 112-A and 201-A have practically the same constants as a W.E. - 101-D. The constants referred to are (u), Rf and Ep.

The RCA - 112-A and the 201-A, are practically the same except their Rf's. The writer believes the 112-A to be more rugged than the 201-A.

The writer recommends substituting 112-A tubes for the 101-D's and (240) tubes for the 102-D's, in the circuit shown in Fig. 27. The tubes shown in Fig. 27 are connected in series. The filament voltage of the RCA - 240's and 112-A's are the same, so they should be connected in parallel.

The writer in general recommends the following changes in the circuit in Fig. 27:

- (1) Substitute the 101-D tubes with RCA - 112-A tubes.
- (2) Substitute the 102-D tubes with RCA - 240 tubes.
- (3) Connect these tubes in parallel.
- (4) Remove the 1.5 ohm resistor in the grid circuit of the 2d tube and insert a 3 volt "C" battery.
- (5) Break connection from terminal 6 of # 201E Input Transformer (before 1st tube) and the variable "C" battery.
- (6) Connect a -13.5 "C" battery in series with lead No. 2 of the No. 61-A Retarding Coil and the filament. Connect the positive terminal of this battery to the negative side of the "A" battery.
- (7) Connect the positive terminals of all "C" batteries to the negative side of the "A" battery.

When a measurement is to be made adjust the current in the filament ammeter to .75 amps. The filament rheostat can be cut down to 6 ohms. The filament voltage supply should be a 6 volt storage battery.

The method of making measurements on the laboratory model of the Milliammeter-Voltmeter-Amplifier is easier than on the D-79017. The writer recommends the construction first with Western Electric tubes and when satisfactory operation is obtained to make a change to R.C.A. tubes. The RCA tubes are cheaper, and they can stand more overload than the Western Electric tubes for they have thoriated filaments.

Perhaps some experimentation may be necessary with "C" battery voltages to get the RCA tubes to operate properly, but the results that will be obtained will be worth the trouble.

CONCLUSION

Since experimentation with this type of apparatus was entirely new to the writer, and since he worked alone, progress was rather slow. Many experiments were performed for the first time at the Virginia Polytechnic Institute, because in years past the Milliammeter-Voltmeter-Amplifier failed to operate satisfactorily.

The writer is glad that this instrument is operating all right now. Furthermore, if future students think the D-79017 too complicated, they may construct the laboratory model that has just been described.

The writer wishes to express his appreciation for the ever willingness of the staff of the Electrical Engineering Department to give assistance when it was needed.

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