THE DEVELOPMENT OF A
LOGARITHMIC INDICATING INSTRUMENT
FOR THE MEASUREMENT OF
RADIO NOISE VOLTAGES
ENCOUNTERED IN RADIO RECEIVERS

A Thesis presented to

The Faculty of Graduate Studies and Research

McGill University

- - - - - -

In partial fulfillment of conditions
required for admission to the degree
Master of Engineering

by

Walter Jesse Ives, B.Sc.(Man.)

Montreal, Can.
Sept. 3, 1946.

Walter J. Ives

TABLE OF CONTENTS

PREFACE

A meter for the measuring of radio noise should give results which are comparable with the effect of the noise as heard in the loudspeaker of a radio receiver, and at the same time be accurate and rapid in operation.

Radio noise from different types of apparatus differs in character; some types of noise have high amplitude but are of short duration, whereas others are more nearly sinusoidal in form. Furthermore the characteristics of the radio receiver upon which the noise impinges will have an effect on the noise characteristics, so that the wave shape of the noise pulse at the output of the receiver may differ materially from that at the input.

The most practical type of noise meter is one which is essentially similar to a radio receiver, with indicating means in the output. Such a device may be made convenient to operate, portable and reliable. The indications of noise intensity for various types of noise on this type of noise meter depend upon the design constants chosen, but it is preferable to have a simple indication such as this type of noise meter provides and then to classify types of noise-making apparatus if necessary, rather than use a complex noise meter which does not alter the noise pulse.

The use of a logarithmic response is an obvious aid in the measurement of widely varying amplitudes which are characteristic of some types of noise.

Three known devices which accomplish this result are as follows:

1. An indicating meter using specially shaped pole pieces.
2. A logarithmic d.c. amplifier between the detector and a linear indicating device.
3. Automatic-gain controlled i.f. stages using the variable-mu tubes.

It is the second device which this paper is concerned with as well as the study of the range and the linearity of the detector output. This logarithmic device may be used in circuits for reading peak, average and r.m.s. where the currents produced by the detector are respectively proportional to the peak, average, and average of the square of the applied voltage.

CHAPTER 1

INTRODUCTION

The whole problem of radio interference is now receiving consideration by the radio and electrical industries and the governments of many countries. The technical problems are being carefully considered and a great amount of data is being collected and exchanged through such organizations as the Electrotechnical Commission, the British Post Office, the Canadian Engineering Standards Association, the Joint Co-ordination Committee of the Edison Electric Institute, National Electrical Manufacturers Association and the American Standards Association.

A method of measuring radio noise is required for two reasons.[1] In the first place, it is needed for measuring the efficacy of any given method of abating the interference and for finding the best method to use in any given case. In the second place it is needed to determine whether a given item or system is capable of causing interference in excess of certain assigned limits. The most important requirement of the method of measurement is that the numerical values it assigns to the very varied kinds and degrees of radio noise shall approximate as closely as possible to their subjective significance of "annoyance values". Another very important requirement arising from the world wide range of radiotelecommunications is that there shall be international understanding and agreement about it.

Radio noise effects are produced by extraneous electrical fields associated with the transient conditions in an electrical circuit.[2] The noise voltage produced by electrical apparatus on a given system depends upon the high frequency voltage generated, the internal impedance of the apparatus, and the character and impedance of the load. This voltage is propagated by conduction, induction, radiation, or a combination of these. All metallic materials whether used normally for electrical systems or for other purposes, may conduct high-frequency energy.

The need for investigation of radio noise measurements arises from the fact that measurements, using noise meters that are now available, show anomalous discrepancies.[3] Various instruments having been calibrated with sine wave signals read differently to as great an extent as 1000 to 1 when they are presumably reading the field intensity from the same noise source. In a noise meter, the detector and the indicating device require extremely careful investigations. Specifications so far set up for such apparatus are definite, but the effectiveness of the devices so specified for measuring noise is questionable. This results in part from the wide variations in the peak values and wave forms of the voltages fed to the device.

Various writers have shown that the a.v.c. circuit used to obtain the logarithmic response has a great influence on the charge and discharge times of the detecting circuit.[4] Also the variation of both detector charge and discharge times with input is evidence of effects of variation of the effective d.c. resistance of the diode during rectifying and quiescent periods respectively. All noise meters have a limited dynamic range. It is quite probable that a very important error of measurement may be produced by the overloading of some component in the noise meter by some kinds of noise such as sharp pulses with low repetition rate.

The ideal noise measuring instrument would be one which would give a numerical value to the nuisance value of the interference. Such an ideal, however, is beyond attainment as the nuisance value of the interference is dependent on the personal judgment of the listener, as well as on all the measurable factors of the interfering surge and the desired signal.

CHAPTER II

SOME DEFINITIONS

Noise:[3] May be defined as any undesired signal having a wide frequency spectrum. Two general types of noise are usually distinguished.

(a) Random or fluctuation noise.

(b) Pulse noise.

Man made noise may be a combination of both types. Pulse noise is defined as individual pulses discretly separated in time. These signals are easier to study both theoretically and experimentally and they are easily defined.

"Random" noise may be defined as a large number of individual pulses which are superimposed. They may be of random amplitude and random phase. This type of noise has also been referred to as "fluctuation noise", "White" noise or "hiss" noise. White noise is in general any noise where the energy is uniformily distributed in the frequency spectrum.

Noise has been distinguished as to whether the individual pulses were overlapping or non-overlapping. Using this distinction, experimental and theoretical results showed that the peak value is proportional to the square root of bandwidth for overlapping pulses.

The conception of random noise and impulse noise are not sufficiently specific to distinguish different types of noise, when it is considered that the measurement of noise must be applicable to wide band reception such as that occurring in speech or telegraph transmission.

As stated before the chief reason for measuring noise is to state definite limits which will prevent satisfactory communication by one means or another. However, the interference to such communication depends upon certain psychological characteristics of individuals who are using the communication equipment. Thus, inevitably certain subjective criteria related to the interfering effect of noise have been incorporated into the criteria for designing noise meters.

Thus the effect of noise on the following should be considered.

a. Telegraphic signals

b. Speech (telephone and radio)

c. Television Signals

d. Radar Signals

In the case of speech there are two types of noise to be considered. (1) Low-level Noise - Here speech is understandable but the effect of noise is one of irritation and fatigue. This is only of concern where the signals are being received for long periods of time. (2) High Level Noise - In this case the intelligibility is of importance.

CHAPTER III

PRESENT NOISE METER SPECIFICATIONS

The following specifications are taken from the Canadian Standards Association, Canadian Electrical Code Part IV and are confined to the output meter and the indicating instrument.[5]

1. Output Meter

   (a) The output meter shall be an approved type of vacuum tube voltmeter, having electrical time constants of 10 milliseconds ± 20% charge and 600 milliseconds ± 20% on discharge. The time constants thus specified are the periods required for the voltage impressed on the weighting circuit to reach 63% of its final charge following a change in the applied voltage which occurs in less than one tenth of a millisecond.

   (b) The indication of the output meter shall not be affected by the connection of monitoring devices, such as headphones, loudspeakers, etc., to the output of the receiver during measurements.

   (c) The output meter shall be connected to the radio receiver through a resistive coupling which matches the output impedance of the receiver to the input impedance of the output meter.

   (d) The output level selected for measurements shall not exceed 20db below the maximum output of the receiver.

2. Indicating Instrument.

(a) The indicating instrument shall be of the permanent magnet, moveable coil type with approximately equal increments of deflection for equal increments of direct current.

(b) It shall have a damping factor not less than 10 nor more than 100, as defined in the American Standards Association for electrical indicating instruments C. 39.

(c) It shall have a response time not less than 200 milliseconds nor greater than 500 milliseconds defined and measured as follows:

A constant current sufficient to produce about two thirds full scale deflection shall be passed through the instrument and the exact deflection noted. The circuit then shall be opened and after the pointer has come to rest at zero the circuit shall be closed again. The time required for the pointer to move from zero to its equilibrium position, as previously noted on the first passage of current, is the response time of the indicating instrument, as here defined.

(d) The indicating instrument shall have two scales, one of which shall be linear and the other shall be marked in decibels.

CHAPTER IV

PRESENT POSITION OF THE PROBLEM

Since the noise is transmitted through the instrument at radio frequencies, detection is necessary before applying the resultant audio frequency pulse to the indicating meter. The indicating meter may be arranged to read r.m.s., average, or peak value of the wave. It is generally recognized that on noise pulses of short duration, meters reading average or r.m.s. do not indicate values as high as those disclosed by listening tests. A peak or quasi-peak indicating device has been found to give meter readings more nearly proportional to the auditory interference experienced. Since a peak reading meter is desired, the meter may be in a detector circuit, thereby eliminating audio amplification. The use of a meter in the detector circuit has further advantage that calibration of the device can be made by application of an unmodulated carrier frequency voltage, thus eliminating the necessity of determining the modulation factor.

A detector for noise measurement should meet special requirements but with due regard for practical design limitations.[2] A typical diode detector, which is the most satisfactory and reliable type detector, is shown in figure 1. The radio frequency voltage, i.e., noise or signal voltage as the case may be, is applied by the preceding amplifier circuits to the input of the final intermediate frequency amplifier tube S. Tube S in turn impresses the voltage on diode D through the

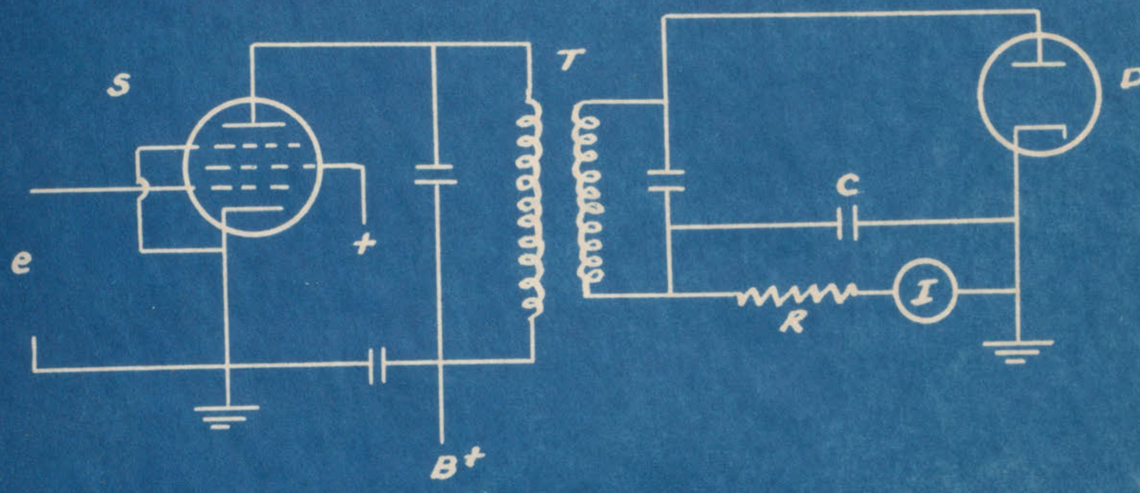


FIGURE 1

DETECTOR CIRCUIT

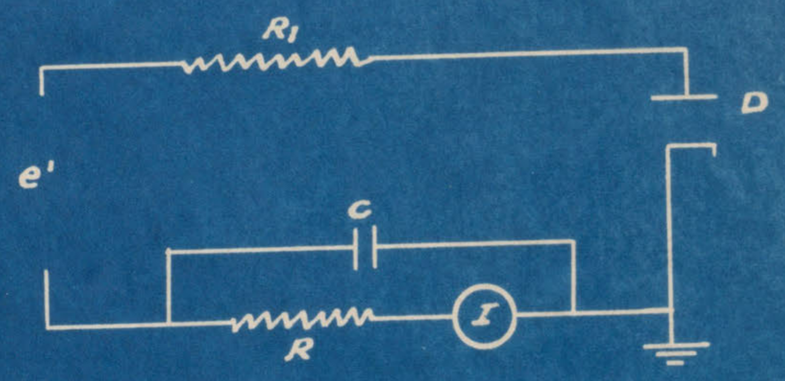


FIGURE 2

EQUIVALENT DETECTOR CIRCUIT

w.j.g./46

intermediate frequency transformer T. In the diode circuit are a resistance R, a condenser C, and the current indicating meter I. Tube S and the transformer T can be replaced by an equivalent voltage e_1 and resistance R_1 as shown in figure 2. Condenser C is charged by e_1, through R_1 and discharges through R. The time constant on charge is then R_1C and on discharge RC.

If voltage e_1 is a suddenly applied potential, condenser C will charge to 63% $(1-\frac{1}{\epsilon})$ of e_1 in time R_1C. On discharge the voltage of C will drop to 37% $(\frac{1}{\epsilon})$ of its initial voltage in time RC. Now if the discharge time constant RC is long in comparison with the charge time constant R_1C, the voltage of C will build up to very nearly the peak value of the applied voltage. In considering the mechanism of build up of voltage to the peak value, it should be borne in mind that noise voltage consists of a series of impulses, the measured voltages reaching essentially the peak value after the first few impulses. In the very rare case of noise consisting of a single pulse, or pulses with a repetion time longer than the discharge time constants of the metering circuit, a value considerably less than the peak would be indicated. However, experience would tend to show that the disturbing effect of such noises on the listener is less than would be indicated by their peak amplitude.

In determining the time constants of the metering circuit consideration must be given to meter characteristics, noise characteristics and to circuit design limitations. An indicating meter which is too rapid in action is expensive and is difficult to read, whereas a meter with too long a time constant makes circuit design difficult. It is desirable that the time constant of the noise meter be determined by the circuit values rather than by indicating meter constants, because the former are more readily determined and may be held more closely. By making the circuit charge time short and discharge time long in comparison with the indicating meter time constant, this may be accomplished.

It is difficult to secure an equivalent resistance on charge (R_1 of figure 2) of less than 20,000 to 30,000 ohms with receiving type vacuum tubes, whereas fixed resistors for discharge (R of figure 2) become difficult to determine accurately and are not stable in value above approximately 5 megohms. This, therefore, in conjunction with the indicating meter constants determines the permissible range of values for C and for charge and discharge time constants.

It should also be borne in mind that the peak voltage is given by IR so that for any value of voltage, the lower we make R, the greater I will become, thus permitting the use of a less sensitive indicating meter. In some cases where it is desired to use a relatively insensitive meter and a high value of R, a d.c. amplifier may be used. From the above considerations, a charge time constant of the order of 10 milliseconds and a discharge time constant of the order of 600 milliseconds are indicated.

A scale on the indicating meter which is logarithmic in character has several advantages over a linear scale. In the first place it fulfills the psychological conditions of Weber's Law and in addition makes the use of fewer attenuator taps possible, with resultant increase in simplicity of construction and use. Its use is an obvious aid in the measurement of widely varying amplitudes which are characteristic of some types of noise.

The logarithmic characteristic is best secured by electrical means. The deflection law of the meter itself is linear, the angular deflection of the pointer being proportional to the current through the meter. The automatic volume control system as used on radio receivers provides a ready means of obtaining such a characteristic. By the use of remote cut-off tubes in the noise meter amplifier stages, a sufficient amount of control can be applied to each stage to obtain a useful input range.

In the case of signals where the ratio of peak to average is large the time constants in the a.v.c. circuit may result in inaccurate readings. The maximum value of this ratio which may be handled by the noise meter without distortion due to overloading and other non-linear circuit effects requires careful consideration.

Some Experimental measurements of the time constants of several commercial noise meters were made by K.A.MacKinnon, C.B.C.[4] In tests with these meters using various sources of noise he found that meters reading the same types of noise gave different results. The discrepancies were noted in noise with high peaks and low energy characteristics so he reasoned that the discrepancy lay in dissimilar transient mechanical characteristics of the indicating meter and dissimilar rates of change of the direct current operating the indicating meter in response to the reception of the difficult noise on the antenna. In connection with this latter characteristic it was emphasized that the formal measurement of the charge and discharge times of the diode rectifier circuit of the two meters is not sufficient. On the contrary it is necessary that the "overall" time constant of the whole noise meter, i.e. from the antenna to the indicating meter, should be measured. This is a reasonable argument because after all the discrepancies arose in a demonstration in which the same radio noise at the antenna gave different readings on the indicating meters.

The results of the transient mechanical characteristic test showed that none of the indicating meters entirely met the required specifications. A study of the graphs of the results of the electrical time constants reveals the great influence of the a.v.c. circuit on the charge and discharge time as indicated by the difference between the "diode" and the "overall" graphs of each instrument. In other words if the a.v.c. circuit has time constants comparable to those of the noise diode, then these are bound to be peculiar effects on the diode time constants.

One solution to this problem of a.v.c. circuit time constants is to use some other means of obtaining a logarithmic response. The major ensuing portion of this paper deals with the development of a logarithmic d.c. amplifier for use between the detector and a linear indicating device.

A study is also made of the voltage range over which the detector circuit provides a linear output and to determine the operating level of the audio system in order to avoid cutting of sharp peaks.

In the study of the latter problem, the National NC-200 communications receiver was used. This receiver has been used for making noise measurements as it has some desirable features for the basis of a noise meter.

CHAPTER V

The Logarithmic D.C. Vacuum - Tube Voltmeter

A direct current logarithmic voltmeter which is founded upon the Maxwellian distribution of velocities of electrons emitted by a hot cathode is described. Because the circuit depends for its operation on a fundamental physical law (The Maxwellian distribution of velocities of the thermoelectrons emitted from a hot cathode), its characteristics are constant and predictable.

Among the principal requirements of a logarithmic voltmeter are:

(1) A truly linear relationship between the logarithm of the input and the output over a large range of inputs.

(2) Stability of response with respect to time and all uncontrollable factors (voltages, bias, electromagnetic and electrostatic pickup)

(3) Simple construction from readily available standard parts.

In the previous chapters it was pointed out that the use of a logarithmic response for measuring noise voltages was desirable. The following constitutes the theory of operation and a description of a practicle circuit for a logarithmic D.C. Voltmeter.

Theory

Maxwell's Distribution of Velocities.[6]

The heat energy that a body contains, which determines its temperature, resides in the kinetic energy of motion of its atoms or molecules, which are in constant random to-and-fro motion.

The greater the heat energy, the higher the temperature and the higher the velocities of motion of the particles. The velocities of motion are not the same for all the particles. Some particles have a relatively low velocity while others have a very high velocity, but the majority have velocities which are not very different from a certain velocity known as the most probable velocity. Maxwell calculated, by the theory of probability, the distribution of velocities of the particles of a gas. The most probable velocity changes with the temperature and is proportional to the square root of the absolute temperature.

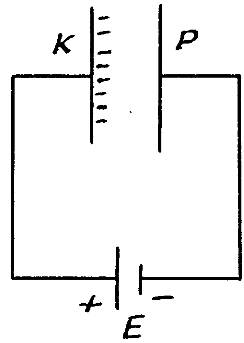
As the temperature of a conductor is increased, the distribution of velocities of the free electrons inside the conductor changes in such a way that more electrons possess a velocity sufficient to carry them through the surface restraint. The electrons which are emitted charge the space outside negatively and leave the body positively charged. Hence, there exists an electrostatic field outside the body urging the emitted electrons back into the body. Thus, a cloud of electrons exists outside the body, having a density dependent upon the temperature and upon the distance from the surface. There is, however, a definite rate of emission of electrons at each temperature, probably independent of the density of the electron cloud outside the body. If an external electric field is applied which is sufficient to draw off the electrons as fast as they are emitted, a certain saturation current per unit of area of surface of the emitting body is obtained at each temperature.

The minimum velocity which an electron must possess in order to overcome the surface restraint corresponds to a certain kinetic energy. This energy is transformed into potential energy on passing through the surface. The distribution of velocities of the outside electrons can be tested experimentally, and the results of several such investigations prove that the initial velocities of emission do follow Maxwell's law for an electron atmosphere in temperature equilibrium with the hot emitter.

The space current, when limited by space charge, differs slightly from that given by the simple voltage law if the initial velocities of emission are appreciable. The distribution of potential between the emitter and the plate under various conditions have been measured and it has been found that the distance and minimum potential increase with a decrease of plate voltage and with an increase of temperature of the emitter in accord with the theory.

The point of minimum potential outside the cathode, caused by the initial velocity of emission of the electrons, is ordinarily very close to the cathode. But when the space current limited by space charge is a very small fraction of the total emission of the cathode, the region of minimum potential, which may roughly be considered as the position of a virtual cathode, moves out to a very appreciable distance from the cathode surface. The position of the virtual cathode is much nearer the grid than normally, and hence the effective shielding of the grid is less.

In the adjoining figure which is idealized, a hot, very large plane K emits thermal electrons which are collected on a plate P against a retarding potential of E volts. Because of the initial velocities, some of the electrons are able to reach the plate even when the plate has a negative or retarding potential.



The number that reach the plate for any retarding potential E, depends upon the temperature of the emitter and the distribution of velocities of the emitted electrons. Assuming that the emitted electrons obey Maxwell's distribution of velocities, the fraction n/NS of the electrons which are capable of moving against a retarding potential E, is given by the Boltzmann equation

$$\frac{n}{NS} = \epsilon^{-\frac{Ee}{KT}} \qquad \text{------} \quad (1)$$

This equation holds when there is no potential minimum between the two electrodes.

The above equation may be written as

$$E = -\left(300\frac{KT}{e}\right) \ln i + \text{constant} \quad --- (2)$$

$$= -\left(690\frac{KT}{e}\right) \log_{10} i + \text{constant} \quad -- (3)$$

where i is the current, k is the Boltzmann's constant, e is electronic charge in e.s.u., and T is the temperature which is characteristic of the Maxwellian distribution.

Experimentally this equation holds for large retarding potential and pure metal cathodes. However, unless the surface is perfectly homogeneous observations will not check the equation because of local contact differences of potential.

The principle of operation with the tube to be described is found in the fact that the insertion of a resistance in series with the grid large in comparison with grid-cathode resistance of the tube will cause grid-cathode voltage to bear a logarithmic relationship to the impressed voltage. Over the range where the plate current is linear with grid-cathode voltage the plate current will be logarithmic with the impressed voltage.

i.e. $\quad I_p \propto \log_{10} E_i$

or $\quad E_i \propto \log_{10} I_p$

Using this principle the grid-cathode voltage is negative and acts as a retarding potential. A logarithmic relationship between the impressed voltage and the grid-cathode voltage is thus obtained in accord with the above theory.

The Circuit:

In figure 3 is shown the first experimental circuit which employs a 6J5 triode as the logarithmic tube. A grid resistor of 2 to 7 megohms was used in this circuit with a plate load of 100,000 ohms and a plate supply of 20 to 30 volts. The plate current that flows with zero applied voltage was balanced out of the meter by means of an equal and opposite current as shown in the diagram.

The 6J5 tube was selected for the logarithmic tube after testing triodes (6SF5, 6C8G, and a pentode power tube 6F6) since it gave the most nearly perfect straight line characteristic.

On graph sheet (1) is shown the relationship of the change in plate current to the logarithm of the input voltage. The linearity of the response is obvious from the curve, as is also the existence of an approximate logarithmic characteristic even at higher input voltages. Here the logarithmic relationship exists over a range of 2 to 200 volts.

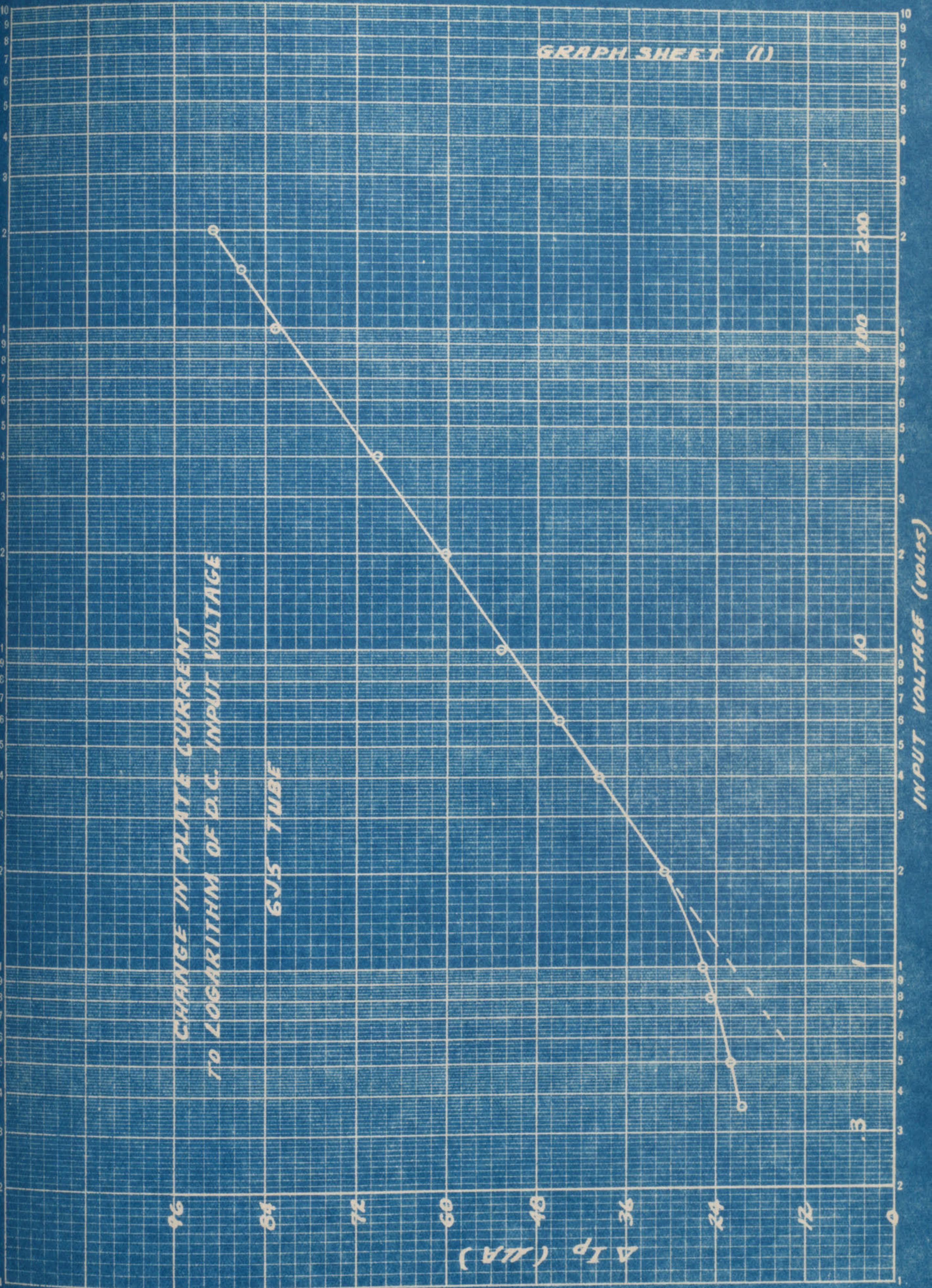
The number of decibels difference in level between P_1 watts and P_2 watts may be stated as

$$10 \log 10 \frac{P_2}{P_1}$$

Since $P = E \times I = \frac{E^2}{R}$, the ratio of $\frac{P_2}{P_1}$ is equal to $\frac{E_2^2}{E_1^2}$ provided R is the same in each case.

Therefore $10 \log 10 \frac{E_2^2}{E_1^2} = 20 \log_{10} \frac{E_2}{E_1}$

(R being constant)


GRAPH SHEET (1)
CHANGE IN PLATE CURRENT
TO LOGARITHM OF D.C. INPUT VOLTAGE
6J5 TUBE
INPUT VOLTAGE (VOLTS)
200
100
10
1
.3
ΔIp (μA)
96
84
72
60
48
36
24
12
0

In the above equation substituting

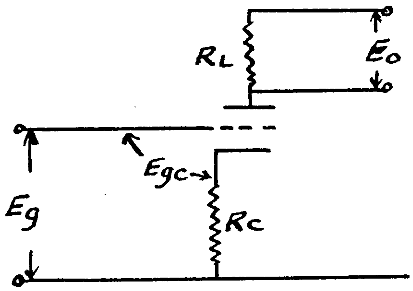
$$E_2 = 200 \quad \text{and} \quad E_1 = 2$$

then

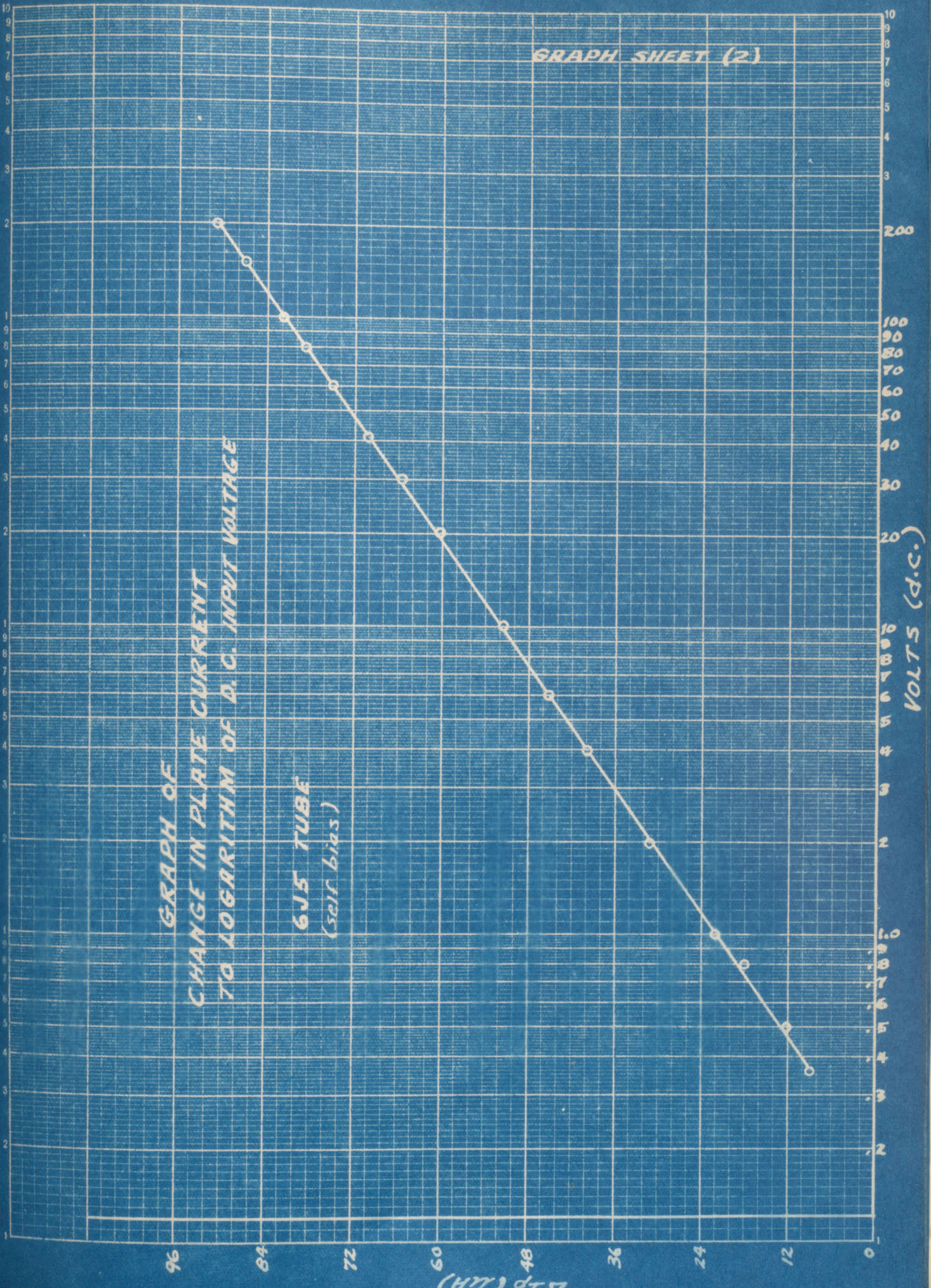
$$db. = 20 \log_{10} \frac{200}{2} = 40 db.$$

Therefore a range of approximately 40 db or two decades is obtainable with this type of circuit.

In order to extend the logarithmic range the circuit shown in figure 4 was used. This circuit is similar to the one in figure 3 except that a cathode bias resistor is employed. The function of the cathode resistor is best explained by the use of the accompanying diagram.



This circuit shows a simple form of current feed back. The voltage fed back is that due to the signal current through Rc , and is nearly proportional to it if Rc is much less then RL . As the signal current is increased (if only slightly) the fed back voltage increases, entirely at the expense of Egc, which is thus unable to maintain the signal to the valve even at its original level. The tendency for the output current to rise is therefore checked, just as if the valve had a large Rp. Current feed back in most types of amplifiers is avoided but used here as in figure 4 it checks the output current at low Eg thus

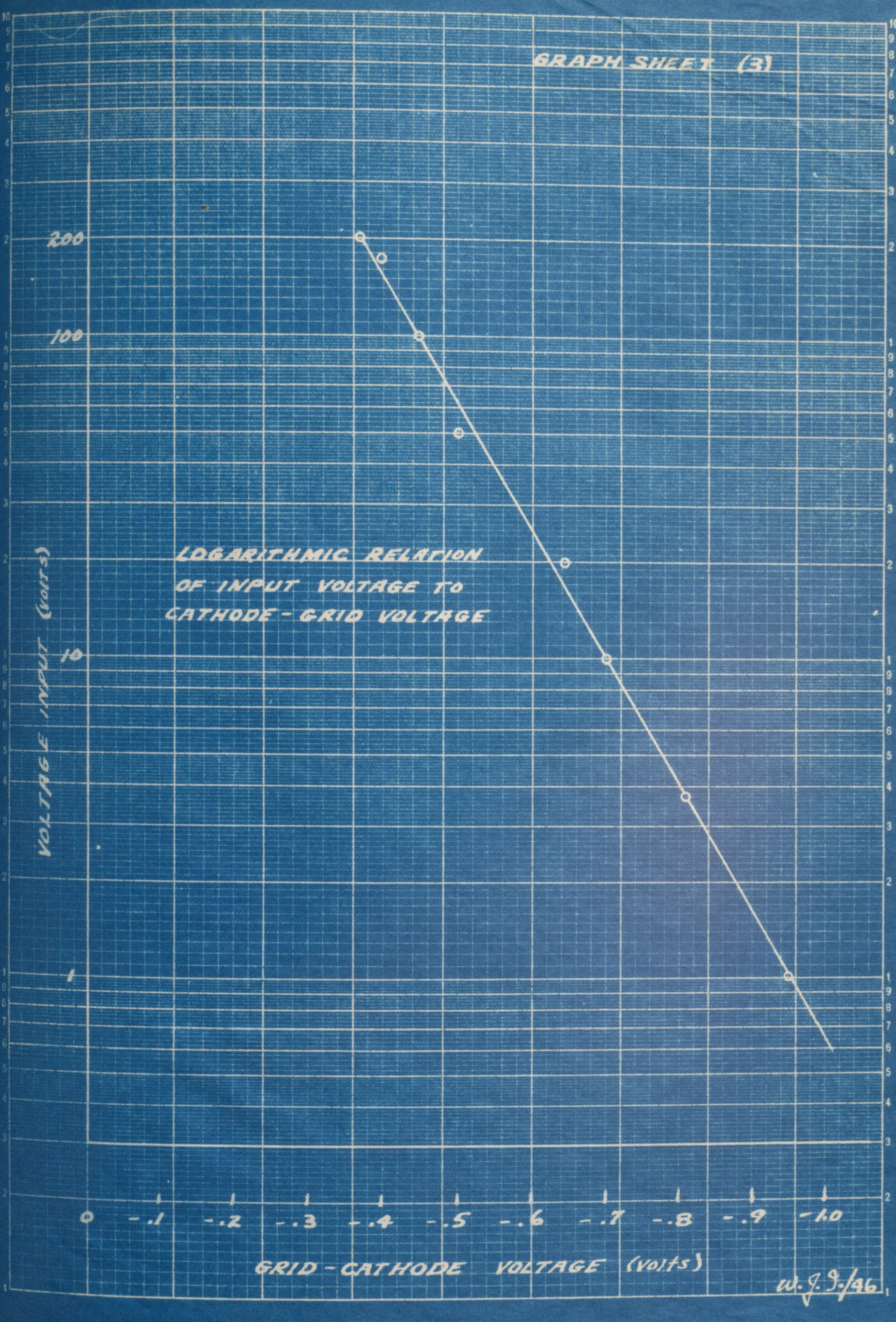

GRAPH SHEET (2)
GRAPH OF
CHANGE IN PLATE CURRENT
TO LOGARITHM OF D.C. INPUT VOLTAGE
6J5 TUBE
(self bias)
VOLTS (d.c.)
200
100
90
80
70
60
50
40
30
20
10
2
1.0
ΔIp (μA)
96
84
72
60
48
36
24
12
0

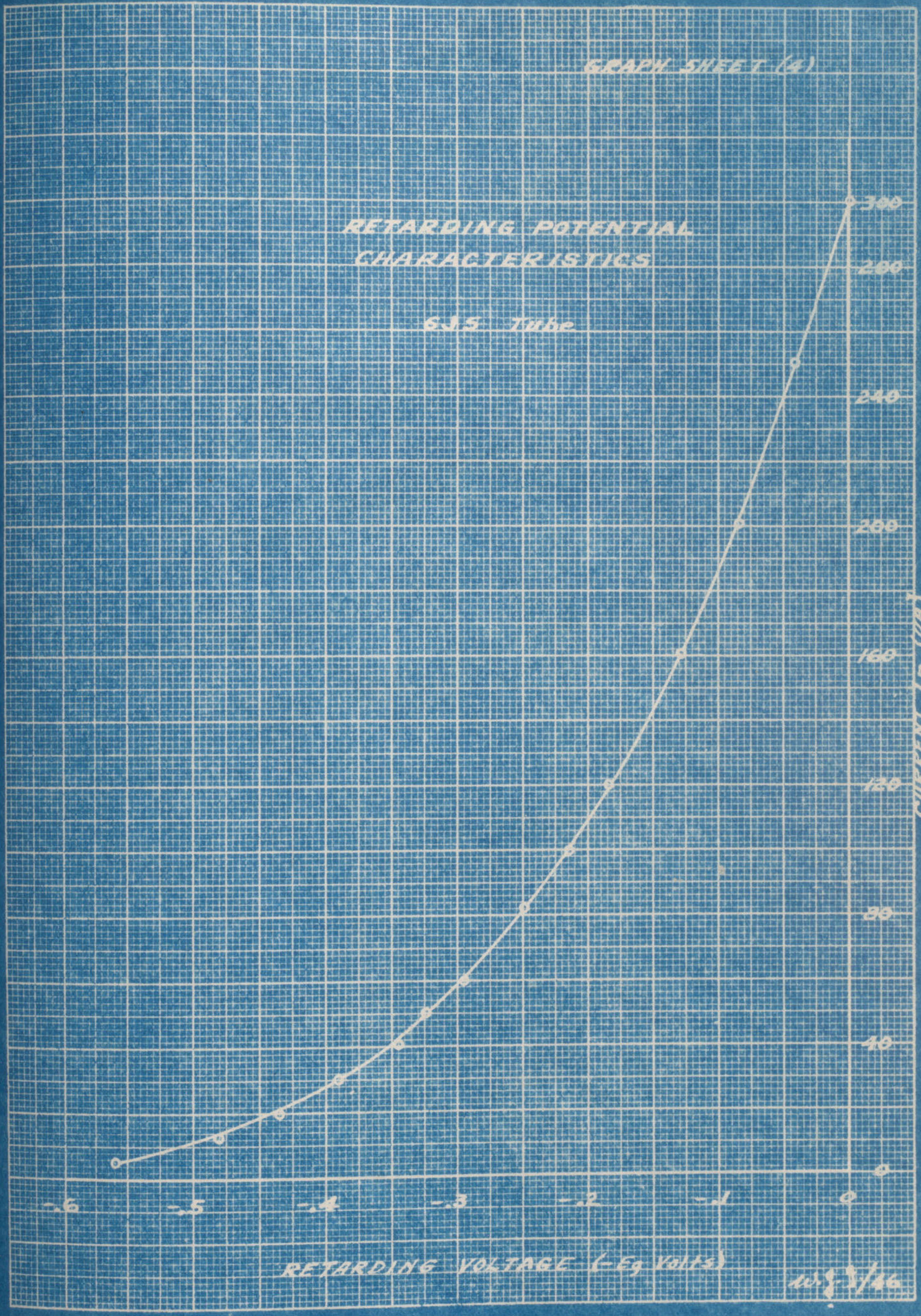
improving the logarithmic characteristic of graph 1. At higher Eg the effect is negligible.

The relationship of the change in plate current to the logarithm of the input voltage is shown on graph sheet (2). The logarithmic relationship as shown extends over a range of 0.5 to 200 volts or about 52 db. This range is satisfactory for the use of measuring noise voltages.

Using the circuit in figure 4 a relationship between the input voltage and grid-cathode voltage was determined. In order to make grid-cathode voltage measurements a substitution method was used. The output of a potentiometer and battery was connected in parallel across the grid to cathode for each measurement made by the use of a d.c. voltmeter. With the d.c. voltmeter across the grid to cathode a change in plate current was compensated for by applying an equal and opposite potential to bring the plate current back to its normal value.

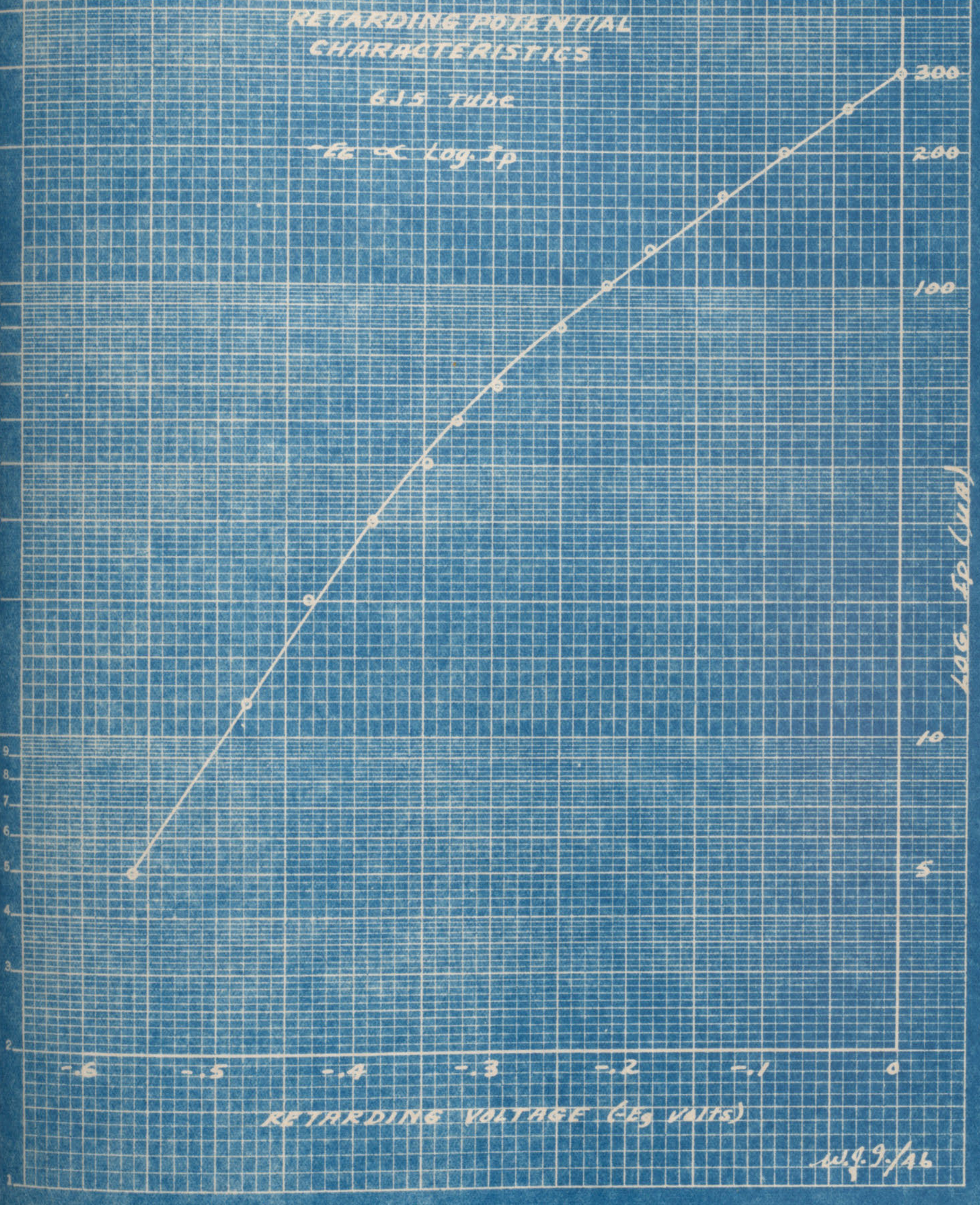
The relationship between the logarithm of input voltage and grid-cathode voltage is shown on graph sheet (3). This graph shows that a logarithmic relationship exists between the two over a range of approximately 40 db. This relation is in accord with the theory and the principle of operation of the logarithmic tube. The grid is negative with respect to the cathode therefore a retarding potential exists.


GRAPH SHEET (3)
LOGARITHMIC RELATION OF INPUT VOLTAGE TO CATHODE-GRID VOLTAGE
VOLTAGE INPUT (VOLTS)
200
100
10
1
0
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
-.9
-1.0
GRID-CATHODE VOLTAGE (volts)
W. J. J./46



GRAPH SHEET (4)
RETARDING POTENTIAL CHARACTERISTICS
6J5 Tube
300
280
240
200
160
120
80
40
0
CURRENT Ip (μA)
-.6
-.5
-.4
-.3
-.2
-.1
0
RETARDING VOLTAGE (-Eg Volts)
W.J. 3/46

GRAPH SHEET (5)



In figure 4(a) is shown a 6J5 tube with grid and plate joined together. A retarding potential of zero to -0.6 of a volt was applied between grid and cathode and the resulting current measured. The normal filament voltage of 6.3 volts was used for heating the cathode.

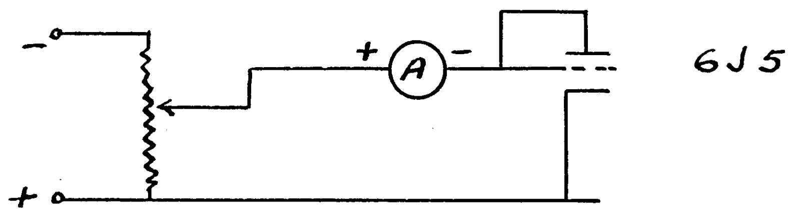


FIG. 4(a)

The results of this test are shown on graph sheet(4) which shows the relation of the retarding voltage and total space current. On graph sheet (5) is shown a plot of the logarithm of the current to the retarding potential. These results indicate that the emitted electrons from the cathode obey Maxwell's law of distribution of velocities over a limited range. Operating conditions for circuit in figure 4 are:

Eg	operates	between	0 to 200	volts
Ep	"	"	13 to 7	"
Ec	"	"	1 to 2.2	"
Epc	"	"	12 to 4.8	"
$\frac{Epc}{u}$	"	"	.60 to .24	"
Egc	"	"	-.95 to -.4	
			-.35 " -.16	

Therefore the portion of the curve on graph sheet 5 over which the tube operates is between -.35 to -.16. Over this portion a logarithmic relation exists.

Bridge Circuit:

The maximum sensitivity obtainable with a vacuum - tube voltmeter is limited by the stability that can be achieved in balancing out the d-c plate current from the meter. This is because the less the current required for full-scale deflection the more precise must be this balance if the deflection in the absence of a signal is not to drift appreciably from zero. The chief difficulty in maintaining an accurate zero balance comes as a result of variations in the tube voltages, though variations in tube characteristics either through aging or merely as a result of the "warming up" of the tube are also troublesome. When small voltages are to be measured by a vacuum-tube voltmeter, it is very important that the power source, including the filament as well as the anode, screen and bias voltages, be carefully regulated. It is also helpful to employ circuit arrangements that are inherently stabilized against changes. Thus it is possible to compensate for the effect of filament voltage changes in filament tubes by obtaining a portion of the grid bias from a resistance in the filament circuit. A more comprehensive balancing system is obtained by using an auxiliary balancing tube to prevent zero drift. By suitable compensating arrangements, this auxiliary tube can be made to have equivalent amplification factor and plate resistance that are the same as for the voltmeter tube, so that when the two tubes are placed in a bridge circuit, the effect of variations in the supply potential on the zero deflection of the output meter can be balanced out.

Such an arrangement is shown in the circuit of figure 5. The bridge circuit consists of a 6F8G tube having each triode connected in two adjacent arms and two equal resistors in the other adjacent arms with a variable resistor between them. Characteristics of each triode of the 6F8G were taken and they were found to be similar to one another as well as to the 6J5.

The voltage to be measured is applied between grid and ground of one voltmeter tube, while the grid of the other voltmeter tube is directly grounded. With no input voltage, the plates of the two triodes are at the same potential, and no current flows in the indicating meter. With d-c voltage applied to the grid of its voltmeter triode, the plate resistance of this triode is changed and the bridge is unbalanced causing a current to flow in the indicating meter. The heater of the twin triode is common to both cathodes, so that changes in initial velocity of electron emission occurring because of fluctuations of cathode temperature with line voltage change appears equally in both sides of the bridge circuit, and because they are balanced out, do not appear on the indicating instrument.

A meter zero set control balances the arm of the bridge to obtain zero meter deflection for the condition of no voltage input to the voltmeter.

Using this circuit arrangement the relationship of change in plate current to the logarithm of the input voltage

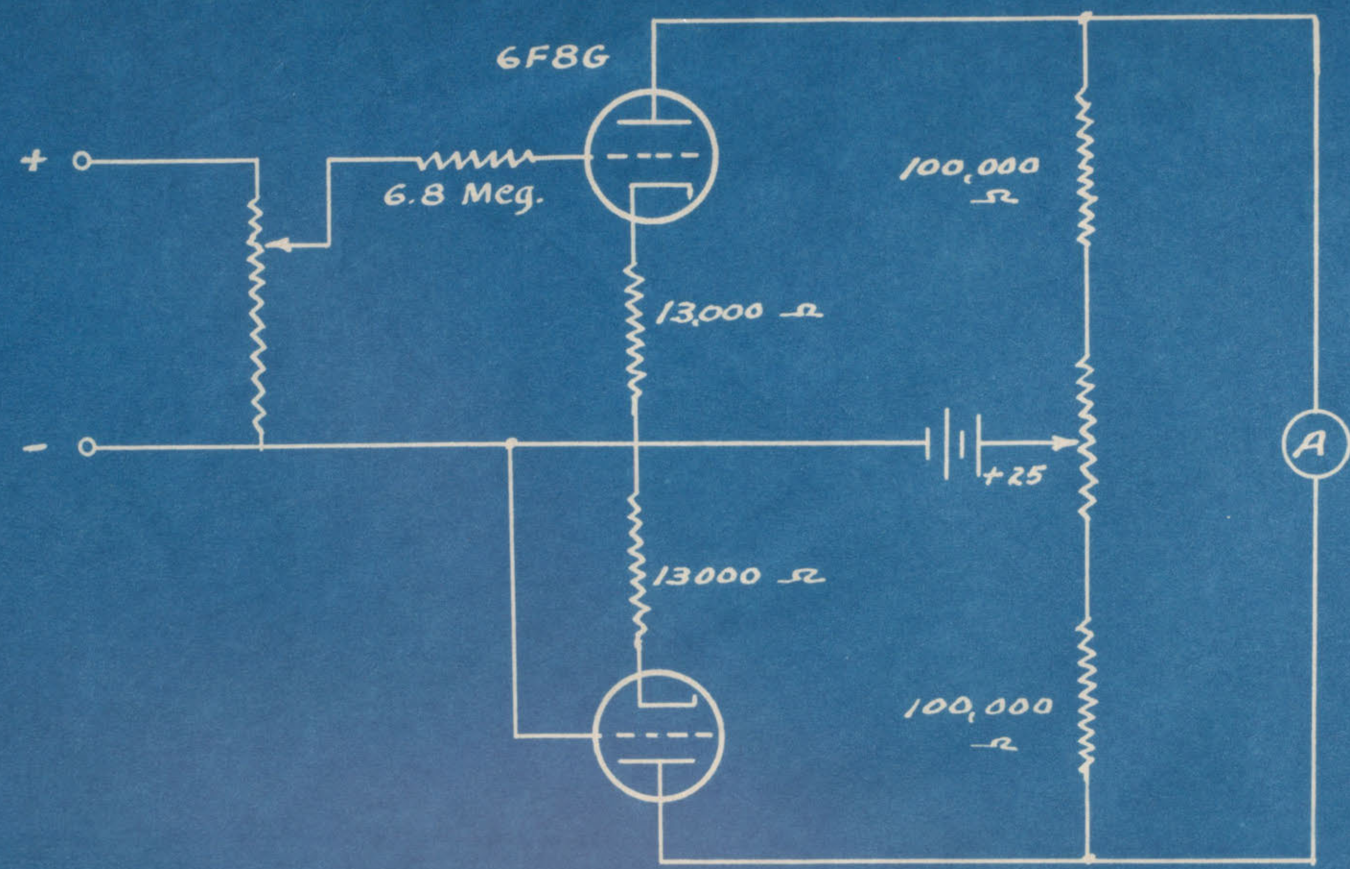
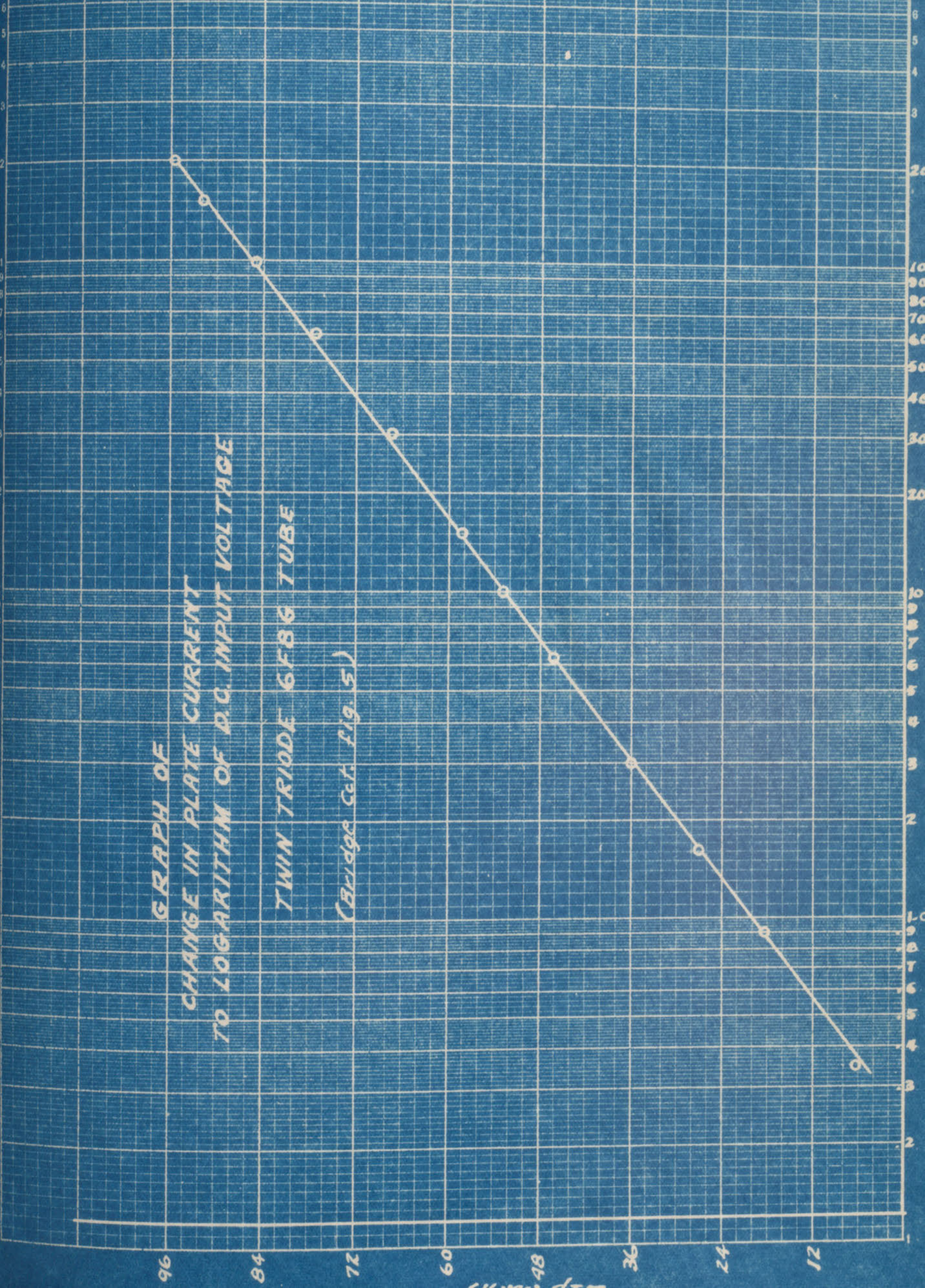


FIGURE 5
BRIDGE CIRCUIT
OF D.C. LOGARITHMIC
VOLTMETER

w.g.g./46

GRAPH SHEET (6)



is shown plotted on graph sheet (6). The logarithmic relationship extends over a range of 0.5 volts to 200 volts input or 52 db as before. The use of this type of bridge circuit reduces the sensitivity to that of the previous arrangements of vacuum-tube voltmeters, but the balance of the d.c. component of the current is now practically independent of variations in filament voltage as well as variations in plate supply voltage.

Bridge Circuit with Power Amplification.

The one undesirable feature with the previous circuit is the small change in plate current which occurs and is of the order of 0 to 100 microamperes. Microammeters have been improved in recent years so that they are no longer regarded as expensive and fragile instruments. However, it appears that a milliammeter would still have advantages when expense, durability and availability are important. Furthermore in order for the indicating meter to meet the proper response times and damping factors as laid down by C.S.A. specifications a higher value of current would be desirable.

The circuit arrangement shown in figure 6 provides the necessary power output so that a milliammeter may be used for measuring the change in plate current. This circuit consists of the 6F8G tube arranged in a bridge circuit to give a logarithmic response as previously described. Directly coupled to the bridge circuit are two 6F6 power tubes in a

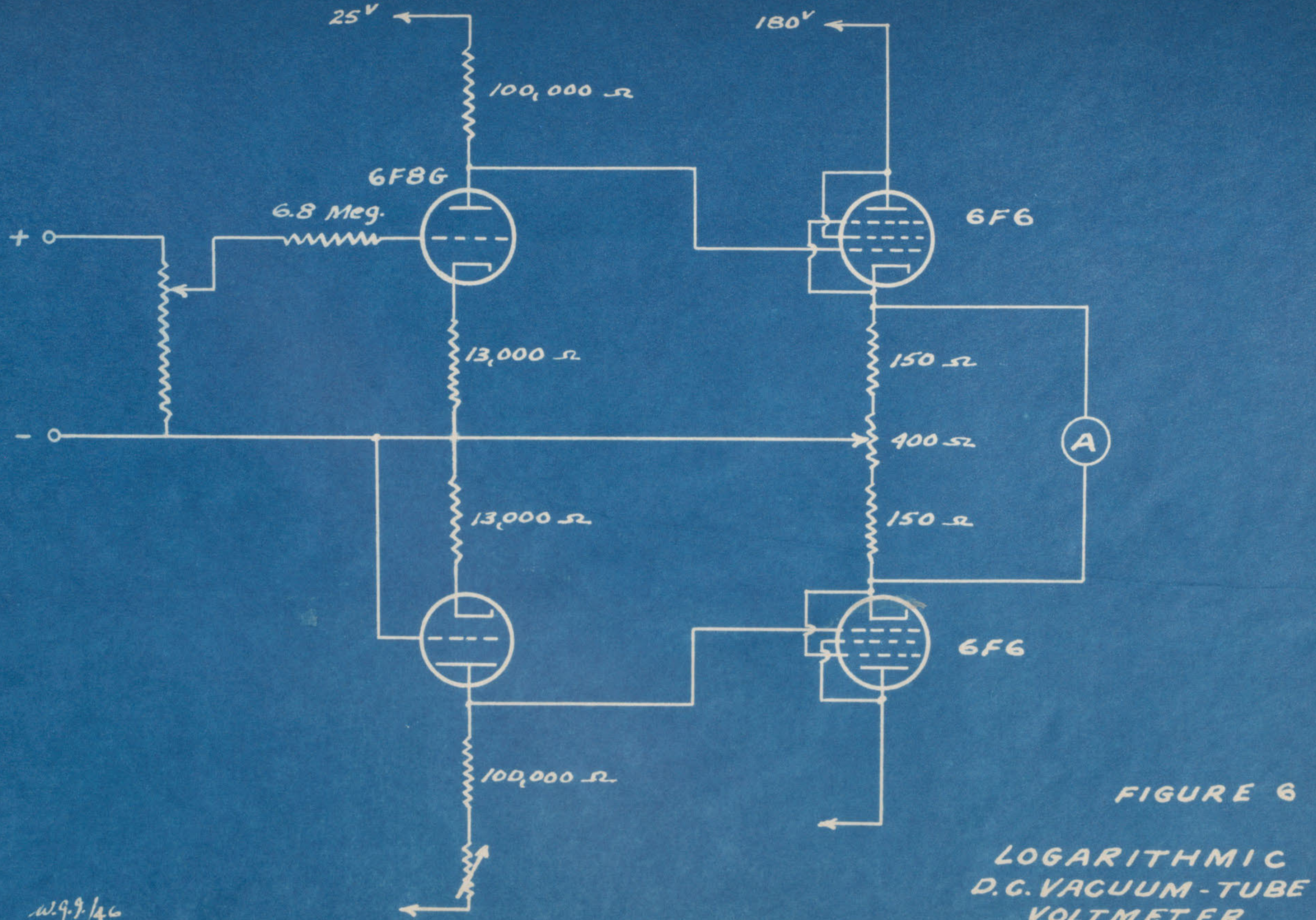
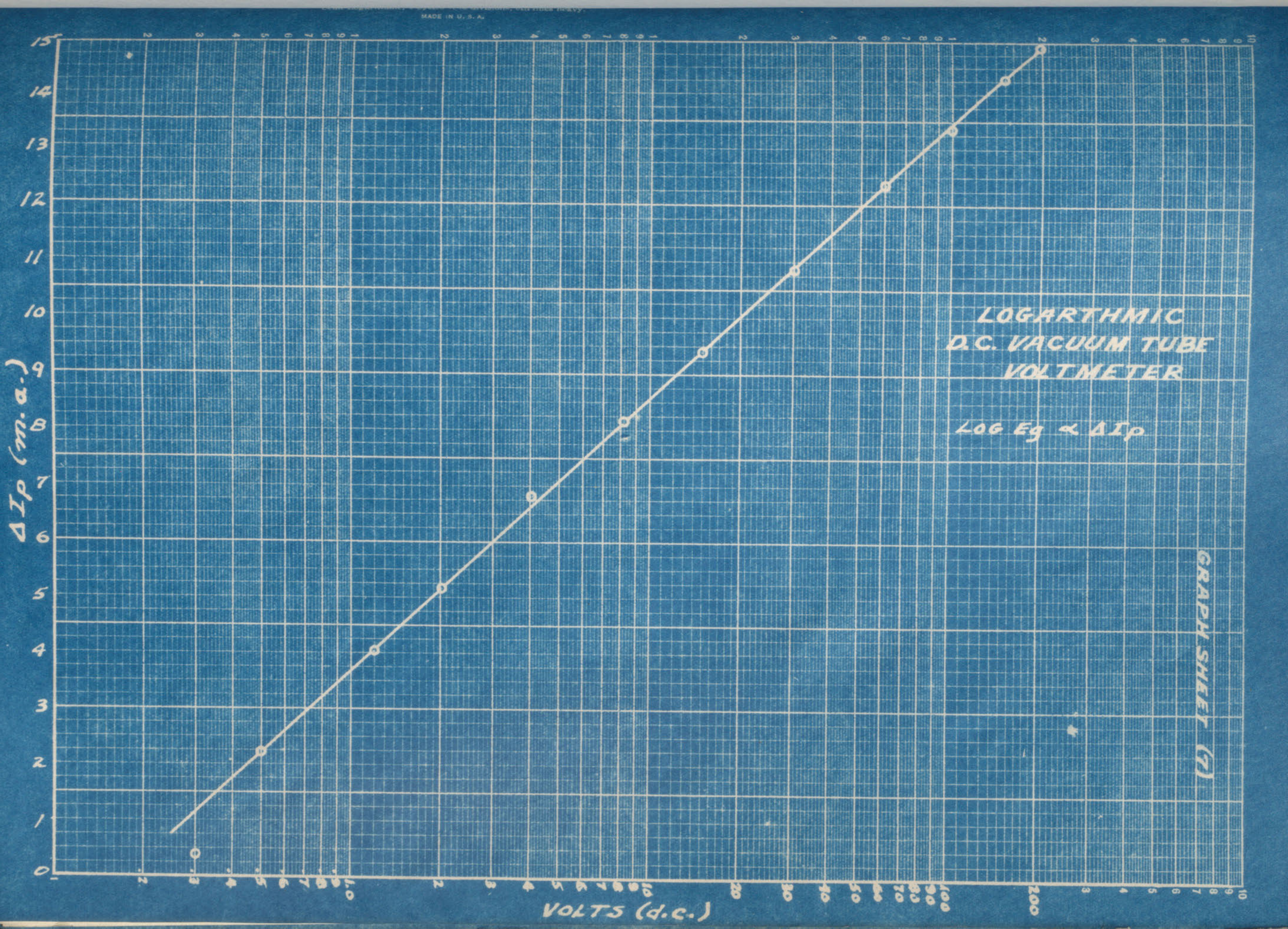


FIGURE 6

LOGARITHMIC
D.C. VACUUM-TUBE
VOLTMETER



LOGARTHMIC
D.C. VACUUM TUBE
VOLTMETER
LOG Eg ∝ ΔIp
GRAPH SHEET (7)
ΔIp (m.a.)
VOLTS (d.c.)
MADE IN U. S. A.

balancdd circuit and used as cathode followers. Across the cathode outputs is a milliammeter which reads the change in the amplified plate current of the logarithmic tube. The use of the cathode follower increases the power output greatly, especially when power tubes are used. The plate voltage output from the logarithmic tube varies between 15 to 7 volts for the circuit components shown in the diagram. The proper value of the cathode resistor in order to get a linear relation between input and output to the 6F6 were determined from the plate characteristic curves for the 6F6 connected as a triode. Using this circuit arrangement an output current as high as 14 milliamperes was obtainable.

The relationship between the change in plate current and the logarithm of the input voltage for this circuit is shown on graph sheet (7). Here again the logarithmic range extends from 0.5 to 200 volts or 52 db. but a greater output current is obtainable then in the previous circuits.

Conclusion:

The linearity and range of the response for this logarithmic vacuum-tube voltmeter is obvious from the curves.

Any error in linearity may be attributed to the error of reading the meters. The accuracy of the meters themselves should also be taken into account. The logarithmic range is about 52 db although somewhat greater range may be possible for a larger input voltage.

As stated in the previous chapters a noise meter is basically a radio receiver. Since the noise is transmitted through the receiver at radio frequencies detection or rectification is necessary before applying the resultant d.c. component of noise to the logarithmic d.c. vacuum tube voltmeter. The d.c. voltmeter described in this section will then give a measure of the logarithm of the d.c. output from the detector provided that the output from the detector is linear. A meter with a scale in decibels is used to measure the output of the logarithmic vacuum-tube voltmeter calibrated according to noise meter specifications.

Although balanced circuits like those shown are advantageous, complete compensation for line voltage fluctuations is not obtained in them. The difficulty arises from slight differences in dynamic characteristics and in heater characteristics of similar tubes. However it was found that the operation of these circuits using battery supply voltage was fairly stable. For cases where these fluctuations are larger or where a more sensitive indicating instrument is to be used, greater stability could be obtained by using a voltage regulated power supply. It can be expected in these circuits that the calibration, depending more then usual upon tube characteristics, will change slightly as the tube age.

In dealing with rapidly varying currents, it is necessary to take into account the rate at which the tube will follow the variations. We may calculate this ability to follow thusly: if the dynamic resistance R is defined as the rate of change of voltage with current, then it is inversely proportional to the current

$$R = \frac{d(-E_R)}{di} = \frac{300KT}{e}\left(\frac{1}{i}\right)$$

$$= \left(\frac{0.1}{i}\right) \text{ (differentiating eqn.(1))} \quad \text{---(4)}$$

Since there is an unavoidable capacity C associated with the logarithmic tube and its circuit, the time constant RC becomes

$$RC = \frac{0.1C}{i}$$

This value will be extremely small and hence the logarithmic voltmeter will follow current variations accurately.

The writer suggests that further investigations should be made of the characteristics of other tubes with regard to retarding potentials as shown on graph sheet (4) and (5). Also the effect on these curves of changing the temperature or voltage of the heating element of the cathode should be investigated. Investigations of these characteristics would determine if a greater logarithmic range could be obtained.

Other possible applications for the logarithmic voltmeter are:

(1) To make it possible to measure a recording on a log scale, so that a large range of inputs can be measured with a constant fractional accuracy.

(2) To make possible electrical multiplication and division by the addition and subtraction of logarithms.

(3) To take the logarithms of such quantities as sound intensity and decaying intensity of a radio active source, in which the logarithm gives some specially useful property or has some special significance.

CHAPTER VI

A Study of Linearity and Voltage Range of the Detector Output.

A study of the voltage range over which the detector provides a linear output is necessary in order to utilize the logarithmic d.c. vacuum-tube voltmeter described in the previous chapter.

Apparatus: The following equipment was used in studying the above problem.

1. National NC-200 Communication Receiver
2. General Radio R.F. Signal Generator.
3. 2 H.P. Vacuum-tube Voltmeters
4. 1 G.R. " " "
5. Cathode Ray Oscilloscope
6. Multi-Range Voltmeter No. 772 Weston
7. Microammeter (range 0-100)
8. Logarithmic D.C. Vacuum-tube Voltmeter. (described in preceding chapter)

Before describing the investigation of the linearity of output from the NC-200 receiver a brief description of the receiver is in order.

The circuit diagram figure 7 shows the component parts of the NC-200 which were utilized for this problem.[9] The NC-200 radio receiver is a twelve tube superheterodyne covering a continuous frequency range from 490 to 30,000 kilocycles and band-spreading the 10,20,40 and 80 meter amateur bands. One of its main features is the stability of its high frequency circuits. The high-frequency oscillator has been designed to eliminate the detuning effect of the R.F. gain control and the even more undesirable motor-boating or fluttering which occurs in most receivers when tuning in strong high frequency signals. Frequency drift has been reduced to a minimum through the use of temperature compensating capacitors not only in the high frequency oscillator circuits but in the R.F. and first detector circuits as well.

The circuit employed on all ranges consists of one stage of radio frequency amplification, a separate first detector and stabilized high frequency oscillator, two intermediate frequency stages, and an infinite impedance second detector. All voltages required by the receiver circuits are supplied by a built in power supply. The remaining audio circuits, a.v.c. and beat frequency oscillator circuits are not used in this particular problem. A crystal filter is connected between the first detector and first I.F. amplifier tubes. Six uniform steps of selectivity and a variable phasing control allow the receiver to be adjusted to almost any operating condition, a highly desirable feature for both short wave communication and broadcast band reception.

The NC-200 receiver has been used as a noise meter and fairly satisfactory results obtained. However, in order to get a logarithmic response the R.F. input was calibrated in decibels and the output was measured by a linear output meter.

This method of obtaining a logarithmic response is rather complex and therefore an output meter which gives a logarithmic response directly would be more desirable.

Method of Measuring the Range of Detector Output.

The circuit in figure 7 shows the portion of the NC-200 receiver over which the range and linearity of output was investigated.

Step(1)

For the input to the antenna of the receiver a 1000 k.c. 30% modulated signal was used. For measuring the d.c. output of the detector a d.c. voltmeter and a micro-ammeter were used. For measuring the detector audio output a vacuum-tube voltmeter was used.

The input voltage was varied from zero to the point where the output registered an overload for each r.f. gain setting. These values for input and output were recorded and curves were drawn.

These curves are shown on graph sheets (8) and (9) for the relation of R.F. input to the d.c. and audio output voltages. Graph sheet (8) shows that the receiver has a linear output up to about 25 volts d.c. at which point it begins to overload. Graph sheet (9) shows that the receiver

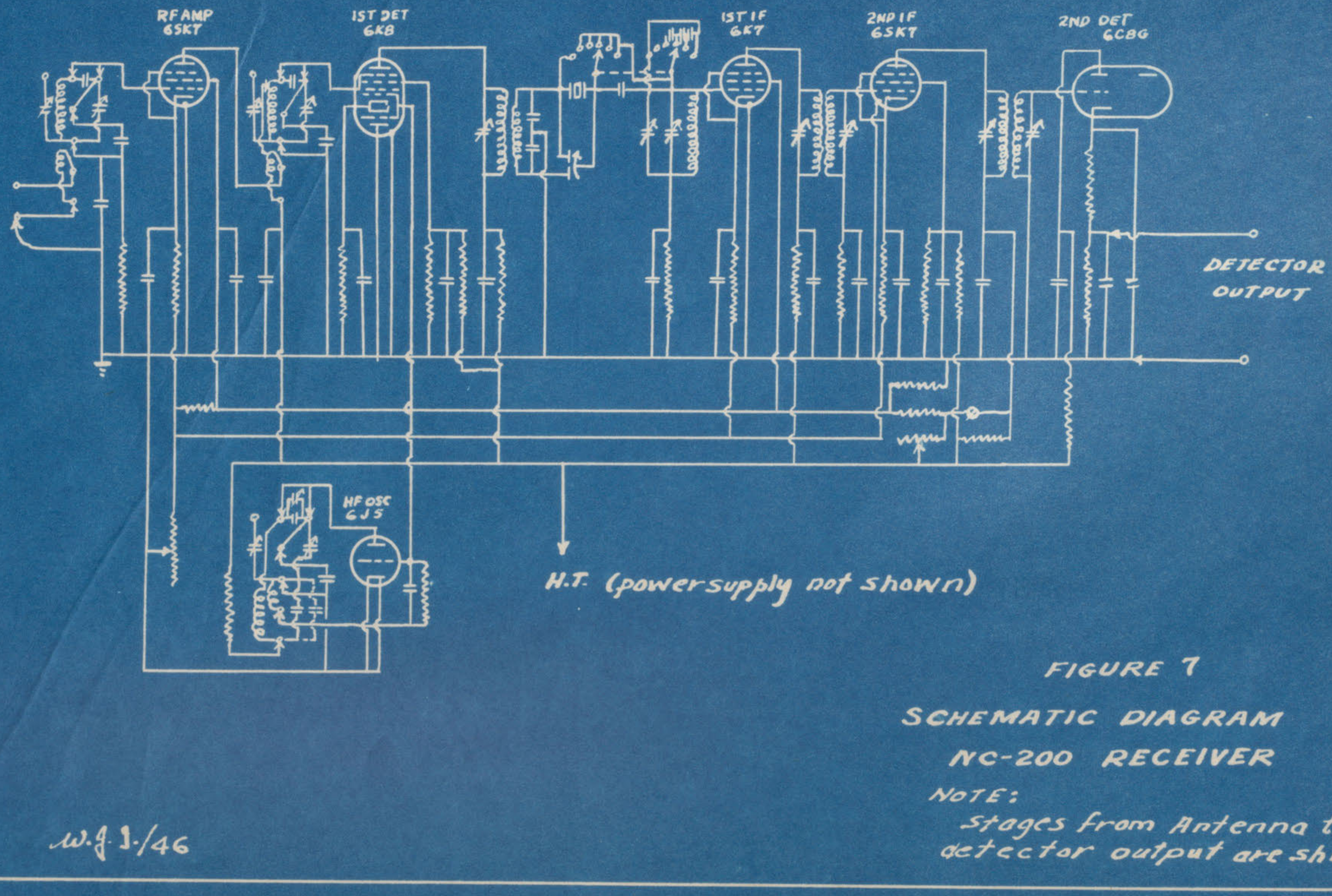
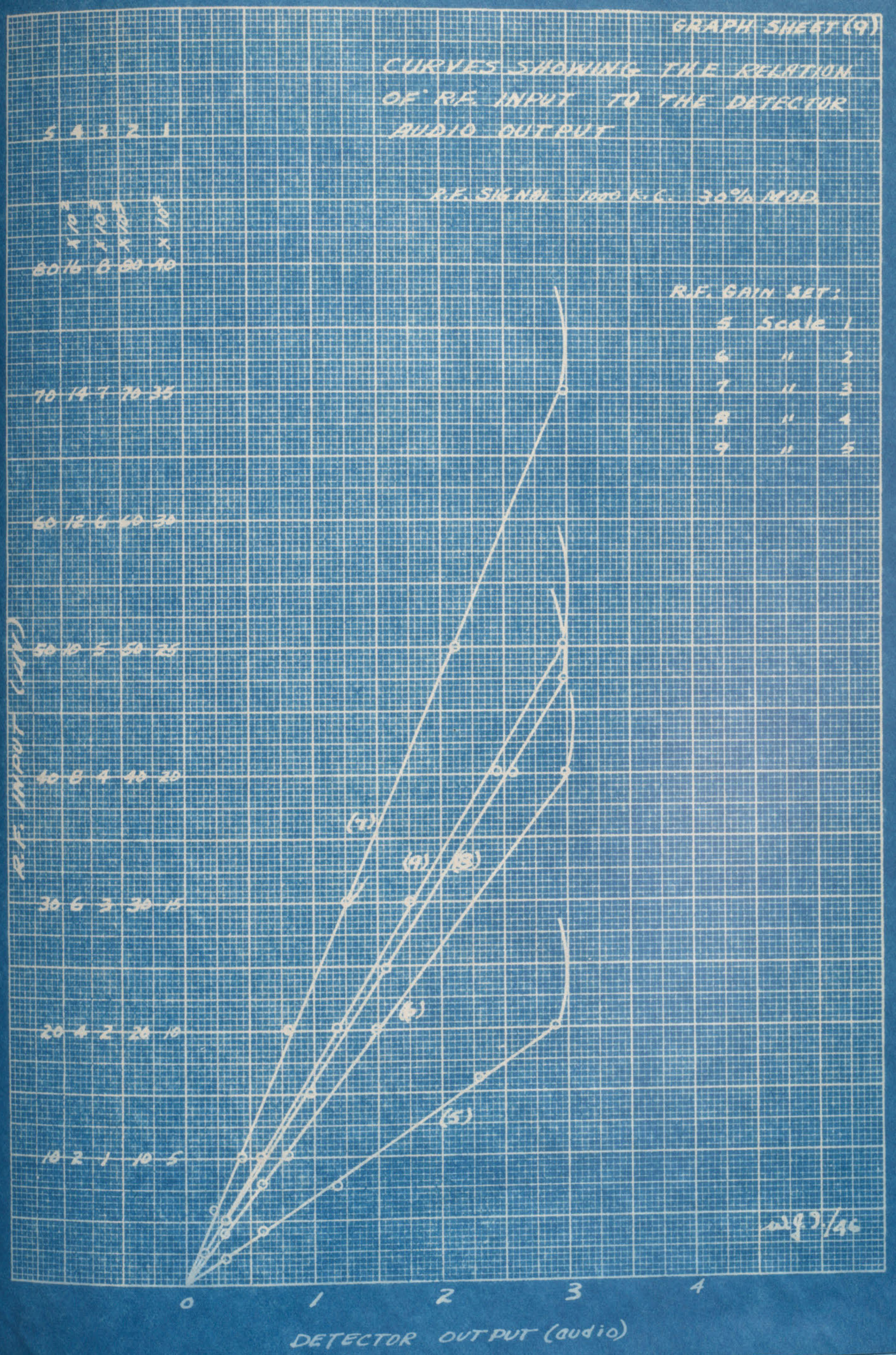
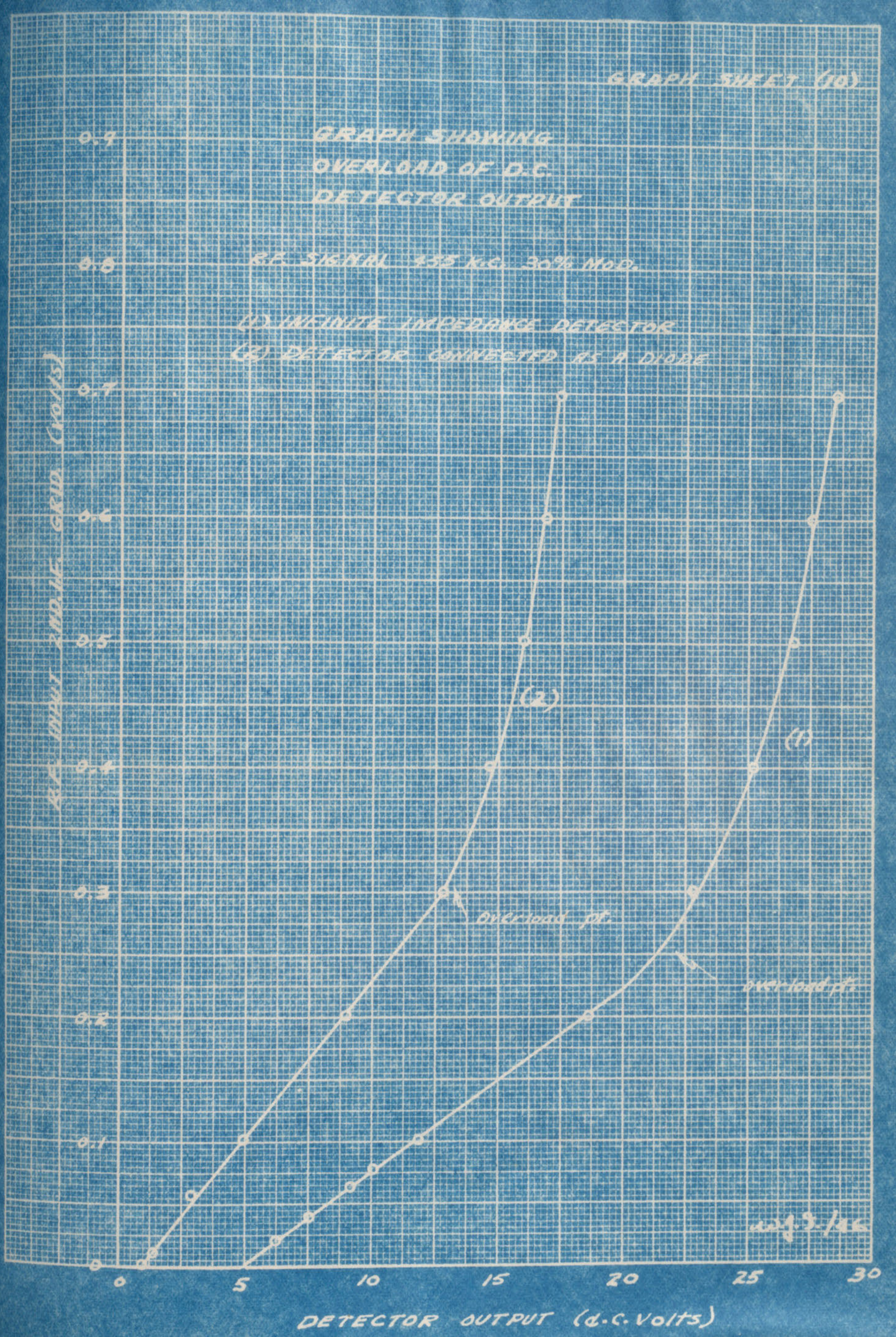


FIGURE 7

SCHEMATIC DIAGRAM
NC-200 RECEIVER

NOTE:
Stages from Antenna to detector output are shown


GRAPH SHEET (9)
CURVES SHOWING THE RELATION OF R.F. INPUT TO THE DETECTOR AUDIO OUTPUT
R.F. SIGNAL 1000 K.C. 30% MOD.
R.F. GAIN SET:
5 Scale 1
6 " 2
7 " 3
8 " 4
9 " 5
5 4 3 2 1
R.F. INPUT
DETECTOR OUTPUT (audio)
0
1
2
3
4
(7)
(9)
(8)
(6)
(5)



GRAPH SHEET (10)
GRAPH SHOWING
OVERLOAD OF D.C.
DETECTOR OUTPUT
R.F. SIGNAL 455 K.C. 30% MOD.
(1) INFINITE IMPEDANCE DETECTOR
(2) DETECTOR CONNECTED AS A DIODE
R.F. INPUT AMPLIF. GRID (volts)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
(2)
(1)
overload pt.
overload pt.
aug. 9./46
0
5
10
15
20
25
30
DETECTOR OUTPUT (d.c. Volts)

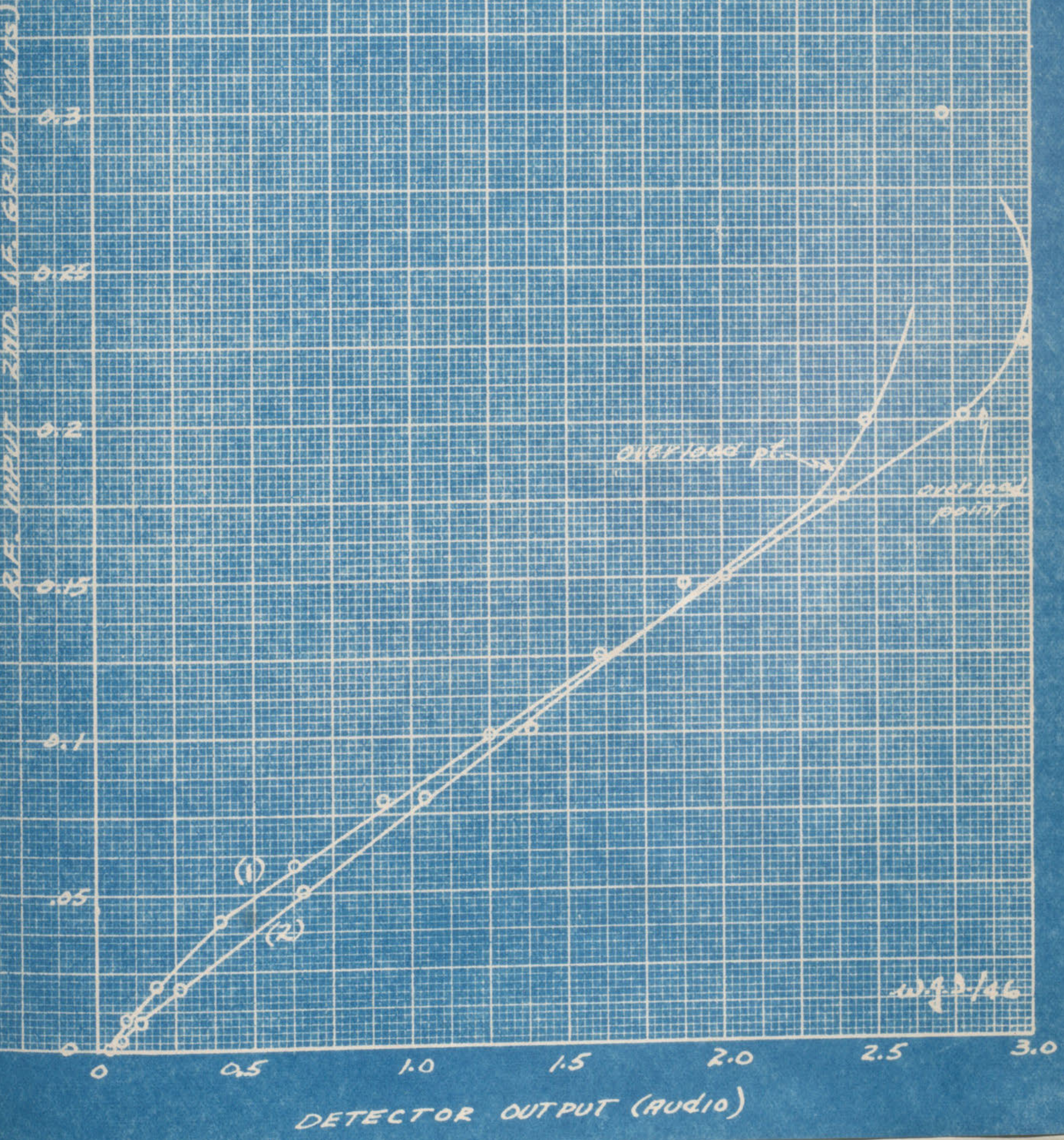
GRAPH SHEET (11)

GRAPH SHOWING OVERLOAD OF DETECTOR AUDIO OUTPUT

R.F. SIGNAL: 455 K.C. 30% MOD.

(1) INFINITE IMPEDANCE DETECTOR

(2) CONNECTED AS A DIODE DETECTOR



overloads at 3.0 volts audio output from the detector. Both the d.c. and audio overload points occurred at the same input voltage.

Step (2)

A similar procedure was carried out for an R.F. input to the grid of the 2nd I.F. tube. For the R.F. input a signal of 455 k.c. 30% modulated was used with the R.F. gain set at its maximum value. From this data curves on graph sheet (10) and (11) were drawn. These curves also show that the output from the second detector overloaded at approximately the same values as before.

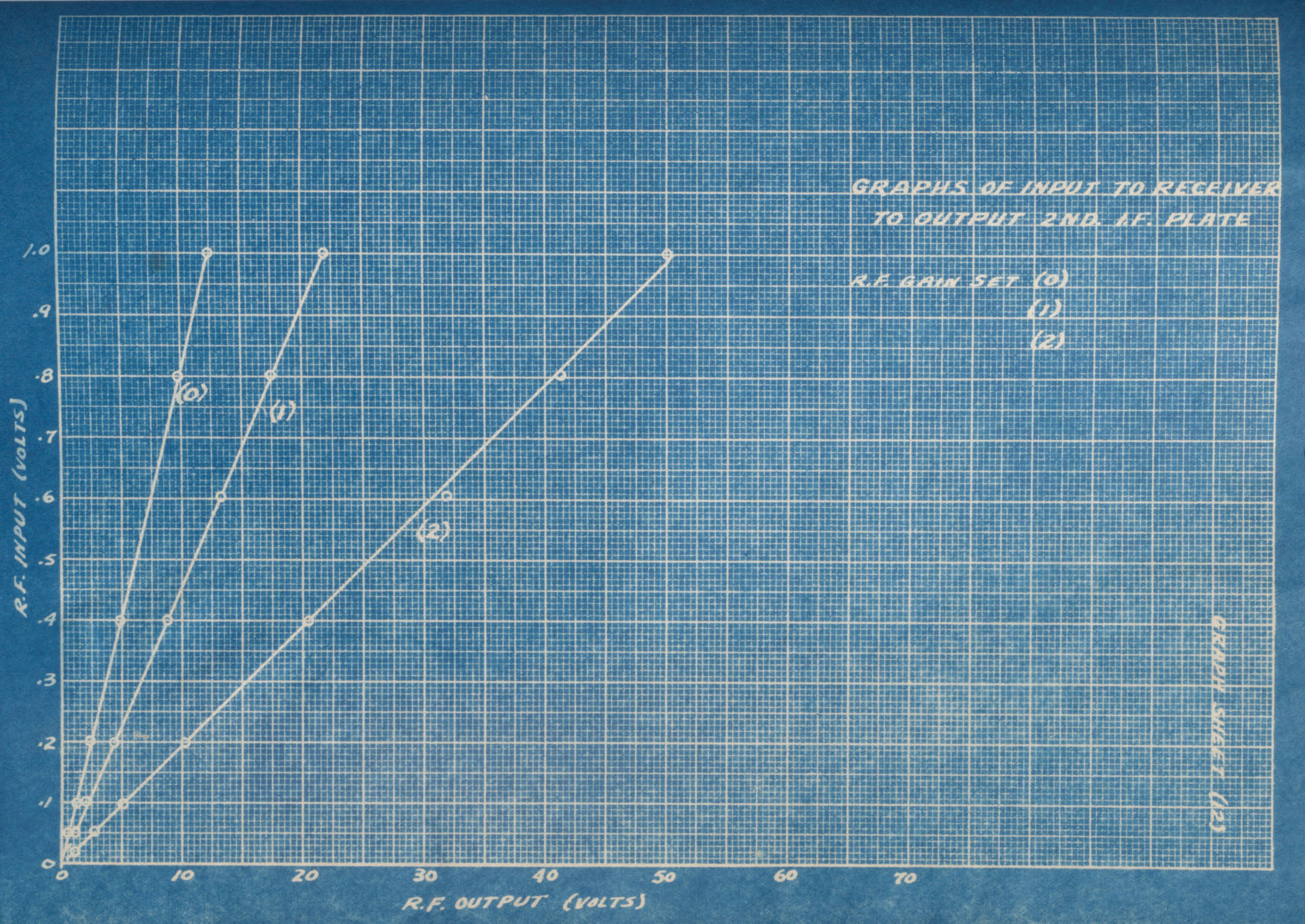
Step (3)

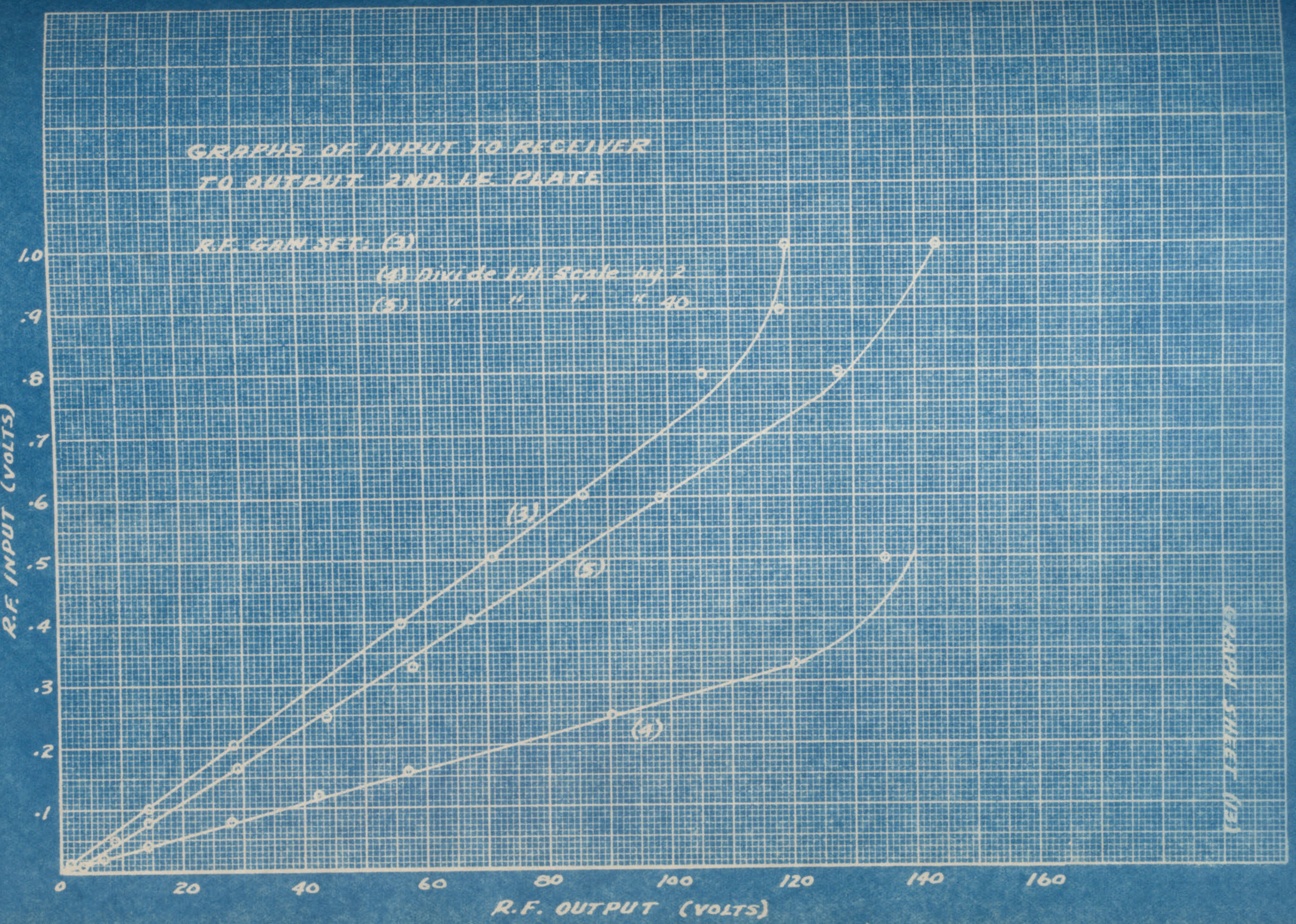
The infinite impedance detector was connected as a diode detector by connecting the plate of the triode to the grid and using a 1 megohm resistor for the load and 50,000 ohms for the I.F. filter. A similar procedure as in step(2) was followed and from the resulting data the curves shown on graph sheet (10) and (11) were drawn. These curves show that overloading occurred at about the same input as when the infinite impedance detector was used.

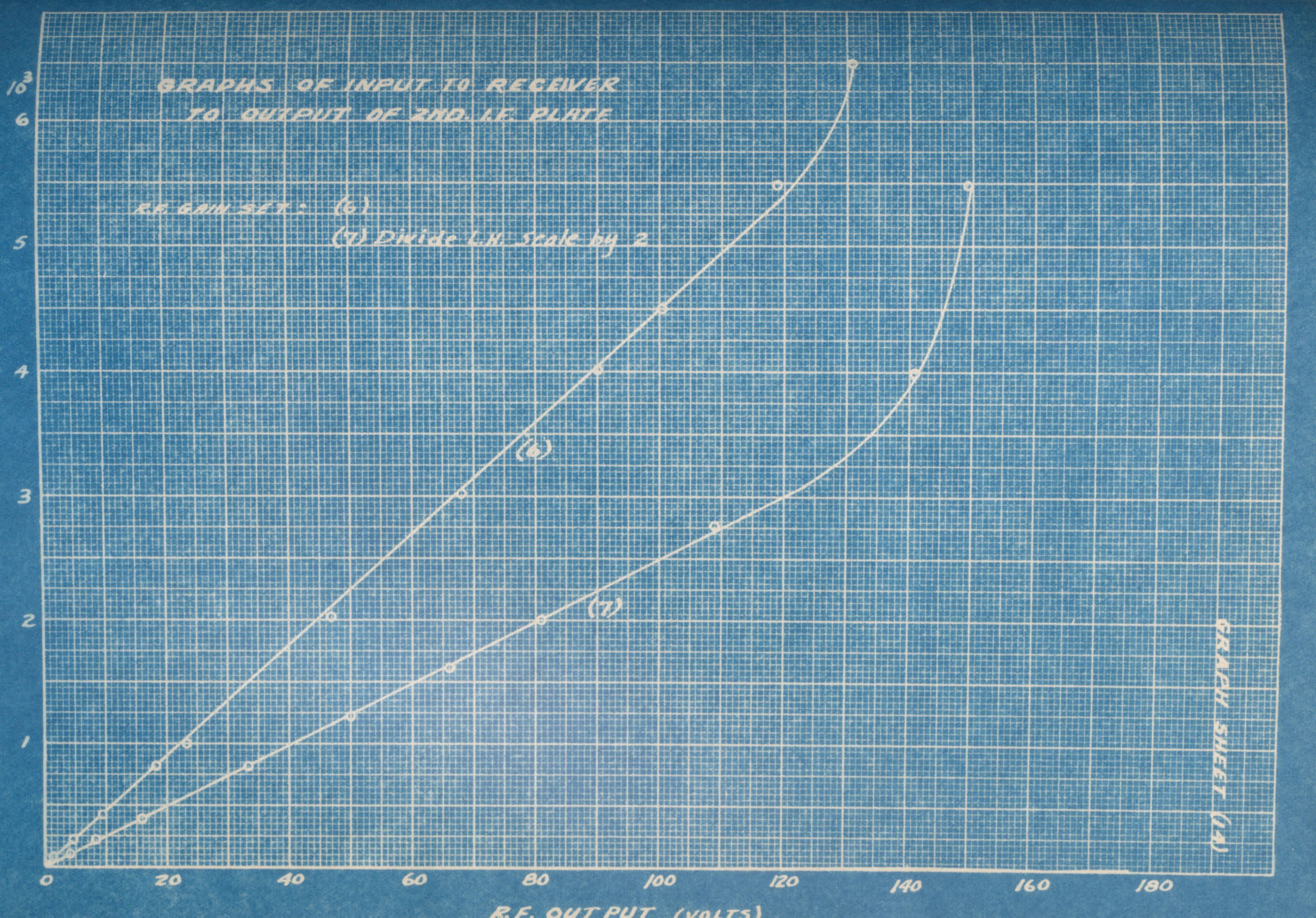
Stép (4)

In this step the range of linearity of the receiver from the antenna input to the 2nd I.F. was determined.

As in the first step a R.F. signal of 1000 k.c. 30% modulated was used as the input to the antenna. To measure the output of the second I.F. at the plate a vacuum-tube voltmeter was used by detuning the primary of the second I.F. transformer to compensate for the detuning caused by the voltmeter.


GRAPHS OF INPUT TO RECEIVER
TO OUTPUT 2ND. A.F. PLATE
R.F. GAIN SET (0)
(1)
(2)
GRAPH SHEET (12)
R.F. INPUT (VOLTS)
R.F. OUTPUT (VOLTS)
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
10
20
30
40
50
60
70
(0)
(1)
(2)


GRAPHS OF INPUT TO RECEIVER
TO OUTPUT 2ND. I.F. PLATE
R.F. GAIN SET: (3)
(4) Divide L.H. Scale by 2
(5) " " " " 40
(3)
(5)
(4)
R.F. INPUT (VOLTS)
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
20
40
60
80
100
120
140
160
R.F. OUTPUT (VOLTS)
GRAPH SHEET (13)



GRAPHS OF INPUT TO RECEIVER
TO OUTPUT OF 2ND. I.F. PLATE
R.F. GAIN SET: (6)
(7) Divide L.H. Scale by 2
(6)
(7)
GRAPH SHEET (14)
10^3
6
5
4
3
2
1
0
20
40
60
80
100
120
140
160
180
R.F. OUTPUT (VOLTS)

From this data the curves on graph sheets (12),(13) and (14) were plotted. These curves show that the output from the second I.F. tube begins to overload at 130 volts but it is linear up until this point is reached.

Conclusion:

The following conclusions and remarks are arrived at from the preceding tests:

1. As shown by the curves on graph sheets (8) and (9) the detector output is linear up to the point of overload which is as stated before at about 3 volts audio output and 25 volts d.c. output. For normal radio receiver operation this would be quite satisfactory as further amplification would take place in the audio stages of the receiver. However for our purpose, we require a linear output from the detector which approaches the range of 0 to 200 volts d.c. in order to utilize the d.c. logarithmic vacuum tube voltmeter described in the previous chapter.

2. Overloading existed for the same input for both the diode detector and infinite impedance detector. The high impedance detector is a special type of bias detector and the advantage of it is that it can handle high level carriers without distortion. This can be understood because a high value of carrier only increases the bias on the cathode. It is almost impossible to drive the grid positive with this circuit. Both of these detectors are capable of giving a

greater output then shown by the curves on graph sheet (10) and (11)

3. The receiver is linear over a wide range from the antenna to the second I.F. output at the plate. The output range extends from zero to 130 R.F. volts as shown by the curves on graph sheets (12), (13) and (14).

4. From the above results it was quite reasonable to suspect that the overloading of the receiver was due to the second I.F. coupling transformer. This fact was proved in the following manner:

An R.F. input signal of 455 K.C. to the grid of the second I.F. tube was used. The output from the second I.F. was measured across the primary of the second I.F. transformer by the use of a vacuum-tube voltmeter. Using a second vacuum-tube voltmeter the output of the secondary of the second I.F. transformer was likewise measured. In both instances the transformer was detuned to compensate for the detuning expect of the voltmeters. A voltage ratio of about 10 to 1 was noted. The limited range of the detector output was attributed to the step down in voltage of the second I.F. transofrmer. All the measurements obtained by using the vacuum-tube voltmeter were checked with an oscilloscope.

Extension of the Linear Range of the Detector Output.

It was previously shown that a linear output of 130 volts from the second I.F. was possible. Therefore with suitable coupling from the second I.F. stage to the detector the range of linearity of the detector should be approximately the same.

In figure (8) is shown a circuit employing direct-capacity coupling between the second I.F. stage and a diode detector. A linear range up to 70 volts d.c. was obtainable from the detector using this circuit. The difficulty encountered with this circuit was in obtaining an impedance match between the second I.F. and the detector.

A type of coupling which gave better results is shown in the circuit diagram figure (9). This circuit employs a complex type of coupling. It is composed of the primary and secondary of the second I.F. transformer that was in the receiver with a condenser across the two sides of the transformer as shown. Using this type of coupling a linear voltage of 130 volts R.F. was obtainable at the plate of the detector.

Tuned amplifiers involving complex coupled systems can be reduced to an equivalent transformer coupled case by the expedient of reducing these circuits to an equivalent inductively coupled circuit, and then calculating the behavior of the resulting equivalent circuit by the formulas for transformer coupling.

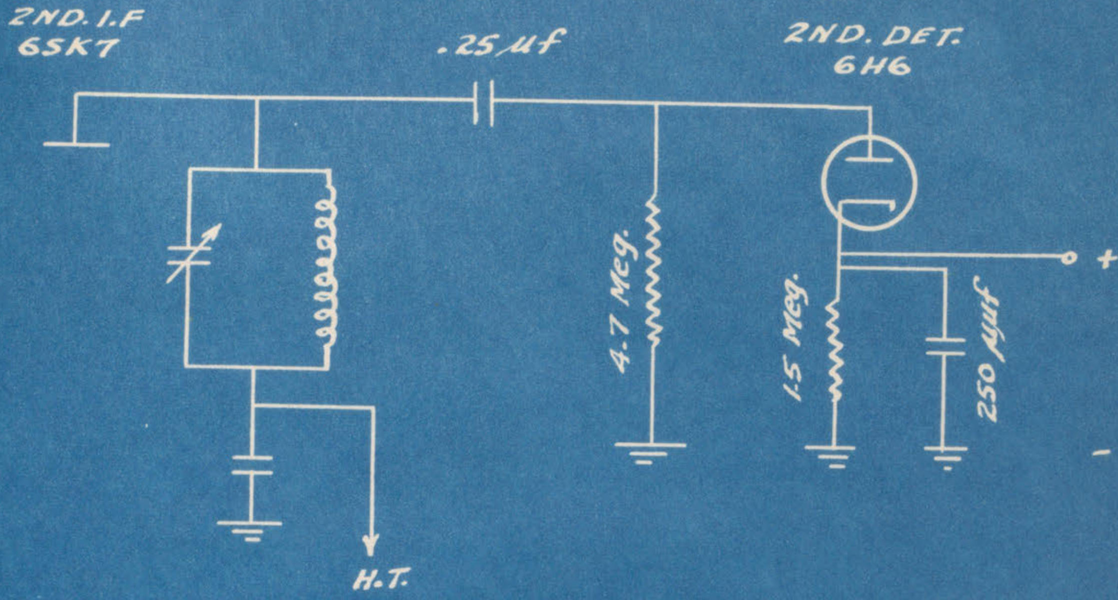


FIGURE 8

CAPACITY COUPLING

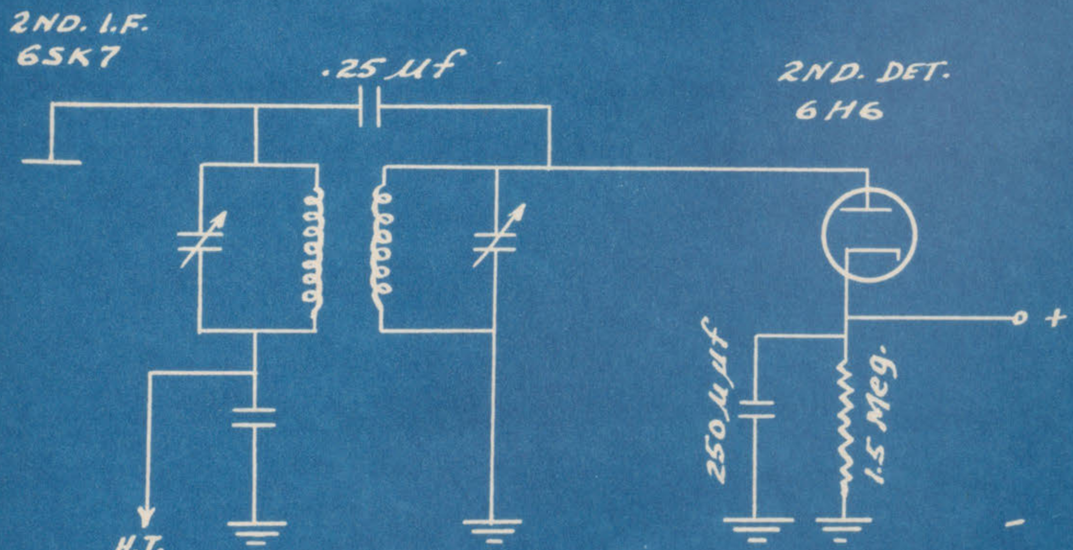


FIGURE 9

HIGH IMPEDANCE COUPLING

w.g.g./46

A 6H6 diode detector is used with a resistive load of 1.5 megohms and a I.F. bypass condenser. This type of a detector was chosen because of its simplicity and reliability of performance. Another advantage of it is that there is no fixed bias in the load circuit as is the case with the infinite impedance detector. That is for zero signal there is zero d.c. output from the detector.

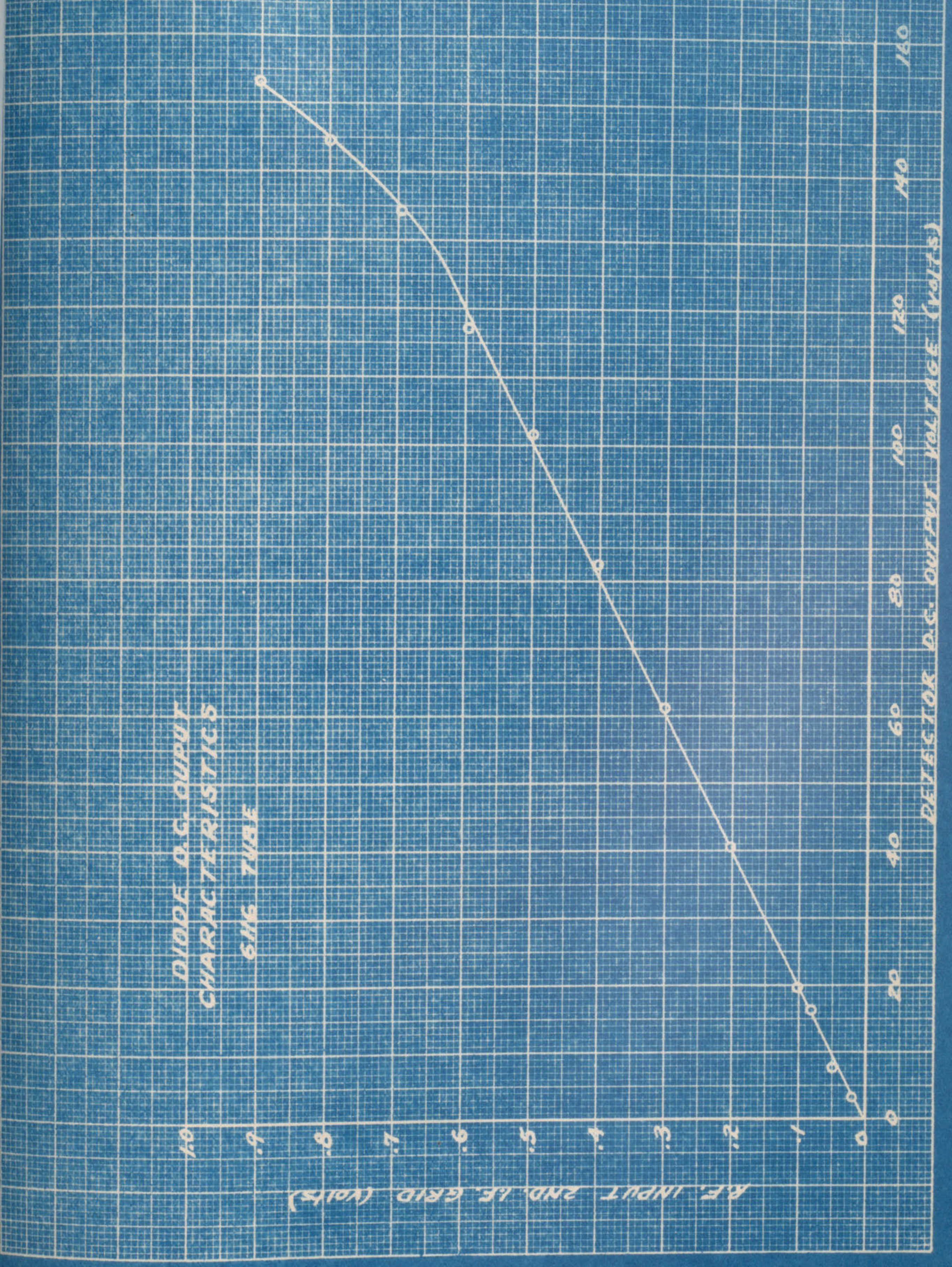
Linearity Response of Circuit in Figure 9.

The range of linearity of this circuit was determined in the following manner: A R.F. signal of 455 K.C. 30% modulated was used as the input to the grid of second I.F. tube and the d.c. output current was measured at the load of the detector with a microammeter. The d.c. output voltage from the detector was calculated from the current and load resistor of 1.5 megohms. The curve on graph sheet (15) was plotted from this data. This curve shows that the d.c. voltage output of the detector is linear over a range of 1 to 135 volts.

Remarks:

Two fundamental types of operation for diodes depend upon the amplitude of the signal applied to the circuit. Square-law detection takes place when the signal amplitude is small and the plate current of the diode is confined to the curved portion of the characteristic near the cut-off point. The "square law" refers to the portion

GRAPH SHEET (15)



of the tubes current-voltage curve through which the current increases as the square of the applied voltage. The other type of operation of the diode is a linear one. The fact that the curve on graph sheet (15) is not linear below one volt is attributed to square-law detection taking place. Above 135 volts output the second I.F. tube begins to over-load which accounts for the non-linearity of detection above this value.

The main disadvantage of using either capacity coupling or the complex coupling as in figures 8 and 9 is that the selectivity of the receiver may be somewhat impaired. However the use of the crystal filter in the first I.F. should ensure sufficient selectivity and offset that which might be lost with using this type of coupling. The use of a 1 to 1 ratio transformer coupled stage would probably be the best type of coupling to use. However as a I.F. transformer having suitable characteristic was not available this fact was not confirmed.

Steep wave-front disturbances involve a broad band of frequencies for their transmission and when transmitted through a selective amplifier undergo a change in shape. The energy content of a high amplitude pulse of short duration is unchanged by a selective amplifier, but its maximum amplitude is decreased and its duration correspondingly increased. Since this shape alteration of sharp pulses takes place in radio receiver in proportion to their selectivity, in order to correlate noise meter indications with radio reception, it is desirable to have comparable selectivity. The overall pass band of radio receivers, from antenna to loud speaker, varies widely, from about 1500 cycles in the lowest priced receivers to 6000 or 8000 cycles in the case of receivers of high fidelity. Since good quality receivers merit additional consideration, the noise meter should have somewhat greater pass band than that of the average receiver. The high frequency end of the pass band is of prime interest, frequencies lower than 60 cycle seldom being of interest in noise studies. The noise meter should then transmit frequencies of 4000 to 5000 cycles, which means the selective circuits should have a band width twice as great because of double side band considerations.

Measurement of Detector Output by D.C.Logarithmic Voltmeter

Figure (10) shows the schematic circuit diagram for measuring the detector output by the use of the logarithmic d.c. vacuum-tube voltmeter. The logarithmic d.c. voltmeter was connected directly to the diode load and overall characteristic of the receiver circuit investigated.

A 1000 K.C. 30% modulated R.F. signal was used as the input to the antenna and values of input to output were taken for various R.F. gain settings. These values were plotted on semi-logarithmic graph paper. The logarithm of the R.F. input voltage was plotted against the output current measured by the milliammeter of the logarithmic d.c. vacuum-tube voltmeter.

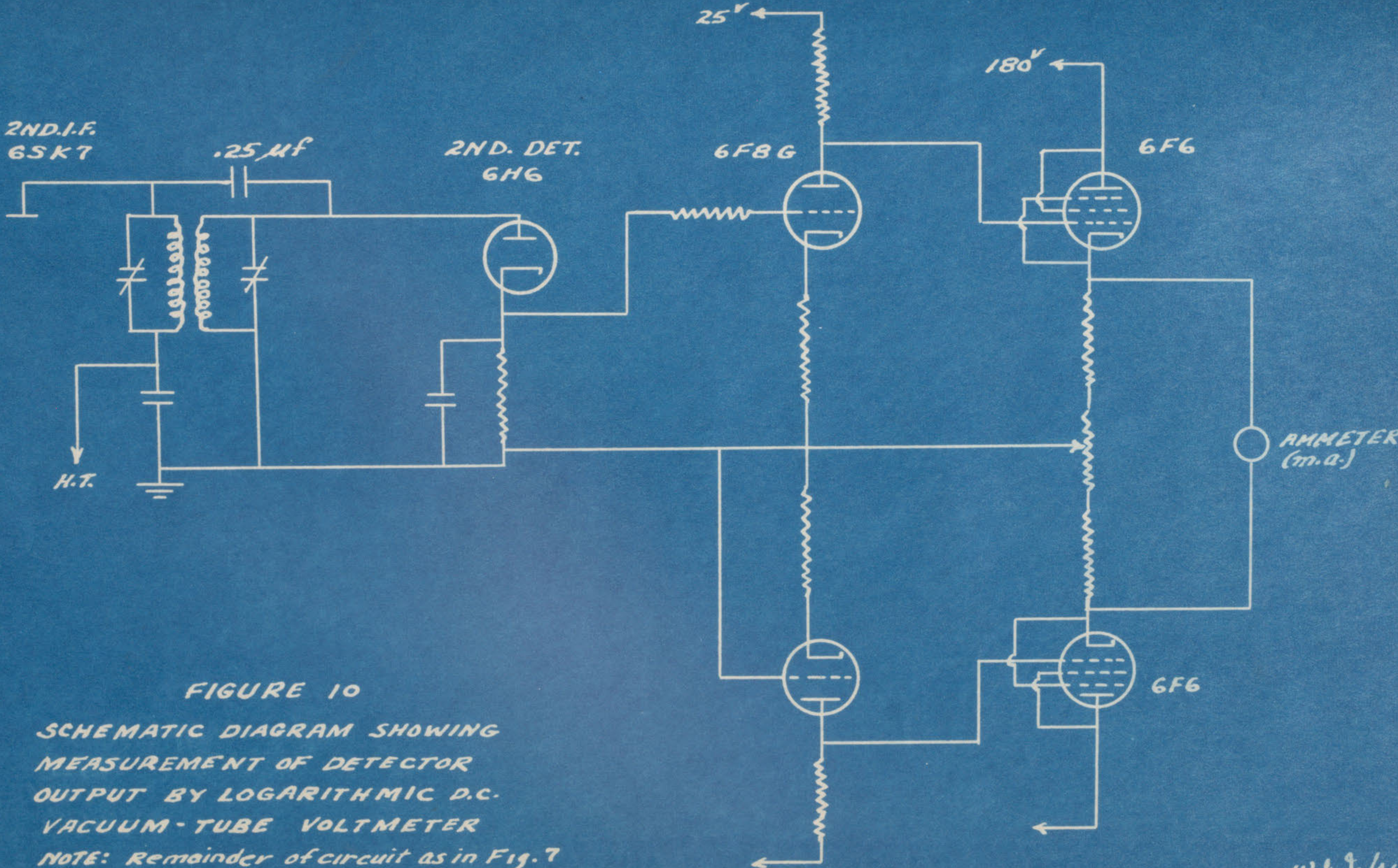
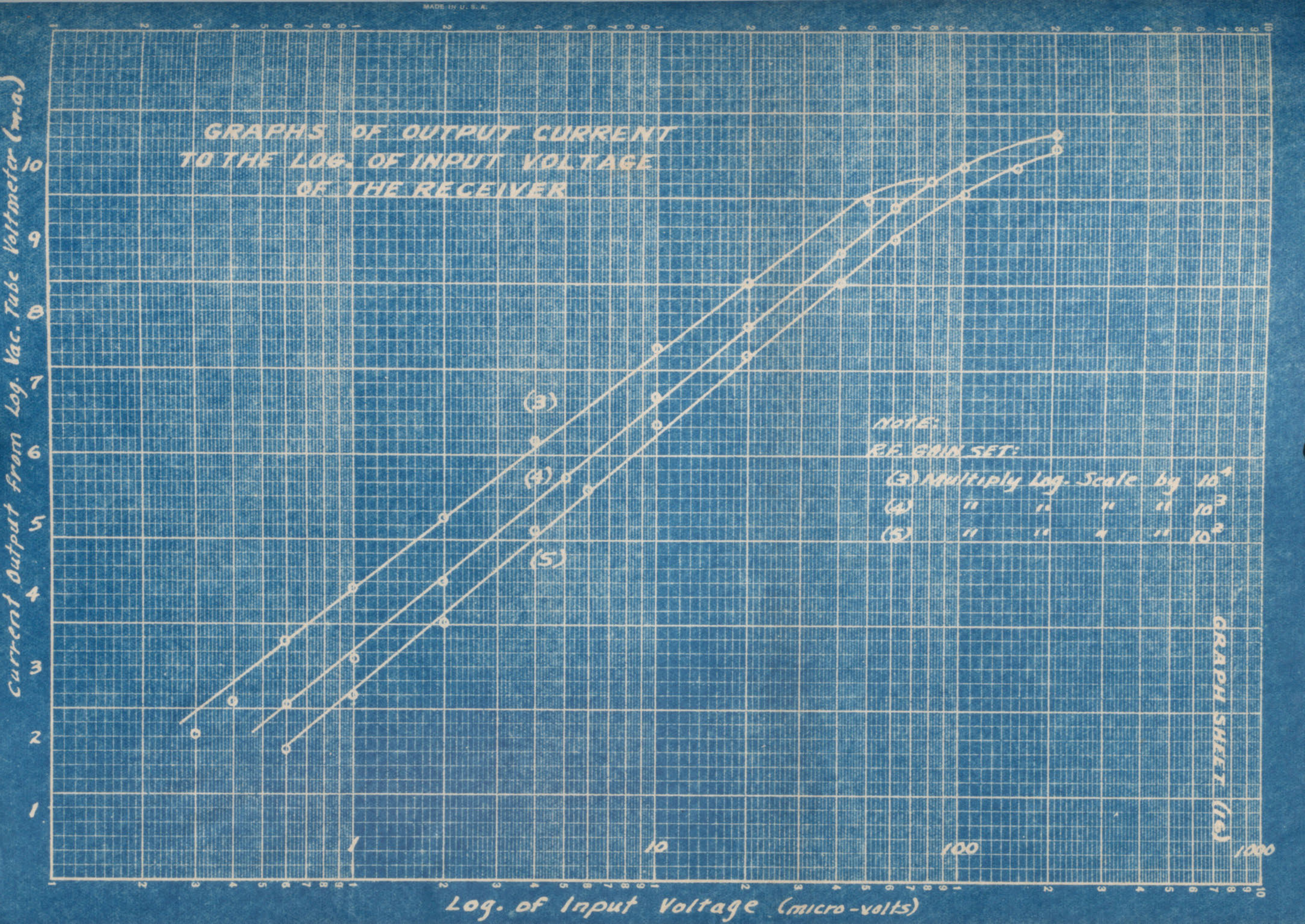


FIGURE 10

SCHEMATIC DIAGRAM SHOWING
MEASUREMENT OF DETECTOR
OUTPUT BY LOGARITHMIC D.C.
VACUUM-TUBE VOLTMETER

NOTE: Remainder of circuit as in Fig. 7
(values of resistors + Condensers shown previously)

W.J.J./46


GRAPHS OF OUTPUT CURRENT
TO THE LOG. OF INPUT VOLTAGE
OF THE RECEIVER
(3)
(4)
(5)
NOTE:
R.F. GAIN SET:
(3) Multiply Log. Scale by 10^4
(4) " " " " 10^3
(5) " " " " 10^2
GRAPH SHEET (16)
1
10
100
1000
Log. of Input Voltage (micro-volts)
Current Output from Log. Vac. Tube Voltmeter (m.a.)
MADE IN U.S.A.

Results:

The curves on graph sheet (16) show that a logarithmic relationship exists over approximately two decades. The overall range of the logarithmic vacuum-tube voltmeter is not fully utilized due to the limited linear output from the detector which was previously discussed.

In this investigation the type IN34 germanium crystal diode was experimented with for possible use as the detector. However using it in place of the 6H6 diode in figure 10 only a small output range was obtainable.

Further investigation of the use of a crystal detector is recommended as new and improved types of crystal detectors are available.

CHAPTER VII

CONCLUSION

In concluding this thesis the writer regrets that lack of time has forced further investigation on the development of this problem to terminate but from the considerations outlined in this thesis the following conclusions have been arrived at:-

1. The development of a logarithmic d.c. vacuum-tube voltmeter which has a logarithmic range of over two decades. This property makes it useful for measuring noise voltages as well as for other useful applications.

2. The development of a detector circuit for the NC-200 receiver to provide a linear output voltage over a range which enables the use of the logarithmic d.c. voltmeter to the greatest advantage.

Suggestions:-

1. The development of a calibrated attenuator for operation in the I.F. amplifier. Since the meter scale is useful over a ratio of inputs of about 100 to 1 by virtue of the logarithmic system used, but in order to cover the entire range of 10 to 100,000 micro-volts, multipliers of 10 and 100 should be used. These multipliers are in the form of attenua-

tors for the noise input and may be of the resistance type, capacitance, or mutual inductance type.

2. Determine optimum time constants for the receiving circuits (grid return circuits particularly) in order to avoid any effect on the indicator of the instrument due to a critical value of these circuits.

3. A further extension of the voltage range over which the detector circuit provides a linear output if possible to make use of fewer attenuator taps.

4. Construction of a complete instrument.

Appendix

Bibliography

1. British Standards Association
Ref. UNSCC (London Office) 16 L.T.S.4 (3)

2. Instruments and Methods of Measuring Radio Noise
C.V. Aggers & Foster A.I.E.E. Technical Paper May 1939.

3. Investigations of the Measurement of Noise
University of Pennsylvania Oct. 31, 1945.

4. Measurements of Time Constants of Commercial
Noise Meters - K.A. MacKinnon, C.B.C.

5. Canadian Standards Association.
Specifications for Interference Measuring
Instruments - Specification C22.4 - No. 101-1945.

6. Theory of Thermionic Vacuum Tubes
E.L. Chaffee McGraw & Hill Pub.

7. Vacuum-Tube Voltmeter
Review of Scientific Instruments, Nov. 1939.
Meagher & Bently.

8. Radio Engineers Handbook - Terman
McGraw & Hill Pub.

9. Instruction Manual - The National NC-200
Communication Receiver.

10. The Electronic Engineering Handbook
R.R.Batcher & W.Moulic
Blakiston Pub. Co.

11. Study of Wave Shapes for Radio Noise MeterCalibration
- C.W. Frick. A.I.E.E. Sept. 1945.

12. Improved Vacuum-Tube Voltmeter.
J.T. McCarthy Electronics - July 1945.

13. Ferris Noise and Field Strength Meter
Instruction Manual.

14. A Vacuum-Tube Voltmeter with Logarithmic Response
F.V. Hunt - Review Scientific Instruments
Vol. 4 No. 12 Dec. 1933.

15. D.C. Amplifier Design Techniques
E.L. Ginzton Electronics Mar. 1944.

16. Transient Peak Voltmeter
Ryerson - Electronics, Sept. 1945.

17. Radio Frequency Measurements
E.B. Moullin.

18. Time Deflection Characteristics of Moving-Coil
Instruments - G.F. Tagg. J.I.E.E. June 1945.

19. Radio Interference - Investigation, Suppression,
and Control. H.O. Merriman & Nixon.
I.R.E. Vol. 27 Jan. 1939.

20. An Experimental Investigation of the Characteristics
of Certain Types of Noise. - K.G. Jansky
I.R.E. Vol. 27, Dec. 1939.

21. Progress in the Development of Instruments for
Measuring Radio Noise - C.M. Burrill
I.R.E. Vol. 29, 1941.

22. Noise Meter - Test Set AN/URM-3 (XD-1)
Coles Signal Laboratory, SCEL. Jan. 1946.

- - - - - - - - - - - -