A STUDY OF THE PEAK VALUES OF TRANSIENT VOLTAGES PRESENT IN THE RADIO-FREQUENCY AND INTERMEDIATE-FREQUENCY AMPLIFIERS OF A COMMUNICATION TYPE RADIO RECEIVER

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PREFACE

In recent years the study of interference of radio reception has come to the fore, partly because the numerical value of this interference is often desired to determine whether or not a given item or system is capable of causing interference in excess of certain assigned limits, and also because an aid to determine the efficacy of any given method of abating the interference and for finding the best method to use in a given case is required. The most important requirement of the method of measurement is that the numerical values it assigns to the varied kinds and degrees of radio-noise shall approximate as closely as possible to their subjective significance or "annoyance values". Another very important requirement arising from the world-wide range of radio telecommunications is that there shall be international understanding and agreement about it.

As a result of these studies international committees have discussed the topic with the idea of drafting specifications for measuring interference which can be used universally. At present the British Standards Institution has one standard, the American Standards Association another, and the Canadian Standards Association still another which has been drafted with the idea of combining the better practices of the other two.

Meters have been designed to each of the above standards and are found to give comparable values on commutator-buzz noise types, but vastly different results on high peak low energy pulses. As a result, these specifications do not seem to be stringent enough and should be revised.

The present specifications adopted make use of a very sensitive communication receiver, with rigid specifications as to its bandwidth and detector time constants. This meter is designed to amplify the noise linearly to a measurable quantity, as many types of interference are of very low voltages, much too low to be recorded on a meter. This receiver must be calibrated quite frequently to make sure that readings by it are dependable. For this work the use of a standard noise source has been suggested, which if coupled to the receiver by standard coupling could always be depended on for accurate calibration of the standard meter. Supplementary to this an internal calibrator should be incorporated in the receiver for calibration in the field as a secondary standard.

This thesis presents a study of the transient response of the radio-frequency and intermediate-frequency circuits of a National type NC-200 commercial superheterodyne communication receiver to pulse excitation. This study was made for the purpose of assisting in the design of the receiver circuits from the point of view of obtaining linear response to radio noise peaks. The results of the investigation show that linear response can be obtained with this type of receiver. Hence, this receiver, with a satisfactory indicator connected to the detector output circuit, may be used as a Noise Meter.

CHAPTER I

INTRODUCTION

Radio noise effects are produced by extraneous electrical fields associated with transient conditions in an electric circuit. In order that apparatus producing these effects can be treated and described in precise terms and the most satisfactory method of radio noise suppression employed in a given case, it is necessary that there be some means of measuring the radio noise voltage which is significant in relation to radio reception. It is also desirable that there shall be a national or better still international understanding and agreement as to the method of measurement.

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, and radiation or a combination of these. This thesis will deal mainly with conducted noise voltage.

The radio noise effect of electrical apparatus on a receiver antenna is influenced by most of the above factors. No definite method has been developed that will permit the calculation of voltage on a receiver antenna when the noise voltage produced by electrical apparatus is known. Furthermore, the characteristics of the receiver have an effect on the noise characteristics, so that the wave shape of the noise pulse at the output of the receiver may differ from that at the input.

Through the co-operative efforts of the Edison Electric Institute, National Electrical Manufacturers Association, and Radio Manufacturers Association, the measurement of radio noise has been placed on an engineering basis, and specifications for a Radio Noise Meter and methods of measurement have been adopted. As mentioned in the preface, instruments made by different manufacturers, according to these specifications, do not give the same measurements of interference from some sources and it is, therefore, apparent that these specifications are incomplete.

The necessity of obtaining comparable measurements of interference by different investigators is an urgent problem. The specifications used for work on this thesis are, therefore, prepared to enable investigators to obtain reasonably accurate results with the use of instruments readily available. They are not intended to prevent the use of other means of investigation, but on the contrary, the development of improved measuring equipment and measuring technique is encouraged.

As mentioned in the preface the ideal instrument for measuring radio interference is one which would give a numerical value to the nuisance value of the interference. This ideal 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. To approach this ideal, however, listening tests have been made, and in fact several meters; namely, the Ferris Model 32 (U.S) Noise and Field Strength Meter, the RCA type 312 R.F. Noise Meter, the Canadian Ferris, and the Marconi-Ekco type TF-379 Interference Measuring Set have been tested in this manner [(1)]. Results of these tests show that these instruments made to the same specifications by different manufacturers give widely different results when used to measure the same interference. This is more evident on types of interference having

(1) For all numbered references see Bibliography (Appendix D).

high peaks and low energy content such as surges, telegraph interference, and automobile ignition interference. Therefore, it has been suggested that a primary standard of noise measurement be established at the National Bureau of Standards, which could consist of a standard set of noise sources and one of the several noise meters now on the market. This noise meter could be calibrated by means of "judgment tests" so that it would read the same as an "ideal" meter on the standard set of noise sources. Having established such a primary standard of noise measurement, it would then be possible to calibrate any particular noise meter in terms of this standard. Before any noise meter can be read in connection with any regulating problems it is necessary to evaluate its readings in terms of the interfering effects of the noise to the average listener. This evaluation could be made once and for all for the standard noise meter and other meters then calibrated in terms of its readings.

In comparing the various types of meter(2) it was found that the AVC circuits had very disturbing effects on the performance of noise meters because their time constants were of the order of the detector circuit, in fact, longer, because the AVC included the diode weighting circuit. Hence, the time constants of the AVC circuit should be very short compared with the detector weighting circuit, in order that the time constants of the latter are the determining ones. This condition is not possible, however, as radio-frequency by-passing required for good receiver design results in a relatively long time constant.

Possible causes of the discrepancies of the present noise meters are as follows:

(1) Variability of pickup devices and methods of using them. A dipole for close fields may produce errors, and a loop antenna may be better here. However, no matter what pickup is used the presence of other electrical conducting materials in the vicinity may cause errors.

(2) The meter measurements are questionable due to the wide variations in peak values and waveforms of the noise voltages measured.

(3) The meters have a limited dynamic range, and some component of the receiver might be overloaded by certain types of noise e.g. sharp pulses with low repetition rates.

As a result, the drafting of a new specification was considered for satisfactory noise meter performance which included a definite definition of noise and the adaptation of the indicator of the noise meter to the recording of that noise. It should also include the definite and unambiguous specification of input coupling devices and their uses.

CHAPTER II

THE WRITING OF THE SPECIFICATION

A. Problems That Should Be Considered

In the writing of the specification for a noise meter, the following should be considered:

1. Definition of Noise
2. Interfering Effect of Noise
3. Present Noise Meter Specifications

1. Definition of Noise

Noise may be defined as any undesired signal having a wide frequency spectrum. Two general types are usually distinquished for the purpose of analysis: a. random or fluctuation noise. b. pulse noise.

Random Noise may be defined as a large number of individual pulses which are superimposed. They may be of random amplitude and phase or constant amplitude and random phase. This type of noise has been referred to as "fluctuation" noise, "white" noise or "hiss" noise. White noise is in general any noise where the energy is uniformly distributed in the frequency spectrum. Pulse noise is defined as individual pulses discretely separated in time which is characterized by ignition noise, generator noise, and regulator noise, and is measured by the pulse amplitude, length, and repetition frequency. Thus, pulse noise is easier to study both theoretically and experimentally and is easily defined.

Noise has been distinguished as to whether the individual pulses are overlapping or non-overlapping (3). Results, both experimental and theoretical, showed that the peak value is proportional to the bandwidth for non-overlapping pulses, and proportional to the square root of the bandwidth for overlapping pulses.

2. Interfering Effect of Noise.

As previously mentioned the main reason for measuring noise is to state definite limits which will prevent satisfactory communication by one means or another. Since personal considerations occur, certain subjective criteria related to the interfering effect of noise have been incorporated into the criteria for designing noise meters.

There is a conflict between the natural desire to design a noise meter which will measure certain specific physical quantities, and the necessity for designing a noise meter that will be useful for indicating which noises produce the greatest interference. It appears impossible to design one noise meter which will satisfy both these requirements. Therefore, both should be considered.

It has been proved by articulation tests that the effect of a given type of impulse noise on the intelligibility of a voice-modulated signal is a function of both the pulse amplitudes and the repetition rate. Therefore, any noise meter which attempts to measure the effect of interfering noise on the signal intelligibility must be capable of taking both into account. For pulses short in duration compared with the highest modulating frequency receivable the peak value of the wave train produced by the pulse passing through the receiver filter is proportioned to the energy content of the original pulse. Hence, though the receiver may alter the wave shape of the noise pulse by decreasing its amplitude its energy content is still the same because its duration is increased. It is anticipated that practically all noise pulses will fall within this limitation.

In this thesis the effects of an impulse noise generator on the circuits of a receiver are studied. This generator has variable pulse amplitude and repetition rate.

3. Present Noise Meter Specifications

With a device of limited bandwidth it is necessary to specify whether the indicator reads peak, average, or instantaneous (such as is obtained with a cathode ray oscillograph) voltage. In general it is necessary to read more than one of these quantities to specify accurately the interference effect. The present "standard" attempts to accomplish this result by choosing appropriate time constants for an intrinsically peak reading indicator. Since peak noise is to be measured in the present problem, a peak reading meter is satisfactory.

Recommendations for noise meters drawn up by the Joint Coordination Committee on Radio Reception of the Edison Electric Institute, National Electrical Manufacturers Association and Radio Manufacturers Association call for a bandwidth of equipment operating in a certain frequency region to be the same as that of typical equipment operating in that region. In the superheterodyne circuit used in noise meters it is necessary to consider the bandwidths of the radio-frequency amplifiers and the intermediate-frequency amplifiers. Usually the latter are much more sharply tuned and hence largely determine the overall bandwidth of the meter. Since good quality receivers merit additional consideration, the noise meter should have a somewhat greater pass band than that of the average receiver.

The problem of pulse distortion in the tuned circuits must be studied thoroughly before the readings obtained with the various types of noise signals can be evaluated.

The input voltage range should be from 10 microvolts to 100,000 microvolts and the device should handle a peak sine wave input of 10 volts with negligible distortion.

B. Problems Considered

Up to now the problems that have been met in the design of a noise meter have been discussed and some have been solved.

The problems tackled in this work should now be discussed and the method of their solution determined, after which recommendations for future work on the subject can be made.

The specification used as a special reference in this work is the C.S.A. Specification C22.4-No. 101-1945, "Specifications for Interference Measuring Instruments and Methods of Measurement." Only those passages relevant to the present problem will be considered.

The problems considered in this work are:

Problem 1.

The development of a suitable input circuit to permit the noise measuring instrument to be used with a short vertical antenna or with a twisted pair transmission line connected to the input terminals.

Problem 2.

A method of calibrating the sensitivity of the receiver. A signal generator will be satisfactory for laboratory work, but a shot noise diode or other small device would be preferable for portable use.

Problem 3.

To investigate the peak values of noise voltages encountered in the radio-frequency circuits and to determine the proper operating levels for these circuits.

Problem 4.

To determine optimum time constants for the receiving circuits (grid return circuits particularly) in order to avoid any effect on the indicators of the instrument due to a critical value of these circuit time constants.

Problem 5.

To check the stability of the receiver with regard to calibration and to determine what, if any, parts of the voltage supply circuits should be voltage regulated.

Problem 6.

To develop a calibrated attenuator for operation in the intermediate-frequency amplifier. This attenuator should preferably be located near the input end of the intermediate-frequency amplifier.

Relevant material from the C.S.A. Specification is

"401. INSTRUMENT APPROVED AS STANDARD

A calibrated receiver and output meter is approved as standard for measuring all types of interference of frequencies of 30 megacycles per second or less when calibrated and operated as hereinafter specified. (See Pars. 403 and 404).

402. ALTERNATIVE INSTRUMENTS

(a) Ferris Model 32, Noise and Field Strength Meter

(b) " " 32-A, " " " " "

(c) " " 32-B, " " " " "

(d) RCA type 312-A R.,F. Noise Meter

(e) " " 312-B R. F. " "

(f) Marconi-Ekco type TF-379 Interference Measuring Set.

402.1 These instruments are not approved for measuring interference having surges of high peaks, such as surges produced by ignition systems of internal combustion engines, instantaneous surges from street railway systems, elevator controls, telegraph apparatus, etc.

402.2. These instruments <u>are</u> approved for measuring most types of interference produced by the normal operation of high voltage transmission lines and apparatus, commutator motors and systems, and apparatus producing radio interference of similar characteristics, provided that all measurements agree within $\pm$ 3 db with measurements taken with a standard calibrated receiver and output meter.

403. CALIBRATED RECEIVER, OUTPUT METER, AND INDICATING INSTRUMENT

403.1 Calibrated Receiver.

(a) The calibrated receiver shall be an approved type, operated under approved conditions, and equivalent to the receiver used in standardization tests; namely, a National type NC-200 commercial superheterodyne receiver calibrated as hereinafter specified. (See Par. 404).

404.3 STANDARD SIGNAL GENERATOR

The standard signal generator, used for calibrating the receiver, shall be a high quality instrument with an output accuracy within $\pm$2 db at any frequency below 30 megacycles."

CHAPTER III

STUDY OF THE PROBLEMS

The problems just mentioned are now studied more fully.

PROBLEM 1. INPUT CIRCUIT

The impedance of the input circuit should be high, so that the voltage existing on the antenna or across a standard coupling network will not be affected by connection of the noise meter [4]. A circuit that will accomplish this is given in the article mentioned. No further study of this particular problem was considered.

PROBLEM 2. CALIBRATION SOURCE

As mentioned in the preface the meter should have a standard calibrator, with a secondary standard incorporated in the meter itself.

In general a signal of known amplitude and wave form is fed into the meter and the meter's response is determined as a function of frequency. The exact type of signal should have the character of noise itself, since it is quite possible that with circuits that may be used, responses to various types of signals will be different.

A. Comparison of Sources

The following sources are compared on a basis of simplicity, stability, frequency range, size, and weight [5].

1. Sine Wave Sources.

These have fair stability. The size and weight will depend on the frequency range desired. Either a calibrated output meter or a well stabilized circuit is required, and maintenance is likely to be a problem in the field.

2. Random Noise Sources.

The best of the random noise sources seems to be the temperature limited or shot diode [6]. If tungsten filaments and highly evacuated tubes are used the stability is good. The circuit is a simple one tube affair. The size and weight are both very small. The output is usable up to 300 megacycles. The frequency range is limited by electron transit time and the internal inductance and capacitance of the diode. It is unnecessary to calibrate the shot diode, the output being proportional to the d.c. component of the plate current. The output is small but within a reasonably wide frequency bandwidth with a typical load impedance, it is more than 5 times the thermal noise of the first stage. This is sufficient for calibration purposes.

3. Spike Noise Sources.

On a theoretical basis the spike noise source (7) with the most extended frequency range is the Purdue charged transmission line. The frequency range extends to 400 megacycles. It is to be emphasised that these results are theoretical and have not been checked experimentally. This source is intermediate between the shot diode and the sine wave source in size and weight. It is at present unsatisfactory due to an instability caused by the contacts. There are several other spike noise sources available such as the Detroit Signal Corps Engineering Laboratory thyratron pulse generator (8) and Harvard's "blocking oscillator" pulse generator. Their frequency range is less than the Purdue source being usable to approximately 50 megacycles, which is satisfactory in the present case. Both sources are stable, the Harvard one being slightly more stable, and both are smaller and lighter than the Purdue source. The outputs of all the sources are sufficient to calibrate the noise meter below 50 megacycles.

B. Source Used

In this thesis a Pulse Generator (for circuit diagram see

Figure 1) designed by the Radio Branch of the National Research Council of Canada for the Canadian Standards Association has been used as a primary standard. This noise source is similar to the Detroit Signal Corps Engineering Laboratory thyratron pulse generator [8]. It produces a positive rectangular pulse of voltage suitable for the simulation of transient and pulse-type noise interference, the amplitude, pulse length and recurrence frequency of which are variable. The amplitude is continuously variable from 30 to 160 peak volts. As this is too high for most of the measurements a calibrated attenuator has been designed to be used with the noise source (Figure 2A), which is a modified Signal Corps BC-1236-A Signal Generator output attenuator. This cuts down the output in steps of (1) 1530, (2) 2860, (3) 27,200 and (4) 340,000. The amplitude is controlled by the potentiometer, P3, labelled OUTPUT. The pulse length is variable from approximately 1 microsecond to 25 microseconds, controlled by the switch S3, labelled PULSE LENGTH, and the pulse recurrence frequency from 1 to 2000 cycles per second, controlled by the two switches S1 and S2.

Potentiometer P1 is adjusted so that the p.r.f. is 1 c.p.s. when S1 and S2 are set at "1". The Kipp sensitivity control, P2, is adjusted so that the Kipp will almost self-trigger in the absence of a triggering pulse from V1.

The apparatus consists of a power supply providing 400 volts unregulated, 300 volts regulated, and -150 volts regulated, with the necessary filament voltages, in addition to the pulse-forming circuits.

A type 884 thyratron oscillator, V1, forms the initial triggering pulse. This positive pulse is obtained from the cathode circuit of V1 and is applied to the control grid of the 6AG7 tube, V2, the frist tube of the Kipp relay, V2-V3. The Kipp is normally quiescent until the arrival of the triggering pulse from V1, which triggers the Kipp, developing a negative-going pulse across the plate load of V2 the duration of which is determined by the RC combination R1-C1. This pulse is applied to the control grid of a 6AG7 reversing and amplifying stage, V4, driving V4 to cut-off and causing the plate voltage to rise to the supply voltage. The positive pulse from the plate of V4 is applied to the control grid of the 6AG7 clipping tube, V5. This stage is operated in the following manner. The pulse shape from V4 is somewhat rounded, and of greater amplitude than required. The plate is held at 300 volts, and the positive-going pulse from V4 drives V5 to saturation for the duration of the pulse. On the cessation of the pulse from V4, V5 returns immediately to cut-off conditions determined by the setting of cathode-bias potentiometer, P3. In this way V5 operates between cut-off and saturation giving a flat top and base to the output pulse, which is obtained from the 1000-ohm cathode resistor of V5.

This noise source is operated in conjunction with a Model P4-E Browning Laboratories Synchroscope which provides triggering action for the source, and gives a visual picture of the output pulse. The triggering pulse is fed from the TRIGGER OUTPUT jack of the synchroscope to the + SYNC. jack of the pulse generator (Figure 2B). The output from the pulse generator is fed to the jack marked SIGNAL on the back of the synchroscope, and also through the attenuator to the receiver.

The vertical input selector is switched to SIG. III, and the rear panel rotary switch to INT. SYNC. position (Figure 2B).

The pulse can be positioned on the screen by the two trigger phase controls which are just below the screen, 180° reversal being obtained by the switch immediately below these. Sweep speeds are (1) 0.5 microseconds, (2) 2 microseconds, (3) 10 microseconds, (4) 25 microseconds.

As mentioned previously this type of pulse generator gives pulses which are similar to impulse noises (Figure 3A), and hence would probably be better for calibration purposes than the sine wave sources, as it more nearly approaches the noise to be measured. An electric shaver was used to verify this and it was found that it produced the same type of pulse as the source used, except that the amplitude varied (Figure 3B). Papers[8, 9] have presented a study of the best type of wave for calibration purposes, and it is very probable that a spike noise source[7] will be adopted as the standard source. In one paper[9] the author discusses waves with steep fronts and proves that sine wave calibration is inadequate. In the other[8] it is shown that with very short pulse lengths the exact shape of the pulse does not matter, and neither does the pulse length; but the noise is proportional to the area under the pulse i.e. amplitude times duration. The author shows that all harmonic components which have a frequency less than $\frac{1}{4d}$ (where d = pulse length) will have approximately equal amplitudes; hence the smaller the pulse length the broader the flat portion of the noise spectrum will be. He also suggests a pulse length of 0.01 microsecond or less. In the present work varying of the pulse length had practically no effect on the output pulse at the detector of the receiver, but the pulse length was considerably larger (10 microseconds) than recommended in the article.

C. Secondary Source.

The most efficient secondary source to be incorporated in the receiver itself seems to be shot noise from a saturated diode. This depends only upon the constancy of the resistance of the input circuit, as does thermal noise. It is preferable to thermal noise as it has a much higher value, and hence would tend to interfere with the thermal noise if the latter were used. This has also been discussed in the comparison of the various calibration sources.

The shot noise voltage is given by

$$Vs^2 = 31.8 \times 10^{-20} \quad IR^2F \quad \text{at } 20^{\circ}C \qquad (10)$$

Vs = shot noise voltage

I = current in amperes

R = input circuit parallel equivalent resistance in ohms

F = frequency pass band in cycles.

Therefore if F and R are constant

$$Vs^2 \propto I$$

F is given by the specification. Therefore R should be made constant. The circuit of Figure 3C may be used for the calibration source. LC is the input tuned circuit and R is a resistance shunted across this circuit during calibration so that the total circuit resistance will be more uniform with frequency. B is a battery of sufficient voltage so that the diode draws saturation current. R1 is a resistor which varies the diode filament temperature until the space current as read by meter I, which may be the output indicator of the noise meter switched to this calibration position, reaches the calibration value. The amplifier gain is then adjusted to standard value.

PROBLEM 3. RECEIVER RADIO-FREQUENCY CIRCUITS

This problem can be divided into 2 parts.

A. The study of the receiver with sine wave input.

B. The study of the receiver with pulse generator input.

Before continuing with this work, a short description of the receiver and its characteristics should be made. As mentioned several times the National type NC-200 commercial super-heterodyne communication receiver was used. The circuit is shown in Figure 4, and the circuit constants of special interest in the Appendix(B).

This receiver is a twelve-tube superheterodyne covering a continuous frequency range from 490 to 30,000 kilocycles with an intermediate frequency of 455 kilocycles, and very stable high-frequency circuits. The sensitivity is particularly high, an input signal of only 1 microvolt providing 1 watt of audio output. The circuit consists of one stage of radio-frequency amplification, a separate first detector and stabilized high-frequency oscillator, two intermediate-frequency stages, an infinite impedance second detector, a self-balancing phase inverter and audio amplifier, and a push-pull audio output stage.

All voltages are supplied by a built-in power supply. There are six uniform steps of selectivity[11]. The antenna input terminals are located at the rear of the receiver chassis near the centre. Average input impedance is 500 ohms. Audio output is obtained by phones or loudspeaker, the phone plug muting the loudspeaker when phone output is required. Maximum audio output is 15 milliwatts at the phones and 8 watts at the speaker. The controls of main interest are the R.F. GAIN which alters the amplification of the R.F. amplifier and two I.F. amplifier tubes, and the CONTROL SWITCH which in the AVC position puts the automatic volume control circuits in operation; in the MVC position, automatic volume control is turned off. It will be noted that both AVC and R.F.GAIN are applied to the same tubes; hence normal operating conditions of the receiver can be obtained with MVC, by merely adjusting the R.F.GAIN till the same audio output is obtained as with normal AVC.

A. The Study of the Receiver with Sine Wave Input.

The receiver performance was first determined for a 30% modulated radio-frequency sine wave input obtained from a Ferris Model 22A Signal Generator. To determine its normal and overload operating conditions, the investigation was conducted as follows:

1. Measurement of normal d.c. voltages.
2. Automatic volume control characteristic.
3. Measurement of R.F. and I.F. grid and plate a.c. voltages.
4. Measurement of sensitivity and study of overload.
5. R.F.GAIN calibration curve.

1. Measurement of normal d.c. voltages.

These measurements were made to give a method of checking the receiver circuits if failure occurred. The receiver control settings for these measurements were (a) R.F.GAIN at maximum sensitivity i.e. = 0, (b) LIMITER = 0, (c) the CONTROL SWITCH at MVC, (d) PHASING = 0, (e) SELECTIVITY = OFF, (f) C.W.O = 0 and

(g) TONE = N. A Weston Model 772 Analyzer with a sensitivity rating of 20,000 ohms per volt was used and the results are tabulated in C. of the Appendix. All voltages were measured between specified terminal and chassis.

2. Automatic Volume Control Characteristic.

This characteristic was taken to determine the normal operating conditions for which the receiver was designed, so that the normal a.c. voltages on the R.F. and I.F. circuits could be measured. The audio output for flat AVC was considered as the normal output. With MVC the R.F.GAIN is adjusted to this output, the set then being considered operating normally.

With R.F.GAIN at maximum sensitivity and AVC in operation the audio voltage output across R16 was measured as the 30% modulated input was varied from 1 microvolt to 1 volt. The input connections were between the antenna terminal and the chassis. The reason that the audio voltage was measured across R16 is that this is the probable point for connecting an indicating instrument. These values were plotted (Figure 5A) and show that the AVC is fairly flat between 1 microvolt and 100,000 microvolts, falling and rising at lower and higher inputs respectively. A Hewlett-Packard Vacuum Tube Voltmeter, Type 400 A, was used for the audio measurements, and will be used for all a.c. voltage measurements unless otherwise stated. The signal input frequency was 580 kilocycles. This frequency was used as stray capacity effects are less at low frequencies. The d.c. voltage across R 16 was also measured with the Weston Analyzer and was 9.5 volts for flat AVC.

3. Measurement of R.F. and I.F. Grid and Plate a.c. Voltages.

The purpose of these measurements was to determine the normal and overload a.c. voltages and by this means determine which stage caused overload, and whether or not the same stage caused overload at all sensitivities; i.e. for all settings of the R.F. GAIN. This would act as a guide as to where an attenuator should be placed in the receiver circuit (Problem 6). The overloaded stage could be easily discovered for if a higher voltage was required to overload a stage then was required to overload the following stage, obviously the first stage caused overload.

This investigation was carried out as follows:

(i) With Vacuum Tube Voltmeters: AVC and MVC.

(ii) With a Cathode Follower circuit.

(iii) With Vacuum Tube Voltmeters in series with a resistor.

(iv) With Vacuum Tube Voltmeters, retuning the I.F. tuned-circuit trimmers.

The Vacuum Tube Voltmeters (VTVM) are the Hewlett-Packard as mentioned above and the General Radio Type 726-A. In (i) with AVC it was found that the voltmeters would read but the readings showed that the AVC was functioning to cause the meters to load and resulted in faulty voltage readings. This was obvious because a voltage gain was not obtained continuously through the R.F. and I.F. circuits. With MVC the R.F. GAIN was adjusted until the same audio output voltage was obtained across R16 as with AVC, thus putting the R.F. and I.F. circuits at their normal operating levels since MVC and AVC are applied to the same tubes.

The voltmeters loaded the set far too much as shown by the voltmeter across R16 whose reading dropped a great deal. This was probably also due to detuning effects as the Hewlett-Packard VTVM has an input capacitance of 15 micromicrofarads and the

General RadioVTVM one of 5 micromicrofarads. Thus a method of measurement which would not effect the tuned circuits would have to be obtained.

In (ii) a cathode follower circuit[12] was used to try to accomplish this. As known this would give a very high input impedance which would probably not load the circuit and also a low output impedance which would not effect the voltmeter. The gain would be practically unity. Unfortunately the input capacitance of this device was sufficient to detune the circuits, so it was discarded due to lack of time to pursue this particular problem any further. This method is a very good one and shows promise of further development. However, it has the limitation that it is only good for low voltages, controlled by the cathode bias of the device which is usually of the order of 1 or 2 volts.

In (iii) the Hewlett-Packard Voltmeter (HP VTVM) could not be brought close enough to the terminal at which voltage was to be measured to minimize stray capacities. The General Radio Voltmeter (GR VTVM) could be used satisfactorily with resistances as low as 0.5 megohms in series with the probe (with the resistance screwed onto the probe to cut down stray capacities), but its lowest measurable voltage is 0.1 volt which is too high for this work. Hence this method was also discarded.

In (iv) satisfactory results could be obtained, but it would be necessary to tune the trimmer of the circuit in the receiver across which the meter is connected to get a correct reading, and then retune when the meter is removed. This was the only really satisfactory method obtained, but it was felt that it was too laborious a method to use with the time available, so the overload characteristics were obtained as in 4.

4. Measurement of Sensitivity and Study of Overload

(i) By sensitivity measurements.

(ii) By linearity measurements.

(i) By Sensitivity Measurements.

One method of determining overload is to measure the overload voltage input at the grids of the R.F. and I.F. tubes by means of the Signal Generator and also the overload output voltage across R16 by means of the HP VTVM. A steady gain should occur from the antenna to the stage that is overloaded, and the same overload output should be obtained with the Signal Generator connected at successive grids. After passing this stage a much larger input and output should be observed. The following results were obtained, with R. F. GAIN at maximum sensitivity, frequency of 580 kilocycles for antenna input and 455 kilocycles for I.F. input, the CONTROL SWITCH at MVC and SELECTIVITY - OFF. As previously mentioned, both MVC and AVC are applied to the same tubes, so that normal operation can be obtained with MVC.

	Normal		Overload	
	Input Microvolts	Output Volts	Input Microvolts	Output Volts
Antenna	0.3	0.49	1.3	1.3
1st Detector Grid	63	"	200	1.29
1st I.F.Grid	620	"	1900	1.29
2nd I.F. Grid	60,000	"	180,000	1.3

2nd Detector Grid over 1 volt.

All these figures show that for overload both the R.F. grid voltage and the audio output voltage increase 3 times approximately. If any but the last stage caused overload this ratio would be larger for stages past the overloaded tube. The 2nd Detector does not overload until a great deal more than 1.3 audio volts appears across R16.

Hence, these results indicate that it is the 2nd I.F. stage that causes the overload. By studying the receiver circuit diagram (Figure 4) it will be seen that the R.F. tube and the I.F. tubes are operated practically identically, so that if any one of these 3 overloads it must be the one farthest from the input, as the a.c. voltages on the others must be less. Hence either the 1st Detector, the 2nd I.F., or the 2nd Detector overloads. The latter does not overload so the only other possibility is the 1st Detector which may overload at minimum sensitivity. This is a possibility as the R.F.GAIN is not applied to this tube. The following results were obtained at RF GAIN = 45. Minimum sensitivity readings could not be obtained as not enough voltage for overload could be obtained from the Signal Generator. However, with the above setting of the R.F. GAIN the sensitivity is down 1400 times (Figure 6).

	Normal		Overload	
	Input Microvolts	Output Volts	Input Microvolts	Output Volts
Antenna	290	0.49	1000	1.56
1st R.F. Grid	5200	"	19,000	1.58
1st Detector Grid	4300	"	14,000	1.55
1st I.F. Grid	20,000	"	73,000	1.6
2nd I.F. Grid	200,000	"	780,000	1.6

All these figures show that for overload both the R.F.Grid voltage and the audio output voltage increase 3.5 times approximately.

These results show that the 2nd I.F. overloads, and it can be anticipated that it does so at minimum sensitivity.

(ii) By Linearity Measurements.

A curve of audio output across R16 against R.F. input was taken similar to the AVC characteristic except that MVC was in operation. This is shown in Figure 5B. It shows that the set is linear up to 1.3 volts audio output and 1.3 microvolts R.F. input as already shown by the gain measurements. The d.c. output voltage was also measured and was found to be 9.5 volts for normal operation, 20 volts for overload, and 34 volts maximum; the 2nd I.F. tube cathode bias was equal to 3.5 volts, measured on the 50 volt scale of the Weston Analyzer.

The R.F.GAIN was then decreased(1)by a factor of 10,R.F. GAIN = 13, (2) by a factor of 100,R.F.GAIN = 25.5, (3) to R.F.GAIN = 77,and (4) to minimum sensitivity, R.F.GAIN = 113, and similar curves were plotted (Figures 5C-5F).(1), (2) and (3) show that the audio output is from about 1.3 volts to 1.6 volts for overload and that the set is linear up to that point. The overload occurs at exactly 10 times, 100 times and 150,000 times as much input respectively. With minimum sensitivity not enough input was obtainable to cause overload, so a curve was taken with R.F.GAIN = 77. The 2nd I.F. cathode bias was as follows: for (1) 5.5 volts, (2) 8 volts, (3) 17 volts and (4) 30 volts on the 250 volt scale.

To decrease the R.F.GAIN by 10, 100 and 150,000 an input of 0.7 microvolts was chosen which was known to be in the linear portion of the receiver. This was then increased 10, 100 and 150,000 times respectively and the R.F.GAIN adjusted to give the same audio output.

The R.F. Voltages at the 2nd I.F. Grid required to produce normal output and overload were then measured. To accomplish this the Signal Generator output was fed to the grid of the 2nd I.F. tube with R.F. GAIN at maximum sensitivity and adjusted for the desired audio voltage, across R 16. These were as follows:

57,000 microvolts for 0.49 volts audio output across R 16 - normal
and 0.17 volts " 1.28 " " " " " ", - overload.

These figures show that for overload both the R.F. grid voltage and audio output voltage increase 2.8 times approximately, verifying linearity up to this point.

The safety factor of the 2nd I.F. tube is 61.4 before grid current will flow at maximum sensitivity, computed on the basis of 3.5 volts cathode bias and 57,000 microvolts R.F. grid voltage. At overload this factor is 20.6, so that grid current will not flow until after overload with sine wave input. Hence, the overload is not in the grid circuit, and is probably in the plate circuit.

These results all tend to show that the 2nd I.F. stage overloads, and that it always is the first to overload no matter what position the R.F.GAIN is in.

Readings are taken with MVC as the receiver will be used with this control setting as a Noise Meter.

5. R.F.GAIN Calibration Curve.

The R.F.GAIN dial was replaced by a circular dial calibrated from 0 to 100 in 100 divisions, being numbered every 10 divisions. The 0 setting denotes maximum sensitivity, but unfortunately the 100 setting is not at minimum sensitivity, which would be about 113 if the scale was numbered higher. However, this dial was calibrated.

This calibration was obtained to determine what effect the R.F.GAIN setting has on the sensitivity of the set. An audio voltage of 0.7 volts across R16 at maximum R.F.GAIN was used as reference. The R.F.GAIN was then increased in steps of 5 and the input increased until the same output was obtained in each case. The curve plotted on semi-logarithmic paper is shown in Figure 6. It is very useful in interpreting the setting of the R.F.GAIN as a type of attenuator for high voltage inputs.

B. The Study of the Receiver with Pulse Generator Input.

This investigation was carried out to see if the receiver would respond to transient voltages as well as it did to sine wave voltages; that is, to see if the same peak voltage can be obtained with noise as with sine wave input, which would indicate that the receiver does not overload with peak noise voltages, any more than with modulated sine wave voltages for which it was originally designed.

The investigation was conducted as follows:

1. Attenuator for pulse generator output.
2. Investigation of overload by sensitivity and linearity.
3. Investigation of the pulse length at radio and audio frequencies.
4. Investigation of 2nd detector time constants.
5. Investigation of output wave shapes with different selectivities.
6. R.F.GAIN calibration curve.
7. Miscellaneous investigations.

1. Attenuator for Pulse Generator Output.

This attenuator is shown in Figure 2A and was mentioned in the study of Problem 2. The only modification from its use in the Signal Corps BC-1236-A Signal Generator is that a 33,000 ohm resistor has been placed in series with the input end to produce a large attenuation (1530) at the first step, and to affect the output of the generator as little as possible. This is likely as the generator output is only across 1000 ohms as a maximum, since it is used in a cathode follower circuit. This resistance is in parallel with the trans-conductance which is about 7700 micromhos, in this case and hence produces an output impedance of 115 ohms. The attenuator output impedance is approximately30 ohms, which is comparable with that of the Detroit Signal Corps Engineering Laboratory model [8]. The whole network is shielded in the metal casing in which it was used originally.

2. <u>Investigation of Overload by Sensitivity and Linearity.</u>

(i) <u>Measurement of Peak Voltage.</u>

Before continuing with this investigation, the method of measuring the noise voltage should be discussed. The HP VTVM is unsatisfactory for this purpose as its time constants are too small and as a result the indication bears no relationship to the true voltage. The GR VTVM has fairly large time constants and is able to record these voltages fairly accurately at least to the extent that the ratio of two successive readings can be assumed to be fairly accurate. The GR VTVM reads 0.707 times the peak of a complex wave, so it was connected across R16 and readings made with it.

A further method of measuring the output was by means of an oscilloscope, a DU MONT Type 175-A Cathode-Ray Oscillograph being used for this work. The scale of the oscilloscope was calibrated to read peak volts, by means of a sine wave signal from the Ferris Signal Generator applied to the grid of the 2nd I.F. tube with the oscilloscope connected across R16, so that it would be calibrated under the load conditions in which it would be used. Since the r.m.s. of a pure sine wave voltage measured by an indicating device is actually the r.m.s. voltage of one-half the wave, it is necessary to have a sine wave (peak to peak) of twice the height of the noise voltage to be measured as the latter is a series of positive peaks e.g. if 1 volt r.m.s. of sine wave input produces 2 inches deflection on the oscilloscope (peak to peak) a deflection of 1 inch (base to peak) would correspond to a noise voltage of 1 volt r.m.s. or 1.414 peak noise volts ($E_p = 1.414\ E$ r.m.s.). This method was used throughout but is very hard on the eyes and also a difficult method for obtaining accurate results. Hence it is hoped that simpler accurate methods will be available in the not too distant future.

(ii) Sensitivity Measurements

The controls for the noise source in all this work were (1) Pulse Length = 10 microseconds, (2) P.R.F. = 20, and (3) C.P.S. = 10, the frequency being about 580 kc.

. With the R.F.GAIN at maximum sensitivity the receiver overloaded no matter what noise input was used, in fact readings below R.F.GAIN = 13 could not be obtained satisfactorily.

The measurement of the various grid overload output voltages was made similarly to the method used with a 30% modulated sine wave input, except that the output audio voltage was measured as discussed in (i) above. Readings could not be obtained at maximum sensitivity due to immediate overloading and at minimum sensitivity due to the inability to overload.

As with sine wave input, irrespective of the grid to which the input signal is applied, overload occurs at the same audio output voltage, approximately 13 volts peak in this case.

However this is not so for the 2nd Detector which cannot be overloaded by the noise source, and hence, it is the 2nd I.F. stage which overloads here as was the case with sine wave voltage. The peak audio output voltage of the 30% modulated sine wave would be (1.3) (3.33) (1.414) = 6.13 volts. The noise voltage thus produces a great deal more output then the sine wave. Hence, the receiver responds differently to sine wave voltages than it does to noise voltages. This may be due to the fact that the response of the 2nd Detector to sine wave is constant up to approximately 5 kilocycles for good receiver design (frequencies above this having been filtered out), whereas, with noise, components above this frequency may get through to the output. However the above measurements show that the receiver amplifies noise voltage without overloading. The wave shape of the output as shown in Figure 7A indicates that there is apparently an exponential decay of the pulse. The receiver thus alters the shape and the pulse length of the noise pulse. This will be discussed in detail later.

The above settings of frequency, pulse length and repetition frequency were considered satisfactory as tests showed that other settings and frequencies produced similar results.

(iii) Linearity Measurements.

As mentioned previously the noise source output pulse is rectangular in shape. The output from R16 is exponential in character at normal operating levels, and slightly humped on overload (Figures 7A and 7B). It is these latter two types of pulse that characterize the output of the receiver, and unless otherwise stated the audio output voltage is always a measure of these two types before and after overload respectively.

An AVC characteristic with R.F. GAIN = 0 as shown in

Figure 8A was taken and it can be seen that the AVC has less control on the receiver circuits with this type of input, than with sine wave input.

In these measurements the audio output was measured with the oscilloscope (the GR VTVM being used merely as a check to see that the oscilloscope was behaving satisfactorily , the voltage ratio of the GR VTVM being similar to the oscilloscope deflection ratio for successive readings). Overload occurred at about 10 volts r.m.s. D.C. output was measured with the Weston Analyzer. The overload was also determined in these cases with a Stark Microammeter 0-100 microamperes, connected in the 2nd I.F. tube grid circuit. This meter was found to read shortly after overload, in fact as soon as the output dropped. This is reasonable, for as soon as the output drops it is evident that the plate current of the 2nd I.F. tube is reduced due to the flow of grid current which develops a voltage across R10 (500,000 ohms, see Appendix B) and thus increases the bias voltage of the tube. This flow of grid current obviously results in an indication on the microammeter. Hence a microammeter in this circuit is very handy for it acts as a good check for overload during investigation. In the final noise meter the indicating instrument should read off-scale at overload and the input signal would have to be attenuated until a reading could be obtained. However, during investigation with no indicating instrument attached to the audio output, the set could overload and possibly readings could be taken in this condition which would be uselsss. This is due to the noise having much the same irritating sound through the earphones as the loud speaker whether at overload or not, causing an aural detection of overload to be difficult, but not impossible. With a sine wave signal the overload is easily determined aurally as the audio output rises to a maximum and falls rapidly as heard and recorded. The writer used the microammeter to advantage in checking to see that the set was not overloaded with noise inputs, and feels that this is a useful device in experimental work.

The linearity curves were taken in a similar manner to those taken with sine wave input except as noted above, and were plotted as shown in Figures 8B-8E. These results show that the receiver operates linearly until a peak audio output of about 13 volts is obtained for the various settings of the R.F. GAIN. With minimum sensitivity insufficient input was obtainable to overload the set. The R.F.GAIN was set at (1) 13, (2) 25.5, (3) 77 and (4) minimum sensitivity, for these readings. The frequency was 560 kilocycles or as near to this as a peak reading could be found. The d.c. output voltage was 6 volts for normal operation and 10 volts for overload. These d.c. voltages are helpful with pulse voltages to show approximately where the normal and overload points occur. The overload in (2) and (3) occurs at exactly 9 times and 26,600 times as much as at (1) respectively.

The peak voltage at the 2nd I.F. grid could not be measured for normal output and for overload by means of the pulse generator due to the fact that the inputs required at the 2nd I.F. grid are somewhere between step (1) of the attenuator for the pulse generator, and direct connection. Obviously a better attenuator system should be used with the pulse generator so that gaps such as this do not occur, but time does not permit one to be made and used.

These results all tend to show that the 2nd I.F.Stage overloads with noise voltage input as well as with 30% modulated sine wave input, and also that the peak noise output voltage at overload is greater than the peak sine wave audio output at overload. However, the linearity of the set ceases quite a bit before overload (Figures 8B, 8C). These curves are very steep in the linear response region, but they indicate where overload occurs which is the main consideration. The steepness is due to a faulty attenuator and should be further investigated.

3. Investigation of the Pulse Length at Radio and Audio Frequencies.

It was noticed previously that the pulse changed shape in passing through the circuits of the radio receiver and also that the pulse length increased considerably. The pulse length of the radio frequency input was 10 microseconds and that obtained across R16 as measured on the oscilloscope was about 400 microseconds. Obviously, something in the receiver circuits has caused a change in this length and it is most probably due to the short sharp noise pulse setting up damped oscillations in the tuned circuits of the intermediate-frequency amplifier, or to the detector time constants.

The pulse length at the audio output was measured by three methods: (1) by applying audio signals from a Model 205AG Hewlett-Packard Audio Oscillator and the output across R16 to the DuMont Type 185 Electronic Switch inputs A and B respectively and viewing the two wave forms on the oscilloscope to which the output of the Electronic Switch was connected as shown in Figure 9A; (2) by using a Type 175-A DuMont Oscillograph with the receiver audio output applied to the vertical axis and a modulating wave from the audio oscillator above applied to the Z-Axis to put dashes on the noise output wave as shown in Figure 9B; (3) by the same method as (2) except that a Measurements Corporation Square-Wave Signal Generator was used to modulate the noise wave form (Figure 9C).

In (1) only a rough measurement could be made as it was difficult to synchronize the two waves. It was found that 3 oscillator waves occupied the same space on the timing axis as one noise wave at an oscillator frequency of 7000 cycles. Hence the pulse length was 428.5 microseconds.

In (2) it was impossible to stop the dashes on the wave entirely, so the counting of the dashes was rather difficult. However, several readings were taken and the results averaged, giving a value of 430 microseconds, which is practically the same value as that obtained in method (1).

In (3) difficulty was encountered in obtaining enough voltage to synchronize the wave to enable the dashes to be counted.. However, this was accomplished by means of a lead from the noise source output to the SYNC terminal on the square-wave generator. The pulse length by this method was 380 microseconds, which is slightly lower than in the other methods.

The pulse length at the output was also measured by method (3) for the different settings of the SELECTIVITY CONTROL, the results being shown below:

Switch Position	Number of Dashes	OSC Frequency (Cycles)	Pulse Length (Microseconds)
OFF	19	50,000	380
1	16	39,000	410
2	19	41,000	454
3	7	4,700	1490
4	7	4,700	1490
5	7	4,000	1750

In the last three switch positions the number of dashes was too difficult to count and hence is not dependable.

The pulse length at the input of the receiver does not seem to matter as it does not alter the audio output pulse length (as discussed in the study of Problem 2).

The output pulse length is probably due to the damped wave trains set up in the intermediate-frequency tuned circuits of the receiver by the noise pulse. If the noise input is connected to the 2nd Detector grid exactly the same type of wave is obtained at the output as was fed in. Hence the wave shape must have been altered in the radio-frequency and intermediate-frequency tuned circuits. Time does not permit further study of this problem. However, in an article[9] the author traces the effect of a square wave from the input of the receiver to the 2nd Detector output, showing how oscillations are set up in the intermediate-frequency tuned circuits which change the square wave to a series of oscillations, the envelope of which appears to have an exponential decay. Another article[13] has a discussion (from a mathematical viewpoint) of the response of a cascade of series tuned circuits to an impulse. The author of this article shows that the peak value of this response is relatively independent of the number of tuned circuits when

$$5 < n < \frac{Q}{2}$$

where n = number of tuned circuits

$$Q = \frac{wL}{R}$$

This is not true in the present case as $n \not> 5$. However, the article is a very good reference for work on this subject.

4. <u>Investigation of the 2nd Detector Time Constants</u>.

This investigation was carried out to see if the 2nd Detector time constants were critical in their effect on the shape and pulse length of the audio noise output and it was found that they were not.

By taking the audio output across either R16 alone or across R15 and R16 in series, the output pulse length did not change at all, and hence the detector time constants do not seem to be the ones that alter the noise wave shape. However, this probability was investigated slightly further to make sure of this assumption.

In this work R15, R16, C18 and C19 (see B. in the Appendix for normal values) were varied and the following results were obtained, the pulse lengths being shown by the number of squares that the base occupies. Hence it gives a relative measure of the pulse length.

Pulse Length	Overall Pulse	Output (Relative)	R15 (Ohms)	R16 (Ohms)	C18 (Mfd)	C19 (Mfd)
6	26	1	5000	25,000	.00025	.001
6	26	0.65	5000	11,100	"	"
6	26	0.39	4070	25,000	"	"
7	25	1.168	2420	"	"	"
6	26	1.168	5000	"	.0001	"
6	26	1.1	"	"	.00035	"
6	26	1.168	"	"	.0001	.00047
6	26	0.932	"	"	.0000091	"
6	24	1.09	"	"	.0001	.0000098

By doubling the original values of C18, C19 the pulse length remained unchanged, and the output dropped very slightly. It is evident from these results that the pulse length has been unaltered and that the amplitude of the output wave changes by varying the resistors R15 and R16. However, the different values of the condensers C18, C19 have little effect at all, even when the selectivity of the intermediate-frequency circuits was altered through its entire range which was done as an extra check. With lower condenser values, however, slightly sharper peaks and better high-frequency response were obtained. Hence the theory that the intermediate-frequency tuned circuits are the ones that alter the pulse seems to be valid. A linearity curve of the receiver was taken at 580 kilocycles with the values of C18 and C19 as shown in the last column of the table above and is shown in Figure 10. This curve shows that the receiver behaves much the same at normal operation and at overload as it does with the original values of C18 and C19.

5. Study of the Output Wave Shapes With Different Selectivities.

This has already been mentioned in connection with the study of the pulse length and in connection with the study of the 2nd Detector time constants.

Photographs have been taken of the noise audio output from the receiver at the various selectivity settings at normal operation and at the OFF position for overload (Figs. 7 and 11.1A to 11.2F). These photographs show that at the settings for higher selectivity the pulse length increases, the decay time is longer and the amplitude of the wave is less. The pulse lengths have been calculated and recorded; the relative pulse amplitudes are as follows; the relative bandwidth figures being put in for comparison:

Switch Position	Normal Amplitude	Overload Amplitude	Bandwidth
OFF	1	1	1
1	0.68	0.721	0.767
2	0.72	0.556	0.573
3	0.534	0.403	0.42
4	0.311	0.281	0.274
5	0.122	0.163	0.113

These readings show that the amplitude drops fairly steadily and is proportional to the bandwidth (as others have proved). Hence it can be easily seen that the bandwidth has a great effect on the noise pulse.

6. R.F. GAIN Calibration Curve.

This curve was taken in exactly the same manner as with sine wave input and a curve drawn (Figure 12). This is almost identical to the one drawn for sine wave input.

7. <u>Miscellaneous Investigations.</u>

(i) Noise pulses through the receiver.

(ii) Attempt to apply noise and sine wave signal simultaneously.

<u>(i) Noise Pulses Through the Receiver.</u>

In the previous investigations no particular mention was made of the shape of the pulses in the various stages of the receiver circuit, except to show photographs of the normal and overload output wave shapes on the oscilloscope with the noise input at the antenna (Figures 7A and 7B).

By feeding the noise input to any of the radio-frequency or intermediate-frequency amplifier grids the same output shape is obtained; but at the 2nd detector grid, however, as previously mentioned, the exact shape of the input wave is obtained at the output except that the output pulse is a continuous joined wave (photograph unobtainable due to national film shortage), while the input wave is a series of open pulses (Figure 3A). This is due to the fact that the output pulse is obtained by the charging and discharging of condensers.

These results again show that the intermediate-frequency tuned circuits determine the output wave form.

A Schick Colonel Electric Shaver was placed near the receiver to radiate noise and to see what type of pulse it would produce at the output across R16, as shown in Figure 3B. This is the same type of output wave as that produced by the pulse generator except that the amplitude varies, and since the Electric Shaver is a common source of pulsed radio interference, it seems that the pulse generator used simulated interference very well.

(ii) Attempt to Apply Noise and Sine Wave Signal Simultaneously.

This was attempted merely as a check to see if the noise output actually was higher than the sine wave output by comparing the amplitudes of the two waves. It was found that the noise overloaded at about 4 times the value of the sine wave in terms of the amplitude measured on the oscilloscope, the peak sine voltage being 7.07 volts and the peak noise 13.3 volts. The application of the sine wave changed the amplitude of the noise registered on the oscilloscope but the noise did not alter the amplitude of the sine wave signals. Because of the interaction between sine wave and noise signals in the oscilloscope, it could not be used for simultaneous comparison of the two.However, it was shown that the output due to noise is greater than that due to sine waves.

PROBLEM 4, TIME CONSTANTS OF RECEIVER CIRCUITS

Previous tests(conducted in Problem 3) showed that these circuits did not draw grid current, and hence the time constants do not matter.

PROBLEM 5, STABILITY

This problem has not been investigated throughly due to lack of time, but it may be said that the screen voltage supply would probably have to be regulated, as it is the critical voltage to be considered.

An article by L.C.F. Horle[14] suggests that the grid bias voltages of the tubes and the detector bias voltage should be obtained from a source independent of the power circuits of the receiver. He also suggests that the line voltage should be constant.

With batteries, which will be used in the field, the gain of the receiver will change with battery usage as well as due to aging of tubes and atmospheric humidity.

The best solution to the problem is probably to have a regulated power supply if it is found that the receiver stability with regard to calibration is poor.

PROBLEM 6, ATTENUATOR

This problem has been discussed, and it seems that a ladder type attenuator made up of resistors would probably be as good as any and reasonably cheap. Since it has been ascertained that the 2nd I.F. stage is the one that overloads, the attenuator could be placed at the input end of the intermediate-frequency amplifier, as suggested in the statement of the problem in Chapter II. This attenuator should reduce the signal applied to the intermediate-frequency amplifier in steps of 1, 10, 100, and 1000, and the attenuation should be independent of frequency. For best results the attenuator should be well shielded.

The attenuator could be of the capacitance or mutual inductance type, but these are not as simple and as inexpensive as the resistance type.

CHAPTER IV

CONCLUSION

The study of noise voltages in the radio-frequency and intermediate-frequency amplifiers of a communication type receiver has been conducted and it has been determined that:

(1) The noise can be amplified as well as the sine wave signal for which the receiver was designed;

(2) the use of a standard pulse noise generator to simulate impulse interference is justified;

(3) the pulse length of the interfering signal is immaterial up to 25 microseconds with the pulse generator used;

(4) the intermediate-frequency tuned circuits determine the shape and the duration of the output noise pulse;

(5) the 2nd I.F. stage causes overload in all cases so that an attenuator will have to be used in the input of the intermediate-frequency amplifier when large peak noise voltages are applied to the receiver input;

(6) the pulse changes shape through the receiver circuits but its energy is constant;

(7) the 2nd detector time constants are the ones which determine the value read on an indicator;

(8) an indicating instrument connected across R16 will register the interference effect of peak noise voltages;

(9) a pulse generator is most suitable for calibration purposes in the laboratory, and the shot noise diode, incorporated in the receiver circuit, in the field;

(10) the bandwidth has a considerable effect on the noise output;

(11) the type NC-200 commercial superheterodyne receiver with regulated voltage supply and an indicating instrument connected

across the audio output can be used as an interference-measuring instrument.

It should be noted that these measurements are only satisfactory for frequencies up to 20 megacycles, and that other methods of measuring interference will have to be adopted above this frequency.

CHAPTER V

RECOMMENDATIONS

The writer recommends the study of the use of an oscilloscope in the indicating circuit to show the shape of the pulse output for normal operation and overload. An objection to this method might be the expense involved but it would be very convenient to have a visual picture of the noise output.

Headphones could be used to determine the type of noise aurally in terms of pulse repetition rate and the annoyance value.

It might be possible to use the R.F.GAIN control as an attenuator as it has been calibrated in terms of input voltage ratios. However it should be equipped with a more accurate setting indicator.

The next step to be investigated should be the setting up of the NC-200 receiver with: (1) a suitable input circuit; (2) an indicating meter in the audio output to measure the interference effect of noise; (3) an attenuator in the 1st I.F. circuit to allow large surges to be passed through the receiver without overloading it; and (4) a secondary calibration source incorporated in the receiver circuit for calibration in the field.

This complete meter would serve many useful purposes, such as: measuring and locating radio noise; measuring signal-to-noise voltage ratios on antennas to determine whether or not the noise voltage is too high to allow satisfactory reception; investigation and analysis of complicated noise problems on transmission and distribution systems; quantitative determination of noise characteristics of electrical apparatus and appliances for the purpose of determining their suitability from a noise standpoint; analyses of situations where special devices have been applied for mitigating noise effects; and the accumulation of data for establishing acceptable noise levels. Through the accumulation and analysis of a considerable amount of data, eventually it will be possible to determine generally acceptable noise-influence voltages for appliances and other electrical apparatus.

Having obtained readings of the nuisance value, methods of improving units can be checked by the meter to see if an improvement has really been obtained.

A question has arisen as to whether the noise of component parts should be checked or the overall noise[15]. The general feeling is that if the component parts are quiet the overall noise should be a minimum.

APPENDIX

A. Apparatus

General Radio Vacuum Tube Voltmeter Type 726-A, Serial No. 1237

Hewlett-Packard " " " Type 400-A

Ferris Model 22A Signal Generator, Serial No. 133

Weston Model 772 Analyzer, Serial No. 71.

DuMont Cathode-Ray Oscillograph Type 208, Serial No. 145

" " " " " Type 175-A " " 281

" " Electronic Switch Type 185 " " 350

Hewlett-Packard Audio Signal Generator Model 205AG
Serial No. B3868

Signal Corps Attenuator from Signal Generator BC-1236-A

Measurements Corporation Square-Wave Generator, Model 71,
Serial No. 548.

Stark Microammeter, 0-100 Microamperes.

B. Important Receiver Circuit Constants.

C 18	2nd Detector Cathode By-pass Condenser	.00025 MFD	1000 V.W.
C 19	" " I.F. " " "	.001 "	500 " "
R 10	" I.F. Grid Filter Resistor,	500,000 ohms.	$\frac{1}{2}$ W.
R 15	" Detector I.F. " "	5,000 "	" "
R 16	" " Load "	25,000 "	" "
R 29	R.F.GAIN Control Variable Resistor	10,000 "	" "

Limiter Cathode	0
" Plate	0
AVC Grid	-24 A T
" Cathode	-38 A T
" Screen	0 T
" Plate	0 T
BF Osc. Grid	-3
" " Cathode	0 "
" " Screen	14 A "
" " Plate	36 A "
Amp-Inv. Grids	0
" " Cathode	4 A
" " Plates	94 B
Audio Grids	-29 A
" Cathodes	-36 A
" Screens	194 B
" Plates	185 B
B+ Common	194 B
B- "	-50 B

A - 0 to 50 volt meter scale

B - 0 to 250 " " "

C - Accurate measurement cannot be made

* - RF GAIN knob set at minimum sensitivity

- Limiter knob set at 10.

T - Control switch knob set at AVC

" - Control switch knob set at CWO

D. Bibliography.

1. Report of Nuisance Value of Radio Interference, Canadian Standards Association, Panel 4, C.E. Code Part IV.

2. Some Experimental Measurements of the Time Constants of Commercial Radio Noise Meters (paper), K. A. MacKinnon, Transmission and Development Engineer Canadian Broadcasting Corporation.

3. A Study of the Characteristics of Noise, V.D. Landon, Proc. I. R. E., 24, November 1936.

4. Instruments and Methods of Measuring Radio Noise, C.V. Aggers, Dudley E. Foster, C. S. Young, A.I.E.E. Transactions, 59, March 1940.

5. Investigations of the Measurement of Noise, Final Report, OEMsr-1478, University of Pennsylvania, Moore School of Electrical Engineering, October 1945.

6. The Temperature Limited Diode as an Absolute Source of Fluctuation Noise, Radio Research Board, Department of Scientific and Industrial Research (British).

7. Standard Radio Noise Signal Generators, Progress Reports 1 and 2 OEMsr-1431, March 1945 and May 1945.

8. Development of Electronic Impulse Noise Generator for the Frequency Range 0.15 to 50 MC, Assignment Memorandum SSB-116-A, Project 2224B-1 (SSB-116) August, 1945. Signal Corps Engineering Laboratory, Detroit Signal Laboratory.

9. A Study of Wave Shapes for Radio-Noise-Meter Calibrations, C. W. Frick, A.I.E.E. Technical Paper, September 1945.

10. Radio Engineers' Handbook, F.E.Terman, McGraw-Hill Book Company.

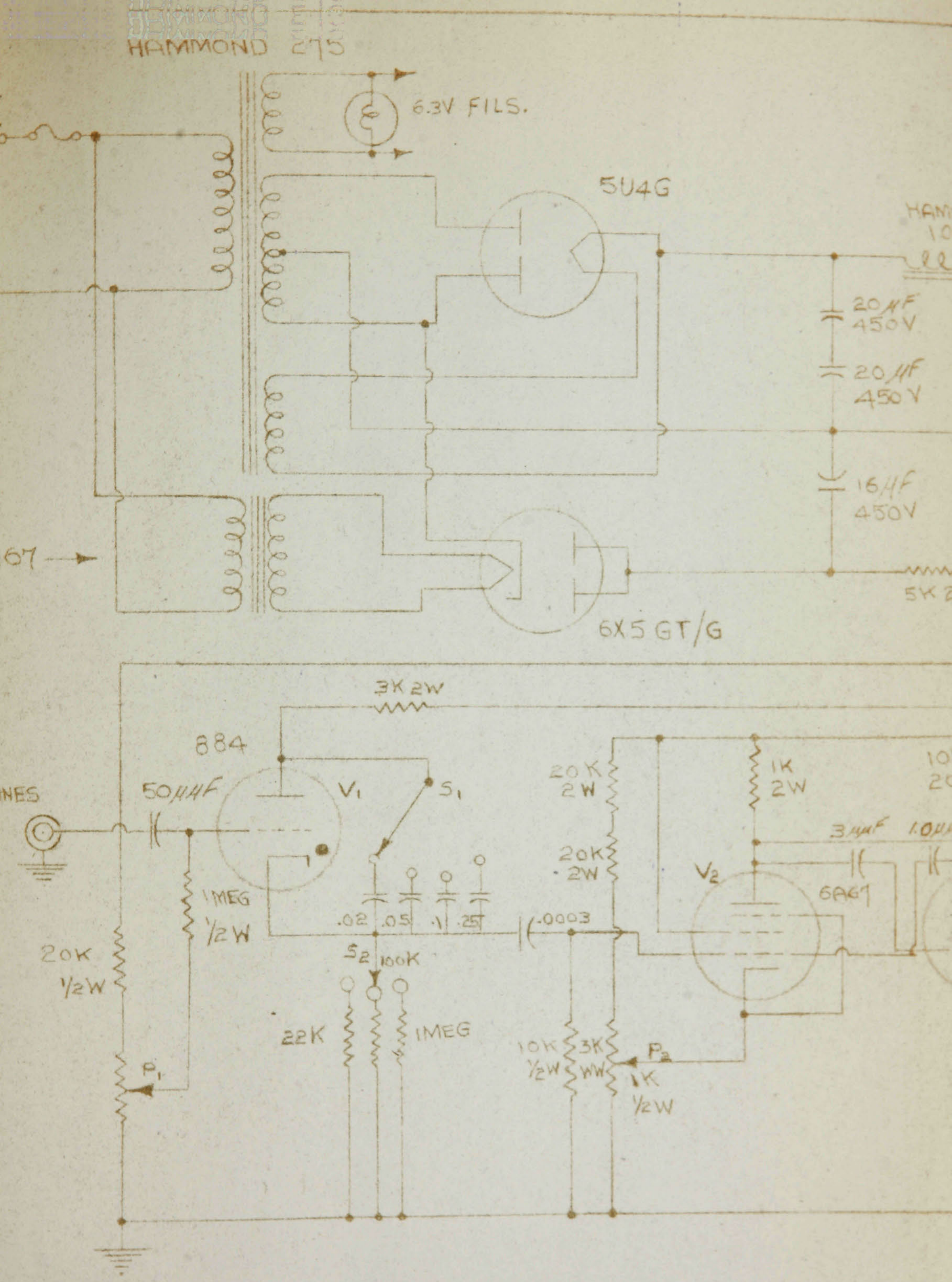
11. Instruction Manual for the National NC-200 Receiver, National Company, Inc.

12. Tubeless Probe for VTVM, Howard L. Daniels, Electronics, February 1945.

13. Impulse Excitation of a Cascade of Series Tuned Circuits, Samuel Sabaroff, Proc. I.R.E., December 1944.

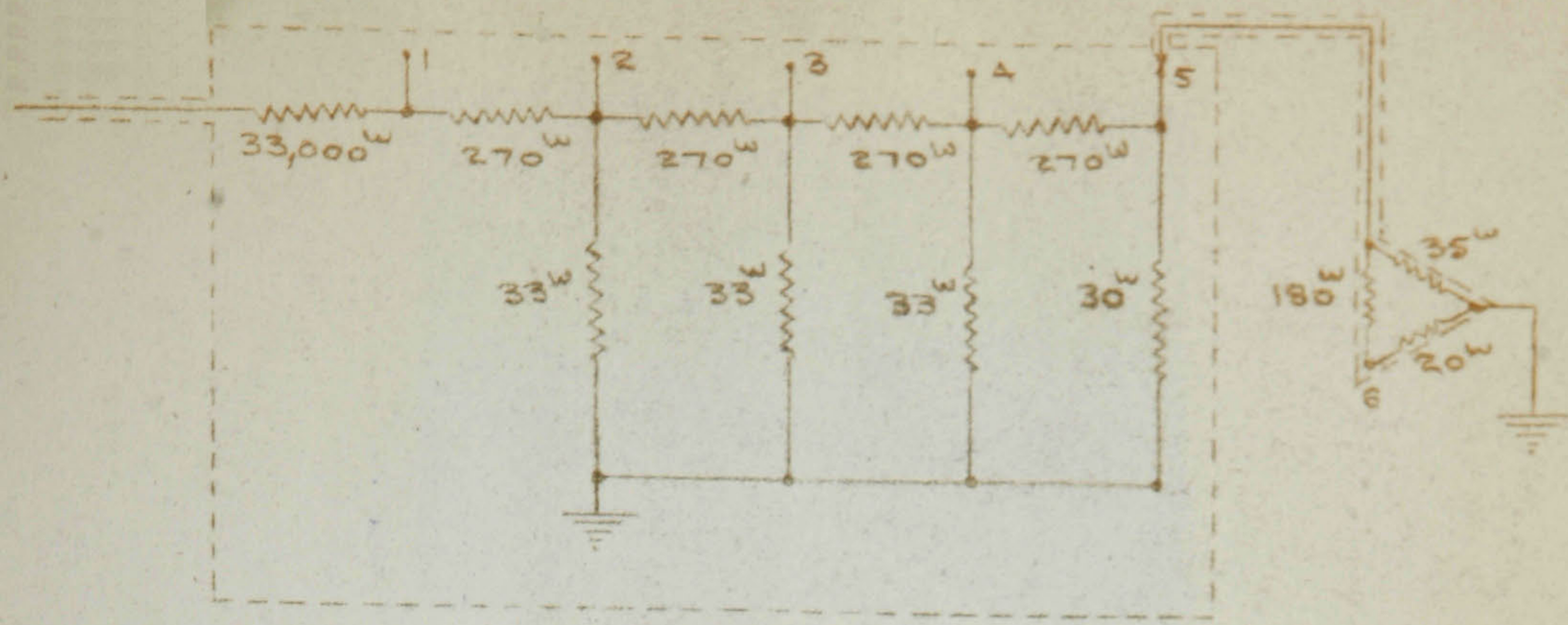
14. The Development of the Radio Noise Meter, Lawrence C. F. Horle, Consulting Engineer, R.M.A. Bulletin No. 16.

15. Minutes of Meeting of ASA Subcommittee A on Specifications for Radio Noise Meters, February 19, 1946.

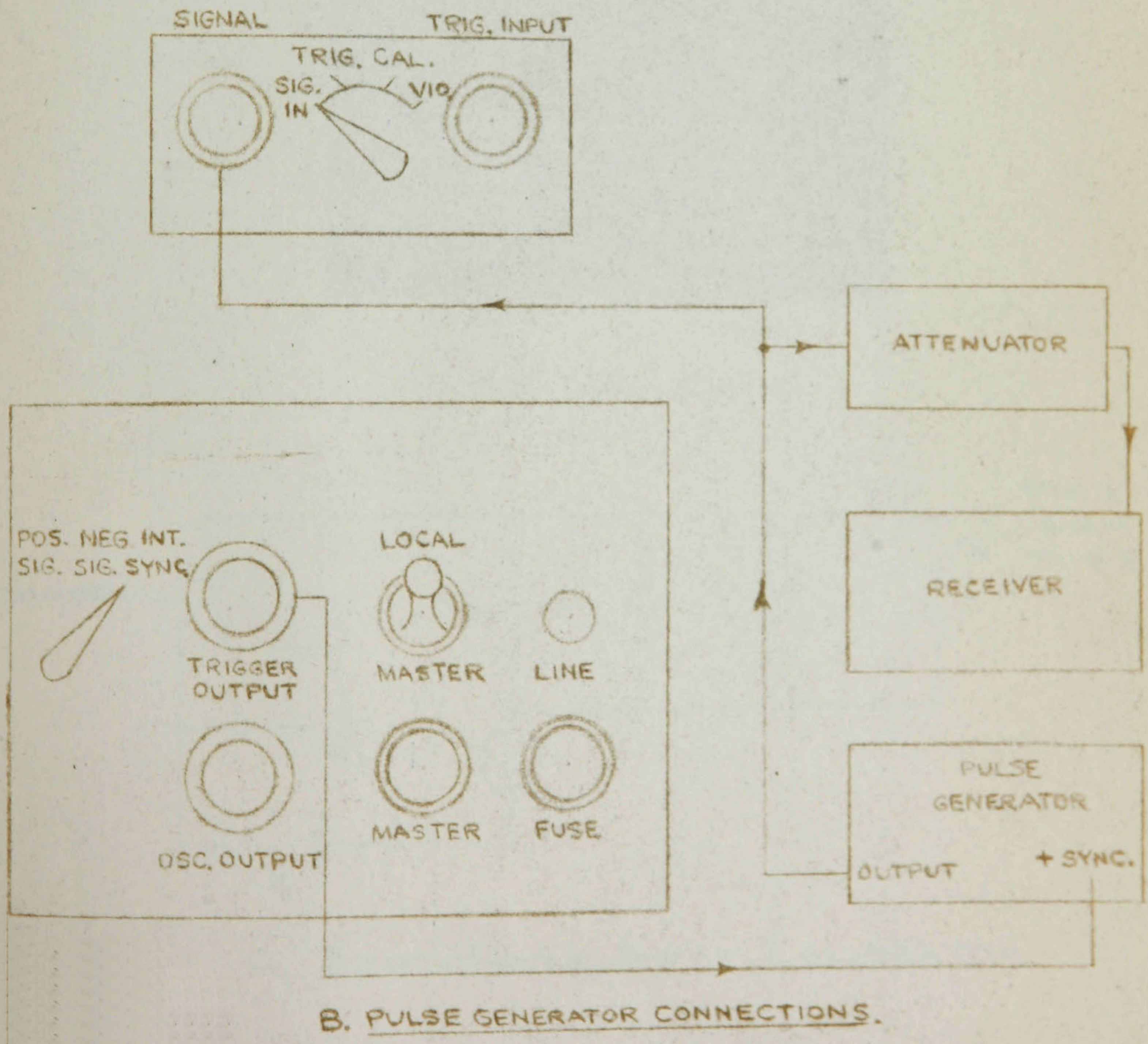


NOTE ALL RESISTORS 1 WATT UNLESS SPECIFIED

FIG. 1

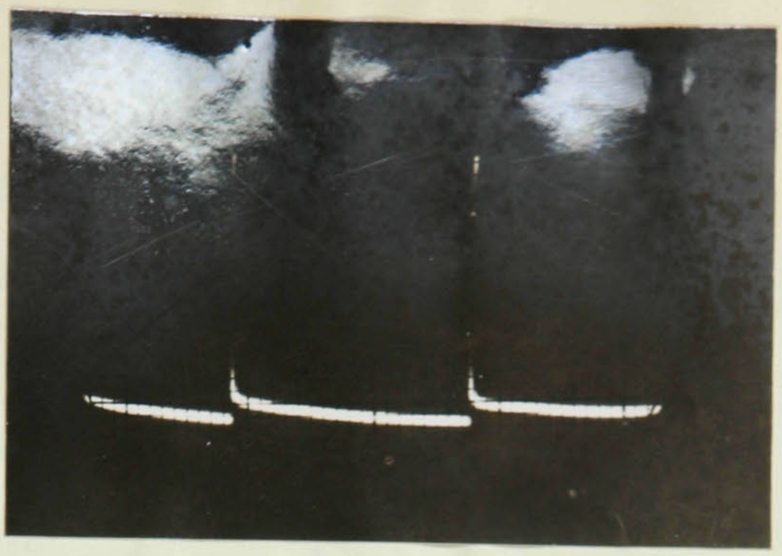


A. ATTENUATOR FOR PULSE GENERATOR.



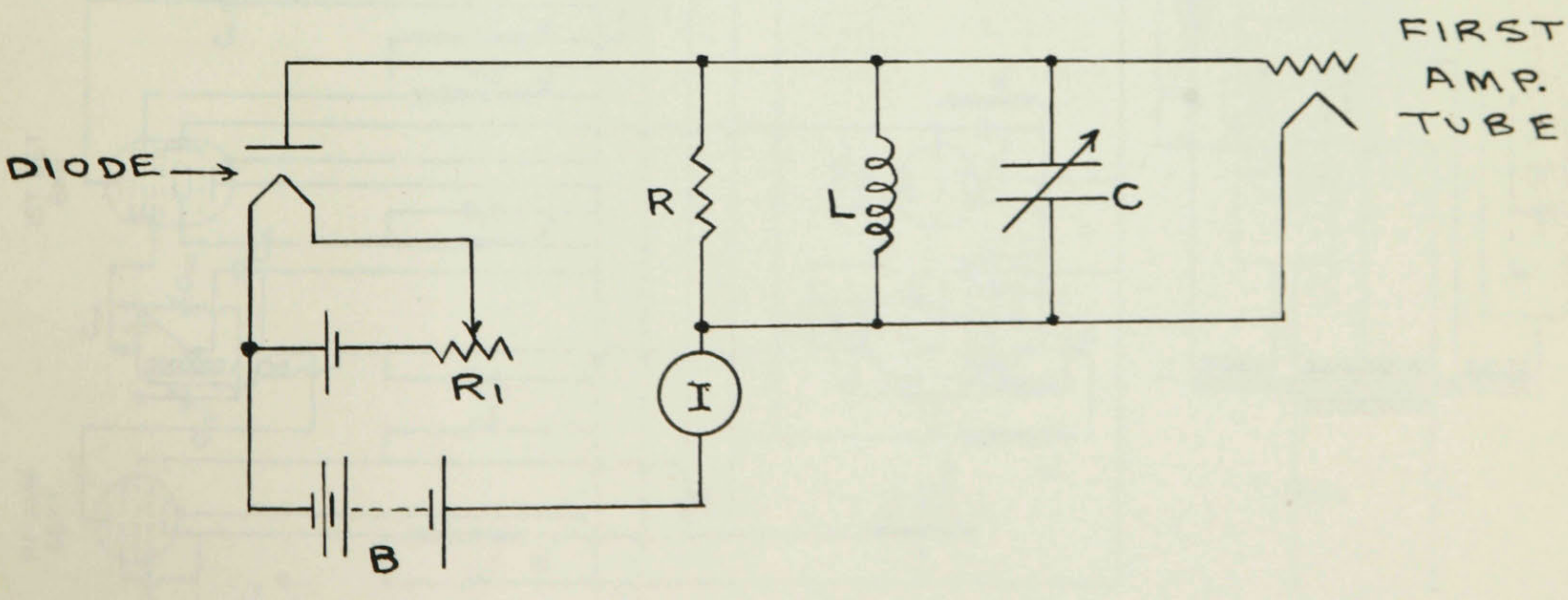
B. PULSE GENERATOR CONNECTIONS.

FIG. 2



A. NOISE PULSE

B. SHAVER PULSE



C. SHOT NOISE DIODE CALIBRATOR.

FIG. 3

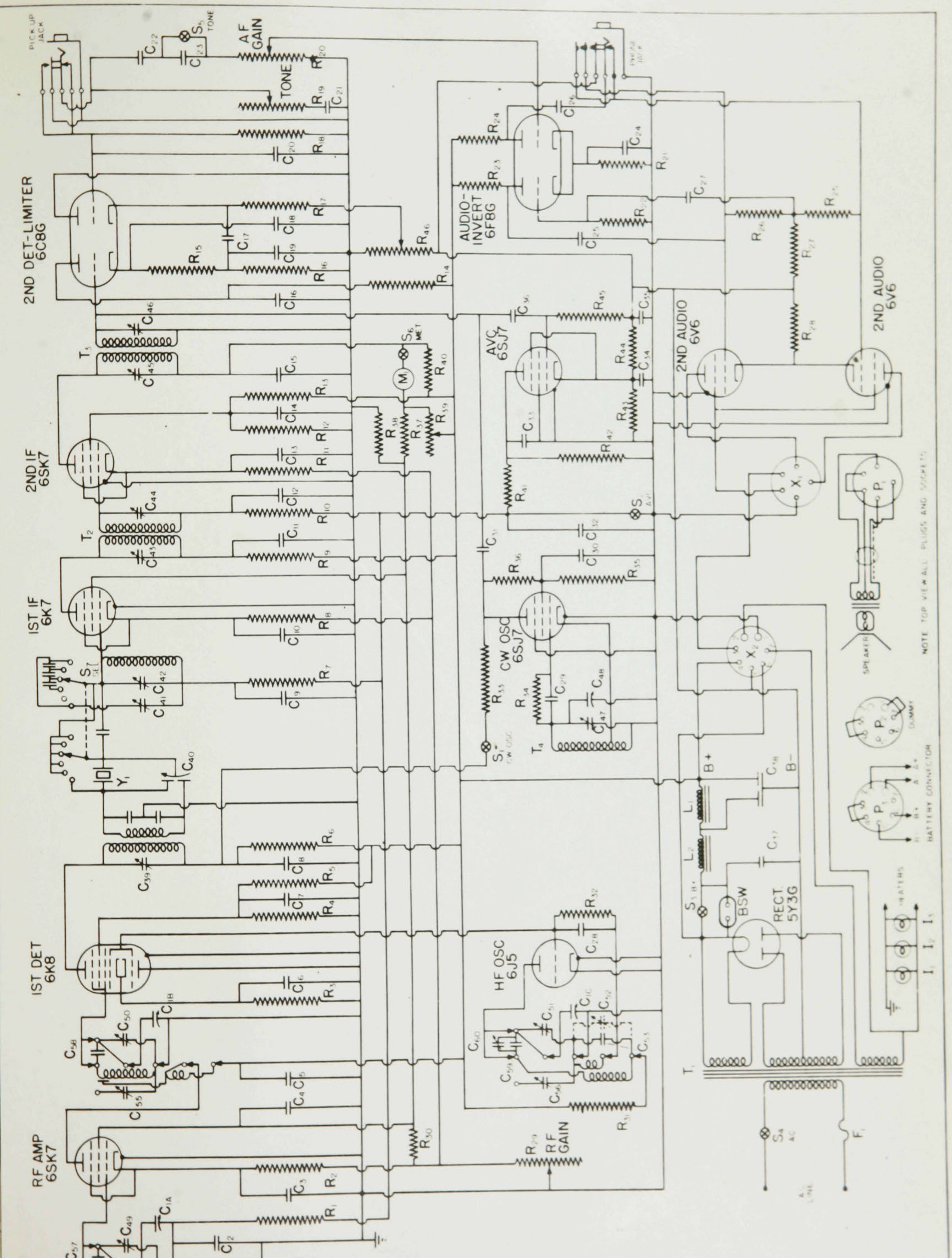


FIG. 4

DWG. NO. 3 SCHEMATIC DIAGRAM

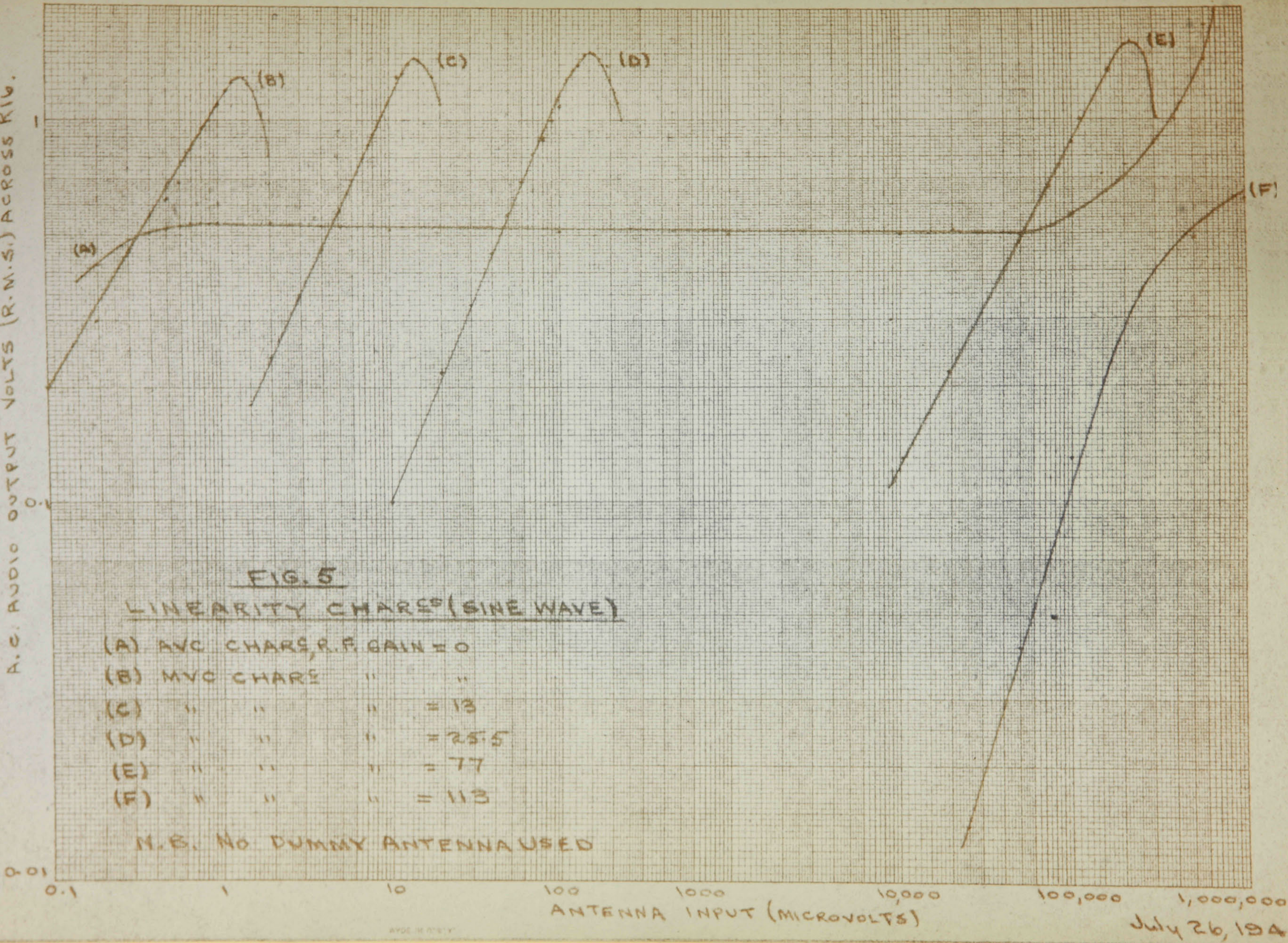
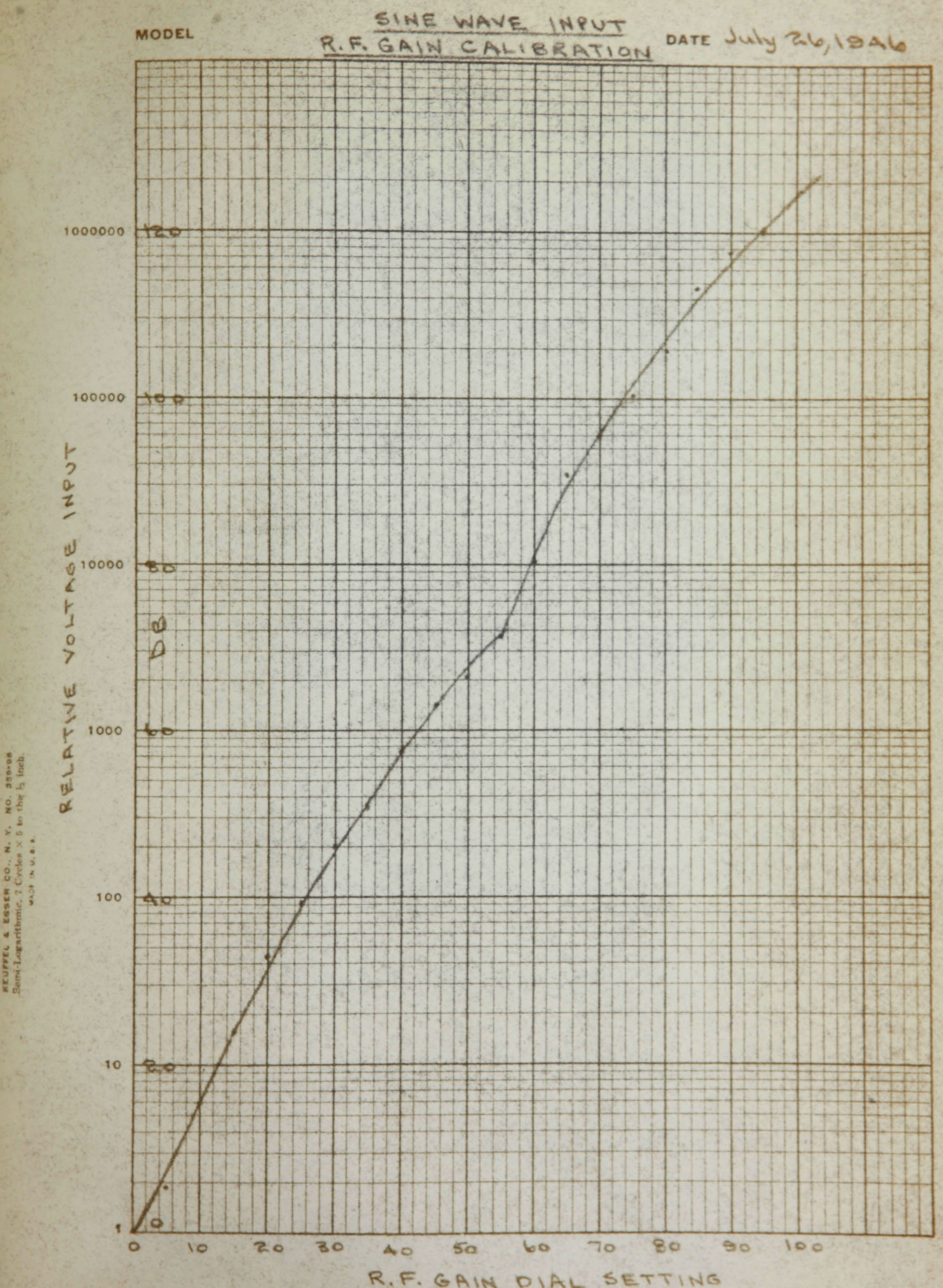
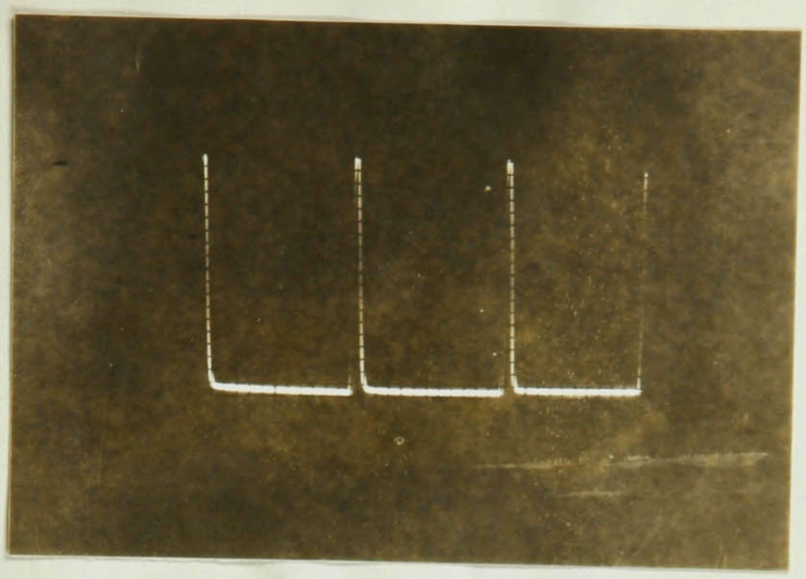


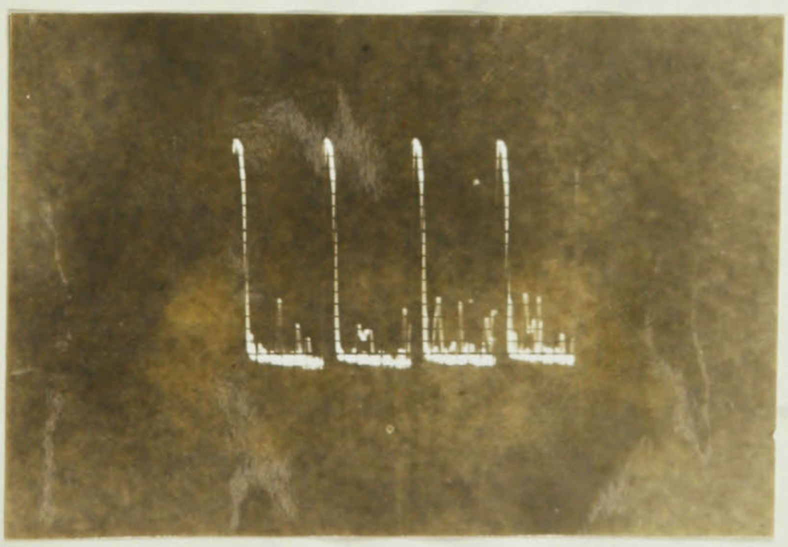
FIG. 5
LINEARITY CHARS (SINE WAVE)
(A) AVC CHARS, R.F. GAIN = 0
(B) MVC CHARS " "
(C) " " " = 13
(D) " " " = 25.5
(E) " " " = 77
(F) " " " = 113
N.B. NO DUMMY ANTENNA USED
(A)
(B)
(C)
(D)
(E)
(F)
A.C. AUDIO OUTPUT VOLTS (R.M.S.) ACROSS R16.
1
0.1
0.01
0.1
1
10
100
1000
10,000
100,000
1,000,000 (1V)
ANTENNA INPUT (MICROVOLTS)
July 26, 1946

FIG. 6


SINE WAVE INPUT
R.F. GAIN CALIBRATION
MODEL
DATE July 26, 1946
1000000
120
100000
100
10000
80
1000
60
100
40
10
20
1
0
RELATIVE VOLTAGE INPUT
DB
0
10
20
30
40
50
60
70
80
90
100
R.F. GAIN DIAL SETTING
KEUFFEL & ESSER CO., N. Y. NO. 359-98
Semi-Logarithmic, 7 Cycles × 5 to the ½ inch.
MADE IN U.S.A.



A. NORMAL NOISE OUTPUT.



B. OVERLOAD NOISE OUTPUT.

FIG. 7

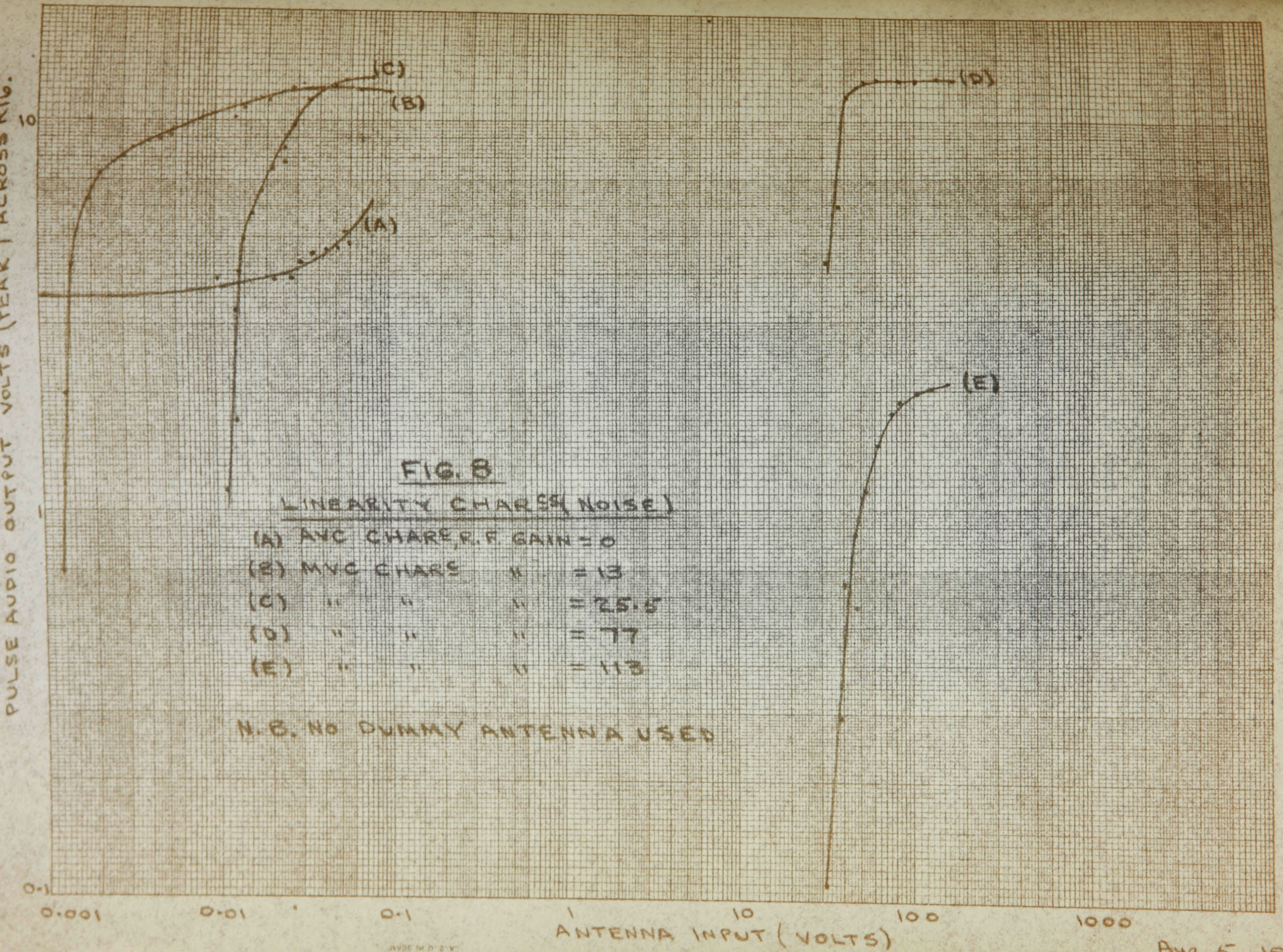
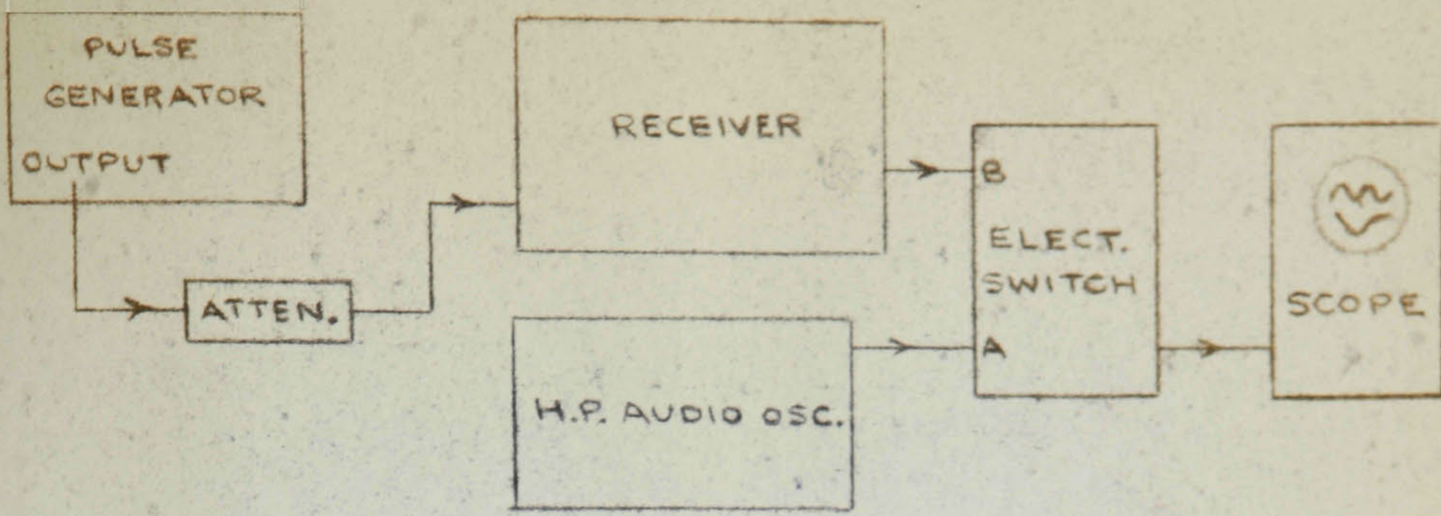
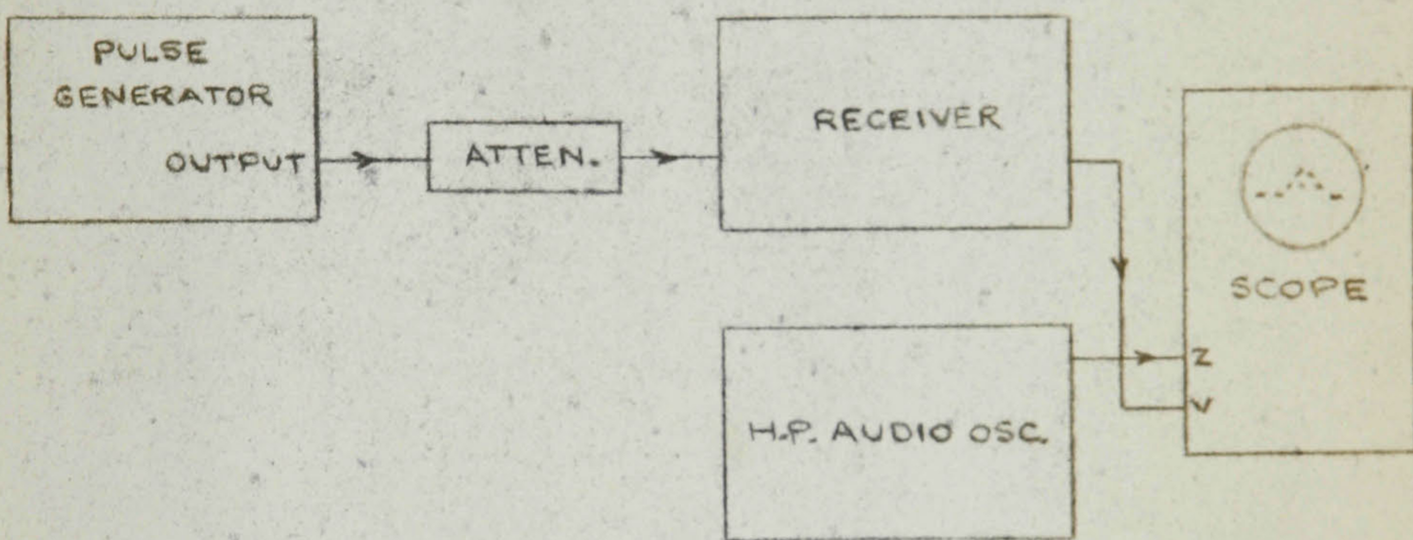


FIG. 8
LINEARITY CHARS. (NOISE)
(A) AVC CHARS. R.F. GAIN = 0
(B) MVC CHARS " = 13
(C) " " " = 25.5
(D) " " " = 77
(E) " " " = 113
N.B. NO DUMMY ANTENNA USED
(A)
(B)
(C)
(D)
(E)
PULSE AUDIO OUTPUT VOLTS (PEAK) ACROSS R16.
ANTENNA INPUT (VOLTS)
0.001
0.01
0.1
1
10
100
1000
0.1
1
10

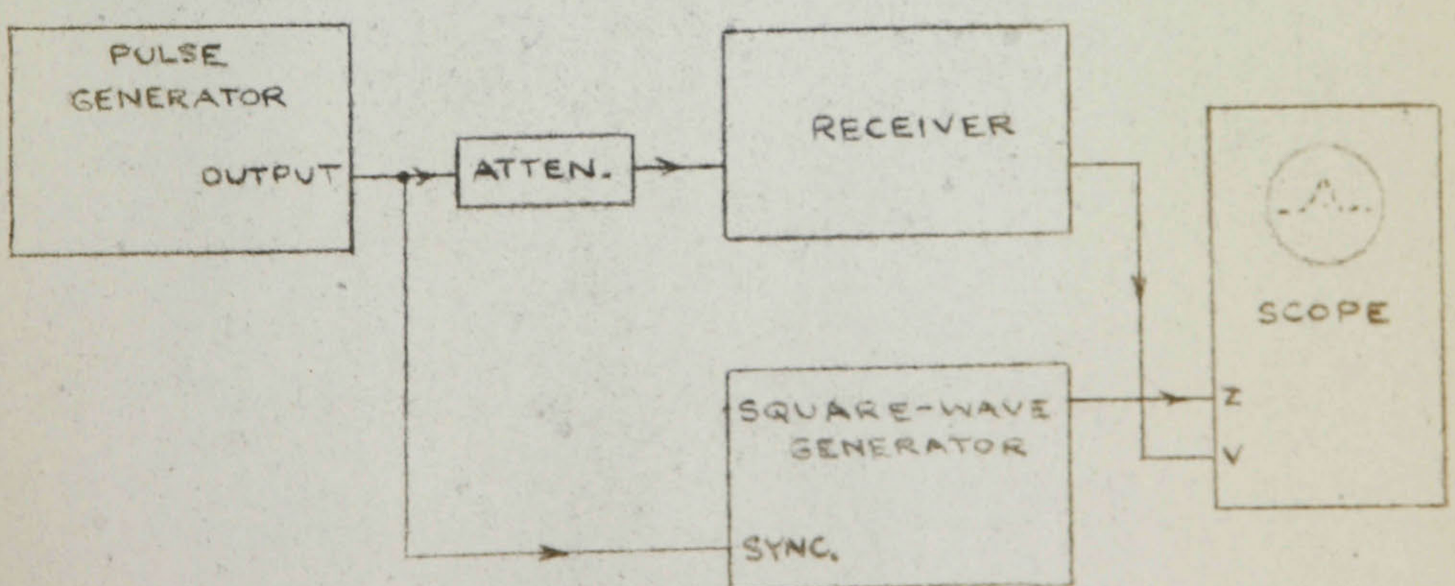
Aug. 5, 1946



A. WITH ELECTRONIC SWITCH.



B. WITH H.P. AUDIO OSCILLATOR.



C. WITH SQUARE-WAVE GENERATOR.

FIG. 9

PULSE LENGTH MEASUREMENTS.

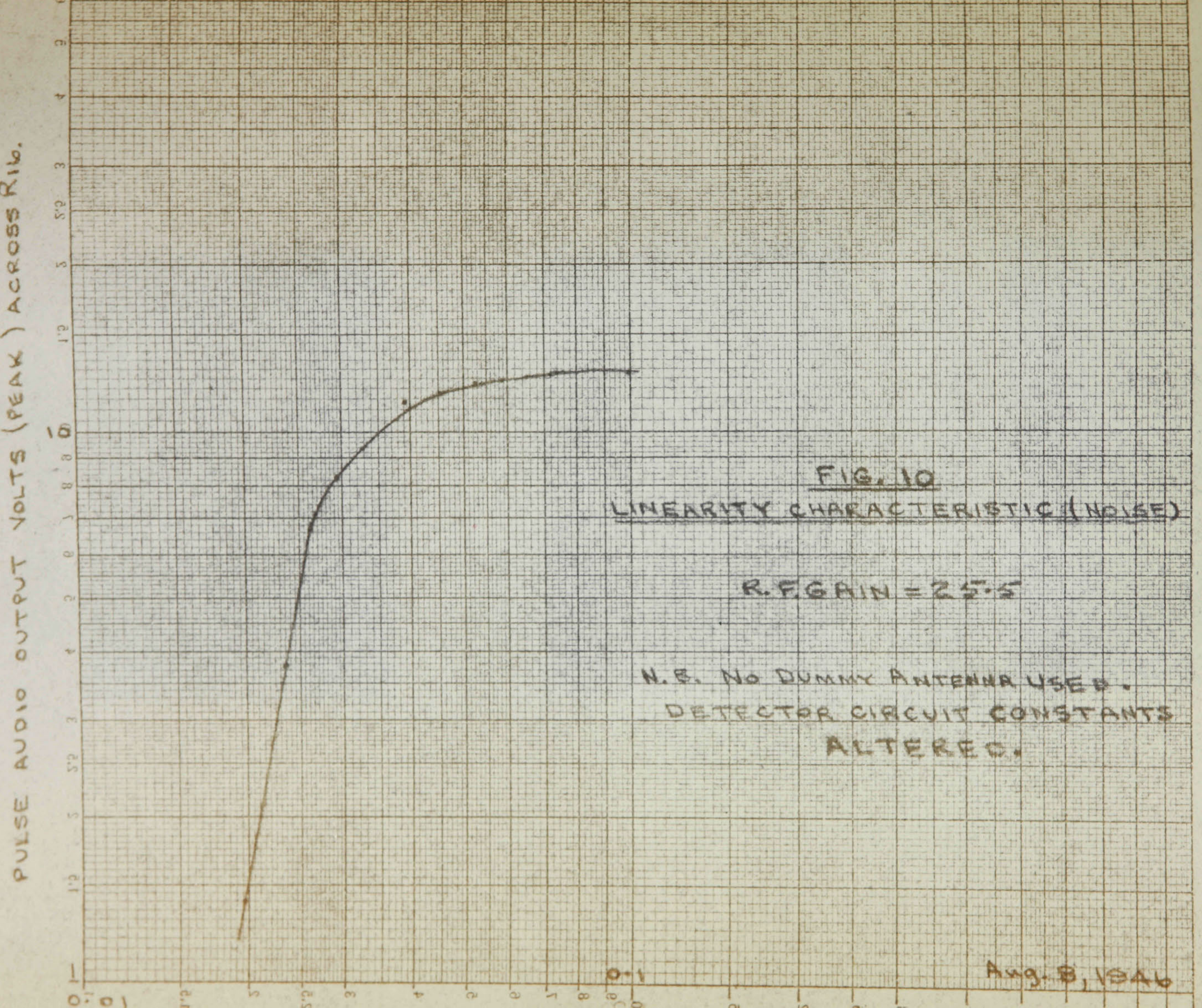
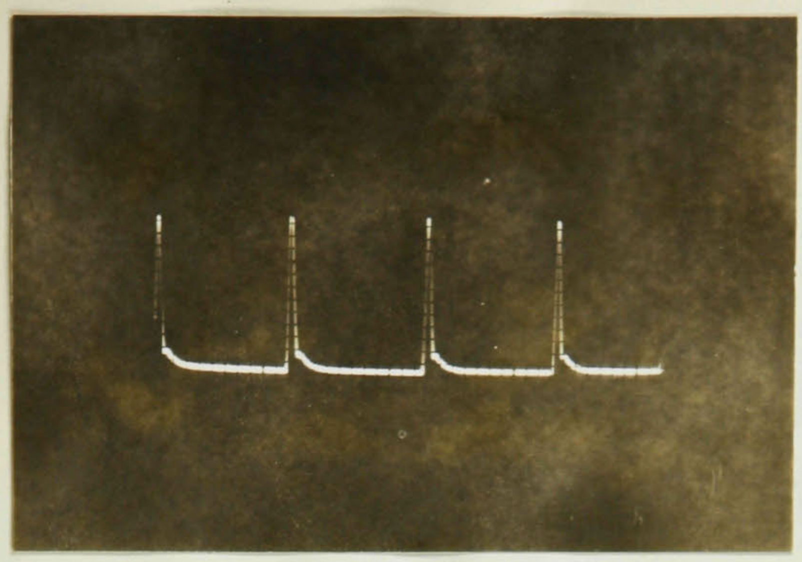
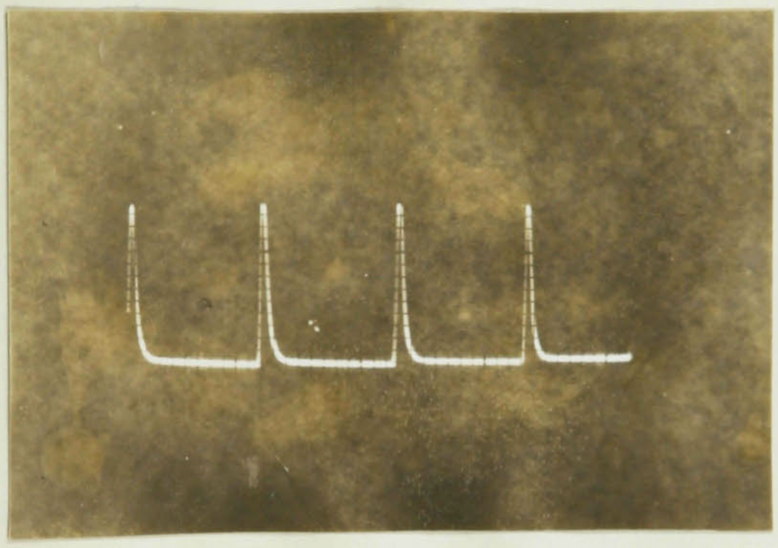


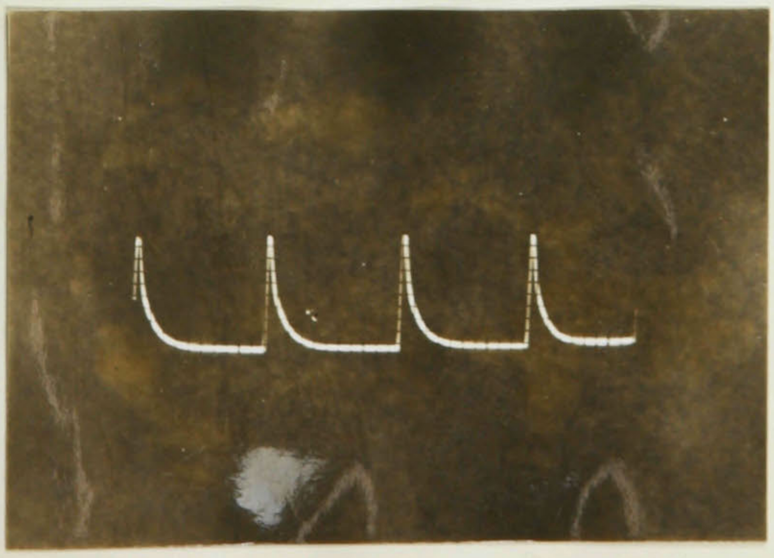
FIG. 10
LINEARITY CHARACTERISTIC (NOISE)
R.F. GAIN = 25·5
N.B. No Dummy Antenna Used.
DETECTOR CIRCUIT CONSTANTS ALTERED.
Aug. 8, 1946
PULSE AUDIO OUTPUT VOLTS (PEAK) ACROSS R16.
0·1
10
1·0



A. SELECTIVITY=1.



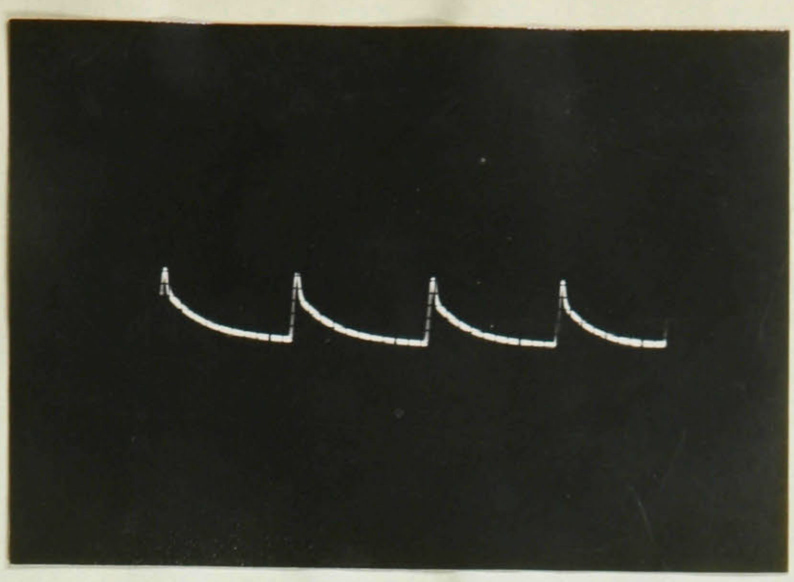
B. SELECTIVITY=2.



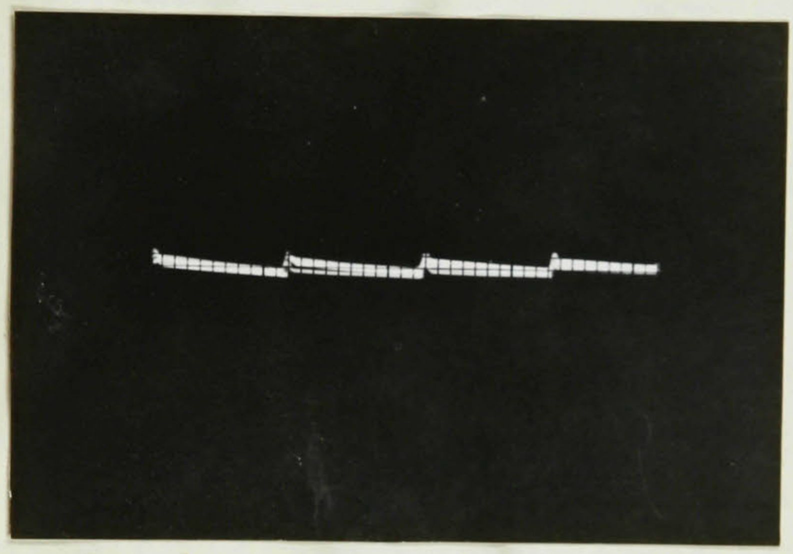
C. SELECTIVITY=3.

FIG.11.1

NOISE OUTPUT



D. SELECTIVITY = 4.



E. SELECTIVITY = 5.

F. SELECTIVITY = 5 (ENLARGED).

FIG. 11.2

NOISE OUTPUT

FIG. 12

PULSE INPUT

MODEL

R.F. GAIN CALIBRATION DATE Aug. 9, 1946