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DEPARTMENT OF COMMERCE
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Methods of Measuring Voltage Amplification of Amplifiers.

Introduction

Amplifier circuits used in radio work fall into two distinct classes depending on whether they are used to amplify the radio-frequency currents before detection or to amplify the audio-frequency currents produced by the detector. These two types of amplifiers are called respectively "Radio-Frequency Amplifiers" and "Audio-Frequency Amplifiers". This paper describes methods commonly used at the Bureau of Standards for measuring the amplification of the two different types. As the amplifiers are most commonly used the voltage amplification is the most important and is the only one considered in this paper.

I. Measurement of Voltage Amplification of Audio-frequency Amplifiers.

With the arrangement here described the voltage amplification of audio-frequency amplifiers having amplification up to 20 000 can be measured at any audible frequency for which a supply voltage is available. Most two stage audio-frequency amplifiers have a voltage amplification of less than 5000 so that they fall well within the range of this method of measurement.

A diagram of the circuit is shown in Fig. 1, the parts being designated as follows:

1. Amplifier under test
2. } Voltage dividers for rough and fine adjustment of
3. } ground potential.
4. }
5. }
6. } Variable resistors as indicated
7. }
8. Slide wire.
9. DPDT quick acting switch
10. Telephone receivers.

The audio-frequency generating set which should be capable of giving about 5 volts at the desired frequency is located at some distance from the test circuit in order to prevent induction in the amplifier or leads. The leads from the batteries to the amplifier are made as short as possible.

If it is desired to measure the input voltage supplied to the amplifier a voltmeter of the thermal type may be connected to the input terminals of the circuit and the value of the input to the amplifier calculated from the value of the resistances.

If the amplifier under test is transformer-coupled where there is no electrical connection between the input and output terminals, one of the output terminals at 9 must be grounded to prevent howling. If it is any other type having the input connected to the output, the output terminals must be ungrounded.

To make a measurement the audio-frequency generating set is adjusted to the desired frequency by comparison with a tuning fork of that frequency. The voltage across it is applied to the input circuit of the amplifier as shown in the diagram. The voltage across the telephone receivers 10 is then adjusted to equal that across R. This is accomplished by varying R and r until the intensity of sound in the telephone receivers is the same for both positions of the switch 10. R is so adjusted that the required setting of r lies well within the limits of the slide wire scale, under the limitation that R must be kept small in comparison with the impedance of the telephone receivers. Resistors 4 and 6 are adjusted to give the least intensity of sound in the telephone receivers with which satisfactory observations can be made. Voltage dividers 2 and 3 are adjusted so that there is no sound in the phones when r = o.

In making comparisons of the intensities of sound in the telephone receivers for both positions of 9 the ear is concentrated on the fundamental frequency of the generator disregarding as far as possible the harmonic frequencies present.

When the intensity of the sound is the same with the switch 9 in either position the voltage amplification

$$\mu_v = \frac{R}{r}$$

The frequency of the generating set is changed and the amplification measured over the audible range. From these data a curve is plotted showing the variation in voltage amplification with frequency.

General Precautions.

Every time resistors 4 and 6 are changed, care should be taken to make sure that there is no output from the test amplifier when r is zero. It is generally desirable, when making measurements, to keep the input voltage constant, since the amplification may vary with changing input.

In making a series of measurements the same pair of telephone receivers should be used throughout the series, and also in the comparison of amplifiers, unless a particular type is specified. A pair of Western Electric, type P - 11, telephone receivers have been used in most of the measurements made with this apparatus.

The measurement described here is open to the criticism that it disregards the power consumed by the input of the amplifier, and likewise takes the voltage across a given pair of telephone receivers as a criterion of the output of the amplifier. The power consumption is not negligible in actual use and it is likely to affect the operation of the detecting device with which it is used in radio reception. The output voltage may vary greatly with different types of telephone receivers.

II. Measurements of Voltage

Amplification of Radio-Frequency Amplifiers

The voltage amplification of Radio-frequency amplifiers consisting of one or more stages of radio-frequency amplification and a detector can be measured with the apparatus herein described at frequencies of 500,000 to 75,000 (wavelengths of 600-4000 meters).

The amplifier and measuring apparatus are completely enclosed in a screen wire cage which shields the apparatus from the radio-frequency generating set and from stray radio-frequency signals or disturbances, and is supplied with modulated radio-frequency and audio-frequency current from apparatus outside of the cage.

Separate measurements are made on the radio, detector, and audio stages, if the amplifier under test combines all three, which may involve separating the connections of the various parts of the instrument.

The method used for this measurement can be understood by reference to Fig. 2. It consists of applying a measured radio-frequency voltage (completely modulated) to the amplifier input and measuring the audio-frequency detector output by comparison with a known audio-frequency voltage of the same frequency; then making a similar measurement on the detector tube alone, applying the radio frequency to the input of the detector tube and measuring its audio-frequency output. By a combination of the two measurements the term involving the detection coefficient is eliminated and the absolute voltage amplification of the radio-frequency stages alone is thus known. The audio-frequency stages are measured separately as described in the measurement of voltage amplification of audio-frequency amplifiers. (See part I).

In Fig. 3 is shown the circuit and apparatus for making these measurements, the cage being represented by the dotted line.

Fig. 3

1. Leads to radio-frequency supply

2. Leads to audio-frequency supply
3. Terminals connected to input of amplifier under test
4. " " " output " " " "
5. DPDT switch
6. Galvanometer shunt resistance
7. Sensitive low-resistance vacuum thermoelement
8. 3-stage audio-frequency amplifier
9. Audio-frequency transformer
10. Grid leak, 2 megohms, and 2.5 volt battery
11. Mica condenser, 0.02 microfarads capacity
12. Crystal detector (carborundum) (These may be replaced
13. Milliammeter (by a thermoelement and (galvanometer
14. Filament battery terminals
15. DPST switch

C. Variable condenser, maximum capacity 0.005 microfarad
G. Sensitive glavanometer
L_1 and L_2 radio-frequency coupling coils
R. Radio-frequency link resistance
R_1 Decade resistance box, 0-1000 ohms
R_2 Decade resistance box, 0-10000 ohms
V. Hot-wire voltmeter, 0-30, 0-150 volts

The modulated radio frequency is supplied by an electron tube radio-frequency generating set enclosed in a metal lined box and placed about 3 meters from the cage. The wave length of the generated radio frequency can be varied from 600-4000 meters using the two coils with which it is equipped. The plate voltage is about 120 v. alternating current supplied by a small 500-cycle motor generator, which also furnishes through a step-down transformer 30 volts to the leads 2.

The radio-frequency voltage having the frequency at which measurements are to be made, is introduced into the cage by means of the coils L_1 and L_2, the coupling of which can be varied. The coil L_2 outside the cage, has an inductance of about 140 microhenries and since it is in an untuned circuit is used over the entire range of wave lengths. Two coils are used at L_1 in the tuned circuit, L_1-C-15-7-R, inside the cage to cover the range of wave lengths required, one the same size as L_2 used from 600-1500 meters, and a larger coil having an inductance of about 860 microhenries used from 1500-4000 meters. This input circuit is tuned to the frequency of the current in L_2 by varying the condenser C.

The amplifier input is the iR drop across the resistance R due to the radio-frequency current flowing through R, and is varied by using different values of R and varying the current through R by changing C. This current is measured by the thermo-element 7, and galvanometer G which are calibrated with the shunt 6 at the value used. The resistances used at R are standard high-frequency link resistances (See Bureau of Standards Circular

74 page 176) varying from 0 to 30 ohms. They must be measured occasionally on a direct current bridge to check their resistance as they do not remain constant.

If the amplifier to be measured has only radio frequency stages and a detector tube, its input and output terminals are connected tothe terminals 3 and 4 respectively; but if the amplifier has one or more audio stages, the terminals 4 are connected inside the amplifier to the output of the detector tube, which will be across the primary of the first audio-frequency transformer, if transformer-coupled stages are used, or across the impedance in the detector tube plate circuit if impedance-coupled stages are used. Telephones are connected to the amplifier in their normal position, using the audio-frequency stages as in actual operation. The filament terminals of the amplifier are connected to terminals 14, and the leads from these terminals connectedto a filament battery. The grounded input terminal at 3 marked G should be connected to the filament side of the amplifier input, and short leads used in all connections to the amplifier.

The audio-frequency comparison voltage is supplied to the switch 5 through twisted leads by the voltage divider at R_1 R_2, consisting of a resistance R_1 variable by one ohm steps from 0-1000 ohms to which are connected the leads the DPDT switch, in series with resistance R_2 variable from 0-10000 ohms in 10-ohm steps. The voltmeter V and supply voltage from the audio frequency source are connected across R_1 R_2 as indicated.

Either the audio-frequency output voltage of the test amplifier or the comparison voltage obtained from the voltage divider is connected to the input of the voltage-indicating circuit by switch 5, and is amplified by the three-stage resistance-coupled audio-frequency amplifier 8 and transformer 9 causing an alternating current to flow in the circuit 9, 12, 13. This current is rectified by the crystal detector 12, and deflects the d.c. milliammeter 13. The detector and milliammeter may be replaced by a thermoelement and galvanometer.

With the frequency of the radio-frequency generating set adjusted to the desired value, the zero resistance link is inserted at R, theswitch 15 closed and the input circuit tuned by varying C until a large deflection is obtained on galvanometer G, being very careful to prevent excessive current flowing through the thermoelement. With switch 5 up, connecting the voltage-indicating circuit to the amplifier output, there should be no deflection on the milliammeter as the test amplifier input is short circuited. If there is a deflection, and it continues even with switch 15 open, it may be due to "howling" of the permanent amplifier 8 and may be eliminated by adjusting the filament current of 8. If a deflection is observed on 13 with 15 closed and none with 15 open, it is due to induction in the test amplifier, or resistance in the contacts at R. The contacts at R should be cleaned and the input leads of the amplifier shortened, eleiminating as far as possible

any induction from the coil L_1 to the amplifier.

When no deflection of 13 is observed with the radio-frequency current flowing (15 closed), resistance links are put in place of the zero resistance at R, always opening 15 before removing a link at R, increasing R until a suitable deflection is obatined on the milliammeter 13.

The comparison voltage is now connected to the voltage-indicating circuit by throwing switch 5 down, and R_1 and R_2 are adjusted until approximately the same deflection on the milliammeter is obtained as previously. Switch 5 is thrown to the up position again and the amplifier input varied by varying C, it being equipped with a small variable condenser for fine adjustment, until exactly the same deflection is obtained with switch 5 either up or down. The audio-frequency output voltage e_t is now equal to the comparison voltage across R_1, and since the voltage E across R_1 and R_2 measured by voltmeter V, is known, the amplifier output voltage -

$$e_t = E \frac{R_1}{R_1 + R_2}$$

The thermoelement and galvanometer being calibrated, the current, i, flowing through R is obtained from the galvanometer deflection, and the radio input voltage

$$e_i = i\,R$$

These measurements are repeated at the different frequencies at which the amplification is to be determined.

Then the input terminals, 3, are disconnected from the amplifier input and connected directly to the detector tube input, removing the connections from the preceding radio-frequency stages to the detector tube if necessary. This can usually be done by leaving the grounded terminal at 3 connected to the filament, and connecting the other terminal temporarily to the grid condenser of the detector tube. Input and output voltages are measured at the same wave lengths at which the previous measurements were made, calling these new voltages of the detector tube alone: e_i' and e_t'

From the following relations:

$$e_t' = \delta (e_i')^2 \text{ and}$$

$$e_t = \delta (\mu_v \; e_i)^2,$$

in which δ is the detection coefficient (See Letter Circular No. 87) of the detector tube and μ_v the voltage amplification of the radio frequency stages; the voltage amplification, combining,

$$\mu_v = \sqrt{\frac{e_t}{e_t'}}$$

for any given wave length if $e_i = e_i'$

General

Some trouble may be experienced by changes in the radio-frequency input while making measurements due to changes in the line voltage from which the audio-frequency generator is run, which may be partially eliminated by running the generator on storage batteries.

In view of the fact that a radio-frequency amplifier, as it is usually assembled, involves three separate pieces of apparatus, it is believed that it is not possible to obtain a significant or adequate determination of the merit of such a device without considering the radio-frequency stages, detector and audio-frequency stages separately, according to the process described here. Data upon the overall amplification, as indicated by a direct determination of the output voltage of the audio-frequency stages relative to the applied radio-frequency voltage, are likely to be of little assistance in locating the weak points of a given combination as an aid to design. It will usually be found that the audio-frequency output voltage of the detector tube alone is less numerically than radio-frequency voltage applied to the first stage, even when there are several stages of radio-frequency amplification, on account of the inherently inefficient operation of the detector.

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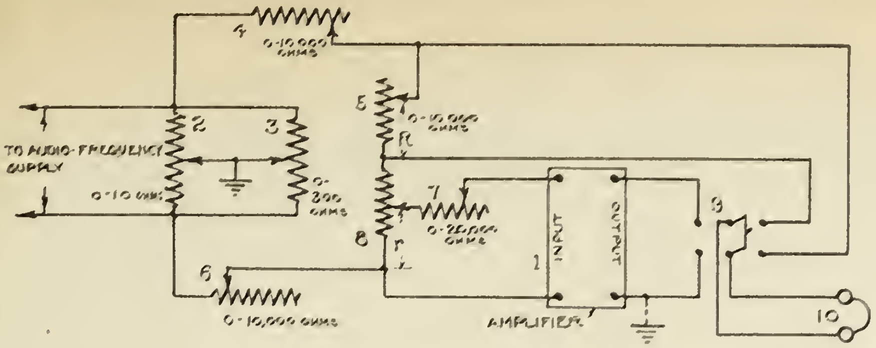

FIG. I. CIRCUITS FOR MEASURING AUDIO-FREQUENCY VOLTAGE AMPLIFICATION.

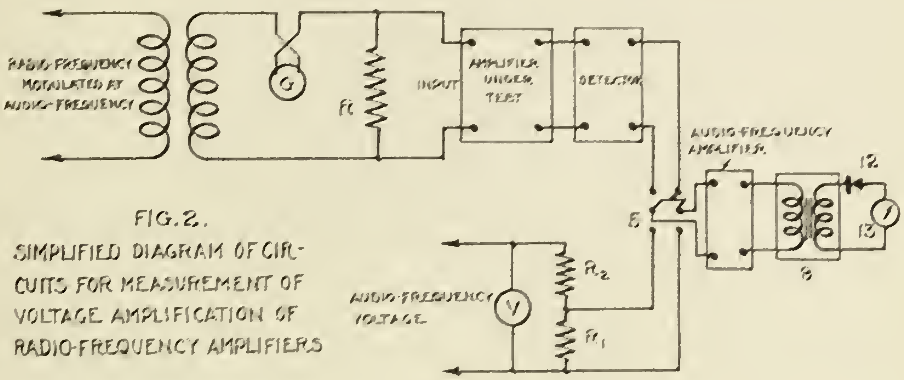

FIG. 2.
SIMPLIFIED DIAGRAM OF CIRCUITS FOR MEASUREMENT OF VOLTAGE AMPLIFICATION OF RADIO-FREQUENCY AMPLIFIERS

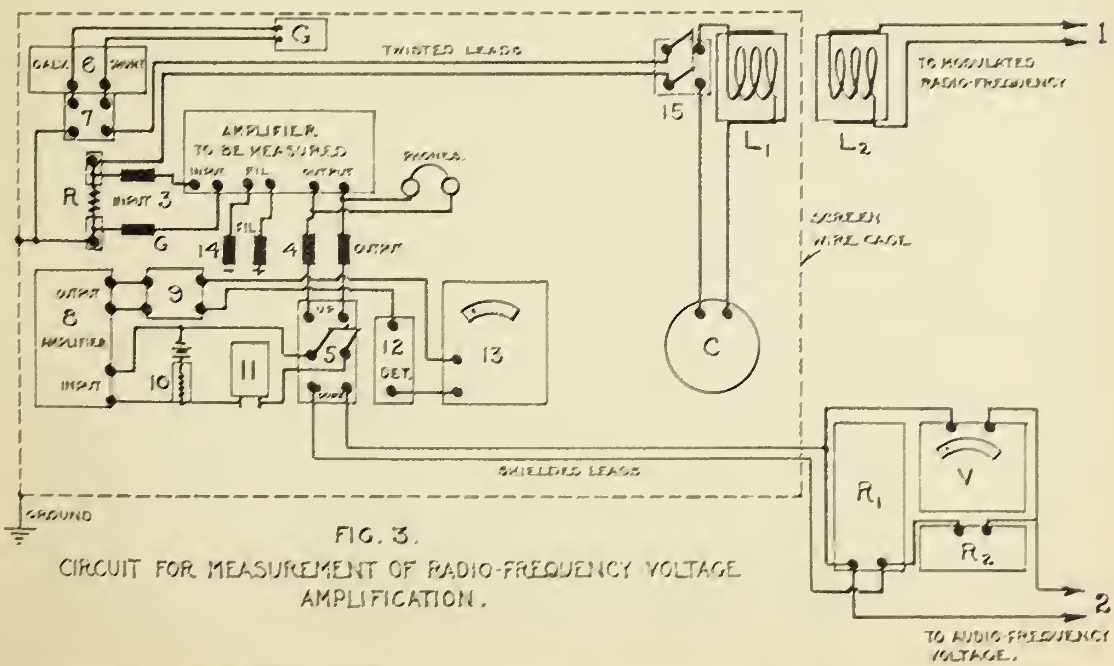

FIG. 3.
CIRCUIT FOR MEASUREMENT OF RADIO-FREQUENCY VOLTAGE AMPLIFICATION.