The Vibratory Characteristics and Impedance of Telephone Receivers at Low Power Inputs

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THE ordinary telephone receiver is one of the most sensitive known detectors of weak alternating currents over a considerable part of the audible frequency range. Its high sensitivity, combined with its simplicity and convenience, have led to its general adoption as the detecting element in the AC impedance bridge and other measuring apparatus employing the nul method. There are also a number of cases outside of the laboratory where a knowledge of the behavior of the receiver operating near its minimum audible power input is of importance. In apparatus developed during the World War, such as that for detecting and locating submarines, in radio reception, and in the reception of various other sorts of signals, the receiver is frequently operated near the threshold of audibility. While it is in general possible to employ a vacuum tube amplifier to render weak signals more easily audible, considerations of cost or increased complication often make it impracticable to do so. In any case, if it is desired to reduce to the limit the minimum audible signal, it is necessary to know the constants of the receiver working on these low power inputs, in order to design intelligently its circuits and other associated apparatus.

Current literature dealing with the sensitivity of telephone receivers indicates that the relation between the impedance and vibratory characteristics of the receiver at currents near minimum audibility to those as ordinarily determined in the laboratory, is not generally known. It would, therefore, seem of interest to publish the results of an experimental determination of receiver characteristics at very low currents. Such an investigation was carried on in 1918 and 1919, using the Western Electric No. 509 radio receiver (the present standard Western Electric Receiver for radio use). The work, however, was done, not merely with the idea of determining the characteristics of this particular instrument, but for the purpose of ascertaining the behavior of receivers in general, near minimum audibility.

Inasmuch as the damped impedance of the receiver—that is the impedance with the diaphragm held motionless—is very close to the impedance obtained with the instrument on the ear, it is commonly used as the basis of circuit calculations. A knowledge of its value for weak currents is therefore of importance. Measurements were first made of the damped impedance of six instruments at a frequency of 1,000 cycles for a wide range of input current, and later the work was extended to the measurement of the vibratory characteristics. A bridge network was used for measuring the current supplied to the impedance bridge and from the circuit constants the current through the receiver under test could be calculated. The resistances in the various arms of the controlling bridge network were chosen so as to furnish an essentially constant current through the receiver under test, although its impedance might vary through a rather wide range. With the extremely small values of currents involved, it was necessary to amplify the power to the bridge balancing receivers approximately 100 TU. For this amount of amplification, it was obviously necessary to take extreme precautions in grounding and shielding the apparatus, in order to reduce to inaudibility the effect of stray fields from the source of current supply. This was success-

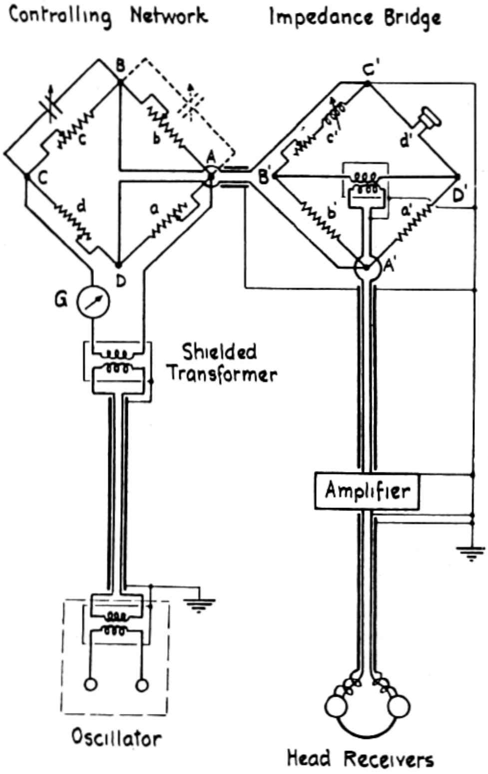

Fig. 1

fully done and the impedance bridge measured impedance accurately with currents as low as 10^{-9} amperes, through the receiver under test. The correctness of the point of balance of the bridge was established by measurements of standard impedances over the range of currents employed in the receiver tests. A schematic diagram of the circuit is shown in Fig. 1.

For measurements of damped impedance, the receiver was placed in a small sound-proof box, with its diaphragm damped by a micrometer depth gauge, which was carefully adjusted so as just to impinge upon the diaphragm. It was necessary to insulate the receiver from mechanical agitation, since minute voltages generated in it were sufficiently amplified to cause an excessive noise in the head receivers.

Fig. 2 shows the damped effective resistance and reactance of the six instruments, taken at 1,000 cycles, plotted on semi-logarithmic paper. It will be seen that below approximately 10^{-6} amperes, the impedance is constant. However, above this value both the effective resistance and the reactance show a consistent increase with the current. The minimum current employed (10^{-9} amperes), is between two and three times the minimum audible current for this type of instrument, but from the data taken there is no reason to suppose that the impedance would vary for smaller currents. This receiver has a winding of 11,000 turns, and it can, therefore, be assumed that this type of structure will have constant impedance below a magneto-

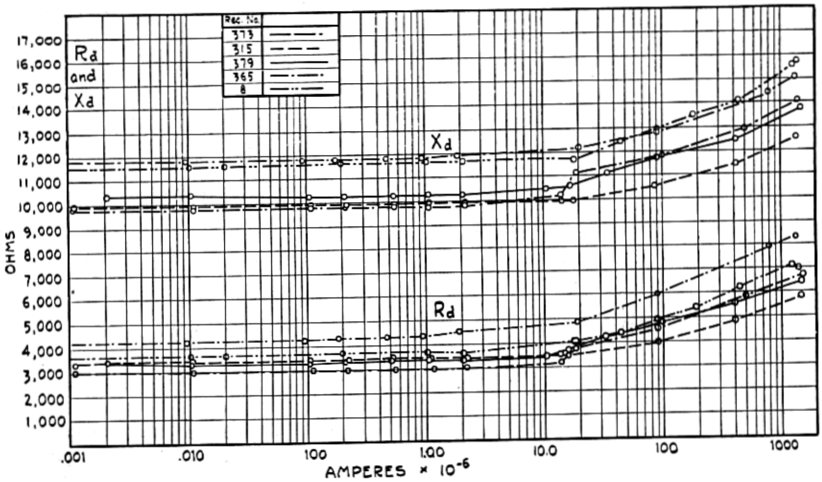

Fig. 2

motive force of .01 ampere turns. For laboratory measurements on this instrument a current of 2×10^{-5} amperes is ordinarily used, and it will be noted that the impedance at extremely low currents is not greatly different.

It is generally known that, in the case of either a steady or an alternating field, the permeability and the shape of the hysteresis loop for ordinary magnetic materials reach limiting values as the magnetomotive force is reduced, that is, further reductions of the magnetomotive force have no effect on these magnetic characteristics. The results cited above show that this condition obtains for a weak alternating field when it is superimposed on a relatively strong steady field.

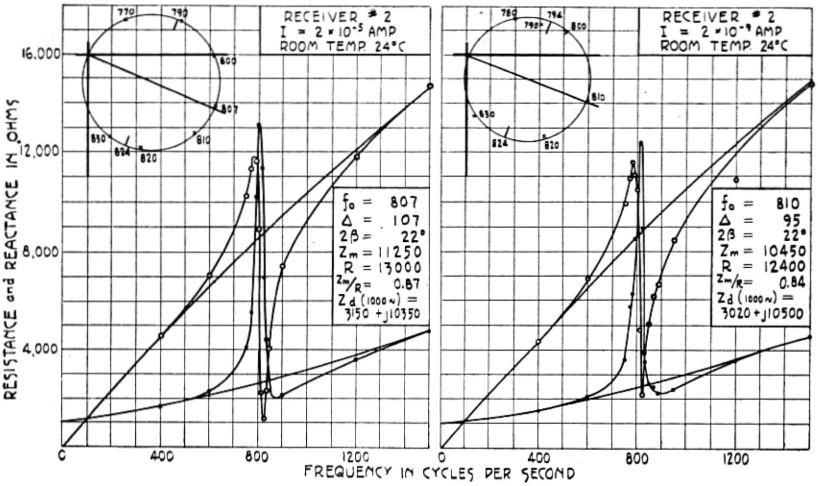

Fig. 3—f_o = natural frequency; Δ = logarithmic decrement per second; 2β = depression angle of principal diameter; Z_m = maximum motional impedance; R = free resistance at resonance; Z_o = damped impedance.

In the measurements of free impedance for determining the vibratory characteristics the small sound-proof box could not be used on account of the proximity of its walls. Accordingly, the receiver and the impedance bridge were placed in a large sound-proof booth with padded walls where the effect of reflection of sound waves was very small. With the diaphragm of the instrument free to vibrate, its efficiency as a sound detector was materially increased and the noise in the head receivers due to the slightest movements of the observer became so serious that it was not feasible to take data with currents of less than 2×10^{-9} amperes.

Fig. 3 shows impedance characteristics, with their associated circles, of the same receiver with currents of 2×10^{-9} and 2×10^{-5} amperes. It will be seen that the differences between these curves are insignificant when one considers the low precision of motional impedance data in the absence of extreme precautions with regard to constancy of temperature, etc. Moreover, other impedance analyses at intermediate values of current agree with the above within the precision of the measurements.

To summarize the results, it may be said that the characteristics of receivers remain substantially unaltered as the current is reduced to the point of minimum audibility. In taking impedance measurements, it is well to use a current which is low enough to be on the flat part of the curve. This can usually be done without the use of amplifiers between the impedance bridge and balancing receivers. The fact that the vibratory characteristics of the receiver remain unaltered as the power input is reduced to the threshold of audibility throws an interesting light on the behavior of the diaphragm material under very small motions. Calculations of the minimum audible amplitude near resonance, based on the fact that the constants of the material remain unchanged, show it to be of the order of 10^{-9} centimeters. This motion is less than the mean molecular diameter of the diaphragm material.