XXV. THE CALIBRATION OF A WAVE-METER FOR VERY SHORT WAVE-LENGTHS

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The object of the work described here was the construction and calibration of a meter with which the frequency of oscillations above 2,000,000 cycles per second might be easily and quickly determined. In this range it is more common to speak of wave-length than of frequency. The product of these two is the speed of propagation of electromagnetic waves in the either, which is approximately 300,000,000 meters per second.

The ordinary wavemeter consists of a simple oscillating circuit, usually an air core solenoid and a variable air condenser, with some device for detecting the alternating current which may be induced by the electromagnetic waves radiated from the source whose frequency is to be measured. The natural period of the circuit is varied by means of the variable condenser, and a maximum current flows when that period is the same as that of the source of radiation. In such a circuit the wave length corresponding to the natural period is proportional to the square root of the product of the inductance and capacity in the circuit. These meters usually have a lower limit of 150 meters or 75 meters. The wave meter constructed in this experiment consisted of the usual three parts, a 23 plate General Radio variable condenser having a maximum capacity of 1030 micromicrofarads, a coil 6.6 centimeters in diameter consisting of 8 turns of number 14 double cottom covered copper wire and having an inductance of 6.12 microhenrys, and a General Radio Co. hot wire galvanometer having a range of 0.01 to 0.25 milliamperes.

The first oscillator used as a source of radiation was of the well known Colpitts type. The tuned circuit consisted of an inductance and two condensers in series. The inductance was made of 21 turns of number 12 double cotton covered copper wire wound on a cardboard cylinder 4.4 centimeters in radius and 12 centimeters in length, with taps at every turn. The total inductance of the coil was about 2 microhenrys. The condensers were variable air condensers with maximum capacities of 500 and 750 micromicrofarads. This gave a maximum wave length of a little over 150 meters. The filament of a five watt power tube, type C302, was connected to the point between the condensers. The plate was connected to the point between the smaller condenser and the coil, through a 0.01 microfared stopping condenser, and to the filament through a 350 volt direct current generator in series with a choke coil made of 100 turns of number 22 cotton covered wire wound on a common spool. The grid was connected to the point between the larger condenser and the coil, and, thru a resistance of 10,000 ohms and a choke coil, to the filament. The filament was heated by a battery of six Edison storage cells.

The oscillator just described, and a second one, similar except that it had a larger tuning coil, were set up and made to oscillate with wave lengths of 150 meters. These wave lengths were measured with a General Radio wavemeter, which was used as a standard in this experiment. Then a pair of 2000 ohm headphones were connected across the condenser of the standard wavemeter. A beat note was heard, the frequency of which was the difference of the frequencies of the two oscillators. This showed that they were not operating at exactly the same frequency. However they could be made to do so, very nearly, by adjusting one of the oscillators until the frequency of the beat note became very low. It was quite possible to obtain a beat note with a tone lower than an octave below middle C on the piano, i. e., with less than 100 vibrations per second. If one of the oscillators, say the one of lower frequency, was operating at 150 meters, or 2,000,000 cycles per second, the frequency of of the other was known to be not over 2,00,100 cycles per second, which corresponds to 148.98 meters. That is, the error in reasonance was not over two hundredths of a meter at 150 meters. This accuracy was much greater than that of either of the wavemeters. So sensitive was this method of determining resonance that changes in the frequency of one of the oscillators, caused by changes in the position of the experimenter's hand due to its effect on capacities in the circuits, were readily noticed, and were, in fact, found to be a source of some annoyance.

Next, the second oscillation generator was operated at 300 meters which was twice the wave length, or half the frequency, of the first. A beat note could be heard between the fundamental of the first and the first overtone of the second. This provided a means of knowing that the first oscillator was operating at half the wave length of the second, with an error not greater than that described above. If the frequency of either oscillator was increased, the beat note disappeared, but if the frequency of the other was correspondingly increased the beat note was recovered. Thus, while the frequencies of both were increased their ratio was maintained constant, namely two to one. In this manner the wave length of the second oscillator was reduced from 300 meters to 150 meters which was at all times directly measurable by the standard wavemeter. The wave length of the first oscillator was reduced from 150 meters to 75 meters, which was at no time directly measurable, but was always known because of its ratio to that of the second. This wave length of 75 meters was compared not only to the first overtone of 150 meters, but also to the second overtone of 225 meters and to the third overtone of 300 meters. Several comparisons of this kind for one frequency furnished checks both as to the number of the overtone and the readings of the standard meter. At suitable intervals throughout this process the wave length fo the first oscillator was measured by the wavemeter constructed in this experiment. These readings together with the known wave-lengths of the oscillations measured indirectly by the standard meter furnished data for the calibration of this low-range wavemeter.

The calibration of the low range wavemeter was carried out in this manner to a lower limit of about 30 meters, i. e., to an upper limit of about 10,000,000 cycles per second. The beat method of calibration was abandoned here because the order of the overtone was becoming high, and because the oscillator, which had been used for the higher frequencies, did not operate well beyond this limit. When an oscillator had been set up for higher frequencies a more direct method of calibration was used.

In the construction of an oscillator for shorter wave lengths the same type of tube was used. The inductance of the tuned circuit was formed by a single loop of number 12 copper wire about 30 centimeters in radius, and the capacity was formed by the plate and the grid, with their connections, of the vacuum tube, (see Figure VI). One end of the loop was connected directly to the plate; the other end was connected through a hot wire ammeter, reading 0.5 to 2.5 amperes, to the grid. The grid was connected to the filament through the same grid leak and choke-coil as before. The loop was broken at its midpoint by a 0.01 microfarad stopping condenser, and the plate side of this condenser was connected to the filament through the 350 volt direct current generator and choke coil. The computed inductance of the loop was 1.6 microhenrys, and the capacity of the elements of the tube was found to be about 11 micromicrofarads. These caused this circuit to have a wave-length of about 8 meters. It was found possible to vary the wave length by varying the size of the loop but it was much more satisfactory to vary the capacity in the circuit. This was increased by placing a variable air condenser in parallel with the plate-grid capacity; it was decreased by replacing the stopping condenser by a variable condenser whose capacity could be reduced until it was comparable with that of the plate-grid capacity. This last method, also, was not very satisfactory.

For determining the wave length of the oscillations produced, two long parallel wires were used. One end of the pair was joined through a hot wire ammeter reading 0.1 to 0.5 amperes, thus forming a loop which provided a loose inductive coupling with the tuned circuit of the oscillator. If the wires were joined at another point by a "bridge," so that the total length of wire in the closed circuit was a small integral multiple of the wave length, standing waves were produced and the ammeter needle deflected. The length of the closed circuit was then measured with a meter stick.

A second and third coil had been wound for the wavemeter. The first already described was designated "A". The second coil "B" consisted of 5 turns 3.3 centimeters in radius, and had 2.51 microhenrys computed inductance; the third "C" consisted of 2 turns 4.75 centimeters in radius, and had a computed inductance of 0.81 microhenrys. The wavemeter with coil "C" was calibrated in the following manner. The bridge wire, the ammeter, and the loop which provided coupling between the oscillator and the parallel wires, were made to have a combined circuit length of 5 meters. Each of the parellel wires was 18 meters long and was marked at each meter of its length. When the bridge had been set to give the longest circuit possible, (41 meters), the capacity in the oscillator circuit was adjusted until resonance was obtained and a maximum current flowed in the parallel wires. The wavemeter was adjusted to resonance and the wavemeter scale-reading and the parallel wire circuit-length were recorded. For one setting of the bridge several wavemeter readings were obtained; these corresponded to different integral ratios of the circuit-length and wave-length. The bridge was then moved so as to shorten the closed circuit two meters and the process was repeated. When sufficient data had been recorded, to each wavemeter reading there corresponded several circuit lengths. The latter formed an arithmetic series whose difference or smallest positive term was the true wave length corresponding to that particular wavemeter reading.

By comparison with the General Radio meter the short-range wavemeter with coil "A" was calibrated from 154 meters down to 49 meters, and with coil "B", from 100 meters down to 29 meters. Then by means of standing waves on parallel wires the wavemeter with coil "C" was calibrated from 41 meters down to 10 meters. Finally, oscillations of various wave-lengths were measured, using each of the three coils. Thus, by comparison among themselves, the calibrations from coils "A" and "B" were extended to the lower limit of the wavemeter scale, and that for coil "C", to the upper limit of the scale. In this comparison remarkably good agreement was obtained. In fact, the agreement was as good as could be obtained by comparing different readings of the meter used as standard. For example, in the first set of readings in the calibration for coil "A", two wave-lengths, which were known to be in the ratio 1 to 2, were measured by the standard meter to be 153 and 310 meters respectively. This shows that considerable error was to be expected in a simple measurement by means of the standard meter. In the last set of observation in the calibration for coil "B", the wave lengths 190, 218, 247, 276, 305, and 336 were read for the second oscillator, and should be integral multiples of the wave length of the first oscillator. If these are called terms 6 to 11 of an arithmetic series, and the first term is computed directly from each, an average of 30.9 is obtained. If they are taken as terms 7 to 12, an average of 27.6 for the first term is the result. The common difference for the set is 29.2 and the probable error is no greater than that of either of the others. This common difference was used in the calibration for coil "B" for three reasons, first, it gave better agreement with the determinations made by direct measurement on the parallel wires, which was considered very reliable, second, error was known to exist in the standard wavemeter, and third, in the last part of this calibration the number of the overtones was not always obvious.

The inductances of the coils were computed by a formula using their mechanical dimensions, and also from results obtained by their use in the wavemeter with a calibrated condenser. A difference of almost constant value, 0.26 microhenrys, was observed between the results given by the two methods. To test the supposition that this difference was the inductance of the galvanometer and the connecting wires inside the condenser box, the galvanometer was connected directly across the terminals of the condenser. This was used as a wavemeter (designated by coil "G") and found to be serviceable over the range 5 to 50 meters. The inductance was computed from the capacity and wave length and found to be 0.25 microhenrys.

This suggests a method for measuring any small inductance. The procedure would be the following. Produce oscillations of a suitable constant wave length, measure this wave length with the wavemeter, replace the wavemeter coil by the unknown inductance, note the scale reading for which this temporary wavemeter is in resonance with the source of oscillations, and, from the calibration curve of the wavemeter condenser, determine the corresponding capacity. Then, for the particular galvanometer used here,

L equals (0.281 w w divided by C) minus 0.255

where L is the inductance to be measured, w is the wave length in meters, and C is capacity in micromicrofarads. This formula gives results in microhenrys. The apparatus used in this experiment should be capable of accurate determination of inductances between 0.20 and 125 microhenrys.

A similar method can be used for determination of capacity, but the following is probably better. After the wave length of a steady source of oscillations has been measured, the unknown capacity is connected in parallel with the wavemeter condenser, and the new setting, giving resonance is noted. The difference of the capacities of the wavemeter condenser for the two settings, which may be obtained from its calibration curve, is the desired capacity since capacities in parallel are simply additive. Advantages of this method are that capacities smaller than the minimum of the calibrated wavemeter condenser may be measured; that the ends of the calibration curve need not be used; and that for very small capacities only the slope of the calibration curve in the neighborhood of some suitable point need be known. By this method the capacity between the grid and plate in a C302 vacuum tube was found to be between 10 and 12 micromicrofarads.

Suggestions as to the object and methods of this experiment were received from Dr. William Schriever, Department of Physics, University of Oklahoma. References consulted are:

"Thermionic Vacuum Tube," Van der Bijl, pages 266 to 314; "The Audion Oscillator," R. A. Heising, Journal of the American Institute of Electrical Engineers, April and May, 1920; "High Frequency Oscillator," W. C. White, General Electric Review, Vol. 19, 771, 1916; "Conferences-Rapports, La Lampe a Trois Electrodes," C. Gutton, pages 89 and 118 and page 164; "The production and the use of ultra short wave-lengths," Rene Mesny, Radio News, May, 1924.