CORRECTION FACTOR FOR THE PARALLEL WIRE SYSTEM USED IN ABSOLUTE RADIO FREQUENCY STANDARDIZATION*

By

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A pair of parallel wires was used in the early days of radio by Hertz, Lecher, Lodge, and others for demonstrating stationary electromagnetic waves. With the development of radio-frequency generating sets producing sinusoidal currents, this experiment became simpler, so that voltage nodes and the corresponding current antinodes can now be located with ordinary thermoelectric instruments with a high degree of precision.

It is the purpose of this paper to give the formulas and the corrections needed when the parallel wire system is used for primary frequency standardization.[1] In the parallel wire system[2] used by the Bureau of Standards the basis of frequency standardization involves the direct measurement of the wave lengths of very short[3] waves (4 to 20 meters in length) on a pair of parallel wires as indicated in Figure 1. The wave length λ is found by moving a shunted thermo-galvanometer G, which is suspended between the two wires, along the wires until it shows a maximum current. This galvanometer arrangement has a very low effective resistance. The point of maximum current is marked on the wires as position I-I and the galvanometer moved still further along the wires until a second current maximum II-II is indicated. The distance I-II between these points of successive current maxima is one-half wave length. If the paral-

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[1] The complete theory is given by the author in a Bureau of Standards Scientific Paper now in press.

[2] A detailed description of the arrangement and the apparatus was given by F. W. Dunmore and F. H. Engel in the Proceedings of The Institute of Radio Engineers, page 467, October, 1923.

[3] For standardizing lower frequencies, a local generating set producing currents of lower frequencies is loosely coupled to the detector and the settings of the frequency meter are compared to the frequency of the short waves by means of the harmonics of the low frequency source.

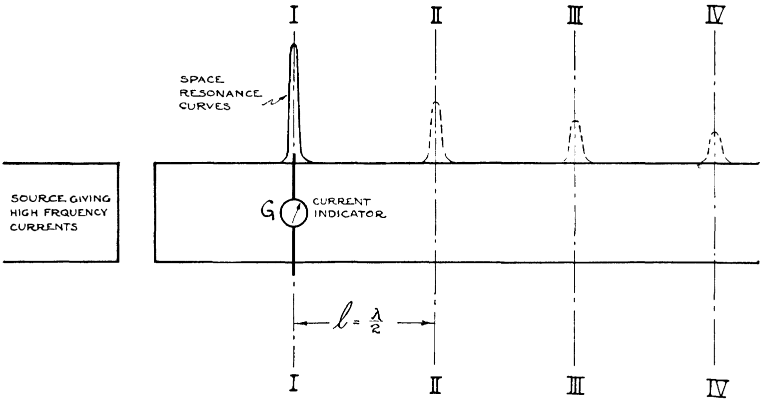

FIGURE 1—The Parallel Wire System of the Bureau of Standards Indicating the Space Resonance Curves as Determined with the Ammeter Bridge

lel wires are sufficiently long a number of such points, as III-III, IV-IV, and so on, may be found. The actual determinations are made with the positions I-I and II-II only since the distance $l=\frac{\lambda}{2}$ can be measured most accurately and the value obtained can be shown to be most reliable. Using a small condenser across the input terminals shifts the two maximum settings closer to the input end without changing the distance between them. The frequency f may be calculated from the formula.

$$f=\frac{v}{2l}$$

where v is the velocity of propagation along the parallel wires. The theory shows that the wave length λ set up on the parallel wire system is just $2l$, that is, twice the distance between two consecutive maximum settings except for a second order small quantity, but the velocity v with which the wave is propagated in the direction of the parallel wires is not the velocity of light ($v_o=2.9982\times 10^{10}$ cm./sec.) but a smaller velocity

$$v=v_o(1-\Delta)$$

This velocity divided by the true wave length λ must be equal to the frequency f.

The frequency f in kilocycles per second is therefore calculated from the formula

$$f=\frac{v_o}{2l}(1-\Delta)$$

where v_o is the velocity of light. Therefore,

$$f=\frac{1.4991\times 10^5}{l}(1-\Delta) \qquad (1)$$

where the distance l between two consecutive maximum settings is expressed in meters. Figure 2 gives a plot for the small quantity Δ for different values of l. This curve is calculated for a parallel wire system using copper wire, 0.145 cm. diameter (number 15 American Wire Gauge) with a spacing of 4.2 cm. between centers.

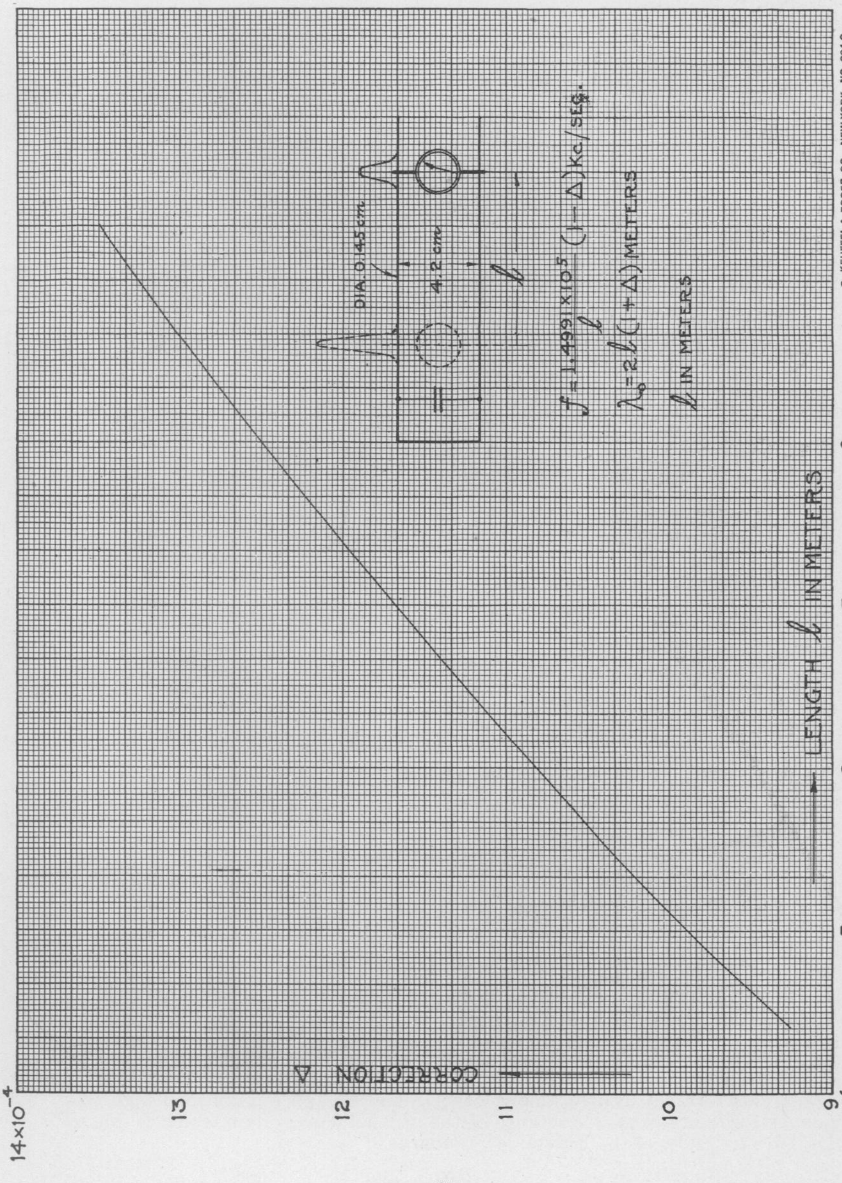

FIGURE 2—Curve Giving the Correction Factor Δ for Different Values of l and Fixed Dimensions of the Parallel Wire System

The calculation is based on the expression [4].

$$\Delta = \frac{\sqrt{r_o}}{8\, l n\, B \sqrt{\omega \left[1-\left(\frac{d}{a}\right)^2\right]}} \qquad (2)$$

where

$$B = \frac{1+\sqrt{1-\left(\frac{d}{a}\right)^2}}{\frac{d}{a}}$$

which for normal spacings between the centers of the wires which are as a rule large compared with the diameter d of the wire gives practically $B=\frac{2a}{d}$

a = distance between the centers of the wires.

d = diameter of the wire.

r_o = the direct current resistance per centimeter length of the double line expressed in electromagnetic c. g. s. units (10^9 e. m. u. = 1 ohm).

$\omega = 2\pi f$.

f = frequency in cycles per second.

Formula (2) is applied as follows: Using for example the parallel wire system of the Bureau of Standards for a frequency $f=2\times 10^7$ cycles per second, a diameter $d=0.145$ cm., and a spacing $a=4.2$ cm., $\frac{d}{a}=0.0345$; $\left(\frac{d}{a}\right)^2=0.00119$ which is in this particular case negligible compared with unity. Hence

$$B=\frac{2a}{d}=57.92.$$

Assuming the resistivity of copper equal to 1,600 c. g. s. units, we find for one centimeter length of the parallel wire system

$$\sqrt{r_o}=\sqrt{\frac{2\times 1600}{\frac{\pi}{2}\times 0.145^2}}=440 \text{ electromagnetic c.g.s. units}$$

and $\Delta=0.00121$, which shows that the frequency would be about 1/10 of a percent too high if the correction term Δ were neglected in equation (1). The result has been substantiated by experiment; frequencies calculated with formula (1) agreed with results

[4] This formula utilizes among other quantities an unpublished high frequency formula for the inductance of the parallel wire system which is due to Dr. Chester Snow of the Bureau of Standards.

obtained by an entirely different method of frequency standardization using Lissajous figures and a standard tuning fork.[5]

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SUMMARY: The above paper describes briefly calculations required in the parallel wire system used by the Bureau of Standards for radio frequency standardization. Formulas involving a correction term are given by means of which the standard frequency can be calculated from the distance between two consecutive maximum settings along the parallel wire system. A numerical example is added, showing the magnitude of the correction term.

[5] This method is described in a Bureau of Standards Scientific Paper now in press.