The General Radio Experimenter

VOL. V, NO. 9 FEBRUARY, 1931

ATTENUATION MEASUREMENTS ON TELEPHONE AND TELEGRAPH LINES

By J. W. HORTON *

IN its most elementary form the measurement of the attenuation of a telephone or telegraph circuit consists of measuring the power delivered to the line at the transmitting end and of measuring the power delivered by the line at the receiving end. The attenuation-frequency characteristic of a line is obtained by repeating these measurements at a suitable number of known frequencies.

In making these measurements, the impedance of the load to which the line delivers energy is generally made equal to, or matched to, the characteristic impedance of the line, which can usually be considered as a pure resistance without appreciable error. If this matching condition is met, the power delivered by the source of energy to the line is identical with the power which the same source would deliver to the load, were the latter connected to the source in place of the line. Furthermore, when the line is connected between the source and the load, the voltage across its input terminals and the voltage across the load terminals may be used as an indication of the power received and delivered, inasmuch as these voltages are impressed upon circuits of equal impedance.

In practice, therefore, the measurement of line attenuation is effected by terminating the line in a suitable load impedance, and in measuring the voltages across its input and output terminals. From the ratio of these two voltages, the attenuation of the line, in transmission units, is obtained by the following equation:

$$N = 20 \log_{10} \frac{V_{in}}{V_{out}} \text{ decibels.}$$

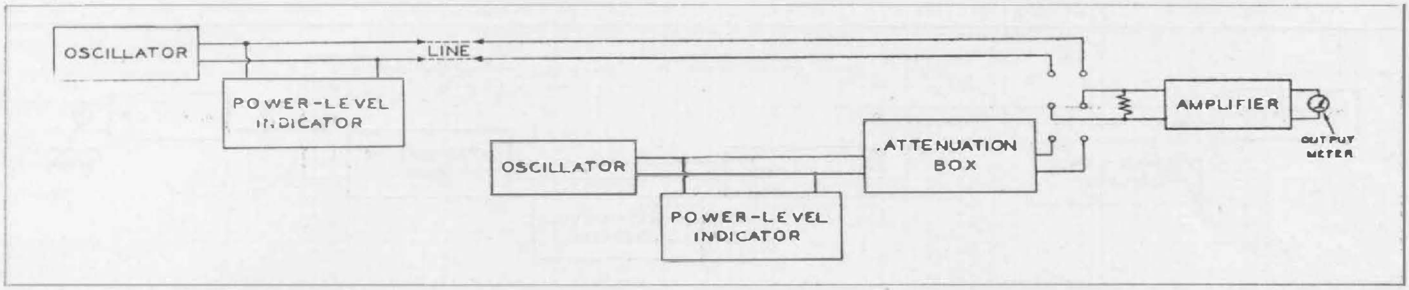

FIGURE 1. Apparatus and connections for measuring line attenuation by the modification of the standard method described in the accompanying article

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In practice, the voltage at the receiving end of the line generally has a magnitude so small that it cannot be measured by any available calibrated instrument. It is customary, therefore, to resort to a substitution method in which a calibrated attenuator, having the same impedance characteristic as the line, is used at the receiving terminal. The arrangement of circuits is shown in Figure 1.

The attenuator receives energy from a source similar to that connected to the transmitting end of the line. The voltage across the input terminals of the attenuator is adjusted to be equal to the voltage across the input terminals of the line; hence, as the impedances are equal, the power delivered is the same in each case. An amplifier having an input impedance equal to the characteristic line impedance, and therefore suitable for use as a load, is connected alternately to the line and to the calibrated attenuator, and the latter adjusted until the output of the amplifier as indicated by any suitable instrument is the same for both connections. When this condition is reached, the voltage set up across the load by the line is equal to the known voltage set up across the same load by the calibrated attenuator. For convenience, the latter is calibrated in transmission units — generally in decibels — and, hence, the attenuation of the line is indicated directly by the setting of the attenuator

As has already been noted, the calibrated attenuator must have the same characteristic impedance as the line. This condition applies only to the input terminals of the attenuator, and it is imposed in order that equal voltages across the input to the line and the input to the attenuator shall indicate equal amounts of power. When this condition is met, it is apparent that the calibrated attenuator presents the same impedance to the secondary source as would the load, were the secondary source and the load connected directly together.

Provided that the input impedance of the attenuator is the same as the load impedance, it is unnecessary for the output impedance of the attenuator to match the load impedance, inasmuch as the indicated attenuation for any setting refers to the actual ratio between the power supplied to the attenuator and the power delivered by the attenuator to the load. In other words, in those attenuation networks which present a constant impedance to the source only (i. e., L-type networks) the loss due to the impedance mismatch on the load side is included in the calibration.

In making the measurement outlined in the preceding discussion it is, of course, necessary to be sure that the frequency of the current supplied to the line and the frequency of the current supplied to the calibrated attenuator are identical. In order to avoid the necessity for repeatedly making this adjustment, and also to permit the measurement to be made in cases

(*Continued on page 7*)

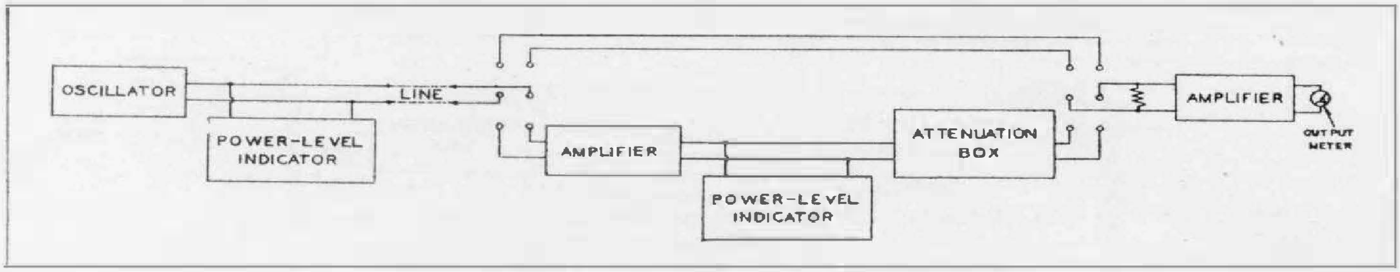

FIGURE 2. A method of measuring line attenuation like that of Figure 1 except that an amplifier replaces the oscillator at the receiving end of the line

SIMPLIFIED INDUCTANCE CALCULATIONS

By JAMES K. CLAPP[*]

WHILE much material has been published on the calculation of the inductance of coils,[†] the formulae given are in general not convenient for engineering use. Two difficulties are encountered in applying the results in engineering practice, one being the involved computations and the other the fact that differences in form and wire sizes and errors in the measurement of these factors introduce errors in the calculations which largely vitiate the utility of precise formulae.

For single-layer coils at radio frequencies (and, with slight modification, for bank-wound coils), Nagaoka's formula probably is the best for general engineering use. While neglecting the shape and size of the cross-section of the wire, the self-capacity of the winding and the variation of inductance due to skin-effect, it may be shown that the formula gives about as good results for high-frequency inductance as can be obtained.

Tables of the values of Nagaoka's correction factor have been prepared, but require considerable time to use due to the necessity for interpolations. The table values may be plotted in the form of a curve, but a more convenient interpolation is made possible by plotting these values on logarithmic scales, as has been done in Figure 3. Where much work of this type is done, the scales may be transferred to a slide-rule

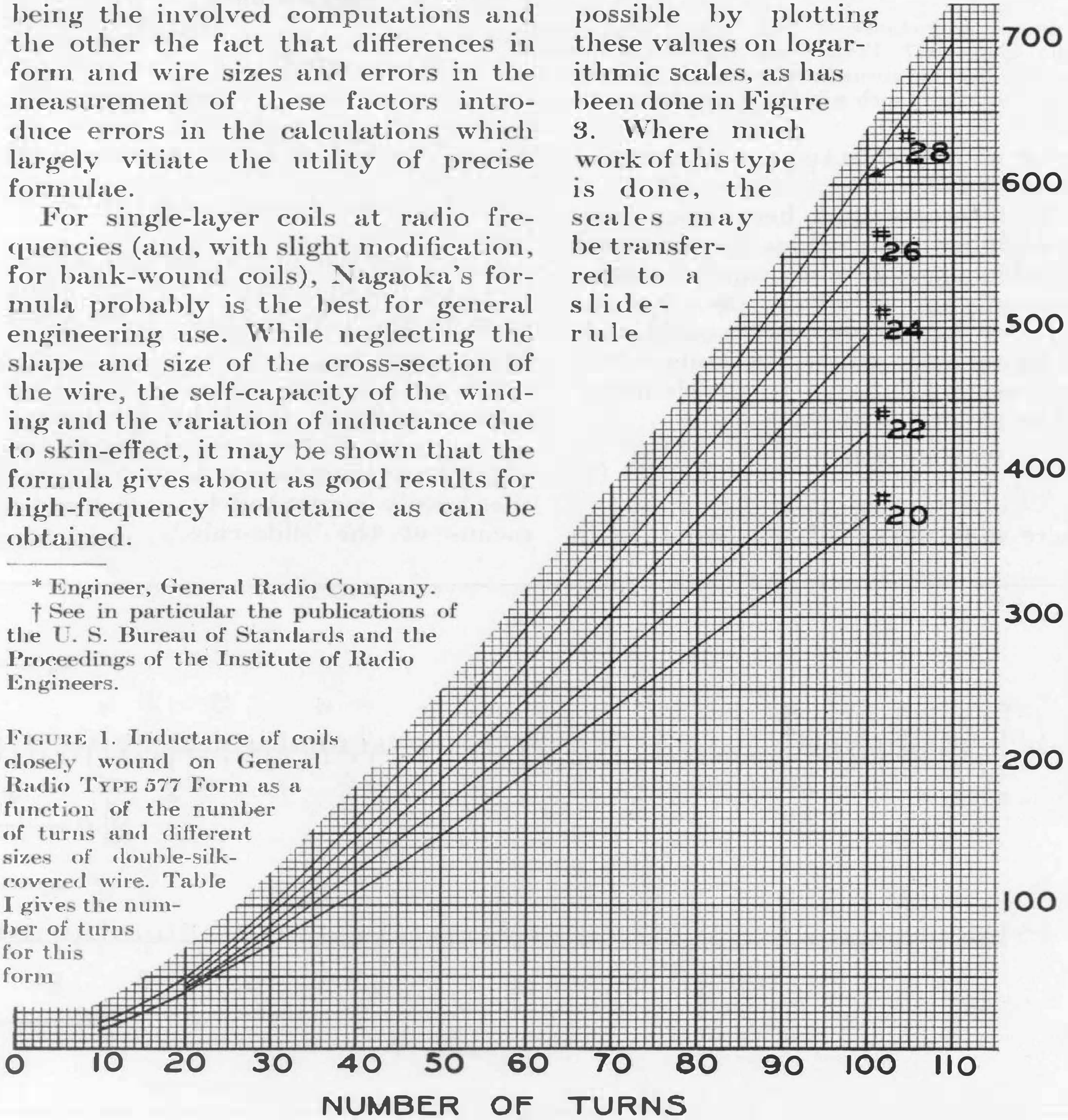

FIGURE 1. Inductance of coils closely wound on General Radio TYPE 577 Form as a function of the number of turns and different sizes of double-silk-covered wire. Table I gives the number of turns for this form

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[*] Engineer, General Radio Company.

[†] See in particular the publications of the U. S. Bureau of Standards and the Proceedings of the Institute of Radio Engineers.

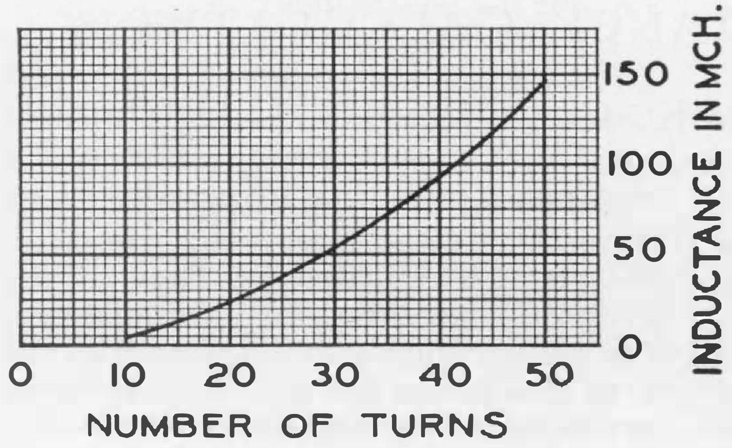


FIGURE 2. Inductance of coils wound on General Radio TYPE 577 Form with double-silk-covered wire in which the turns have been equally spaced in order to fill the 2-inch winding space. Here, $n_o = \frac{1}{2}n$

so that no reference to printed material is required.

The formulae given here, when carefully applied, give values of inductance to within about two per cent. for single-layer coils and to within about five per cent. for four-layer bank-wound coils for frequencies where the coils would serve as normal tuned-circuit elements.

The general formula is

$$L = \frac{0.1003a^2n^2K}{b}, \quad \text{microhenrys (1)}$$

where a is radius of a mean turn in inches, n is the number of turns, b is the length of the winding in inches, and K is Nagaoka's correction factor which is a function of $\left(\frac{2a}{b}\right)$ or the ratio of diameter to length of the winding.

If n_o is the number of turns per inch, the inductance and ratio of diameter to length are more conveniently given by:

$$L = 0.1003a^2nn_oK, \quad \text{microhenrys (2)}$$

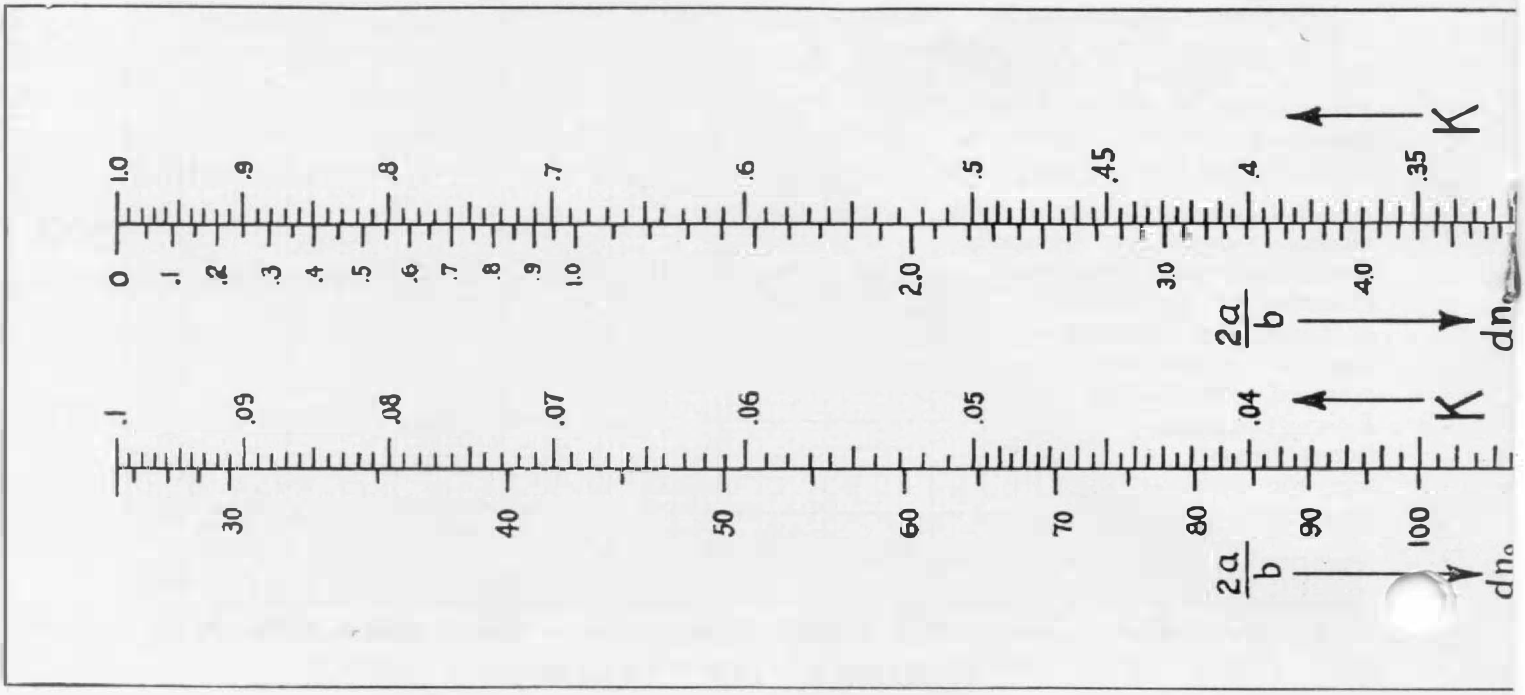
or $L = 0.0251d^2nn_oK,$ microhenrys (3)

$$\text{where } \frac{2a}{b} = \frac{2an_o}{n} = \frac{dn_o}{n} \quad \text{numeric (4)}$$

and d is the diameter of the mean turn in inches.

Given the size of wire and its insulation and the diameter of the coil form, n_o as wound, is found from Table I and $\frac{dn_o}{n}$ is readily computed for any desired number of turns. Read the corresponding value of K from the scales at the left. The inductance is then easily computed by means of the slide-rule.

FIGURE 3. Values of
different values of $\frac{2a}{b} =$



For banked windings of not too great depth as compared with the diameter, a close approximation for the inductance is obtained by using Nn_o for the turns per inch (where N is the number of banks) and $\frac{dNn_o}{n}$ for the ratio of diameter to length.

Then $\frac{2a}{b} = \frac{dNn_o}{n}$ numeric (5)

and $L = 0.0251 d^2 N n n_o K$, microhenrys (6)

The number of turns required for a desired value of inductance cannot be directly calculated since K varies as n is varied. With given types of windings experience will indicate an approximate value for the number of turns. If the computations are carried out and the inductance obtained is near the desired value, the correct number of turns to give the desired value may be obtained by readjustment, since K does not vary rapidly with n. Where many values are required it is simpler to calculate a sufficient number of values for a curve. The required values may then be read off directly. (See Figures 1 and 2, for example.)

TABLE I

WINDING DATA FOR CLOSELY WOUND COILS

SIZE OF WIRE B & S	TURNS PER INCH					TOTAL TURNS FOR FULL 2-INCH FORM
	Enamel	Single Silk	Double Silk	Single Cotton	Double Cotton	Double Silk
20	29	27	25	27	25	50
22	36	34	30.5	34	30	61
24	45	43	38	41	35	76
26	57	52	45	50	41	90
28	71	64	53	60	48	96
30	88	80	66	71	55	110
32	120	95	76	84	62	124

EXAMPLES OF CALCULATIONS

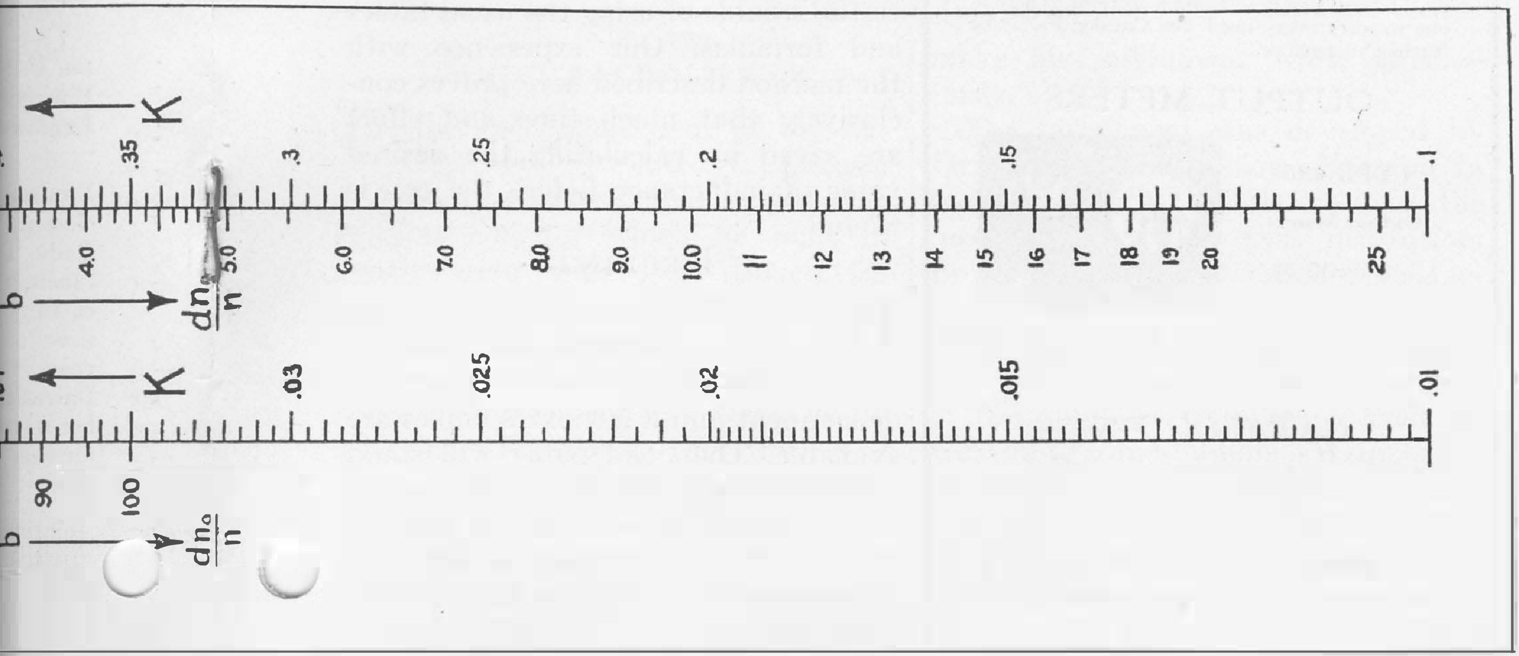
Given: Form diameter = 2.75 inches (General Radio Company TYPE 577 Form). Wire size = No. 20 double-silk-covered. *Find:* The inductance for coil of 35 turns.

Procedure: In Table I find $n_o = 25$

$$\frac{dn_o}{n} = \frac{\left(2.75 + \frac{1}{25}\right)25}{35} = 1.99$$

From scales, opposite 1.99 for $\frac{dn_o}{n}$, read

…URE 3. Values of Nagaoka's constant *K* for …erent values of $\frac{2a}{b} = \frac{dn_o}{n}$ on a logarithmic scale



$K = 0.526$

$$L = 0.0251 \times (2.79)^2 \times 35 \times 25 \times 0.526$$
$$= 90.0 \text{ microhenrys.}$$

For a rough estimate, the diameter of the form may often be taken as the diameter of a turn. In the above example this procedure gives $\frac{dn_o}{n} = 1.965$, $K = 0.530$ and $L = 88$ microhenrys, which differs from the previous value by about 2.5 per cent.

For bank-wound coils an example is as follows:

Given: $d = 2.75$, $n_o = 25$, $N = 4$, and $n = 200$

$$\text{Then, } \frac{dNn_o}{n} = \frac{\left(2.75 + \frac{4}{25}\right) 25 \times 4}{200}$$
$$= 1.455.$$

From Figure 3, $K = 0.604$

$$\text{Then } L = 0.0251 \times \left(2.75 + \frac{4}{25}\right)^2 \times 4$$
$$\times 25 \times 200 \times 0.604 = 2570 \text{ microhenrys.}$$

Many experimenters and many engineers "design" inductors by guessing at the number of turns, then peeling off wire until the correct value of inductance is obtained rather than go to the trouble of using the usual tables and formulas. Our experience with the method described here proves conclusively that much time and effort are saved by calculating the desired value of inductance before the coil is wound.

REPRINTS

REPRINTS of Mr. Clapp's article have been prepared on bond paper for the use of our own engineering department and a few extra copies are available. The bond paper will stand handling much better than the paper on which the *Experimenter* is printed. A copy of the reprint may be had without charge by writing to the General Radio Company.

FOR MEASUREMENTS OF ATTENUATION

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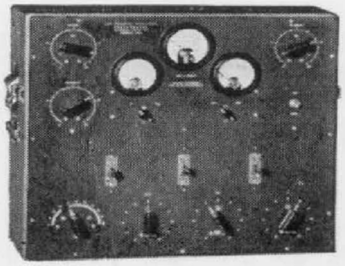

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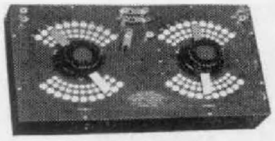

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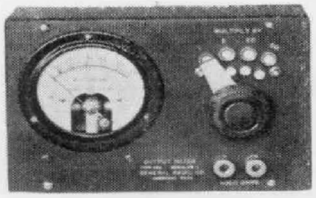

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HORTON: ATTENUATION MEASUREMENTS

(*Continued from page 2*)

where a duplicate source may not be available at the receiving end, it is possible to carry out the measurement as indicated in Figure 2. In this figure it will be noted that the oscillator of Figure 1 is replaced by an amplifier which may be connected to the line whenever the load is connected to the output of the calibrated attenuator. The amplification of this secondary source amplifier is adjusted until the voltage across the input end of the attenuator at the receiving terminal is the same as the voltage across the input end of the line at the transmitting terminal. In this case, it is apparent that the frequency of the current delivered to the attenuator must be identical with the frequency delivered to the line. One objection to this method lies in the fact that the wave supplied to the attenuator may fail to duplicate exactly the wave supplied to the line, due to the presence of interference picked up by the latter.

It should be noted, in connection with the alternative source of local current just described, that it is unnecessary for the input impedance of the secondary source amplifier to match the line impedance, inasmuch as the efficiency of this connection plays no part in the measurement. It should further be pointed out that it is quite unnecessary to know the gain or amplification of the source amplifier, or of the load amplifier used in making the voltage comparison; the frequency characteristics of these amplifiers are, consequently, of no importance in connection with the attenuation measurement, provided that the gain is adequate at all frequencies.

To summarize the requirements imposed on the measuring equipment, therefore, we note that the calibrated attenuator must be designed so as to have the same input impedance as the line with which it is to be compared, and that the impedance of the voltage-indicating amplifier, which is connected alternately to the line and to the calibrated attenuator, must match this characteristic impedance.

MISCELLANY

CARDIOTACHOMETER

IN the July, 1930, issue of the *Experimenter*, Horatio W. Lamson described an instrument called the cardiotachometer which he built in collaboration with Paul Bauer, for measurement of a patient's heart at rest or during exercise.

Two of our readers have written that a similar instrument was described by Dr. Ernst P. Boas in the *Archives of Internal Medicine* for March, 1928. Mr. Lamson did not then know of Dr. Boas' cardiotachometer or he would have referred to it, inasmuch as it had many features he found necessary to make his instrument work satisfactorily.

The instrument was developed by Dr. Boas at Montefiore Hospital in New York City, while he was the medical director of that institution. From the outset, Dr. Benjamin Liebowitz was associated with him in the work. They were fortunate in obtaining help in the design and construction of the amplifier from Dr. Alfred N. Goldsmith and Julius Weinberger, Theodore A. Smith, and George Rodwin of the Radio Corporation of America. Subsequent developments of the instrument were worked out by Dr. William W. Macalpine, at that time fellow in the department of physics at Columbia University.

Dr. Boas has given us a great deal of information about the use of the apparatus and anyone interested in heart measurements should read the results of his measurements in the following articles: Boas and Goldschmidt, "Continuous Recording of the Heart Rate During Operations," *Journal American Medical Association*, XCIV (1930), 1210; Boas and Weiss, "The Heart Rate During Sleep as Determined by the Cardiotachometer," *Journal American Medical Association*, XCII (1929), 2162; Boas and Goldschmidt, *Klinische Wochenschrift*, IX (1930), 1115; and Boas, "The Ventricular Rate in Auricular Fibrillation Studies with the Cardiotachometer," *American Heart Journal*, IV (1929), 449.

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PRECISION WAVEMETERS

OWNERS of General Radio TYPE 224, TYPE 224-A, and TYPE 224-L Precision Wavemeters will be interested in knowing that we have just completed the preparation of a new instruction book to cover all three instruments. If you have one of these precision wavemeters, you are entitled to a copy without charge. Please mention the type number and serial number of your wavemeter in your request.

VOLUME CONTROLS

ACCORDING to some of the General Radio Company's advertising, an article on the use of volume controls in high-quality sound systems was to have appeared this month. Unfortunately, it has been necessary to postpone the appearance of this article to a future issue of the *Experimenter*. We hope that no reader has been inconvenienced.

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