TRANSMISSION CHARACTERISTICS OF NON-LOADED TOLL AND TOLL ENTRANCE CABLE PAIRS

CONTENTS

1. GENERAL

1.01 This section presents information on transmission characteristics of non-loaded pairs in toll entrance and toll cables with copper wires of 16 and 19-gauge (AWG) of nominal capacitance of .062 mf per mile over a frequency range up to 150 kc. The data are based on measurements on full size quadded cables but for engineering purposes can, in general, be applied to small size cables. The attached tables and graphs show typical values of attenuation, phase shift, characteristic impedance and primary constants for these gauges. Some information is also included on 10 and 13-gauge quadded cable, 16 and 19-gauge paired cable, 16-gauge spiral-four disc-insulated .025 mf/mile cable, and 10-gauge .055 mf/mile paired cable. In some cases, information is given for frequencies above 150 kc. The values given herein are representative values only and considerable variation may be expected from cable to cable and even between pairs within a single cable.

1.02 In addition to covering a much wider frequency range than formerly, data given herein include the effects of temperature on the cable characteristics. The values given on the attached tables and curves are believed to be the best available information at this time.

1.03 This section deals largely with the application of carrier frequencies to toll and toll entrance cables, but the fundamental transmission theory which applies to toll and toll entrance cables at these frequencies can also be applied to other wire transmission systems. For this reason the first part of this section will present some of the basic theory and fundamental formulas applying to transmission lines in general. Whether the transmission is at voice frequencies or at frequencies in the television range the wires will still act as guides to the electrical energy, although the distribution of currents across the sections of the wires changes a great deal as the frequency is increased.

1.04 The basic transmission theory assumes that the line is what is called a smooth line, which means that every part of the line is just like every other part of the line. Thus, if the line were cut up into one-foot lengths the resistance, etc., would be the same for all of these one-foot lengths. Besides the series resistance of the wires of a pair there will be a certain small amount of leakage from one wire to the other. This is known as leakage conductance. It is easy to see that two wires placed so close together as wires are in a cable will act somewhat like the two plates of a condenser and will therefore have a certain electrical capacitance. Finally, since the currents usually carried by these wires are alternating, there will be a certain amount of magnetic flux surrounding each wire and this flux will change as fast as the currents themselves alternate. This change in the flux between the two wires, or the variation in the amount of flux linking the wires of a pair, will produce an electromotive force tending to oppose the current which produces the flux in the first place. The amount of this back emf is determined by the inductance of the pair of wires. These four quantities*, series resistance R, series inductance L, shunt conductance G, and shunt capacitance C determine the behavior of the line as a transmission line.

1.05 It is well known that the series resistance of a line carrying alternating current is not the same as the direct current resistance. An important factor in producing this change in resistance with frequency is the phenomenon known as skin effect. A second factor is known as proximity effect, which, as its name indicates, is a change in current caused by the presence in its neighborhood of the other conductor or conductors and the sheath.

1.06 It was mentioned above in connection with the series inductance of the line that the variation in current produces a back emf. If the current in a wire is of very low frequency or direct current, the current is distributed uniformly across the section of the wire, but if the frequency be increased the current flowing in the central portion of the wire will produce a counter emf to the voltages in portions of the wire surrounding it. In order to balance this counter emf, more current flows in the outer portion of the wire, resulting in a concentration of current in the outer layers of wires at high frequencies. This current concentration near the surface of conductors at high frequencies is called skin effect.

1.07 In a similar way the flux linkages from one wire of a pair to the other wire of a pair produce counter emf's so that there is a tendency for larger currents to flow in the adjacent portions of the two wires. This produces an unsymmetrical distribution of the currents in the separate conductors and since it is caused by their nearness to each other, it is known as the proximity effect.

1.08 Temperature effects are much more pronounced at carrier frequencies than at voice frequencies and the daily and annual variations are larger in aerial cables than in underground cables. It is well known that the resistance of a copper conductor changes rapidly with temperature and this resistance change has a large effect on the attenuation. The temperature coefficient for a-c resistance is not the same as for d-c because of skin and proximity effects. The other constants of the pair are also affected by temperature and contribute additional small amounts to the change in attenuation with temperature.

1.09 Manufacturing processes can be subjected to a certain amount of control but there remain small variations in the finished product. These manufacturing variations can be corrected for in part by proper splicing of the cutting lengths so far as the overall circuit is concerned but there will, in general, still remain a certain amount of irregularity in the circuit as installed.

1.10 In a given reel length of cable there will be obvious differences in length of the inside and the outside pairs. In addition there are differences in capacitance, and other primary constants caused by the different surroundings of given pairs. For example, a pair in the layer next to the sheath will have its constants affected by the presence of the lead sheath on one side and the copper-paper combination on the other side of the pair but a pair in the center of a cable is surrounded by a symmetrical mixture of copper and paper as well as by the lead sheath. These differences will also show up as irregularities since the constants may vary from reel to reel along the installed cable.

1.11 Another cause of differences between constants of cables is the presence of copper sheath or shields. These shields may be either static shields surrounding all the pairs in the cable or they may be layer shields put in for the purpose of separating inner and outer groups of pairs. Such shields have the largest effect on pairs in the adjacent layers, but these effects are also largely averaged out by the splicing arrangements. The presence of coaxial pairs in the same cable with 19-gauge paper-insulated pairs also introduces small changes in the characteristics of the paper-insulated pairs.

1.12 The static shields and layer shields mentioned above are put in to reduce noise or crosstalk. The problems of noise and

* Although R, L, G and C are called constants, they vary a great deal from cable to cable and from pair to pair, as will be shown later.

crosstalk are treated in other sections and are not considered here.

2. FORMULAS*

(A) Exact Formulas

2.01 The fundamental line formulas will be given first in general form. Following the general formulas will be given the formulas which may be used for special cases, such as for very high frequencies, etc.

2.02 The most important quantities in the application of transmission theory to the engineering of a telephone system are the attenuation, phase change and characteristic impedance of the line. These in turn are expressed in terms of the distributed constants of the line per unit length, namely, the resistance R in ohms, the inductance L in henrys, the conductance G in mhos, and the capacitance C in farads. The usual unit of length is the mile, and the designation smooth or distributed constants means that all parts of the line are exactly alike and that the values are those which would be obtained by measurements and computations based on an infinitely long line, or, what amounts to the same thing, on a line terminated in its characteristic impedance.

2.03 Although these quantities are all spoken of as constants, as noted above they are not actually constant but vary with the frequency and with the temperature of a given line.

Propagation Constant

2.04 The propagation constant at any frequency, f, for a unit length of line having the uniformly distributed primary constants, R, L, G and C per unit length is given by the formula

$$P = \alpha + j\beta = \sqrt{(R+j\omega L)(G+j\omega C)} \qquad (1)$$

In this formula the real part α gives the attenuation constant in nepers, and the imaginary part β gives the phase constant in radians. The equation may be solved for α and β, giving

$$\alpha^2 = \frac{1}{2}\left[\sqrt{(R^2+\omega^2L^2)(G^2+\omega^2C^2)} + RG - \omega^2LC\right] \qquad (2)$$

$$\beta^2 = \frac{1}{2}\left[\sqrt{(R^2+\omega^2L^2)(G^2+\omega^2C^2)} - RG + \omega^2LC\right] \qquad (3)$$

* See Part 9, References, Particularly Chapter XII of Reference No. 1, Chapter XX of Reference No. 2, Page 272 of Reference No. 4 and Page 244 of Reference No. 10.

Attenuation Constant

2.05 The attenuation constant as given by Equation (2) in nepers may be transformed into decibels by multiplying the value obtained from Equation (2) by 8.686. The derivation of this relation is covered in a section of the Educational Training Material series. If R, L, G and C are given on a per mile basis the attenuation computed from Equation (2) will also be on a per mile basis.

Phase Constant or Wavelength Constant

2.06 The imaginary component β in Equation (1) is called the phase constant since it indicates the change in phase of voltage or current in circular radians per unit length of line. Thus, if R, L, G and C are given on a per mile basis, computations of the phase constant from Equation (1) or (3) will give β in radians per mile.

2.07 Since by definition β represents the phase change in one mile and the frequency f designates the number of complete waves or cycles per second so that the angle of rotation is $2\pi f$ radians per second, the number of miles traversed per second, that is, the velocity of propagation is therefore

$$V = \frac{2\pi f}{\beta} = \frac{\omega}{\beta} \text{ miles per second} \qquad (4)$$

Moreover, the distance traversed in a second is also equal to the frequency times the wavelength so that the velocity of propagation is also given by the equation

$$V = f\lambda \qquad (5)$$

where λ = the wavelength in miles if V is the velocity in miles per second for the frequency f cycles per second.

Comparison of Equations (4) and (5) shows that the wavelength is given by the equation

$$\lambda = \frac{V}{f} = \frac{2\pi}{\beta} \qquad (6)$$

Characteristic Impedance

2.08 The characteristic impedance of the smooth line referred to above is

$$Z_o = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \qquad (7)$$

This expression represents the impedance of an infinitely long circuit or of a circuit terminated by the characteristic impedance itself. It is independent of the length of the circuit since if a piece be cut off from an infinite line, there will still remain an infinite line.

(B) Approximate Formulas

2.09 A very useful approximate form of Equation (2) for attenuation is

$$\alpha \doteq \frac{R}{2}\sqrt{\frac{C}{L}} + \frac{G}{2}\sqrt{\frac{L}{C}} \doteq \frac{R}{2Z_o} + \frac{GZ_o}{2} \qquad (8)$$

In deriving this formula* it is assumed that ω^2L^2 is large as compared with R^2, and that ω^2C^2 is large as compared with G^2. These conditions are closely enough realized in non-loaded cable circuits at carrier frequencies so that the error in using Formula (8) instead of the accurate Formula (2) is about 3 per cent for 19-gauge cable pairs at 30 kc, about 1-1/2 per cent at 50 kc and about 1/2 per cent at 100 kc. The value of α as in Equation (2), is given in nepers by Equation (8), and the values computed therefrom must be multiplied by 8.686 to change to db.

2.10 With the same assumptions regarding ωL and ωC, the phase constant given by Equation (3) reduces to

$$\beta \doteq \omega\sqrt{LC} \qquad (9)$$

radians.

2.11 The velocity of propagation from Equation (4) is then approximately

$$V \doteq \frac{1}{\sqrt{LC}} \qquad (10)$$

2.12 The characteristic impedance for lines such that ω^2L^2 and ω^2C^2 are large as compared with R^2 and G^2, respectively, reduces to

$$Z_o \doteq \sqrt{\frac{L}{C}} \qquad (11)$$

2.13 These approximate formulas are convenient for rough calculations but care must be exercised to see that the assumptions made apply to the particular case at hand.

(C) Formulas for Primary Constants

2.14 The formulas given above assume that the primary constants are known for a smooth line. In what follows these constants for a smooth line will be called true constants.

2.15 If the attenuation, phase and characteristic impedance of the line are known, the true constants can be determined from Equations (1) and (7) giving the following formulas from which R, L, G and C may be obtained directly.

$$R + j\omega L = Z_o\ (\alpha + j\beta) \qquad (12)$$

$$G + j\omega C = \frac{(\alpha + j\beta)}{Z_o} \qquad (13)$$

2.16 Although the Formulas (12) and (13) give the primary constants directly in a very simple way, it is generally impracticable to make all of the required measurements on a cable as actually installed and moreover there is ordinarily very little reason for determining the primary constants in the field.

2.17 The formulas which have been given in various places** for skin effect and proximity effect assume that the wires involved are widely separated from other wires and are surrounded by air. Such conditions are not fulfilled in a cable where the pairs are surrounded by paper, air, copper and lead, and any attempt to formulate their effects gives at most an approximate formula. An idea of the magnitudes of these other effects may be obtained from the curves which are attached.

3. PRIMARY CONSTANTS

(A) Resistance

3.01 Typical values of the resistance per mile of Nos. 10, 13, 16 and 19 AWG (American Wire Gauge) copper cable pairs are shown on Table 1, Page 101, and by the curves on Pages 115, 119 and 120. These tables and curves extend to frequencies of 150 kilocycles and apply to pairs of nominal capacitance of .062 mf per mile.

3.02 The a-c resistance of pairs of wires in cables is increased by the skin effect, but there is an additional large increase because of the proximity effect. This proximity effect is another name for the effects caused by the presence of the other wires in the cable and the lead sheath. The curves on Page 116 show the computed values of a-c resistance for 16 and 19-gauge pairs based on the formulas for skin effect** and typical measured values of resistance for 16 and 19-gauge pairs. The formulas for skin effect apply to a wire surrounded by air and at a great distance from other conductors. The difference between the two curves shows the amount added because the wires in a cable are surrounded by paper, copper of the other pairs and the lead sheath. The increase for 19-gauge pairs at 60 kilocycles is about 15 ohms per mile and at 100 kilocycles is about 22.5 ohms per mile.

3.03 The changes in a-c resistance with temperature are more pronounced than the changes in d-c resistance with temperature.

* Reference No. 1, Page 147.

** See References 9, 13 and 14.

Table 1, Page 101, shows typical values of the resistance of No. 16 and No. 19 AWG cable pairs over the temperature range from 0° to 110° F for various frequencies up to 150 kc. Curves of resistance vs temperature are shown on Pages 117 and 118 for 16 and 19-gauge pairs for temperature 0° to 110°F. The variation of resistance of 16-gauge pairs with frequency is shown for temperatures of 0°, 55° and 110° on Page 119 and for 19-gauge pairs on Page 120. Up to 50 kc the changes in resistance of 13-gauge pairs with temperature are about one-half as great as the changes in resistance of 16-gauge pairs. The changes in resistance of 10-gauge pairs with temperature are about 1/4 those of 16-gauge pairs to 50 kc.

3.04 Typical values of the coefficient of resistance increase with temperature, $\frac{\Delta R}{R}$ in ohms per ohm per degree F are shown on Page 121 for 19-gauge pairs. These may be converted to percentage changes by multiplying by 100. For example, the change in d-c resistance of 19-gauge pairs at 65° is 0.22 per cent of its resistance at 65°, that is, if the temperature increases to 66° the d-c resistance increases by .22 per cent; if the temperature decreases to 64° the d-c resistance decreases by 0.22 per cent. At the same time the a-c resistance at 150 kc increases or decreases by only 0.10 per cent.

3.05 The temperature of cables buried in ducts ranges from about 35° to 75°F during the year with an annual average of about 55°F. Cables buried only a foot or so under ground have a considerably larger annual temperature variation than cables buried in the deeper ducts, but the actual depths of buried cable range from about 1 foot to 3 feet. Aerial cables are at about the same temperature as the surrounding air in cloudy and cold weather. On very hot, sunshiny days with no wind, the temperature of the wires inside the cable sheath may range as much as 20 to 25 degrees higher than the temperature of the air surrounding the sheath. This large difference must be allowed for in the computations of aerial cable constants at high temperatures.

(B) Inductance

3.06 Typical values of the inductance per mile of Nos. 10, 13, 16 and 19 AWG cable pairs are shown on Table 2, Page 102. The curves on Page 122 show 55° data vs frequency for 10 and 13-gauge pairs. The curves on Pages 123 and 124 show the inductance vs temperature of 16-gauge and 19-gauge pairs in millihenrys per mile over the temperature range from 0° to 110°F at various frequencies to 150 kc. Pages 125 and 126 show the inductance of 16-gauge and 19-gauge pairs vs frequency for temperatures of 0°, 55° and 110°F.

(C) Capacitance

3.07 Typical values of the capacitance of Nos. 10, 13, 16 and 19 AWG cable pairs of nominal .062 mf/mile cable are shown for frequencies up to 150 kc on Table 3, Page 103. Page 127 shows the capacitance in microfarads per mile vs frequency for Nos. 10 and 13 AWG pairs at 55°F. Page 128 shows capacitance vs temperature for 19-gauge pairs at frequencies from one to 150 kilocycles. The curves on Pages 129 and 130 show typical values of the capacitance per mile vs frequency for 16 and 19 AWG pairs at 0°, 55° and 110°F.

(D) Leakage Conductance

3.08 Typical values of the leakage conductance of Nos. 10, 13, 16 and 19 AWG cable pairs are shown on Table 4, Page 104. Pages 131 and 132 show conductance per mile vs frequency for 16-gauge and 19-gauge pairs at 0°, 55° and 110°F. The conductance vs temperature is plotted on Pages 133 and 134 for 16-gauge and 19-gauge pairs at frequencies up to 150 kilocycles. The same data plotted vs frequency on log-log paper, that is, paper having both scales logarithmic, Page 135, give points very close to straight lines over a large frequency and temperature range. This indicates that the conductance is related to frequency by a formula of the Type $G = Af^k$, where A and k are constants. No complete data for 10-gauge pairs are available and the values given in the table are estimated values only.

3.09 The value of leakage conductance depends a great deal upon the type of drying process used in the manufacture of the cable. The usual measure of the effectiveness of the drying is the quantity $\frac{G}{2C}$ the leakage conductance divided by twice the capacitance. The average value of $\frac{G}{2C}$ for 1000 cycles at the usual factory room temperature, 70°F, is about 8.3 for cable of nominal .062 mf/mile capacitance. The value of $\frac{G}{2C}$ increases with frequency and at the same time decreases with temperature in very nearly the same way G changes since the changes in capacitance C with temperature are relatively small.

3.10 There are many factors which may cause variations in the value of leakage conductance obtained for any particular piece of cable manufactured. Among these factors are the dielectric constant of the paper, gauge of the wire and the pressure used in the manufacturing process. The dielectric constant of the paper, in turn, depends upon a number of factors such as the amount of air contained in the paper or, in other words, the porosity of the paper and the amount of impurities contained in the paper. These affect the leakage conductance and the capacitance in a complicated way. About 40 per cent of the space around the wires inside the sheath is filled with paper and the remaining 60 per cent with air. Any moisture remaining in the cable in spite of the drying process also exercises an important effect upon the conductance and capacitance. The dielectric constant of cables averages about 1.7 to 1.9.

(E) Layer to Layer Variations of the Primary Constants

3.11 Because of the differences in length, pressure and surroundings of the pairs, the primary constants are not the same in all layers of a large cable. Typical values of the average percentage amount of variation from layer to layer are shown on Page 136 for a number of layers in a full size toll cable for frequencies from 10 to 60 kilocycles.

(F) Primary Constants of 16-Gauge Pairs in Disc-Insulated Cable

3.12 Typical values of the primary constants of No. 16 AWG pairs in spiral-four disc-insulated (Type J) cable at 55°F are shown on Table 5, Page 105 for frequencies up to 150 kilocycles per 100 feet of sheath length. Such cables are usually short (toll entrance) and the 100-foot values are more convenient to use than values on a per mile basis. Changes of these primary constants with temperature are slight except for the resistance. The d-c resistance has the usual temperature coefficient of .00221 ohm per ohm per degree F, at 55°F. At 150 kilocycles the percentage change in resistance is about half as much as the d-c change. Capacitance and inductance change about 1/2 per cent for a 50°F temperature change.

4. ATTENUATION AND PHASE CHANGE

(A) Typical Values

4.01 Table 6, Page 106, shows typical values of attenuation in db per mile for Nos. 10, 13, 16 and 19 AWG cable pairs at frequencies to 150 kilocycles. Curves on Pages 137 and 138 show the attenuation vs frequency of 16-gauge and 19-gauge pairs at 0°, 55° and 110°F.

4.02 Table 7, Page 107, shows typical values of phase change β for Nos. 10, 13, 16 and 19 AWG cable pairs for frequencies to 150 kilocycles. Page 139 shows the phase change in radians per mile vs frequency at 0°, 55°, and 110°F for No. 16 AWG cable pairs.

(B) Attenuation Changes with Temperature

4.03 The large changes in cable constants with temperature produce correspondingly large changes in attenuation as shown by Table 7, Page 107. The attenuation of 19-gauge pairs vs temperature is plotted at frequencies ranging from one to 150 kilocycles on Page 140.

4.04 The changes in attenuation with temperature are not the same at all frequencies. This is shown by the curves on Page 141 showing the change in db per degree F per mile plotted vs frequency for Nos. 16 and 19 AWG pairs. This difference between the values of the temperature coefficient at different frequencies is called twist. Typical values of twist referred to 28-kilocycle values for 19-gauge pairs are shown on Page 142. The change in attenuation with temperature for 13-gauge pairs is about 1/2 the change shown on Page 141 for 16-gauge pairs. The change for 10-gauge pairs is about 1/4 the change for 16-gauge pairs.

4.05 The large contribution of the resistance component to the variation of attenuation with temperature is shown for No. 19 AWG pairs by the curves on Page 143. The curves also show the components of the attenuation-temperature coefficient due to the capacitance C, inductance L, and leakage conductance G. It will be seen that for frequencies above about 21 kilocycles the component added by capacitance changes is more than neutralized by the conductance and inductance changes which are negative, so that the total is less than the R component alone.

(C) Disc-Insulated Cable

4.06 Typical values of attenuation and phase change at 55°F of 16-gauge pairs in Type J disc-insulated cable are shown on Table 8, Page 108, for frequencies up to 150 kilo cycles. Temperature changes are slightly smaller than for quadded 16-gauge pairs.

(D) Low Capacity 10-Gauge Paired Cable

4.07 Insertion losses in decibels per mile determined from measurements at about 60° temperature on a 5.14-mile length of 10-gauge paper—insulated .055 mf/mile pair cable at Charlotte, N.C., are shown on Table 13. Page 113. The inner and outer groups differed from their average by as much as 3 per cent below 50 kc but were substantially identical at higher frequencies.

(E) Building-Out Cable

4.08 Building-out cable is designed to have the standard capacitance of .062 microfarads per mile. The other constants of 19-gauge pairs in building-out cable are close to the values given for 19-gauge pairs in toll cable.

4.09 The resistance of 22-gauge pairs in building-out cable is about twice the resistance of the 19-gauge pairs at voice frequencies. The other primary constants are designed to be closely equal to the 19-gauge values. Attenuation and characteristic impedance are somewhat higher than for 19-gauge pairs. Data (1000 ft. basis) given in Table 14, Page 114, for 22-gauge emergency cable may also be used for 22-gauge building-out cable.

(F) Emergency Cable

4.10 Cable is sometimes used for emergency construction on open-wire lines. The characteristics of 22-gauge emergency cable and 19-gauge "CL" emergency cable are given on Table 14, Page 114. The "CL" emergency cable is rubber-insulated and is made up of 7 or 19 quads of 19-gauge conductors.

5. CHARACTERISTIC IMPEDANCE

5.01 Typical values of the characteristic impedance are shown on Table 9, Page 109, for Nos. 10, 13, 16 and 19 AWG pairs for frequencies to 150 kc. The curves of Pages 144 and 145 show the resistance and reactance components vs frequency for Nos. 16 and 19 AWG pairs at 55°F.

5.02 The magnitudes of changes in the components of characteristic impedance with temperature are not very large in the carrier frequency range. This is shown by the data on Table 9, Page 109, which gives typical values of 16-gauge and 19-gauge characteristic impedance at temperatures of 0°, 55° and 110°F for frequencies to 150 kilocycles. It will be seen that both components increase with temperature at low frequencies but at high frequencies the resistance component decreases with temperature while the magnitude of the reactance component increases with temperature.

5.03 Typical values of the characteristic impedance of 16-gauge pairs in spiral-four Type J disc-insulated cable at 55°F are shown on Table 10, Page 110, for frequencies up to 150 kilocycles. Temperature changes are slightly smaller than for quadded 16-gauge pairs.

5.04 Characteristic impedances measured on the 5.14-mile length of .055 mf/mile 10-gauge paper-insulated pair cable at Charlotte, N.C., are given on Table 13, Page 113. The presence of the shield around the inner group reduces its impedance by about 13.5 per cent at 150 kc.

6. PHASE DELAY AND VELOCITY OF PROPAGATION

6.01 The transmission time of an unmodulated single frequency wave is given by the ratio $\frac{\beta}{\omega}$ which is called the phase delay. The phase delay of a modulated wave is also $\frac{\beta}{\omega}$ but the transmission time is approximately given by $\frac{d\beta}{d\omega}$, called the envelope delay. Table 11, Page 111, shows typical values of phase delay in microseconds per mile for Nos. 10, 13, 16 and 19 AWG pairs for frequencies to 150 kilocycles. Since the phase characteristic vs frequency at carrier frequencies is substantially linear, the slope of the phase characteristic, that is, the envelope delay, is very nearly a constant.

6.02 Representative values of the velocity of propagation (or the ratio ω/β) for Nos. 10, 13, 16 and 19 AWG cable pairs at 55°F are shown on Table 12, Page 112, at frequencies to 150 kilocycles.

7. DATA OBTAINED BY DIRECT MEASUREMENT

7.01 Data presented in the previous parts largely were obtained by computations based on open-circuit and short-circuit impedance measurements made on reel lengths of standard toll cable placed in a room whose temperature could be controlled as desired. Measurements of this kind are generally not practicable for actually installed cable. In the first place, the temperature cannot be controlled and in the second place, for cables several miles or more in length there is very little difference between open and short-circuit impedance. It is possible, however, to obtain measurements of attenuation and characteristic impedance, while determining the average temperatures by means of d-c resistance measurements with reasonable accuracy.

7.02 Curves on Page 146 show the insertion loss between 125-ohm resistances measured on a section of toll entrance cable at Denver, Colorado. These curves show data for Nos. 13, 16 and 19-gauge pairs at frequencies up to 200 kilocycles. The different curves for each gauge represent data for different pairs in the cable. Curves on Page 147 show the average results of attenuation measurements made on 19-gauge pairs in a section of the Morristown-Easton A cable at frequencies from 8 to 60 kilocycles. These curves show a small difference between the average attenuations of the inner and outer groups for this particular cable. This difference reflects the difference in length of the pairs and the effect of the sheath on the resistance and inductance of the outer group as well as differences in capacitance and conductance of the two groups. Similar attenuation measurements were made on 10-mile sections of two cables near LaGrange, Indiana, with results as shown on Page 148. These measurements covered a long enough time to get both winter and summer values and temperature correlations were obtained by means of d-c resistance measurements. It will be observed that the two cables differed by as much as 0.1 db per mile at higher temperatures and frequencies. Cable A which has the larger attenuation is full size (112 quads). Cable B is oversize (212 quads). The attenuation variation with temperature computed from these data is shown on Page 149 for three of the four cables measured. The curves for Cables A and B differ somewhat but are close to the 19-gauge curve shown on Page 141 based on the laboratory measurements.

7.03 Impedance measurements on certain pairs in the toll entrance cable (Nos. 13, 16 and 19-gauge) at Denver, Colorado, gave the results shown on Page 150. The irregularities in these curves are caused by reflections, both within reel lengths and at splices in the cable. There are large variations in the values measured on different pairs of the same gauge in these cables. This is generally true of results of measurements on pairs of cable as actually installed as a consequence of the addition of effects caused by many small irregularities.

7.04 Page 151 shows average results of impedance measurements made on ten pairs in one of the cables at LaGrange, Indiana.

8. EXTENSION TO VERY HIGH FREQUENCIES

8.01 Some of the laboratory measurements were extended to frequencies as high as 3000 kilocycles representing a full wavelength for the particular reel being measured. The curves on Page 152 give the attenuation of 16-gauge pairs at frequencies to 2000 kilocycles as obtained from laboratory measurements and from measurements on 3.6 miles of aerial cable at Ticonderoga, New York. Similar 19-gauge data are shown on Page 153 for frequencies up to 700 kilocycles. The change in attenuation per degree F for the 16-gauge pairs measured at Ticonderoga is shown on Page 154 for frequencies up to 1100 kilocycles. At the high frequencies the variation per degree depends upon the temperature of the cable, the variation decreasing rapidly as the temperature is increased. Corresponding data on the change of attenuation per degree F for 19-gauge pairs at frequencies up to 700 kilocycles are shown on Page 155. The rate of change is much larger than for 16-gauge but decreases with temperature in about the same way at high frequencies.

9. INSERTION LOSSES DUE TO CABLE OF VARIOUS LENGTHS

9.01 Wherever it is necessary to connect open-wire circuits to non-loaded cable circuits, reflection losses will be introduced because of the differences in impedances of the two types of circuits. If a section of non-loaded cable is inserted in an open-wire line, there will be reflection losses at both ends. In addition, there will be other losses depending upon the length of the cable as well as upon its characteristics. The curves on Page 156 show the total loss introduced by inserting various short lengths of cable between 600-ohm resistances for frequencies up to 30 kc. Page 157 shows the same data for various frequencies from 1 to 30 kc plotted vs the length in miles. The values given on these curves are about the same as the actual losses which occur when a length of non-loaded 13, 16 or 19-gauge cable pair is inserted in an open-wire circuit.

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11. LIST OF TABLES AND DRAWINGS* (ATTACHED)

* All data given in the tables and drawings are typical values obtained from measurements on full size cables unless otherwise noted on the table or drawing.

TABLE 1

TYPICAL VALUES OF RESISTANCE

NOS. 10, 13, 16 AND 19 AWG PAIRS IN QUADDED TOLL CABLES

Frequency Kilocycles per Second	Resistance - Ohms per Pair Mile							
	10 Ga.	13 Ga.	16 Gauge			19 Gauge		
	55°	55°	0°	55°	110°	0°	55°	110°
0	10.1	20.5	35.5	40.2	45.2	74.2	84.1	94.2
.05	10.1	20.5	35.5	40.2	45.2	74.2	84.1	94.2
.1	10.1	20.5	35.6	40.2	45.3	74.2	84.1	94.2
.2	10.2	20.5	35.6	40.2	45.3	74.2	84.1	94.2
.5	10.3	20.5	35.6	40.3	45.3	74.2	84.2	94.3
1	10.7	20.6	35.6	40.3	45.3	74.2	84.2	94.3
1.5	11.0	20.7	35.7	40.4	45.4	74.3	84.3	94.3
2	11.4	20.8	35.8	40.5	45.5	74.3	84.4	94.4
3	11.8	21.1	35.9	40.6	45.6	74.5	84.5	94.4
4	12.4	21.5	36.1	40.9	45.8	74.6	84.6	94.6
5	13.1	21.8	36.4	41.1	46.0	74.7	84.8	94.8
6	13.7	22.1	36.6	41.4	46.2	75.0	85.0	94.9
8	14.9	23.0	37.4	42.0	46.7	75.5	85.3	95.2
10	16.0	23.8	38.1	42.8	47.4	76.0	85.8	95.6
12	17.2	24.6	38.9	43.6	48.3	76.6	86.4	96.2
16	19.7	26.5	40.9	45.5	50.1	78.1	87.7	97.5
20	21.7	29.0	43.2	47.7	52.2	80.0	89.5	98.9
25	23.9	32.2	46.0	50.6	54.9	82.4	91.7	101.1
30	26.1	35.5	49.0	53.7	58.2	85.1	94.3	103.5
35	28.2	38.7	52.0	56.6	61.3	88.0	97.2	106.3
40	30.3	41.5	55.0	59.8	64.5	90.8	100.0	109.1
50	34.5	47.5	61.0	65.8	70.6	96.9	106.0	115.0
60	38.1	52.5	66.3	71.6	76.7	103.2	112.2	121.2
75	44.0	60.2	74.2	79.8	85.3	112.5	121.3	130.3
100	53.0	71.3	85.8	91.8	97.8	127.5	137.5	146.0
120	60.0	79.0	93.5	100.0	106.5	139.5	149.3	158.1
150	70.0	90.0	104.1	111.4	118.8	156.6	166.0	175.4

TABLE 2

TYPICAL VALUES OF INDUCTANCE

NOS. 10, 13, 16 AND 19 AWG PAIRS IN QUADDED TOLL CABLE

Frequency Kilocycles per Second	Inductance - Millihenrys per Pair Mile							
	10 Ga.	13 Ga.	16 Gauge			19 Gauge		
	55°	55°	0°	55°	110°	0°	55°	110°
0	1.060	1.074	1.102	1.103	1.105	1.116	1.117	1.117
.05	1.059	1.074	1.102	1.103	1.105	1.116	1.117	1.117
.1	1.058	1.073	1.101	1.103	1.104	1.116	1.116	1.117
.2	1.056	1.072	1.101	1.103	1.104	1.116	1.116	1.117
.5	1.053	1.069	1.101	1.102	1.104	1.116	1.116	1.117
1	1.047	1.065	1.100	1.101	1.103	1.115	1.116	1.116
1.5	1.042	1.062	1.099	1.101	1.102	1.115	1.116	1.116
2	1.036	1.058	1.098	1.099	1.101	1.115	1.115	1.116
3	1.026	1.051	1.095	1.097	1.099	1.114	1.114	1.115
4	1.015	1.045	1.092	1.095	1.097	1.113	1.113	1.114
5	1.005	1.040	1.091	1.093	1.095	1.112	1.112	1.113
6	.997	1.034	1.089	1.092	1.093	1.110	1.111	1.111
8	.978	1.023	1.085	1.087	1.089	1.109	1.109	1.110
10	.962	1.012	1.080	1.084	1.086	1.107	1.107	1.108
12	.949	1.004	1.076	1.080	1.083	1.105	1.105	1.106
16	.926	.987	1.068	1.072	1.076	1.100	1.101	1.102
20	.907	.973	1.059	1.065	1.069	1.096	1.097	1.099
25	.887	.960	1.049	1.055	1.060	1.089	1.092	1.095
30	.871	.950	1.040	1.046	1.052	1.083	1.086	1.090
35	.855	.940	1.031	1.038	1.044	1.077	1.081	1.086
40	.840	.930	1.022	1.029	1.036	1.070	1.075	1.080
50	.812	.916	1.007	1.014	1.021	1.059	1.065	1.070
60	.790	.906	.994	1.001	1.008	1.047	1.054	1.060
75	.770	.892	.977	.984	.992	1.033	1.040	1.047
100	.750	.870	.956	.963	.970	1.011	1.017	1.024
120	.740	.860	.943	.950	.957	.994	1.001	1.009
150	.730	.850	.928	.934	.941	.972	.979	.986

TABLE 3

TYPICAL VALUES OF CAPACITANCE

NOS. 10, 13, 16 AND 19 AWG PAIRS IN QUADDED TOLL CABLE

Frequency Kilocycles per Second	Capacitance - Microfarads per Pair Mile						
	10 & 13 Ga.	16 Gauge			19 Gauge		
	55°	0°	55°	110°	0°	55°	110°
0	.06100	.05808	.05903	.05992	.06066	.06144	.06224
.05	.06099	.05807	.05902	.05992	.06065	.06143	.06223
.1	.06099	.05807	.05902	.05992	.06064	.06142	.06222
.2	.06098	.05805	.05901	.05991	.06061	.06140	.06221
.5	.06097	.05803	.05900	.05990	.06054	.06135	.06219
1	.06095	.05799	.05897	.05989	.06045	.06129	.06215
1.5	.06092	.05795	.05895	.05988	.06037	.06124	.06212
2	.06090	.05792	.05894	.05986	.06030	.06120	.06210
3	.06086	.05786	.05891	.05984	.06019	.06116	.06207
4	.06083	.05780	.05888	.05982	.06010	.06113	.06205
5	.06080	.05775	.05885	.05980	.06002	.06110	.06203
6	.06078	.05770	.05884	.05978	.05995	.06108	.06201
8	.06074	.05762	.05879	.05975	.05983	.06104	.06198
10	.06070	.05755	.05876	.05972	.05975	.06100	.06195
12	.06066	.05747	.05872	.05969	.05967	.06096	.06193
16	.06058	.05736	.05866	.05964	.05955	.06090	.06190
20	.06050	.05728	.05862	.05959	.05945	.06085	.06188
25	.06045	.05719	.05856	.05954	.05935	.06079	.06184
30	.06040	.05710	.05851	.05950	.05925	.06074	.06181
35	.06035	.05704	.05846	.05947	.05918	.06069	.06179
40	.06030	.05698	.05842	.05944	.05911	.06065	.06177
50	.06020	.05688	.05837	.05940	.05900	.06058	.06173
60	.06010	.05678	.05831	.05936	.05891	.06051	.06170
75	.06000	.05667	.05824	.05932	.05881	.06043	.06166
100	.05990	.05650	.05813	.05927	.05868	.06034	.06160
120	.05986	.05640	.05806	.05925	.05863	.06029	.06156
150	.05980	.05630	.05798	.05922	.05857	.06024	.06153

TABLE 4

TYPICAL VALUES OF CONDUCTANCE

NOS. 10, 13, 16 AND 19 AWG PAIRS IN QUADDED TOLL CABLE

Frequency Kilocycles per Second	Conductance - Micromhos per Pair Mile							
	10 Gauge*	13 Gauge	16 Gauge			19 Gauge		
	55°	55°	0°	55°	110°	0°	55°	110°
.05	.40	.25	.28	.18	.11	.10	.06	.04
.1	.90	.42	.40	.24	.15	.15	.09	.06
.2	1.2	.65	.62	.36	.23	.26	.16	.10
.5	2.1	1.40	1.22	.72	.47	.75	.40	.25
1	3.3	2.5	2.40	1.36	.88	1.80	.93	.56
1.5	4.6	3.5	3.65	2.00	1.30	3.00	1.58	.92
2	5.9	4.4	5.00	2.65	1.70	4.35	2.35	1.35
3	8.0	6.4	7.80	4.15	2.70	7.50	4.05	2.30
4	10.0	8.5	10.7	5.8	3.70	11.0	5.95	3.40
5	12.0	10.6	14.0	7.6	4.75	14.9	7.95	4.65
6	14.0	12.7	17.0	9.6	5.90	18.5	10.1	6.00
8	18.5	17.0	24.2	13.8	8.60	27.5	15.0	8.80
10	24	21.	32.0	18.5	11.4	36.8	20.1	11.9
12	29	27.	41.0	23.5	14.4	47.0	25.8	16.0
16	40	37.	58.0	34.5	21.0	66.0	37.9	22.0
20	51	47.	75.0	46.2	28.0	88.0	50.5	29.5
25	65	62.	99.0	62.5	38.0	115.	70.0	40.5
30	78	78.	124.	80.6	49.0	144.	87.5	52.0
35	93	95.	151.	100.	60.0	175.	109.	63.5
40	108	112.	180.	119.	72.0	205.	151.	76.2
50	140	150.	240.	161.	98.0	260.	178.	104.
60	170	190.	290.	205.	127.	321.	226.	136.
75	220	245.	370.	276.	171.	415.	303.	184.
100	300	350.	510.	400.	251.	575.	440.	268.
120	370	440.	620.	510.	327.	700.	560.	345.
150	470	590.	800.	680.	449.	900.	740.	475.

* Estimated.

TABLE 5

TYPICAL VALUES OF
PRIMARY CONSTANTS OF PAIRS OF SPIRAL-FOUR 16 GA. CABLE
DISC-INSULATED CONDUCTORS
PER 100 FEET
55° F.

Frequency Kilocycles	Resistance Ohms	Inductance Millihenrys	Conductance Micromhos	Capacitance Micromicrofarads
d-c	0.801	-	-	-
0.3	.808	0.0378	0.0009	471.8
1	.822	.0368	.0014	471.7
2	.841	.0345	.0024	471.7
3	.860	.0329	.0035	471.6
4	.877	.0318	.0047	471.6
6	.908	.0306	.0074	471.5
8	.933	.0300	.0100	471.4
9	.948	.0298	.0120	471.4
10	.960	.0296	.0136	471.4
12	.984	.0294	.0180	471.4
14	1.005	.0293	.0225	471.3
16	1.027	.0292	.0270	471.3
20	1.075	.0290	.0370	471.2
27	1.160	.0288	.0585	471.2
30	1.190	.0288	.0670	471.2
40	1.290	.0287	.0990	471.2
50	1.380	.0285	.134	471.2
75	1.600	.0280	.227	471.2
80	1.640	.0279	.247	471.2
100	1.795	.0277	.320	471.2
120	1.940	.0275	.395	471.2
140	2.080	.0273	.473	471.2
150	2.148	.0273	.513	471.2

TABLE 6

TYPICAL VALUES OF ATTENUATION

NOS. 10, 13, 16 AND 19 AWG PAIRS IN QUADDED TOLL CABLE

Frequency Kilocycles per Second	Attenuation Decibels per Pair Mile							
	10 Gauge	13 Gauge	16 Gauge			19 Gauge		
	55°	55°	0°	55°	110°	0°	55°	110°
.05	.085	.122	.157	.168	.179	.231	.247	.263
.1	.119	.171	.220	.236	.252	.326	.348	.371
.2	.162	.237	.308	.330	.354	.457	.491	.523
.5	.238	.336	.473	.505	.548	.714	.767	.819
1	.297	.467	.638	.691	.744	.98	1.06	1.14
1.5	.331	.533	.719	.790	.860	1.20	1.27	1.35
2	.356	.577	.790	.870	.950	1.35	1.44	1.54
3	.388	.633	.898	.995	1.09	1.54	1.68	1.80
4	.416	.671	.985	1.09	1.20	1.71	1.88	2.04
5	.445	.696	1.04	1.16	1.28	1.83	2.03	2.21
6	.464	.718	1.08	1.21	1.33	1.95	2.15	2.34
8	.517	.762	1.14	1.27	1.41	2.09	2.31	2.54
9	.542	.770	1.17	1.30	1.43	2.15	2.38	2.61
10	.565	.800	1.19	1.32	1.46	2.20	2.43	2.67
11	.590	.820	1.21	1.35	1.48	2.24	2.48	2.73
12	.611	.835	1.23	1.37	1.50	2.28	2.53	2.78
14	.668	.900	1.27	1.42	1.55	2.34	2.60	2.88
16	.700	.914	1.32	1.46	1.59	2.40	2.67	2.96
20	.800	1.04	1.41	1.55	1.68	2.51	2.77	3.07
25	.895	1.17	1.53	1.66	1.80	2.63	2.90	3.18
27	.931	1.22	1.57	1.70	1.84	2.68	2.95	3.23
30	.99	1.27	1.64	1.78	1.91	2.76	3.02	3.30
35	1.08	1.39	1.76	1.90	2.03	2.89	3.15	3.43
40	1.18	1.51	1.87	2.01	2.14	3.02	3.28	3.55
50	1.37	1.75	2.11	2.24	2.38	3.26	3.53	3.80
57	1.50	1.88	2.26	2.40	2.54	3.43	3.71	3.98
60	1.55	1.95	2.33	2.46	2.60	3.51	3.78	4.04
75	1.82	2.26	2.65	2.79	2.92	3.88	4.16	4.42
80	1.91	2.35	2.75	2.90	3.03	4.00	4.29	4.55
90	2.08	2.55	2.96	3.11	3.24	4.25	4.54	4.80
100	2.25	2.72	3.16	3.31	3.45	4.50	4.79	5.05
120	2.59	3.08	3.55	3.70	3.85	5.00	5.29	5.54
140	2.94	3.43	3.93	4.08	4.24	5.50	5.79	6.04
150	3.11	3.58	4.12	4.27	4.43	5.73	6.02	6.28

TABLE 7

TYPICAL VALUES OF PHASE CHANGE

NOS. 10, 13, 16 AND 19 AWG PAIRS IN QUADDED TOLL CABLE

(Multiply values given by 57.3 to get degrees per mile)

Frequency Kilocycles per Second	Phase Change - Radians per Pair Mile							
	10 Gauge	13 Gauge	16 Gauge			19 Gauge		
	55°	55°	0°	55°	110°	0°	55°	110°
.05	.010	.014	.018	.019	.021	.027	.029	.030
.1	.015	.020	.026	.027	.029	.038	.040	.043
.2	.021	.029	.037	.039	.042	.054	.057	.061
.5	.037	.048	.060	.064	.068	.086	.092	.098
1	.060	.074	.087	.092	.100	.124	.133	.141
1.5	.084	.097	.110	.116	.124	.155	.166	.175
2	.108	.120	.133	.140	.148	.185	.195	.205
3	.156	.167	.181	.189	.197	.237	.249	.261
4	.204	.214	.229	.237	.245	.285	.299	.312
5	.252	.262	.272	.280	.288	.332	.348	.363
6	.300	.310	.322	.332	.340	.379	.394	.412
8	.390	.405	.418	.428	.436	.473	.490	.510
10	.488	.500	.513	.523	.533	.569	.587	.604
12	.575	.596	.607	.620	.632	.660	.680	.710
16	.758	.784	.796	.810	.824	.860	.876	.895
20	.944	.970	.982	1.00	1.02	1.05	1.07	1.09
25	1.17	1.20	1.22	1.24	1.26	1.30	1.32	1.34
30	1.39	1.43	1.46	1.48	1.51	1.54	1.57	1.59
35	1.61	1.66	1.66	1.71	1.75	1.78	1.82	1.85
40	1.82	1.89	1.90	1.95	1.99	2.03	2.06	2.10
50	2.23	2.34	2.36	2.42	2.46	2.51	2.55	2.59
60	2.64	2.79	2.81	2.89	2.94	2.99	3.05	3.09
75	3.25	3.46	3.49	3.59	3.66	3.69	3.76	3.82
100	4.26	4.54	4.63	4.71	4.78	4.86	4.98	5.08
120	5.08	5.42	5.50	5.60	5.68	5.78	5.89	6.00
150	6.30	6.73	6.82	6.94	7.05	7.16	7.28	7.41

TABLE 8

TYPICAL VALUES OF
ATTENUATION AND PHASE CHANGE OF
PAIRS OF SPIRAL-FOUR 16 GAUGE CABLE
DISC-INSULATED CONDUCTORS
PER 100 FEET
55° F.

Frequency Kilocycles	Attenuation Decibels	Phase Change Radians
0.5	.0050	.00063
1	.0083	.00127
2	.0105	.00190
3	.0122	.00273
4	.0134	.00343
6	.0145	.00483
8	.0153	.00624
9	.0158	.00694
10	.0162	.00765
12	.0168	.00908
14	.0172	.01052
16	.0178	.0119
20	.0188	.0148
27	.0203	.0199
30	.0210	.0220
40	.0230	.0291
50	.0248	.0362
75	.0288	.0540
80	.0294	.0577
100	.0324	.0718
120	.0352	.0858
140	.0380	.0999
150	.0393	.1068

TABLE 9

TYPICAL VALUES OF CHARACTERISTIC IMPEDANCE

NOS. 10, 13, 16 AND 19 AWG PAIRS IN QUADDED TOLL CABLE

Frequency Kilocycles per Second	Characteristic Impedance - $Z_o = R_o - jX$ (Ohms)							
	10 Gauge	13 Gauge	16 Gauge			19 Gauge		
	55°	55°	0°	55°	110°	0°	55°	110°
.05	585-j506	748-j721	999-j974	1050-j1035	1103-j1089	1402-j1388	1482-j1471	1556-j1548
.1	377-j352	529-j505	709-j687	745-j728	783-j768	993-j980	1050-j1038	1103-j1093
.2	275-j241	379-j352	506-j482	531-j511	558-j539	706-j690	746-j731	783-j770
.5	191-j140	258-j212	329-j297	345-j315	361-j333	453-j431	478-j457	501-j482
1	156-j88	193-j139	244-j200	254-j214	265-j227	328-j297	345-j317	361-j335
1.5	145-j66	170-j106	215-j163	225-j173	235-j185	275-j242	288-j254	295-j274
2	140-j53	158-j85.7	196-j139	205-j148	213-j157	245-j202	255-j215	265-j229
3	134-j38	146-j62.7	173-j105	178-j113	183-j121	210-j158	217-j169	223-j180
4	132-j31	140-j49.7	158-j82.1	163-j88.7	165-j95.8	190-j130	194-j140	200-j150
5	130-j26	138-j41.5	152-j65.2	154-j71.8	156-j78.0	177-j112	182-j121	187-j131
6	129-j23	135-j35.3	148-j54.5	150-j59.7	151-j65.0	170-j96.0	174-j107	179-j115
8	127-j19	133-j28.0	144-j42.7	145-j47.4	145-j52.0	159-j78.2	162-j86.5	164-j94.0
10	126-j16	131-j23.4	142-j36.5	142-j40.1	142-j44.3	152-j66.0	153-j72.5	155-j79.2
12	125-j14	130-j20.3	141-j32.5	140-j35.4	140-j39.0	147-j57.5	150-j63.8	151-j70.2
16	123-j12	129-j16.5	139-j26.5	138-j29.0	138-j32.0	143-j44.9	144-j50.2	145-j55.0
20	122-j11	128-j14.6	138-j22.9	137-j25.0	136-j27.0	141-j37.0	141-j41.4	141-j45.1
25	120-j10	127-j13.0	137-j18.9	136-j21.0	135-j23.0	139-j30.5	139-j34.4	138-j37.8
30	119-j9	126-j11.9	136-j15.9	135-j17.5	134-j19.0	138-j26.7	137-j29.7	137-j32.5
35	118-j8	125-j11.2	135-j13.9	134-j15.2	134-j17.3	138-j23.6	136-j26.1	136-j29.0
40	117-j8	125-j10.5	135-j12.5	134-j14.0	133-j15.8	137-j21.5	135-j23.9	135-j26.0
50	116-j7	124-j9.7	134-j11.9	133-j12.9	132-j14.0	136-j18.5	134-j20.3	134-j22.0
60	115-j7	123-j8.9	133-j10.5	132-j11.8	131-j12.8	135-j16.4	133-j17.9	133-j19.4
75	114-j6	122-j8.2	132-j9.5	131-j10.4	130-j11.2	134-j14.3	132-j15.6	131-j16.8
100	112-j6	121-j7.3	131-j8.3	129-j9.0	128-j9.8	132-j12.1	131-j13.1	130-j14.1
120	111-j5	120-j6.7	130-j7.5	128-j8.0	128-j8.9	131-j11.1	130-j12.0	129-j13.0
150	111-j5	119-j6.1	129-j6.5	127-j7.2	126-j7.9	130-j10.0	129-j10.7	128-j11.4

TABLE 10

TYPICAL VALUES OF
CHARACTERISTIC IMPEDANCE OF
PAIRS OF SPIRAL-FOUR 16 GAUGE CABLE
DISC-INSULATED CONDUCTORS
55° F

Frequency Kilocycles	Impedance - $Z_0 = R_0 - jX$
0.3	705 - j645
1	428 - j324
2	350 - j230
3	307 - j157
4	290 - j125
6	272 - j 93.9
8	263 - j 75.0
9	261 - j 68.2
10	258 - j 62.7
12	256 - j 54.0
14	254 - j 47.7
16	253 - j 43.0
20	226 - j 36.0
27	249 - j 29.1
30	248 - j 26.5
40	246 - j 21.0
50	245 - j 19.0
75	244 - j 16.0
80	244 - j 14.1
100	243 - j 13.3
120	241 - j 12.0
140	241 - j 10.3
150	240 - j 10.1

TABLE 11

TYPICAL VALUES OF PHASE DELAY (β/ω)

NOS. 10, 13, 16 AND 19 AWG PAIRS IN QUADDED TOLL CABLE

Frequency Kilocycles per Second	Phase Delay - Microseconds per Pair Mile							
	10 Gauge	13 Gauge	16 Gauge			19 Gauge		
	55°	55°	0°	55°	110°	0°	55°	110°
.05	31.8	44.7	57.3	60.5	66.8	85.9	92.3	95.5
.1	23.9	31.9	41.4	43.0	46.2	60.5	63.7	68.4
.2	16.6	23.0	29.4	31.0	33.4	43.0	45.4	48.5
.5	11.8	15.3	19.1	20.4	21.6	27.4	29.3	31.2
1	9.6	11.7	13.8	14.7	15.9	19.7	21.2	22.4
1.5	8.9	10.3	11.7	12.3	13.2	16.5	17.6	18.5
2	8.6	9.59	10.6	11.1	11.8	14.6	15.5	16.3
3	8.3	8.86	9.60	10.0	10.5	12.6	13.2	13.8
4	8.1	8.53	9.11	9.43	9.75	11.3	11.9	12.4
5	8.0	8.34	8.65	8.90	9.16	10.5	11.1	11.5
6	8.0	8.21	8.54	8.81	9.02	10.0	10.4	10.9
8	7.9	8.06	8.37	8.52	8.67	9.41	9.75	10.1
10	7.8	7.96	8.17	8.32	8.48	9.06	9.34	9.61
12	7.6	7.90	8.00	8.22	8.38	8.75	9.02	9.42
16	7.6	7.80	7.92	8.06	8.20	8.56	8.71	8.90
20	7.5	7.72	7.81	7.96	8.12	8.36	8.52	8.69
25	7.4	7.66	7.78	7.91	8.02	8.26	8.40	8.55
30	7.4	7.61	7.71	7.84	7.99	8.18	8.31	8.45
35	7.3	7.56	7.63	7.78	7.96	8.11	8.28	8.41
40	7.2	7.52	7.56	7.76	7.92	8.06	8.20	8.34
50	7.1	7.45	7.50	7.73	7.83	7.99	8.12	8.24
60	7.0	7.40	7.45	7.68	7.74	7.95	8.09	8.20
75	6.9	7.33	7.40	7.61	7.78	7.84	7.98	8.11
100	6.8	7.23	7.36	7.50	7.60	7.74	7.92	8.02
120	6.7	7.19	7.30	7.43	7.53	7.67	7.81	7.96
150	6.7	7.14	7.24	7.37	7.48	7.60	7.72	7.86

TABLE 12

TYPICAL VALUES OF VELOCITY OF PROPAGATION
55° F
NOS. 10, 13, 16 AND 19 AWG PAIRS IN QUADDED TOLL CABLE

Frequency Kilocycles per Second	Velocity - Miles per Second			
	10 Gauge	13 Gauge	16 Gauge	19 Gauge
.05	31,000	22,380	16,540	10,830
.1	43,000	31,390	23,270	15,710
.2	59,000	43,550	32,220	22,050
.5	84,000	65,540	49,090	34,150
1	103,000	85,430	66,840	47,240
1.5	111,000	97,010	81,250	56,780
2	115,000	104,310	89,760	64,440
3	120,000	112,850	99,730	75,700
4	123,000	117,270	106,050	84,060
5	124,000	119,940	110,230	90,280
6	125,000	121,770	113,550	95,690
8	127,000	124,010	117,440	102,590
10	128,000	125,550	120,140	107,040
12	130,000	126,580	121,610	110,880
16	132,000	128,260	124,120	114,760
20	133,000	129,490	125,660	117,440
25	134,000	130,570	126,470	119,000
30	136,000	131,420	126,760	120,370
35	137,000	132,240	128,600	120,830
40	138,000	133,060	129,120	122,010
50	141,000	134,260	129,330	123,200
60	142,000	135,170	130,230	123,610
75	145,000	136,380	131,280	125,330
100	147,000	138,270	133,320	126,300
120	149,000	139,160	134,640	128,000
150	150,000	140,080	135,650	129,470

TABLE 13

INSERTION LOSS AND CHARACTERISTIC IMPEDANCE
10 GAUGE PAPER INSULATED TOLL ENTRANCE CABLE
MEASURED AT CHARLOTTE, NORTH CAROLINA

Kilocycles per Second	Insertion Loss* (Average) db/mi.	Characteristic Impedance $Z_o = R_o - jX$ (Average) Outer Group	Inner Group
1	0.36	190 -j77	182.5-j72.5
5	0.43	152.8-j25.2	143.3-j25.2
10	0.56	149.5-j16.9	139.5-j17.3
15	0.67	145.9-j13.9	135.5-j13.2
20	0.77	145.8-j 9.6	135.9-j10.4
25	0.86	144.8-j10.0	135.0-j11.4
30	0.94	143.5-j 9.5	131.7-j 9.2
40	1.06	141.8-j 8.8	132.7-j 8.5
50	1.20	140.0-j 4.6	132.3-j 7.9
60	1.31	141.7-j 2.6	129.1-j 6.2
80	1.52	141.9-j 6.0	128.5-j 5.2
100	1.72	139.4-j 3.4	128.6-j 1.2
120	1.90	142.2-j 2.5	127.4-j 1.3
140	2.07	144.1-j 1.9	128.5+j 0.9
150	2.18	145.0-j 4.5	127.7-j 0.8

*Insertion Loss measured between 135 ohm resistance on 5.14 mile length of cable. Temperature about 60° F.

TABLE 14

CONSTANTS OF 22-GAUGE EMERGENCY CABLE AND 19-GAUGE CL EMERGENCY CABLE

55°F

		Primary Constants - Per 1000 Feet		1000 Cycle	
		DC Resistance	Inductance Milhenrys	Conductance Micromhos	Capacitance Microfarads
22 Ga. Side		31.5	0.19	0.25	.012
Phantom		15.7	0.13	0.40	.019
19 Ga. CL Side	Dry	17.5	0.26	(a)	.021
	Wet	17.5	0.26	(a)	.027*
Phantom	Dry	8.7	0.09*	(a)	.047
	Wet	8.7	0.09*	(a)	.054*

(a) Leakage conductance at 1000 cycles is negligible as compared to capacitance susceptance.

* Estimated

		Secondary Constants - Per 1000 Feet		
		Propagation Constant	Characteristic Impedance	Attenuation Decibels
22 Ga. Side		.0339 + j.0351	$647/\underline{43.8°}$	0.29
Phantom		.0299 + j.0314	$363/\underline{43.4°}$	0.26
19 Ga. CL Side	Dry	.0324 + j.0356	$365/\underline{42°}$	0.28
	Wet	.0368 + j.0404	$320/\underline{42°}$	0.32
Phantom	Dry	.0347 + j.0370	$170/\underline{43°}$	0.30
	Wet	.0372 + j.0397	$160/\underline{43°}$	0.32

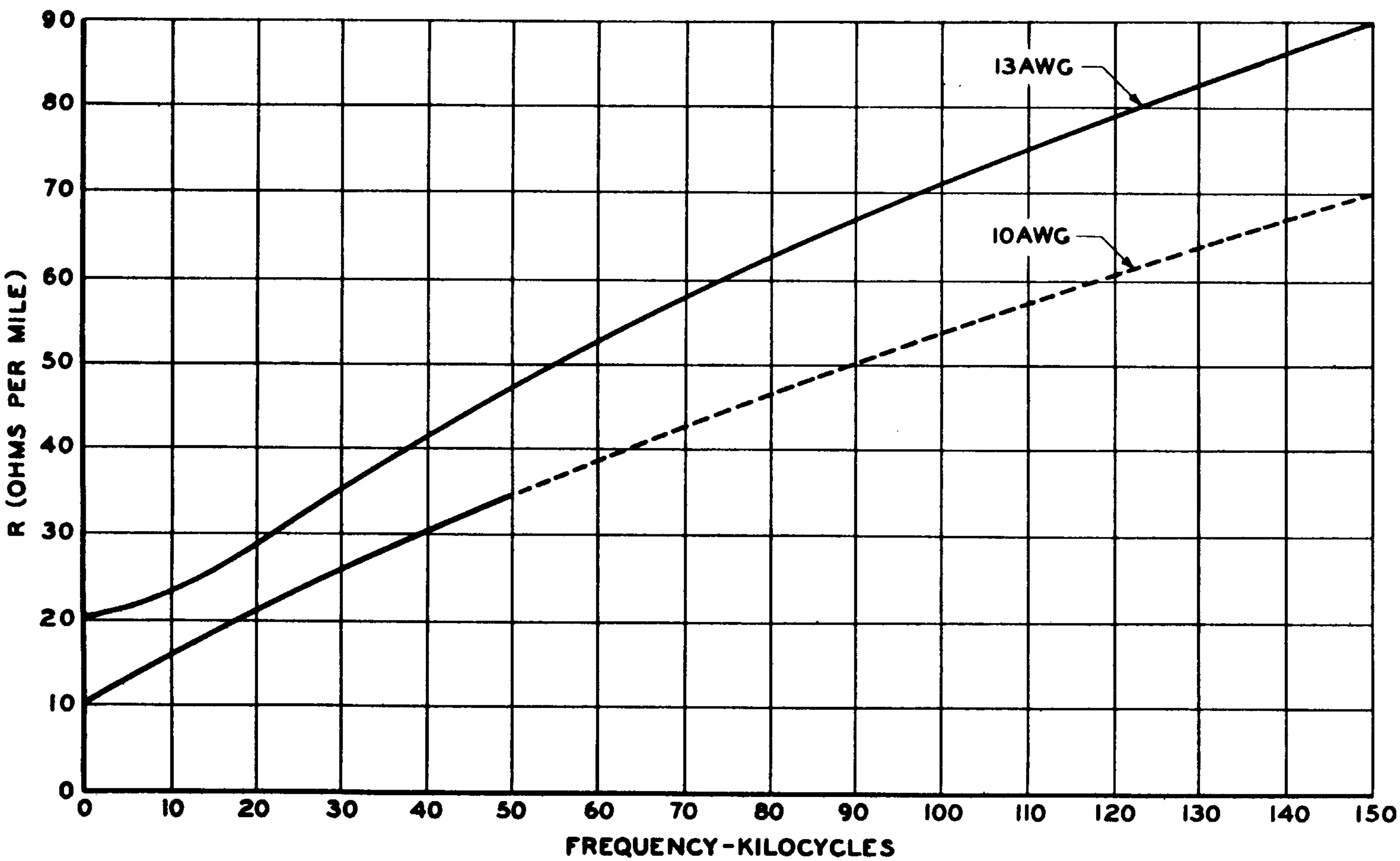
BELL TELEPHONE LABORATORIES, INC.

ES-855700
C.M.H 4-30-41

TYPICAL VALUES OF RESISTANCE PER MILE VS FREQUENCY

TEMPERATURE 55°F.

10 & 13 AWG PAIRS



ES-855700

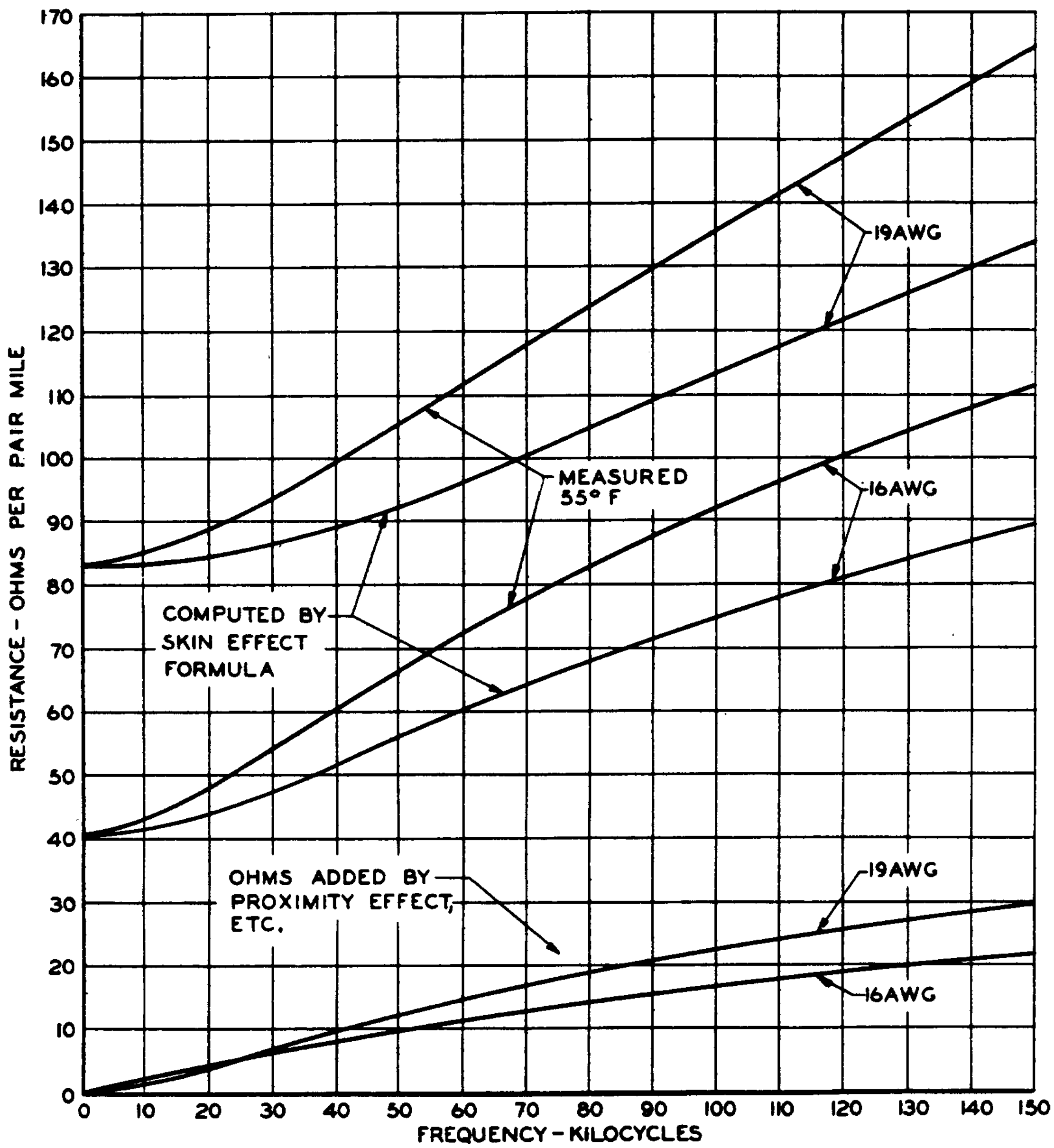
BELL TELEPHONE LABORATORIES, INC.

ES-855701
C.M.H. 4-30-41

RESISTANCE VS FREQUENCY

MEASURED VALUES AND VALUES COMPUTED BY FORMULAS FOR SKIN EFFECT

DIFFERENCE SHOWS PROXIMITY SHEATH AND OTHER EFFECTS
16AWG AND 19AWG

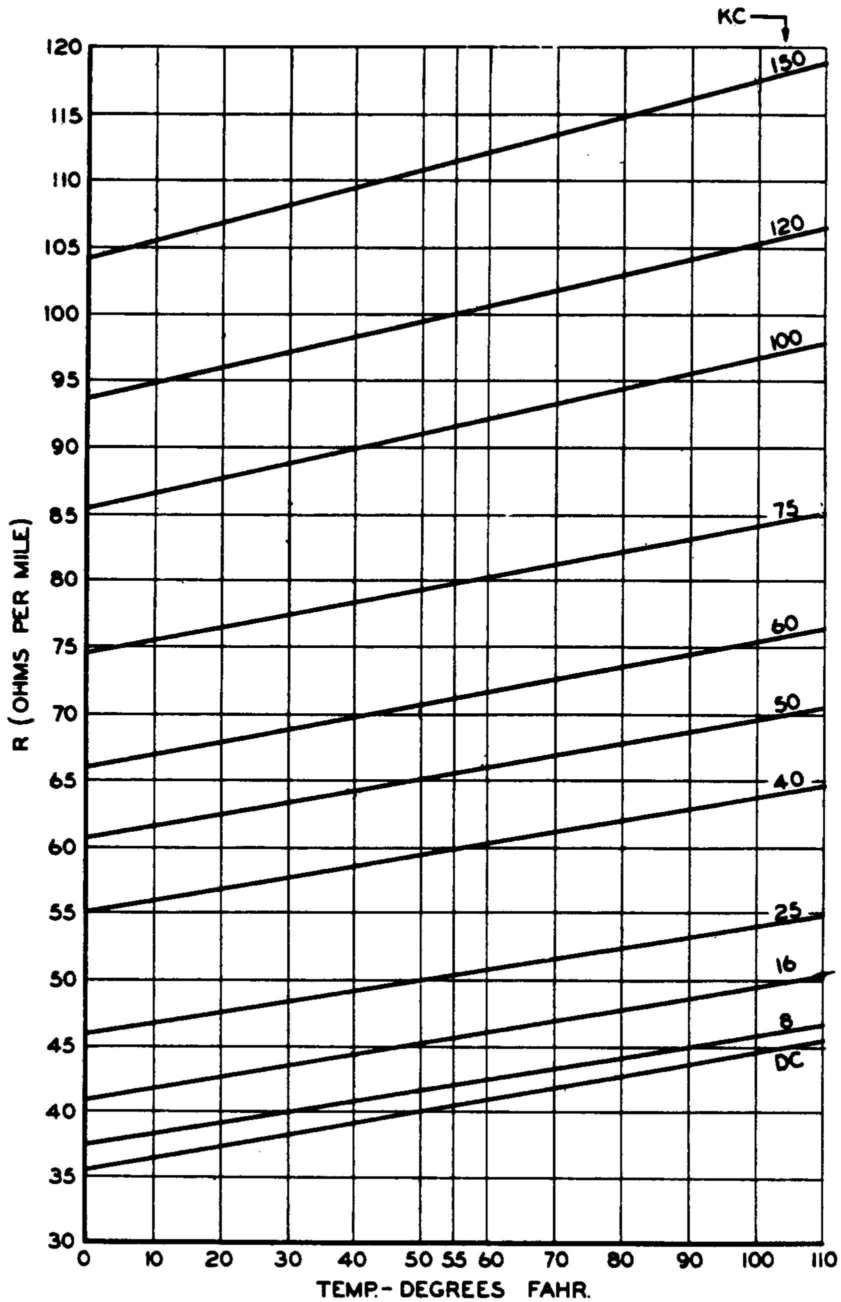


BELL TELEPHONE LABORATORIES, INC.

ES-855702
C.M.H. 4-30-41

TYPICAL VALUES OF RESISTANCE PER MILE VS TEMPERATURE

16 GAUGE PAIRS



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ES-855703
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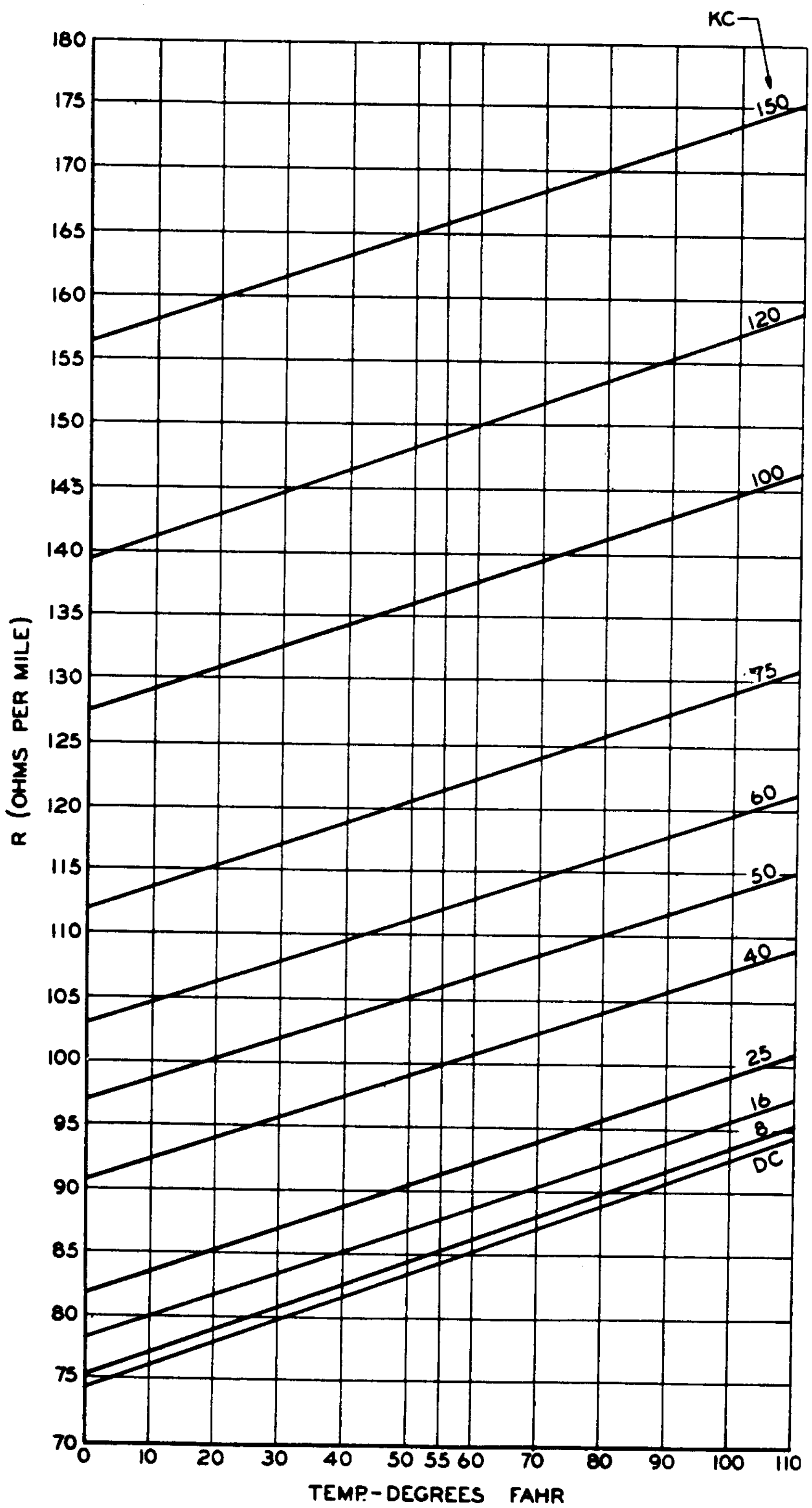
TYPICAL VALUES OF RESISTANCE PER MILE VS TEMPERATURE

19 GAUGE PAIRS



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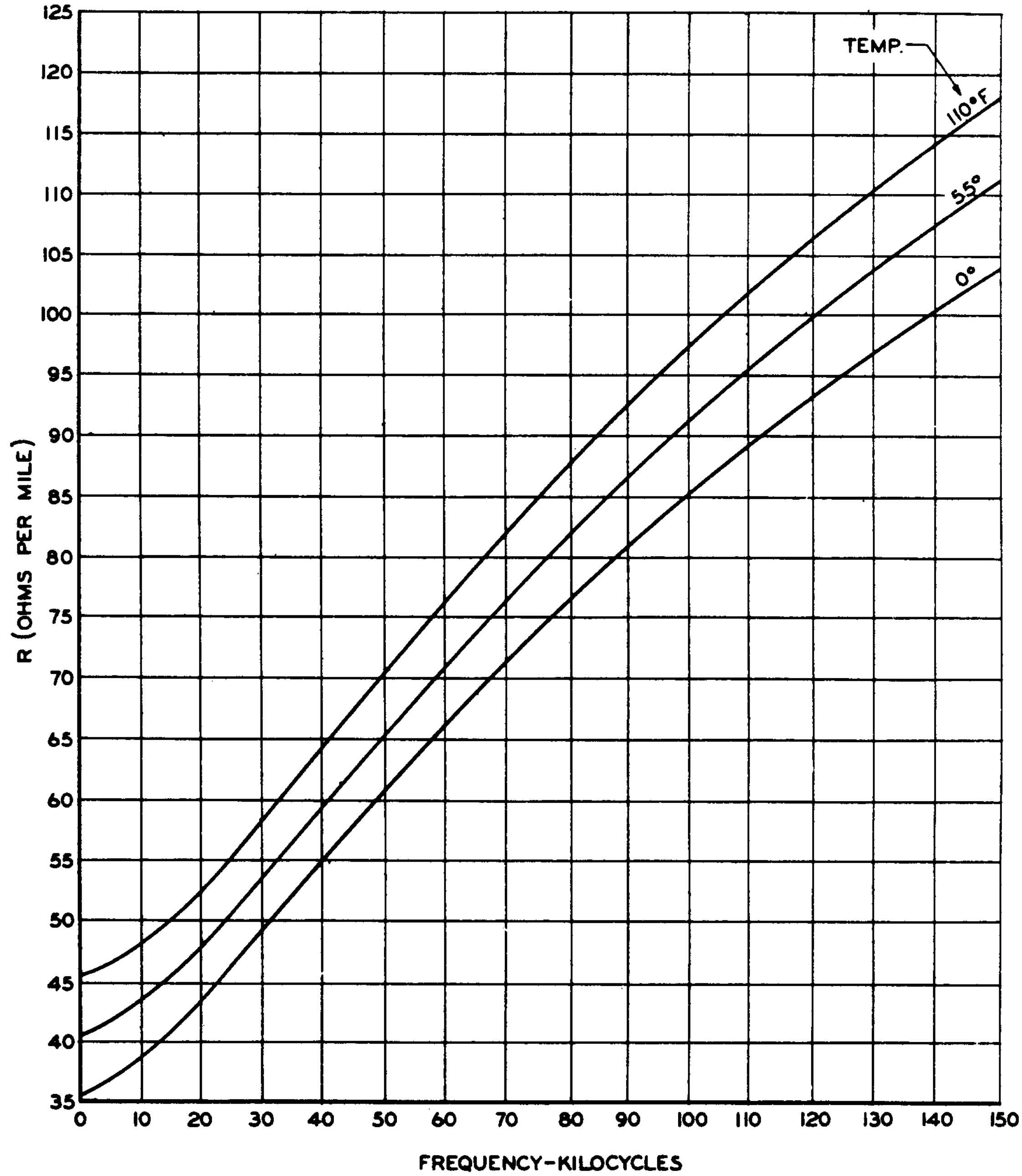
ES-855704
C.M.H 4-30-41

TYPICAL VALUES OF RESISTANCE PER MILE VS FREQUENCY

16 GAUGE PAIRS

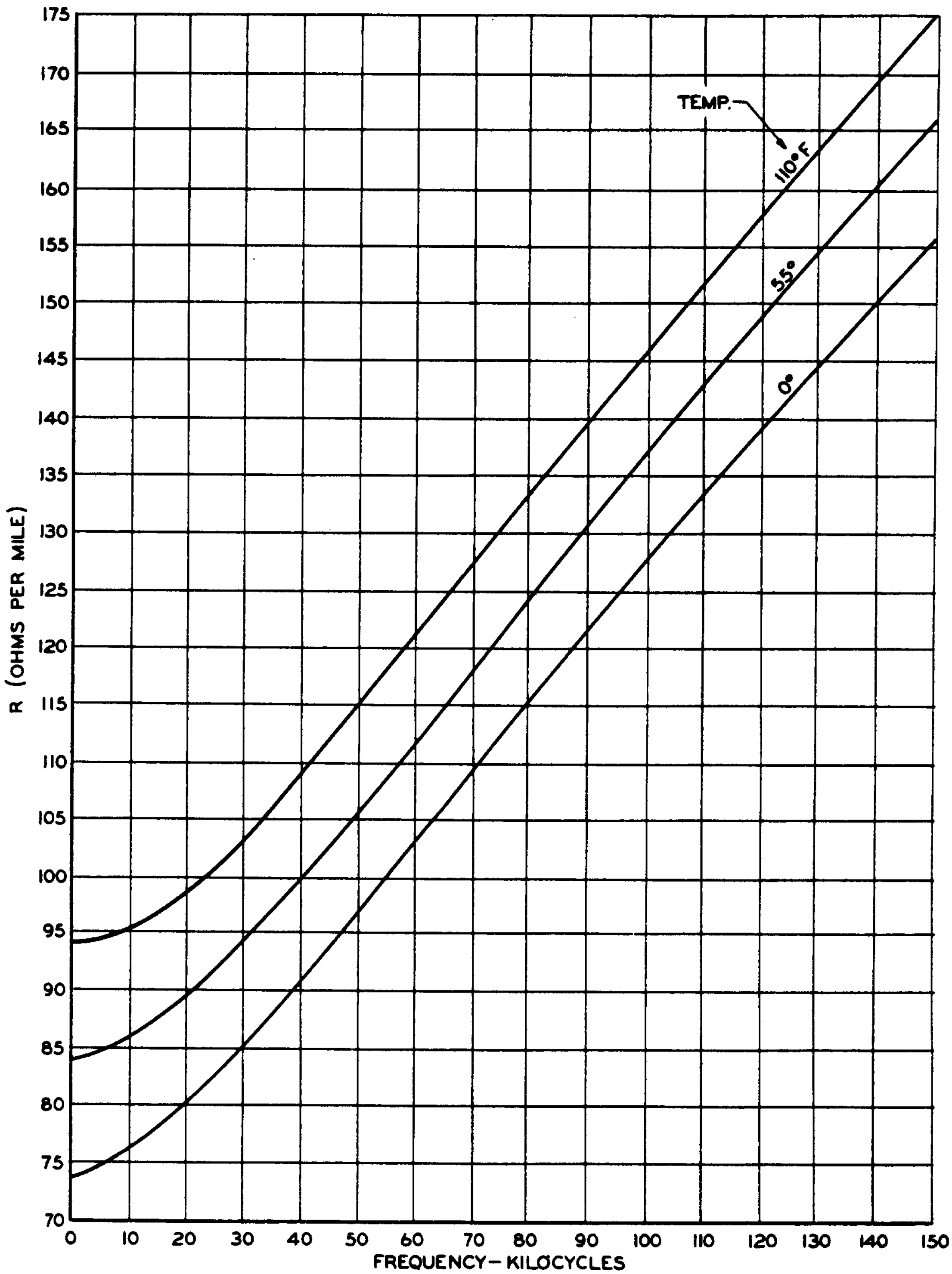


BELL TELEPHONE LABORATORIES, INC.

ES-855705
C.M.H. 4-30-41

TYPICAL VALUES OF RESISTANCE PER MILE VS FREQUENCY

19 GAUGE PAIRS

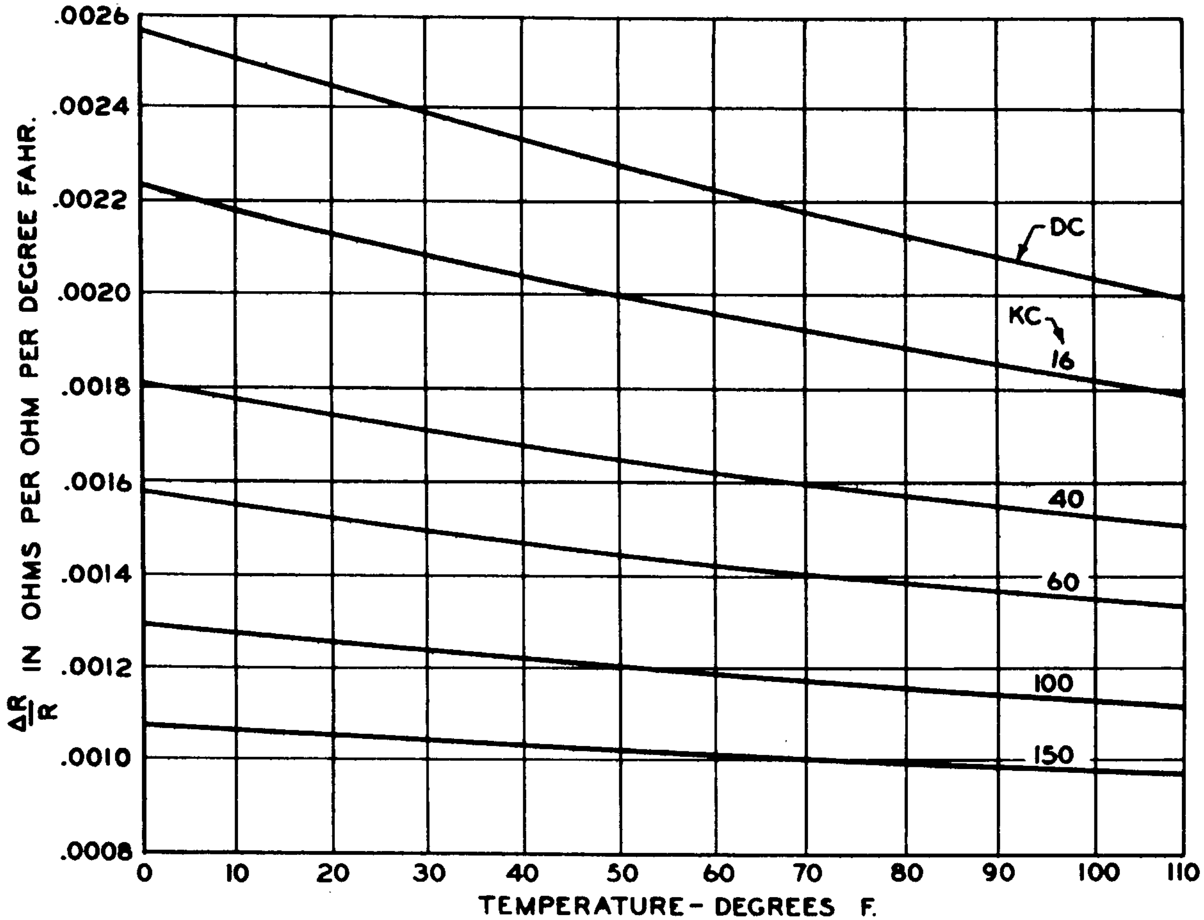


BELL TELEPHONE LABORATORIES, INC.

ES-855706

TYPICAL VALUES OF RESISTANCE-TEMPERATURE COEFFICIENT

19 GAUGE PAIRS



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BELL TELEPHONE LABORATORIES, INC.

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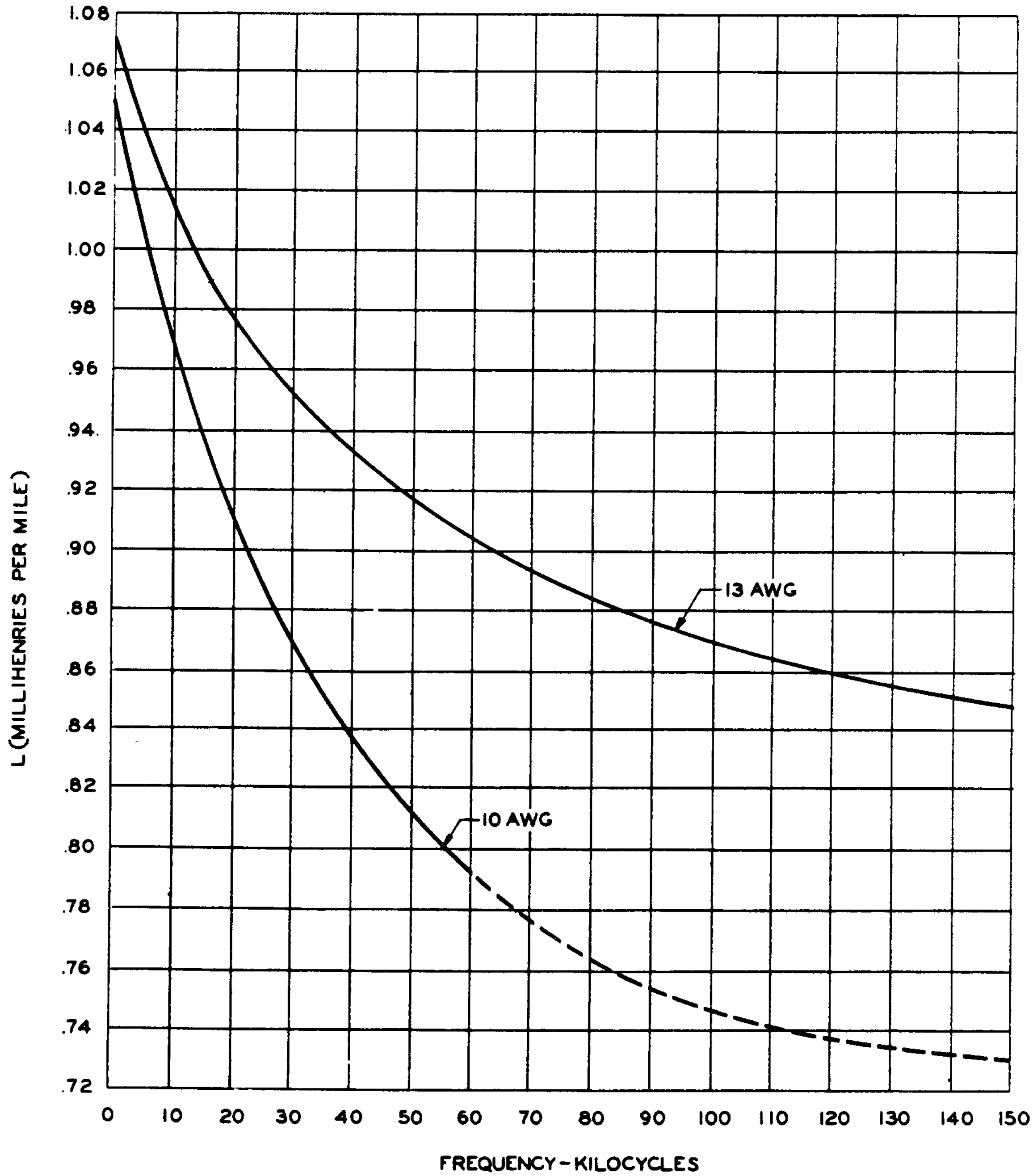
TYPICAL VALUES OF INDUCTANCE PER MILE VS FREQUENCY

TEMPERATURE 55° F

10 & 13 AWG PAIRS



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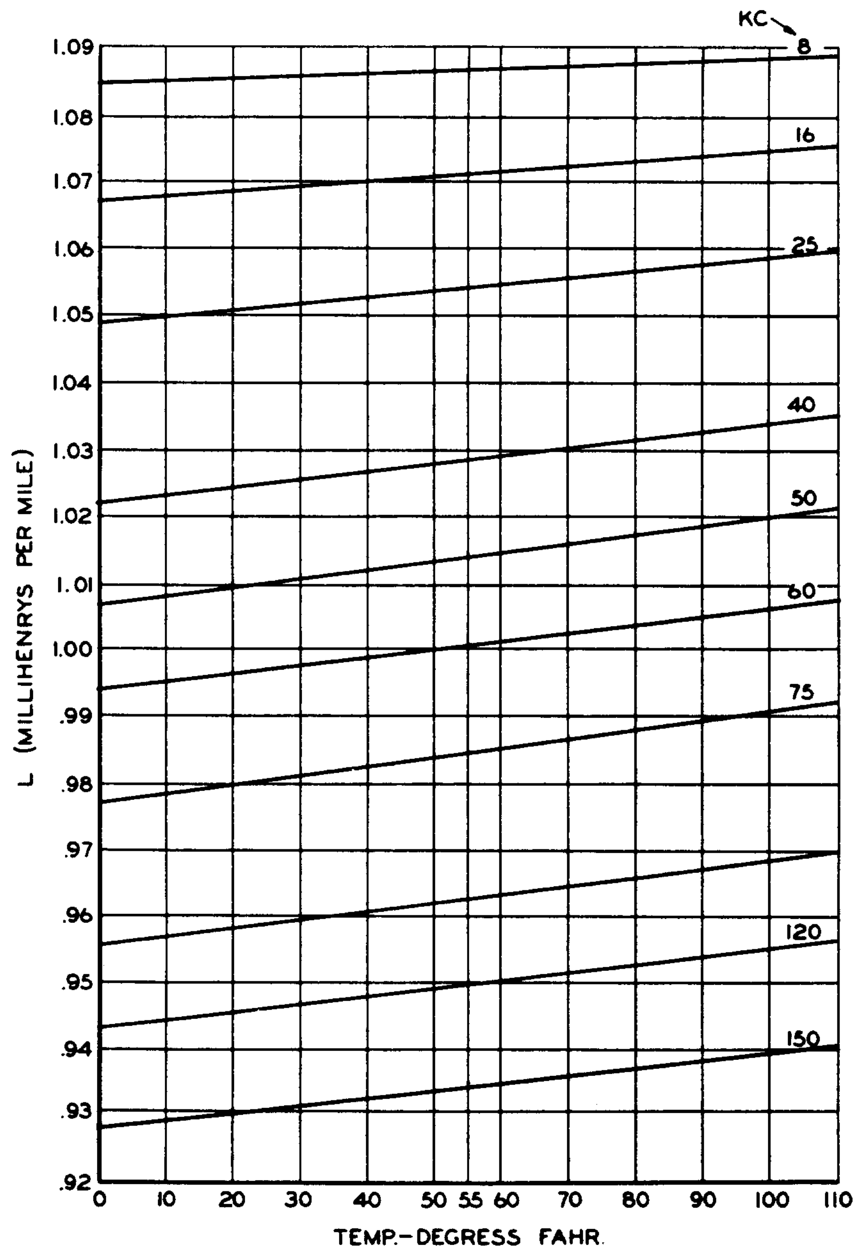
ES-855708
C.M.H. 4-30-41

TYPICAL VALUES OF INDUCTANCE PER MILE VS TEMPERATURE

16 GAUGE PAIRS



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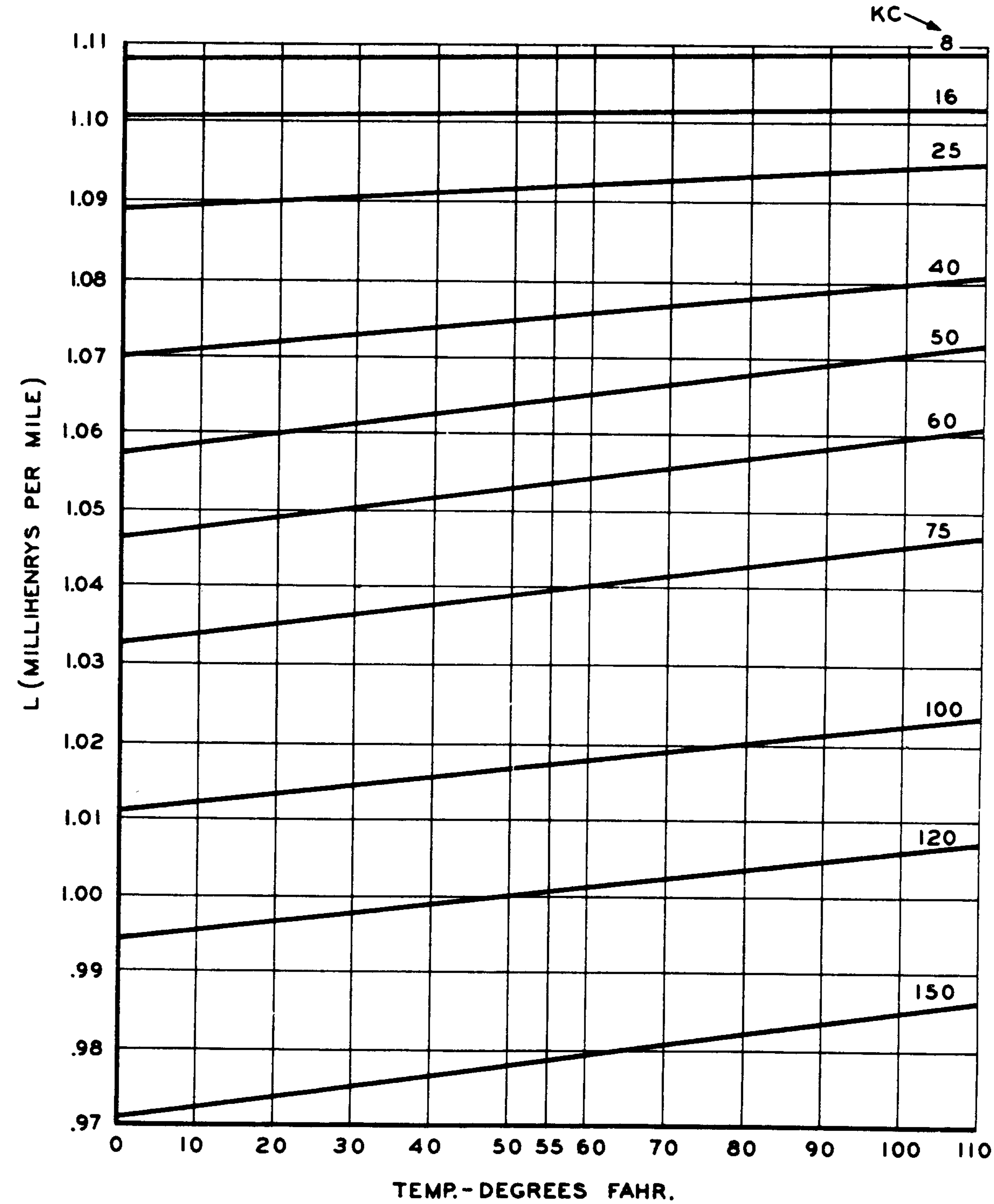
ES-855709
C.M.H. 4-30-41

TYPICAL VALUES OF INDUCTANCE PER MILE VS TEMPERATURE

19 GAUGE PAIRS



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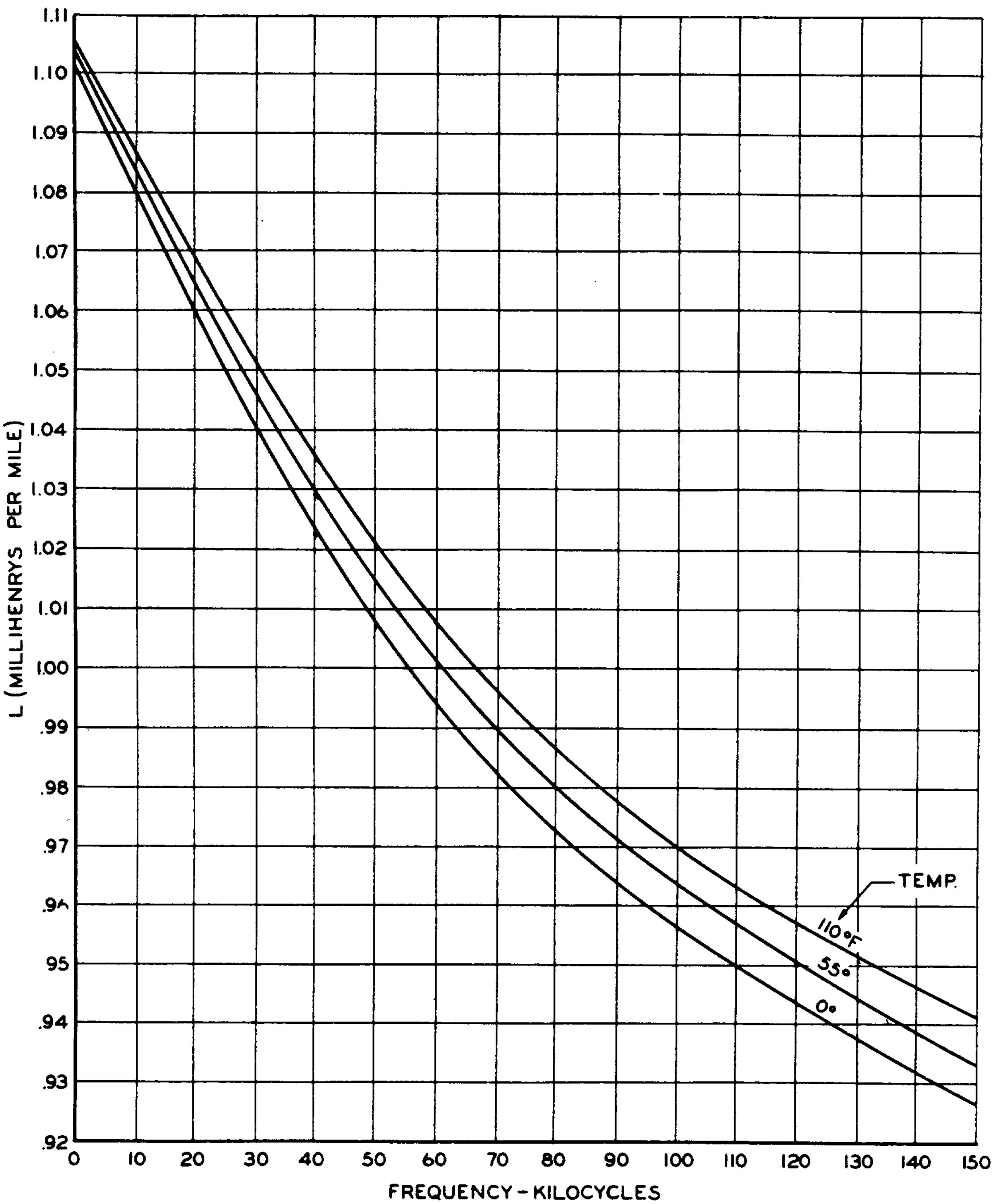
ES-855710
C.M.H. 4-30-41

TYPICAL VALUES OF INDUCTANCE PER MILE VS FREQUENCY

16 GAUGE PAIRS



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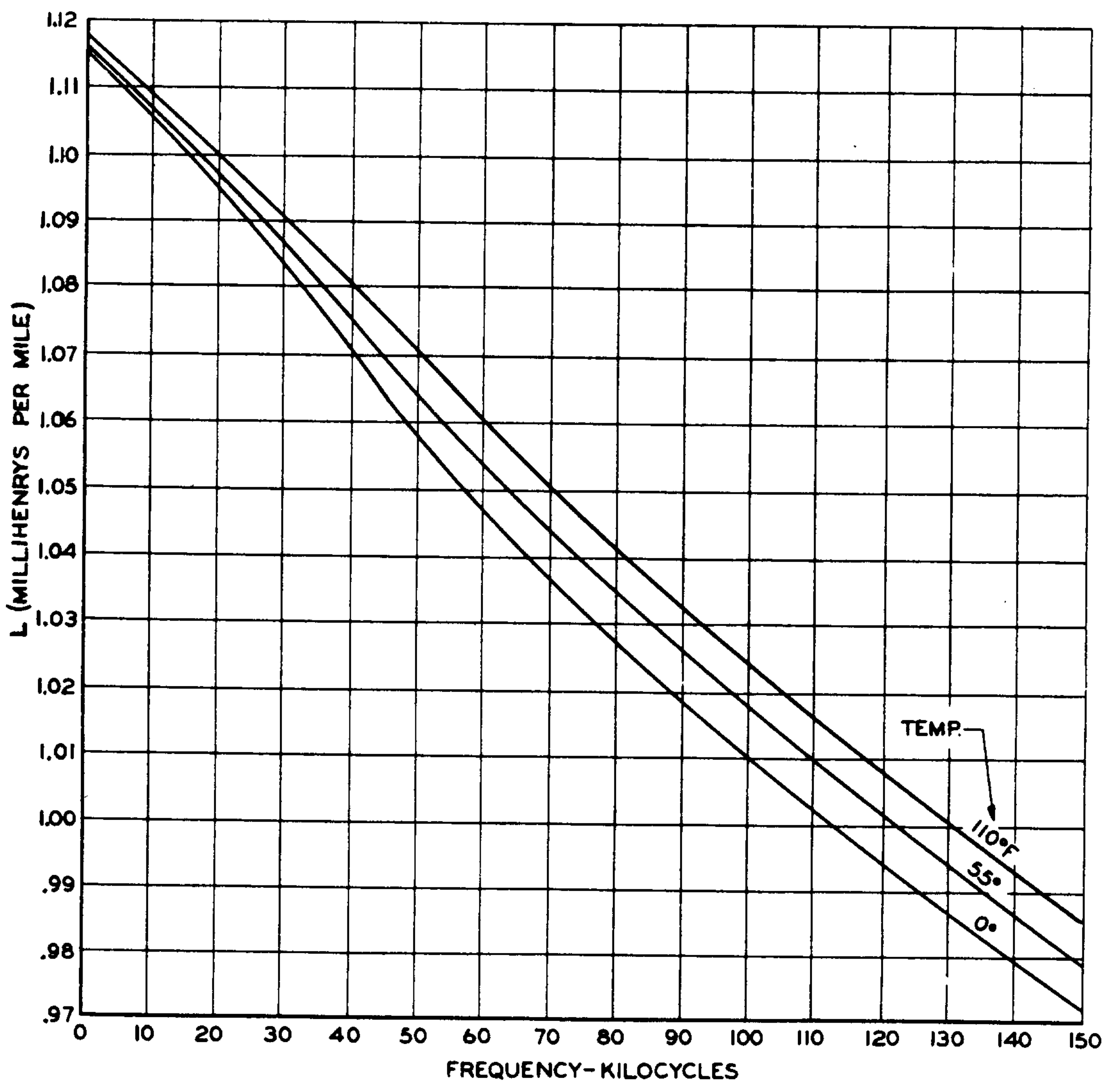
ES-855711
C.M.H. 4-30-41

TYPICAL VALUES OF INDUCTANCE PER MILE VS FREQUENCY

19 GAUGE PAIRS



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ES-855712
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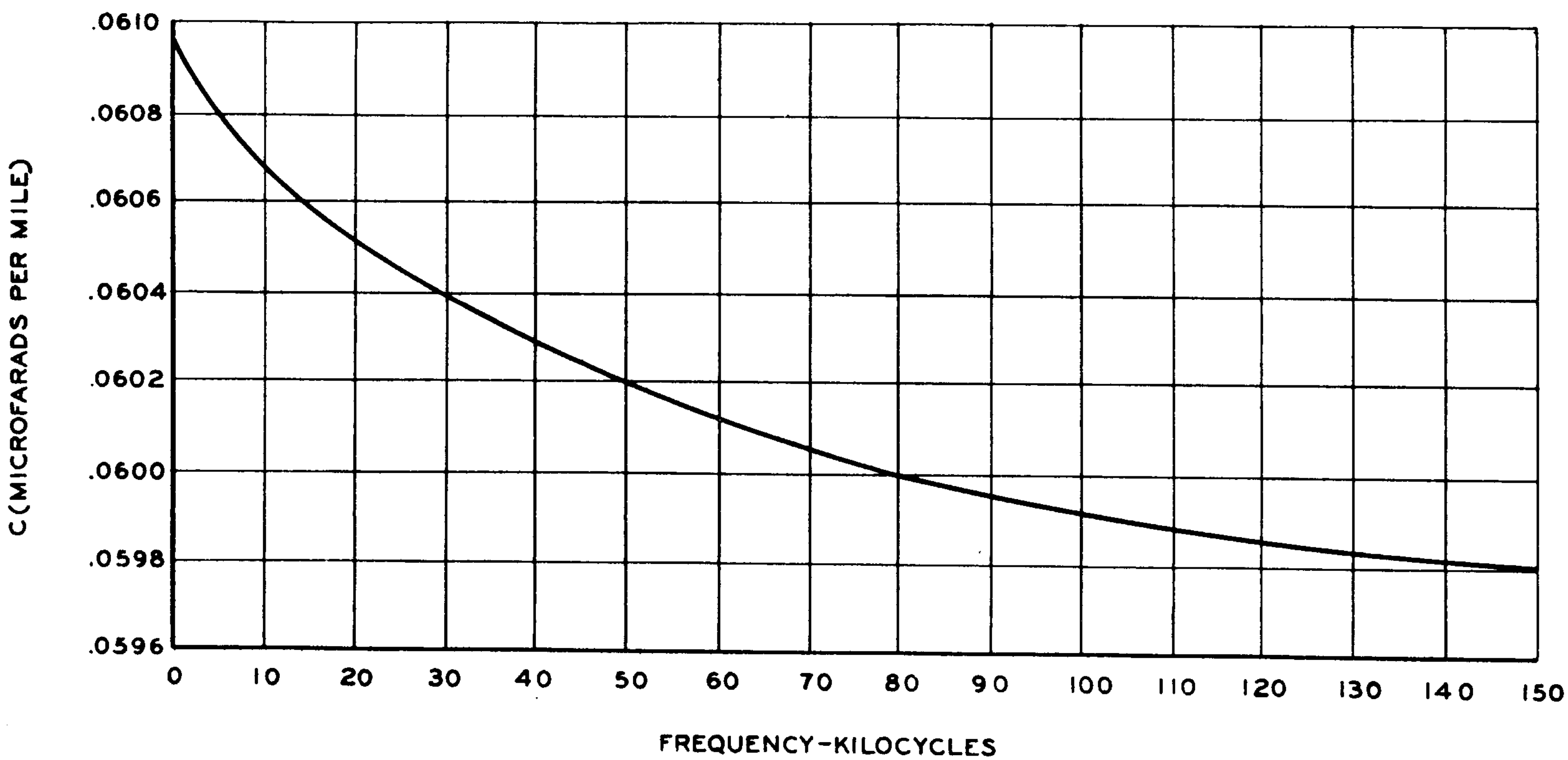
TYPICAL VALUES OF CAPACITANCE PER MILE VS FREQUENCY

TEMPERATURE 55° F
10 & 13 AWG PAIRS



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C.M.H. 4-30-41

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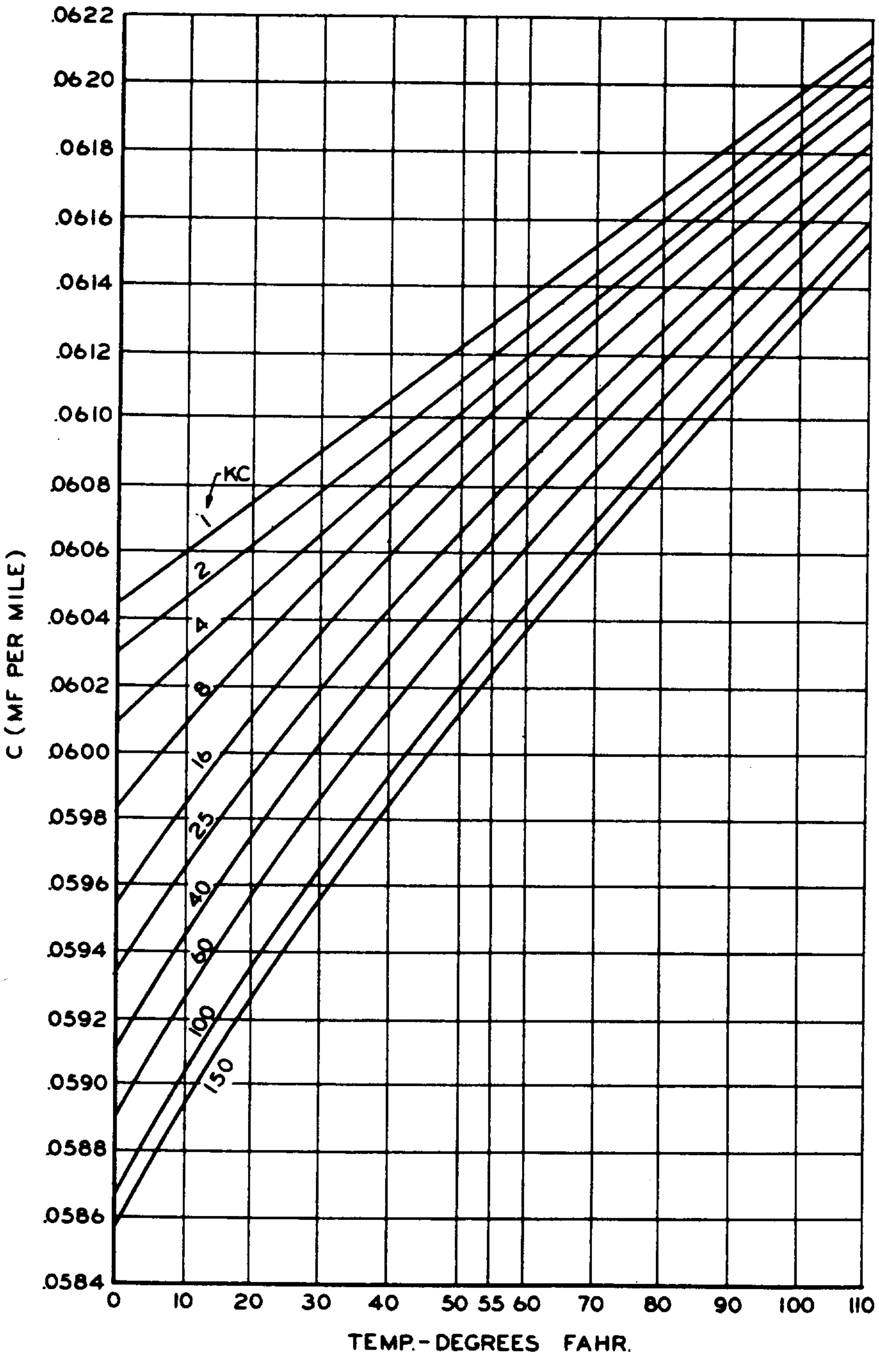
ES-855713
C.M.H. 4-30-41

TYPICAL VALUES OF CAPACITANCE PER MILE VS TEMPERATURE

19 GAUGE PAIRS



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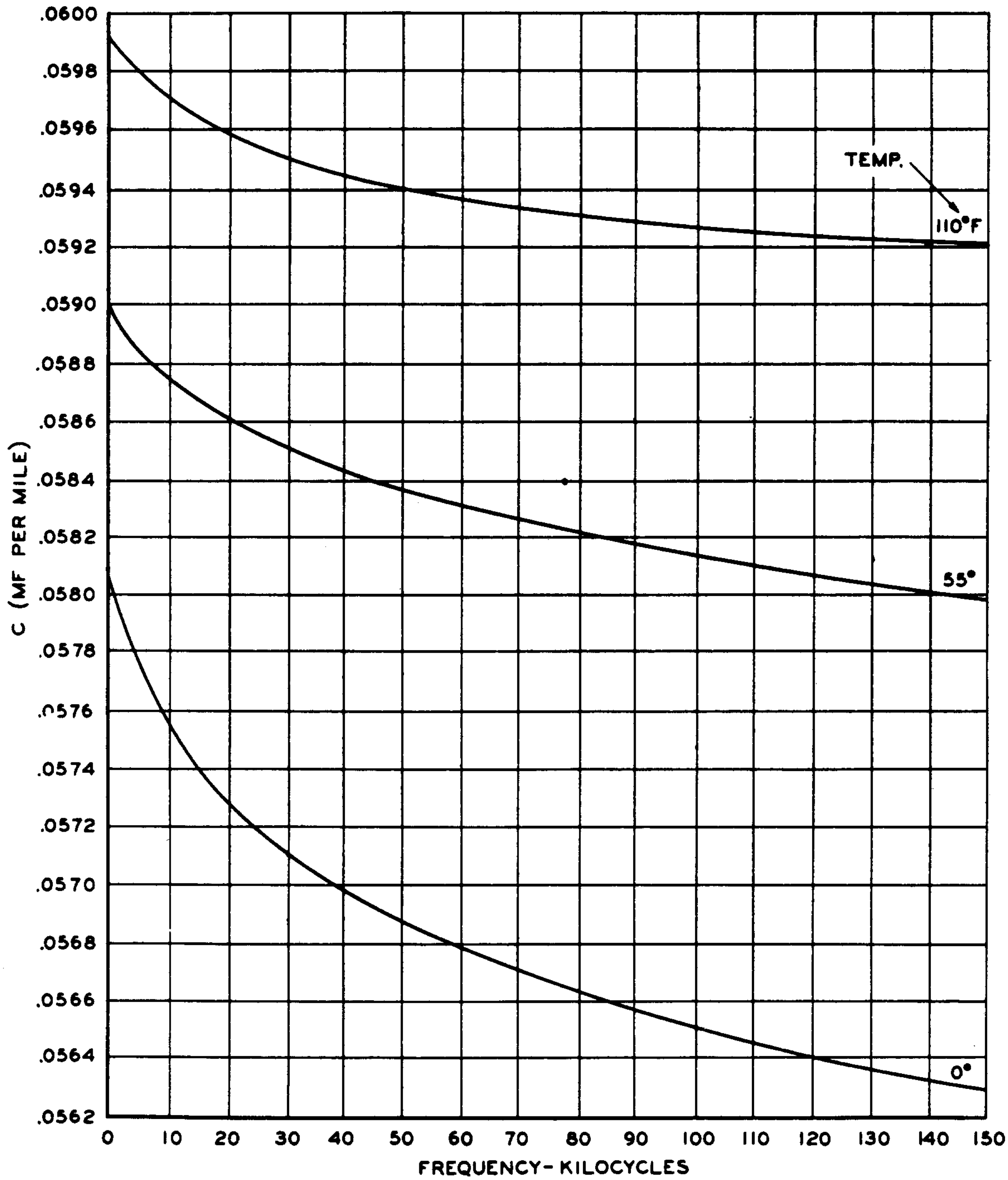
ES-855714
C.M.H. 4-30-41

TYPICAL VALUES OF CAPACITANCE PER MILE VS FREQUENCY
16 GAUGE PAIRS



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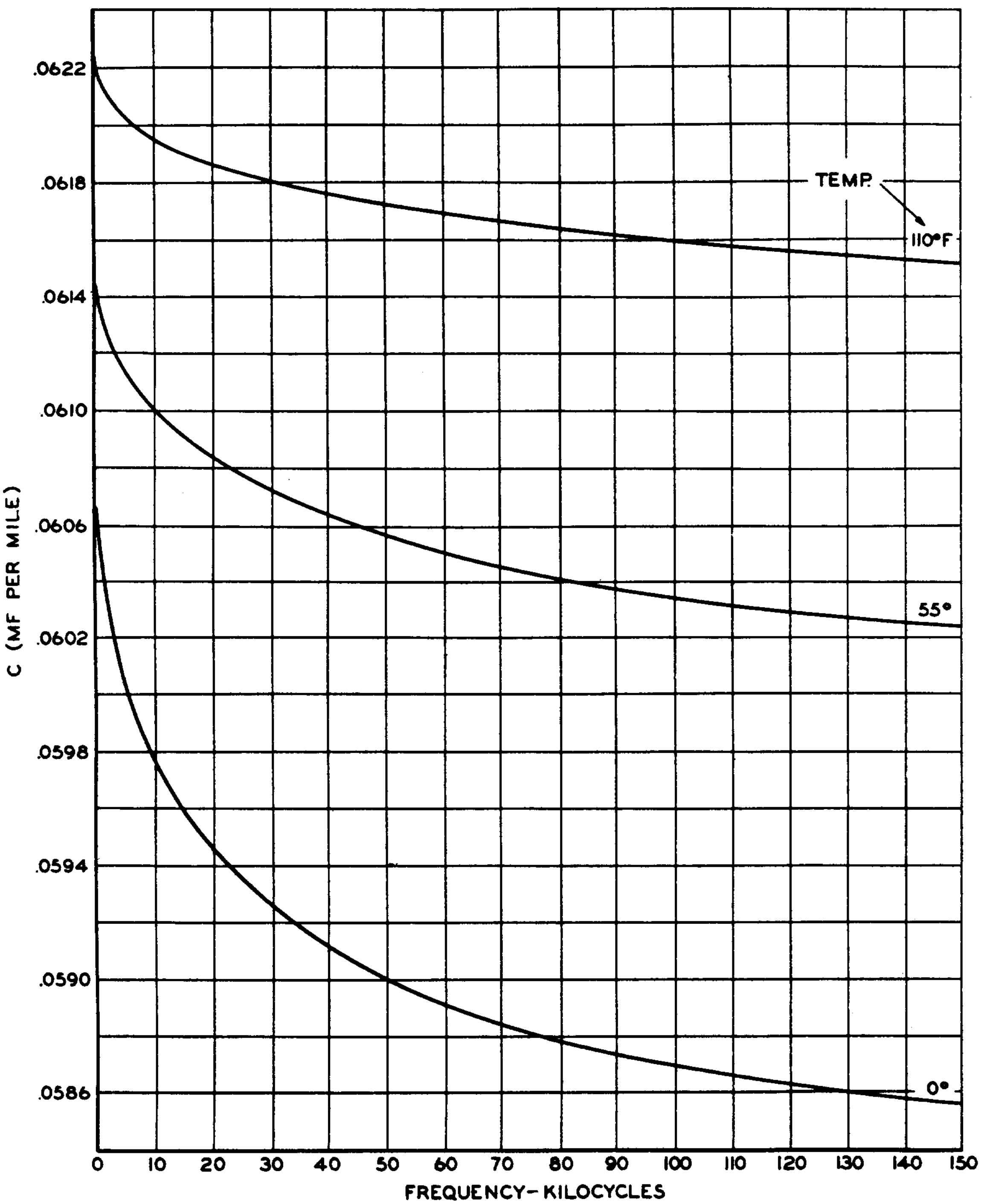
ES-855715
C.M.H. 4-30-41

TYPICAL VALUES OF CAPACITANCE PER MILE VS FREQUENCY

19 GAUGE PAIRS

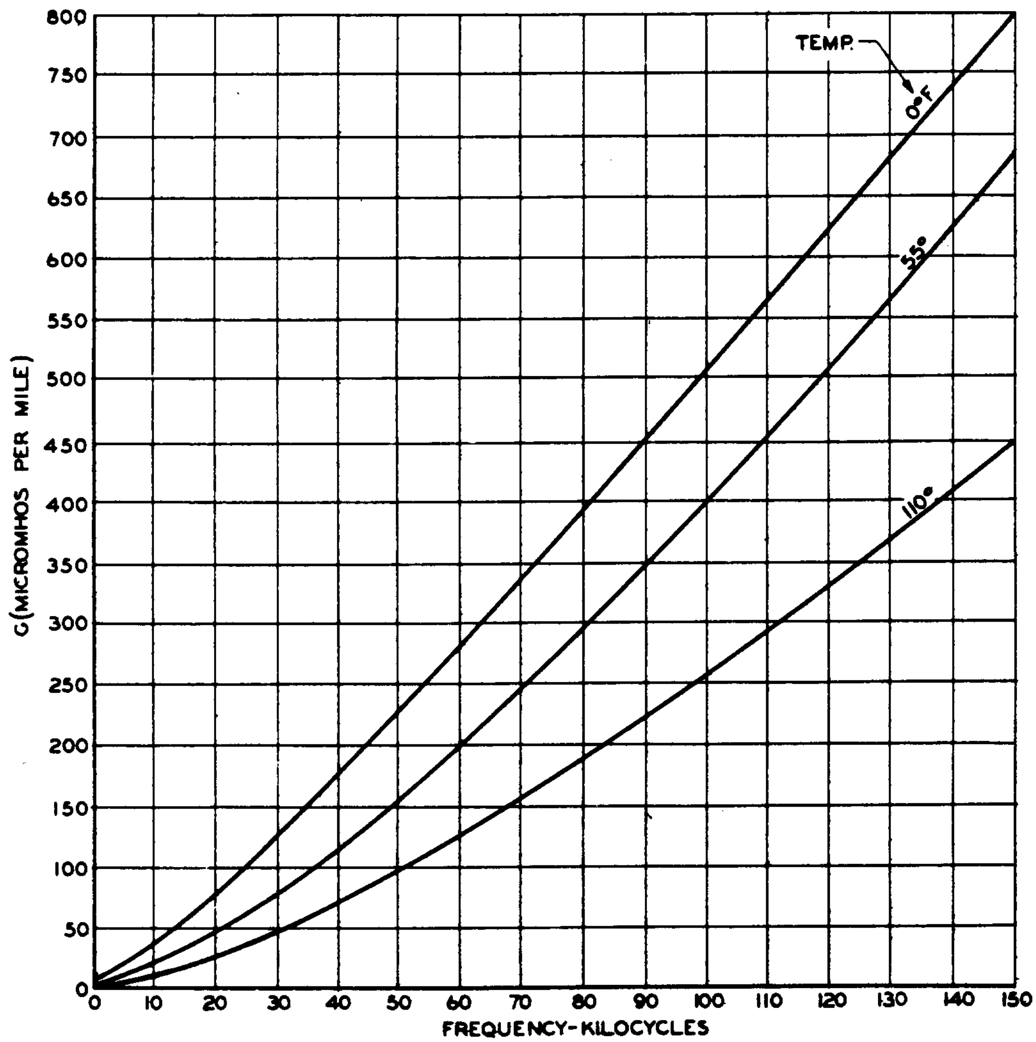


BELL TELEPHONE LABORATORIES, INC.

ES-855716
C.M.H. 4-30-41

TYPICAL VALUES OF CONDUCTANCE PER MILE VS FREQUENCY

16 GAUGE PAIRS

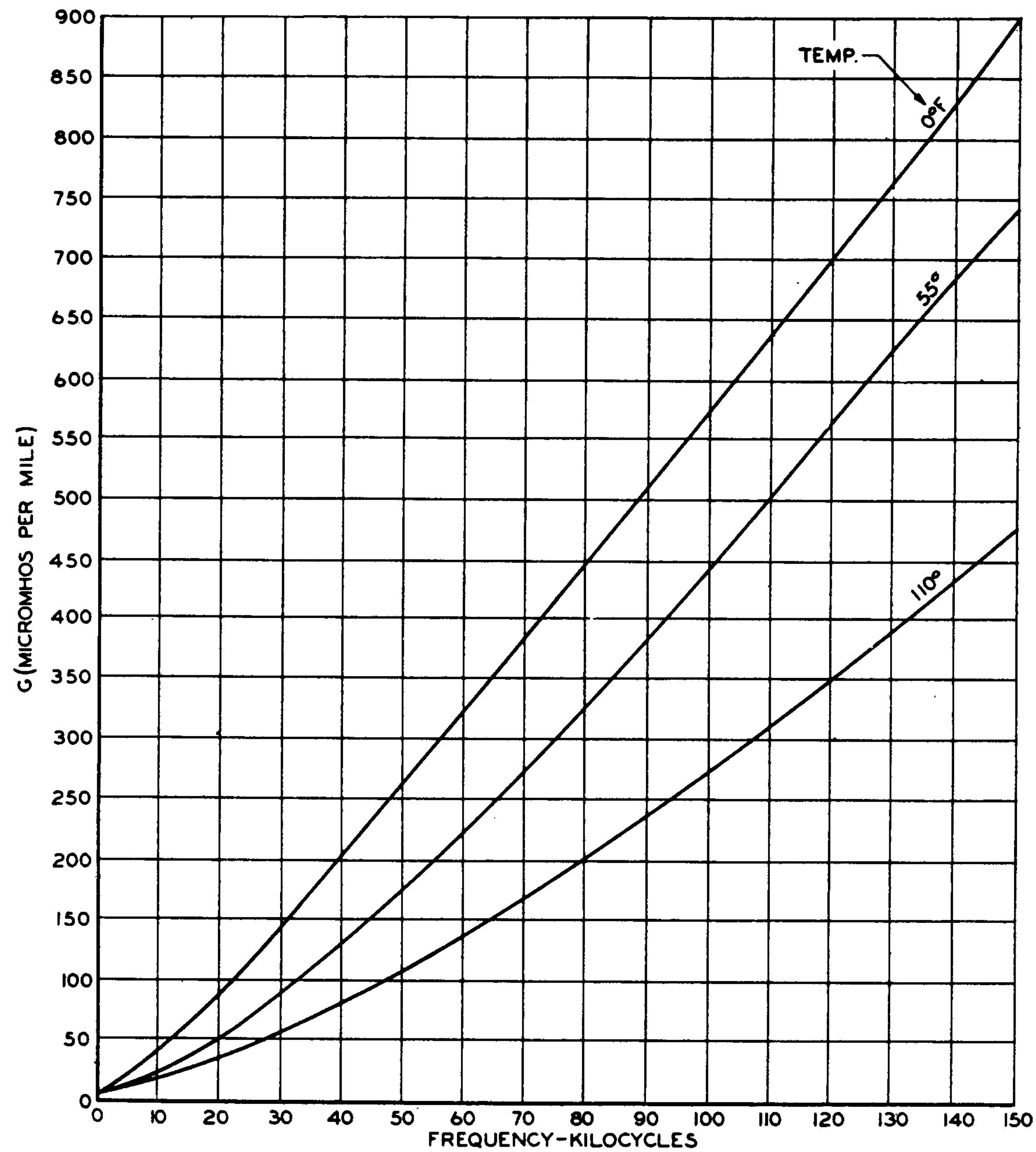


BELL TELEPHONE LABORATORIES, INC.

ES-855717
C.M.H. 4-30-41

TYPICAL VALUES OF CONDUCTANCE PER MILE VS FREQUENCY

19 GAUGE PAIRS



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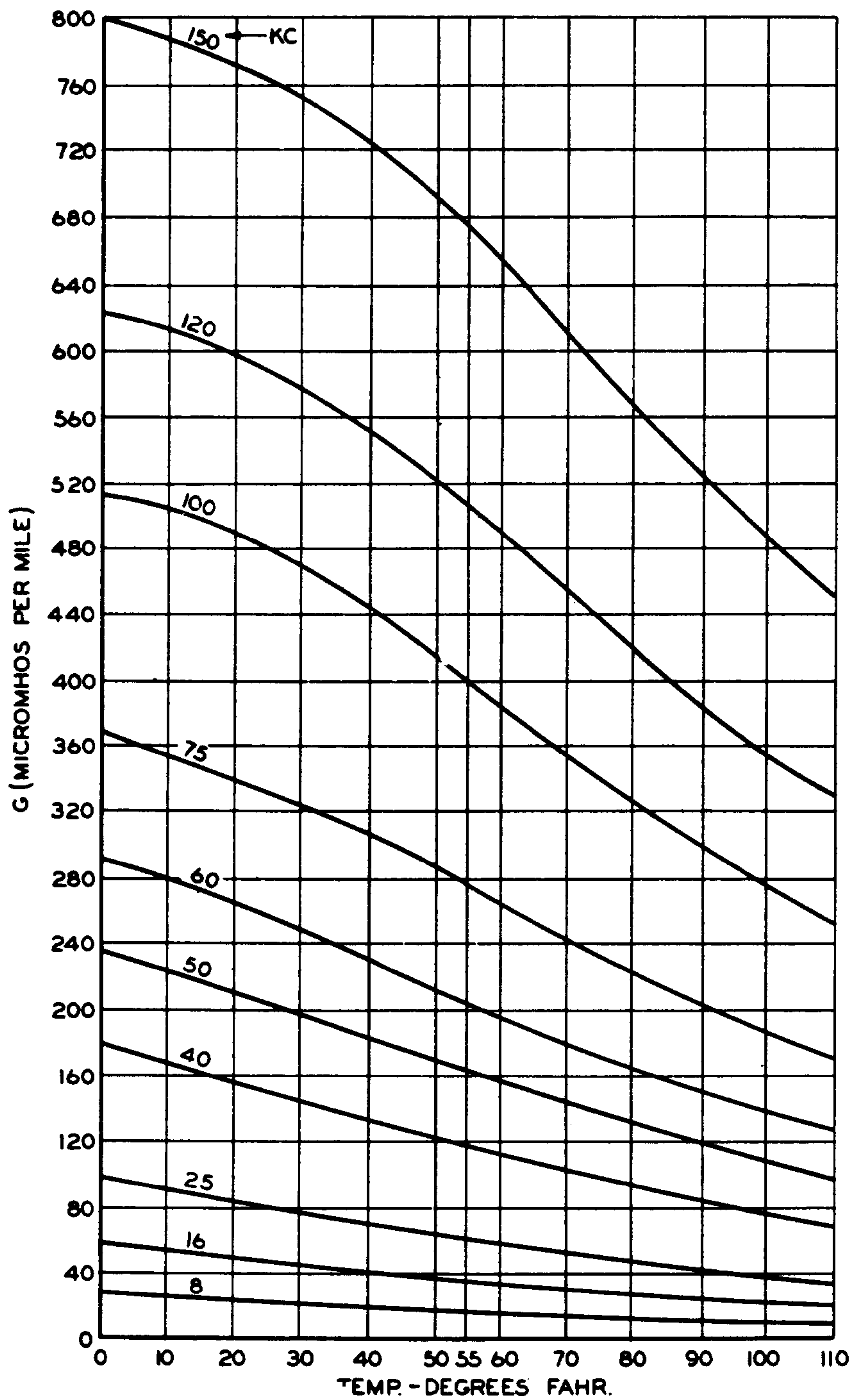
ES-855718
C.M.H. 4-30-41

TYPICAL VALUES OF CONDUCTANCE PER MILE VS TEMPERATURE

16 GAUGE PAIRS

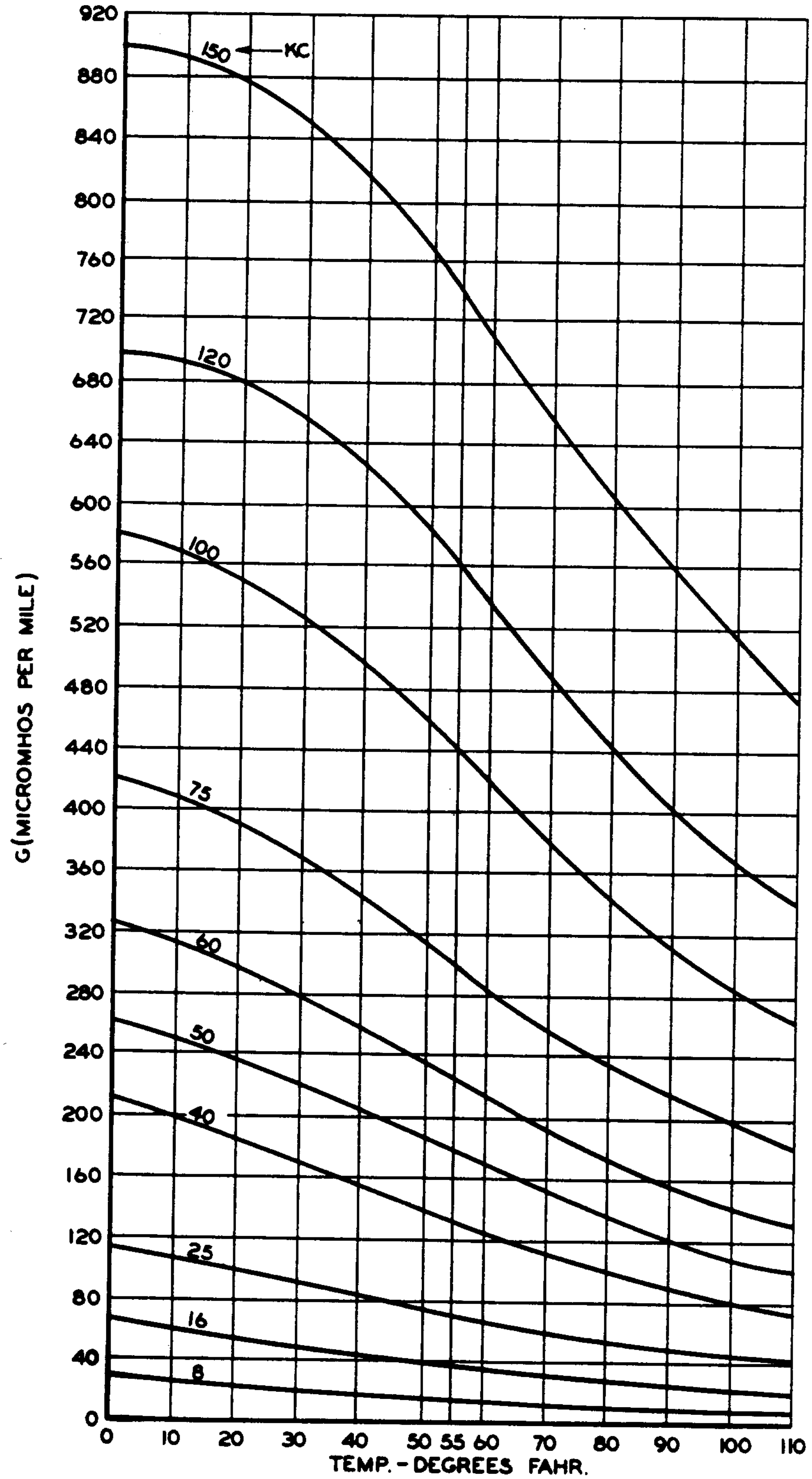


BELL TELEPHONE LABORATORIES, INC.

ES-855719
C.M.H. 4-30-41

TYPICAL VALUES OF CONDUCTANCE PER MILE VS TEMPERATURE

19 GAUGE PAIRS



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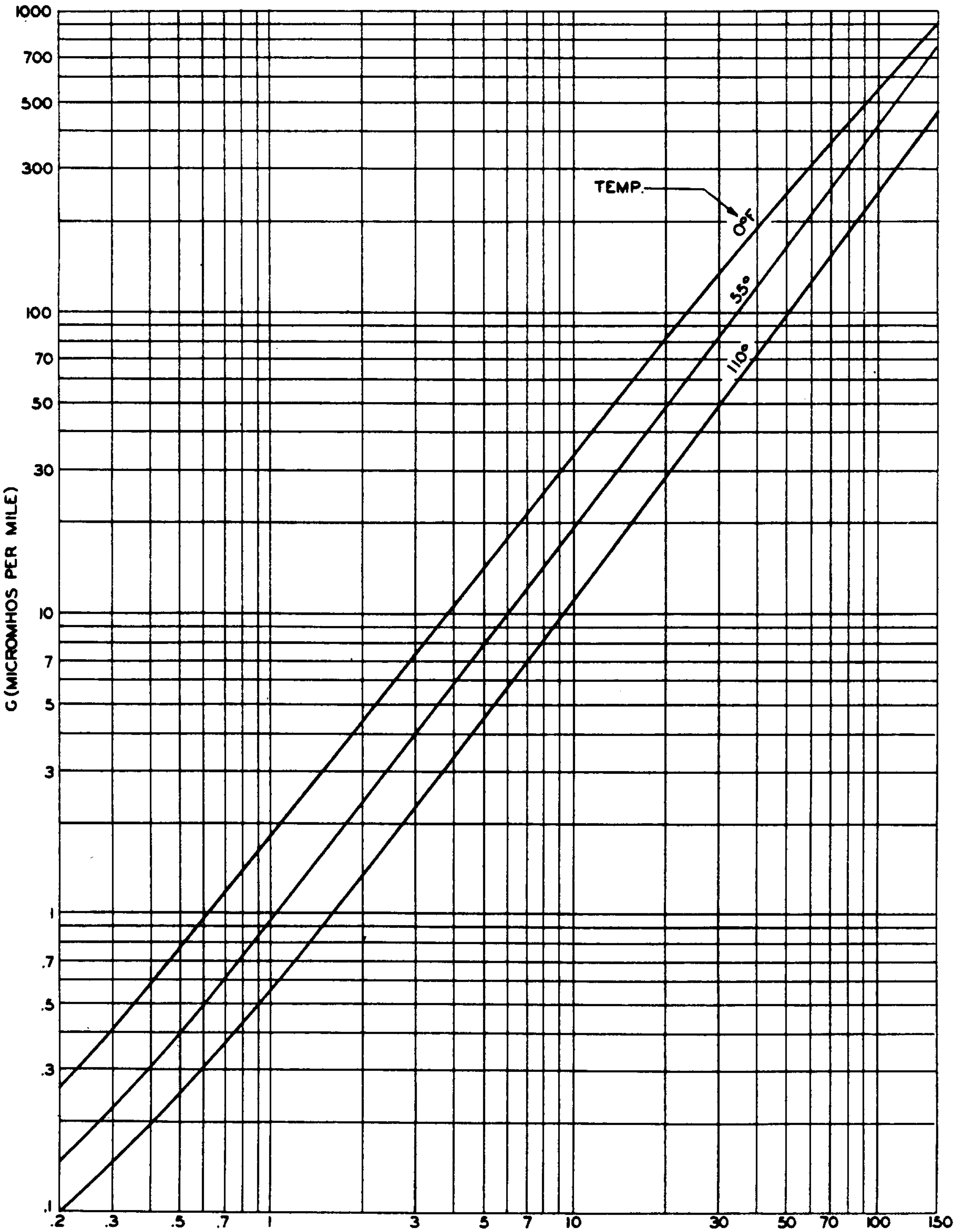
ES-855720
C.M.H. 4-30-41

TYPICAL VALUES OF CONDUCTANCE PER MILE VS FREQUENCY
19 GAUGE PAIRS



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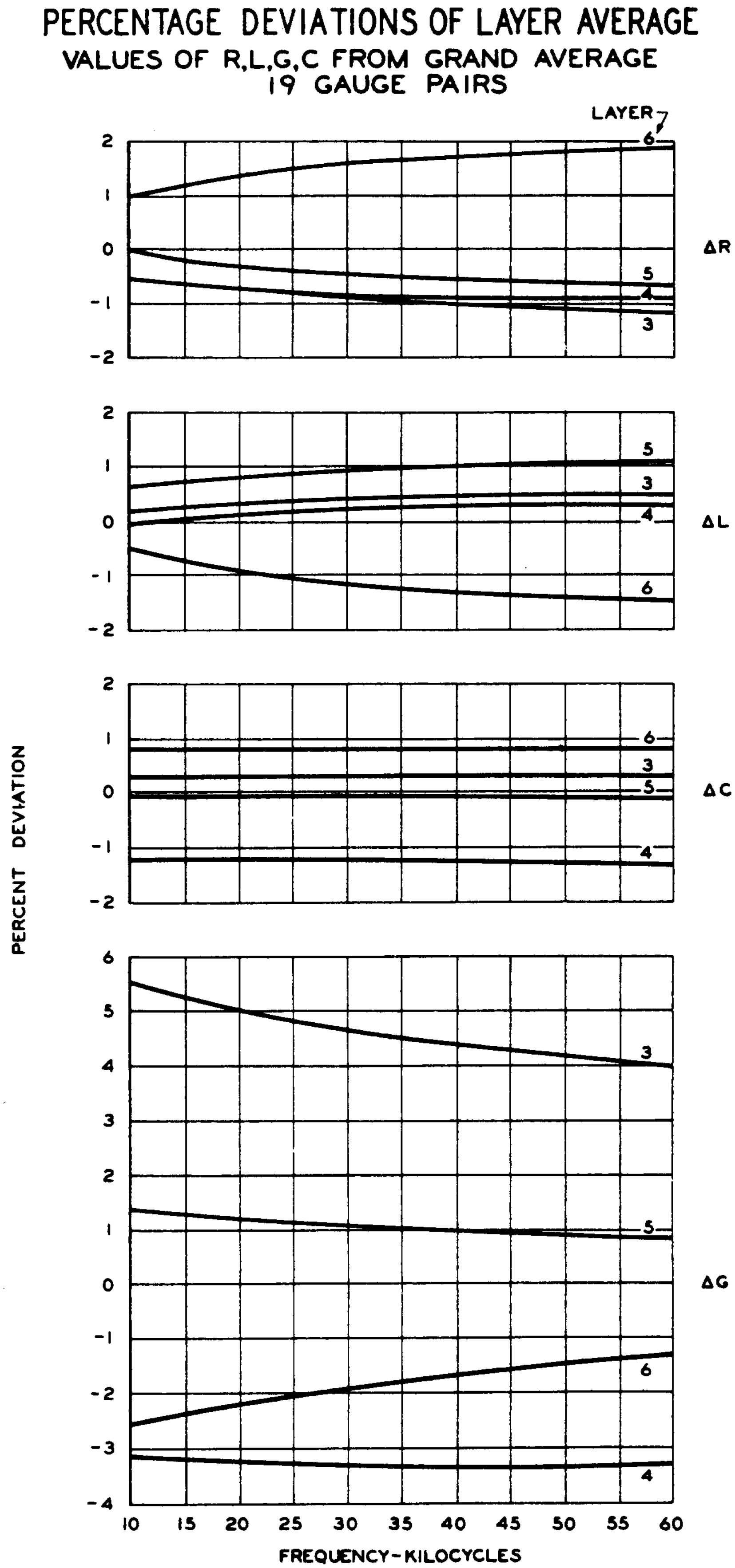

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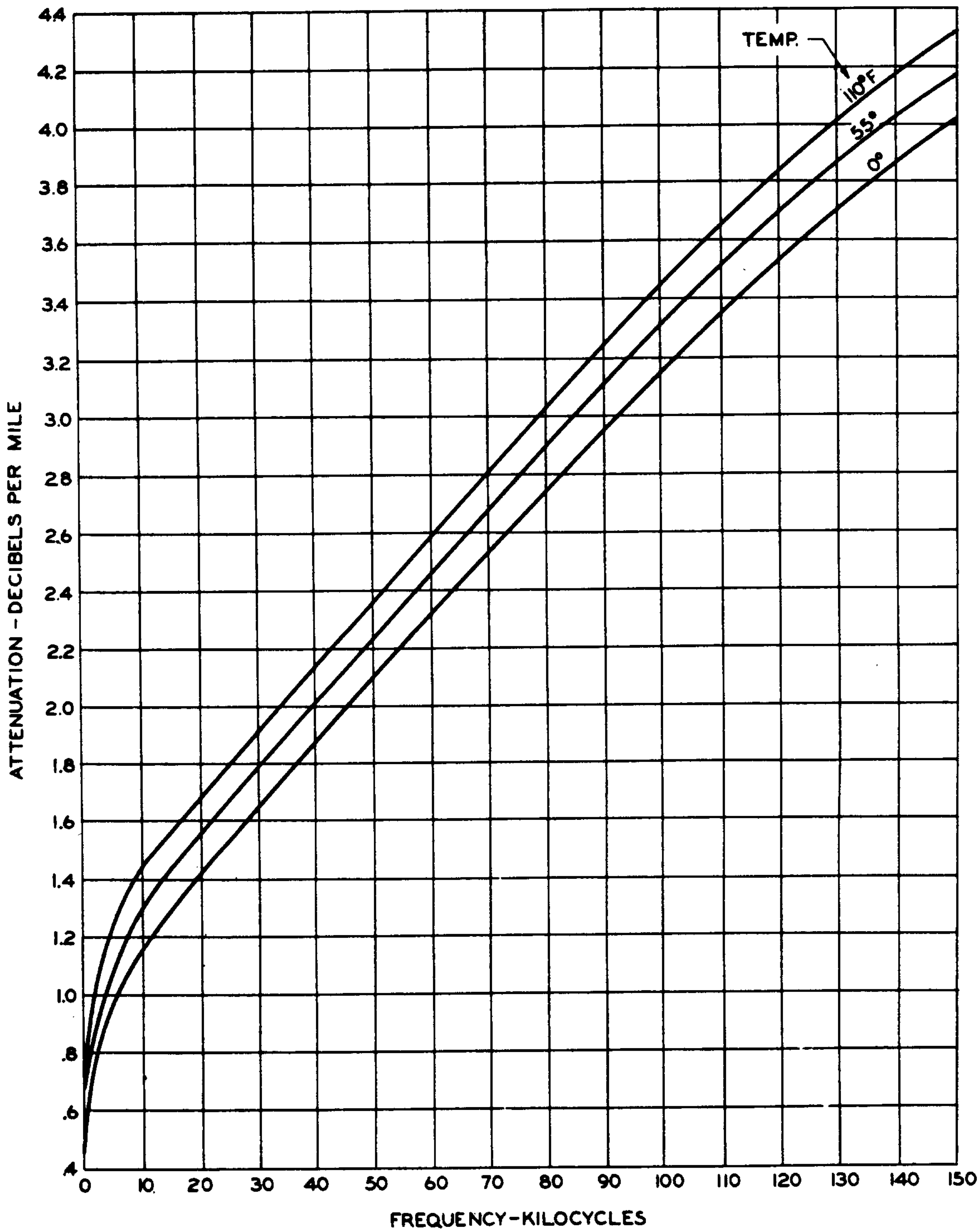
ES-855722
C.M.H. 4-30-41

TYPICAL VALUES OF ATTENUATION VS. FREQUENCY

16 GAUGE CABLE PAIRS



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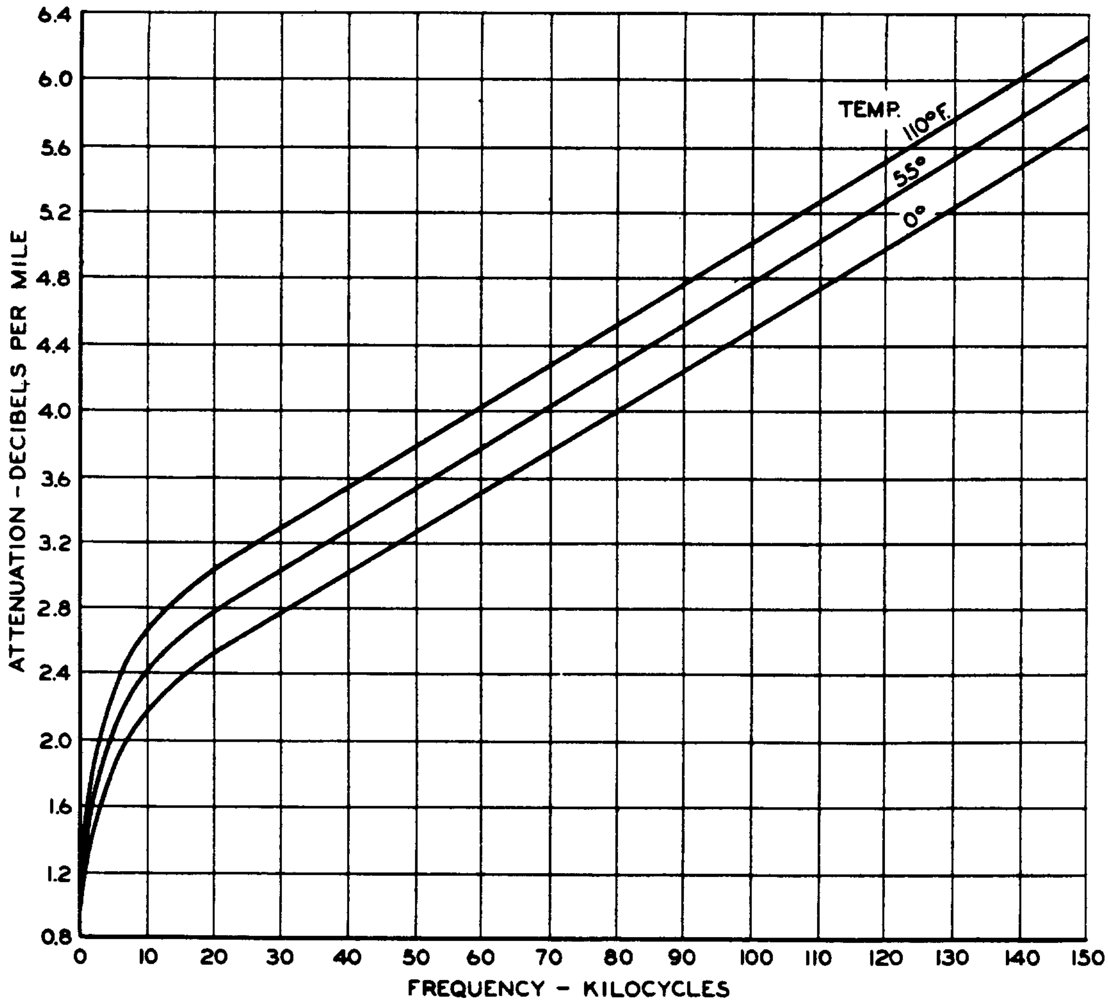
TYPICAL VALUES OF ATTENUATION VS FREQUENCY

19 GAUGE CABLE PAIRS



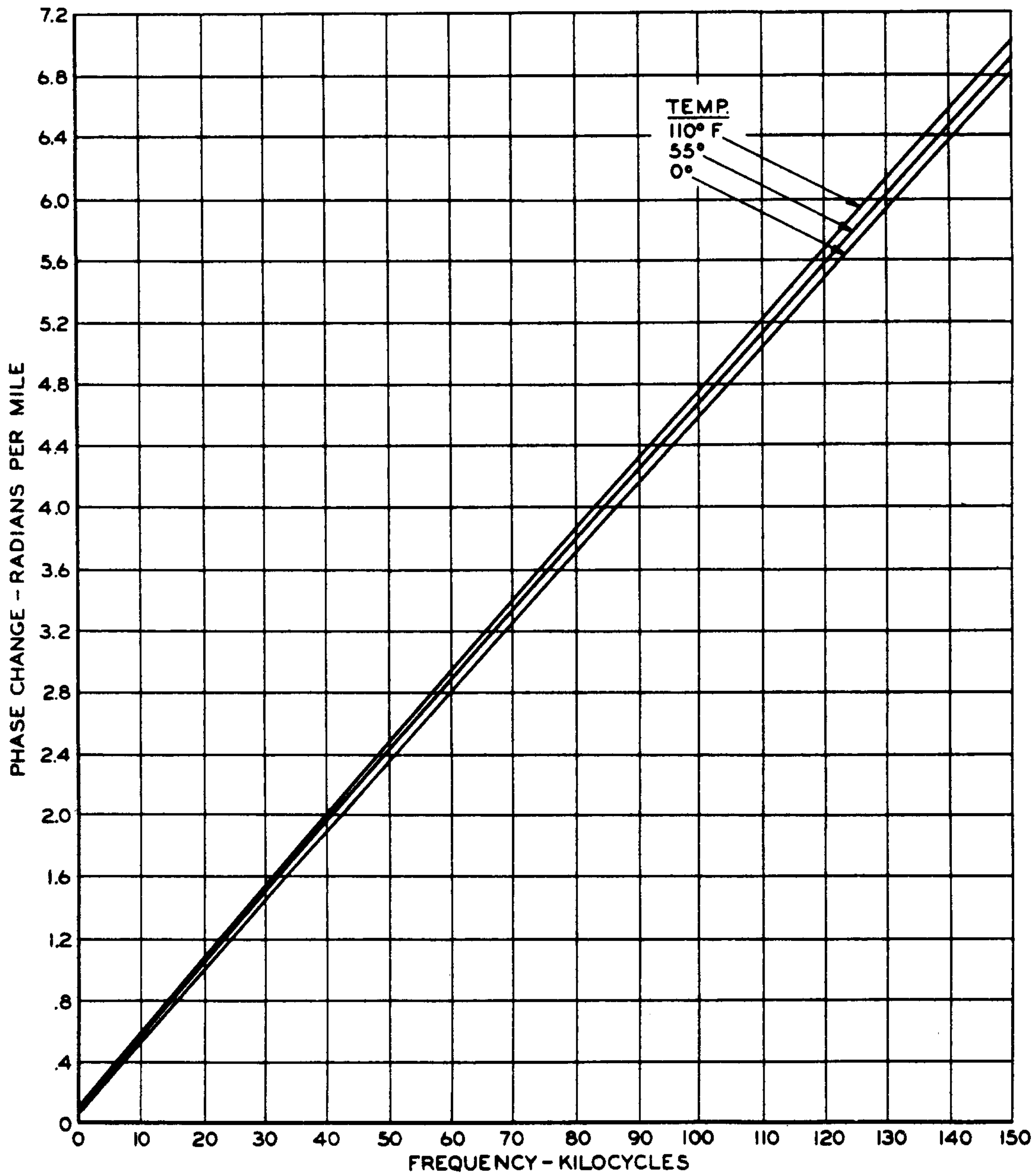
BELL TELEPHONE LABORATORIES, INC.

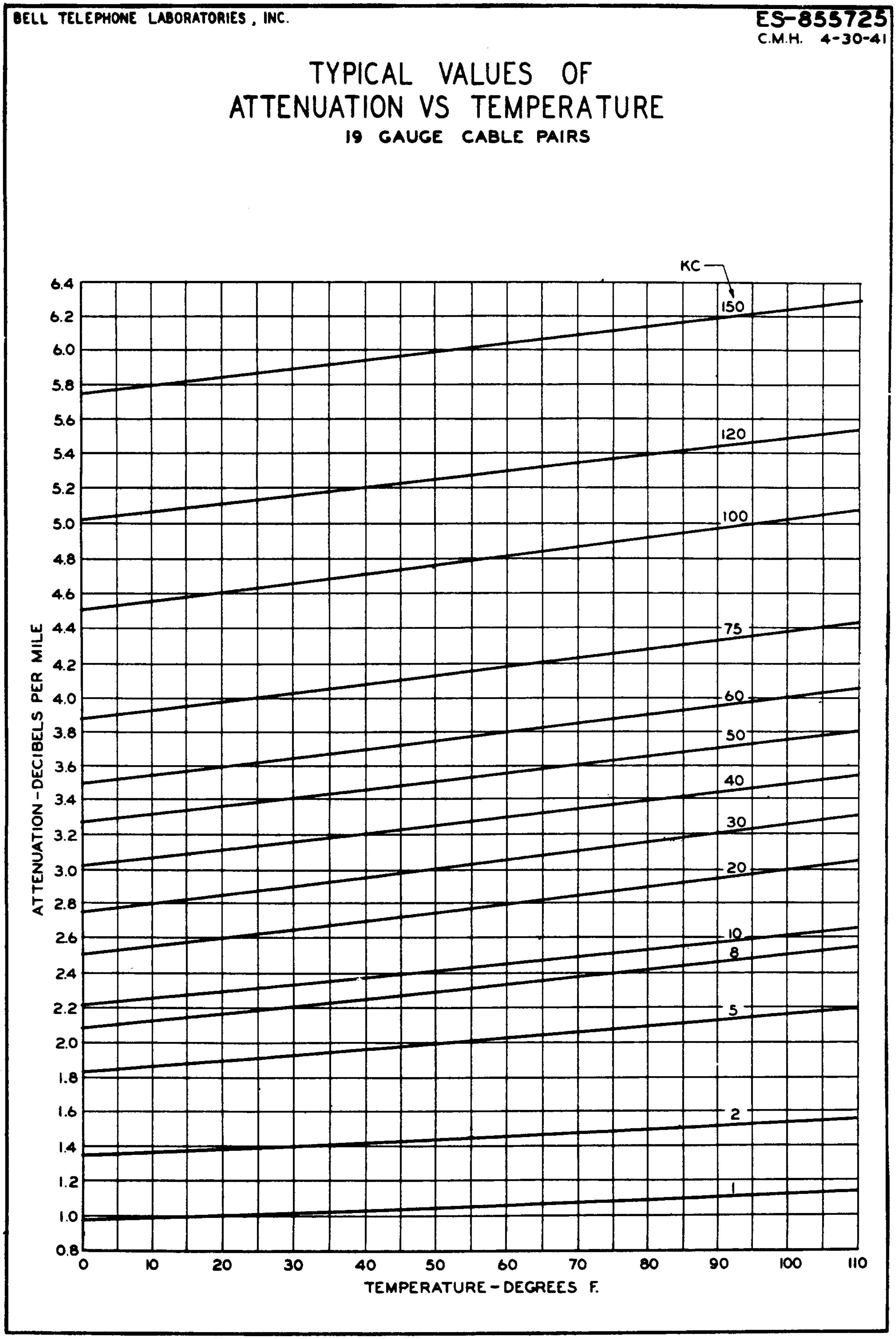
ES-855724
C.M.H. 4-30-41

TYPICAL VALUES OF PHASE CHANGE VS FREQUENCY

16 GAUGE PAIRS

(MULTIPLY VALUES GIVEN BY 57.3 TO GET DEGREES PER MILE)



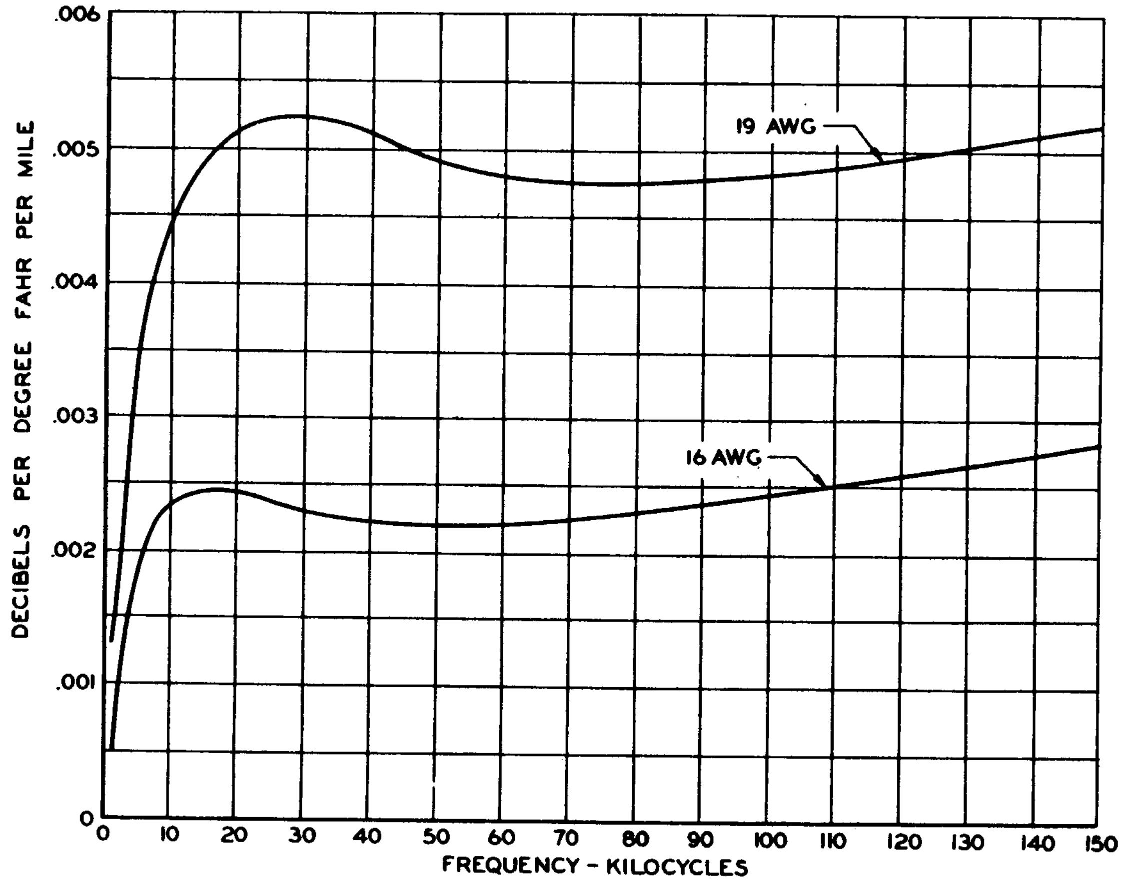

BELL TELEPHONE LABORATORIES, INC.
ES-855725
C.M.H. 4-30-41
TYPICAL VALUES OF
ATTENUATION VS TEMPERATURE
19 GAUGE CABLE PAIRS
KC
150
120
100
75
60
50
40
30
20
10
8
5
2
1
ATTENUATION - DECIBELS PER MILE
6.4
6.2
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0
10
20
30
40
50
60
70
80
90
100
110
TEMPERATURE - DEGREES F.

BELL TELEPHONE LABORATORIES, INC.

ES-855726
C.M.H. 4-30-41

TYPICAL VALUES OF TEMPERATURE VARIATION OF ATTENUATION VS FREQUENCY

16 AWG AND 19 AWG PAIRS



ES-855726
C.M.H. 4-30-41

BELL TELEPHONE LABORATORIES, INC.

TYPICAL TWIST CHARACTERISTIC

19 AWG CABLE PAIRS

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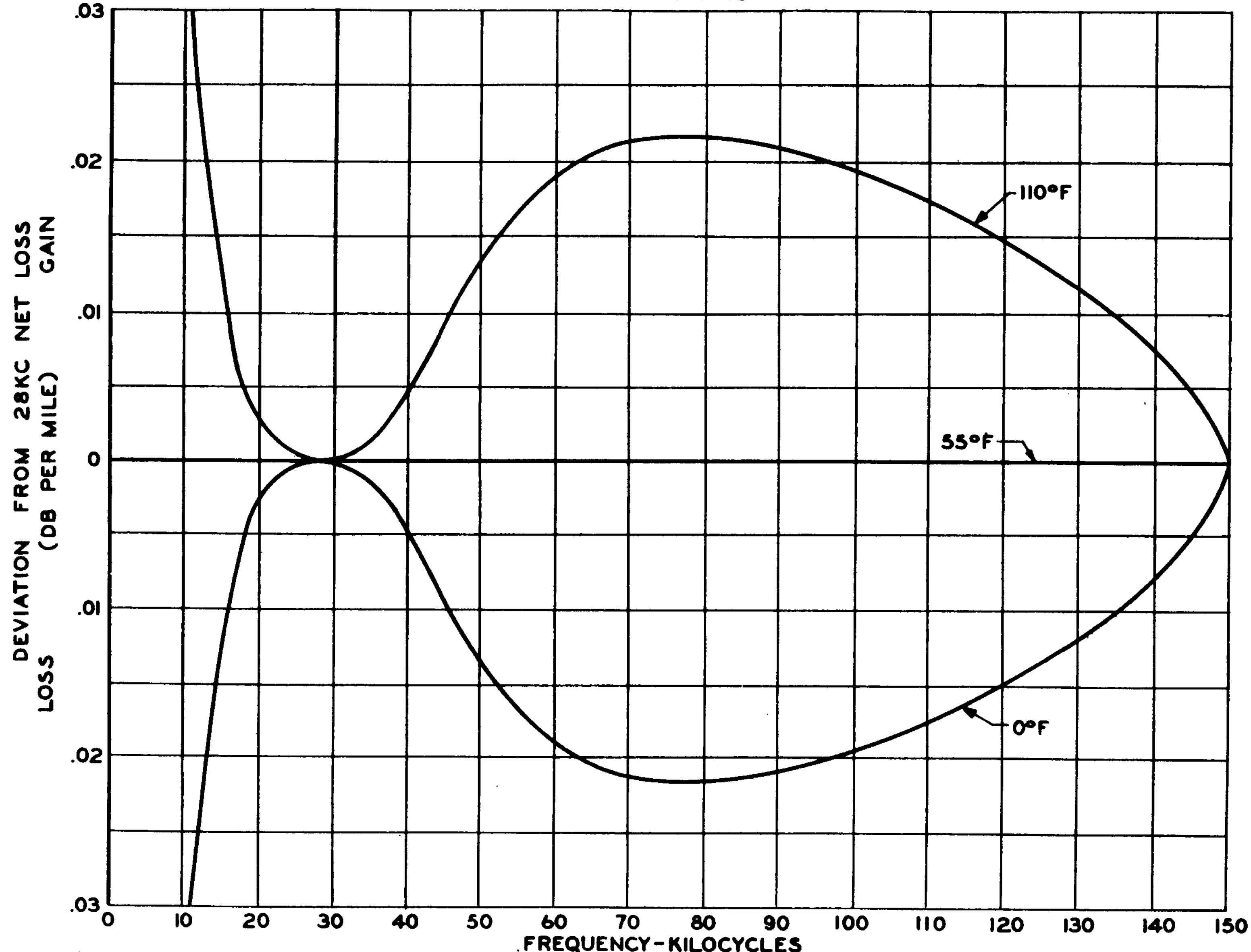

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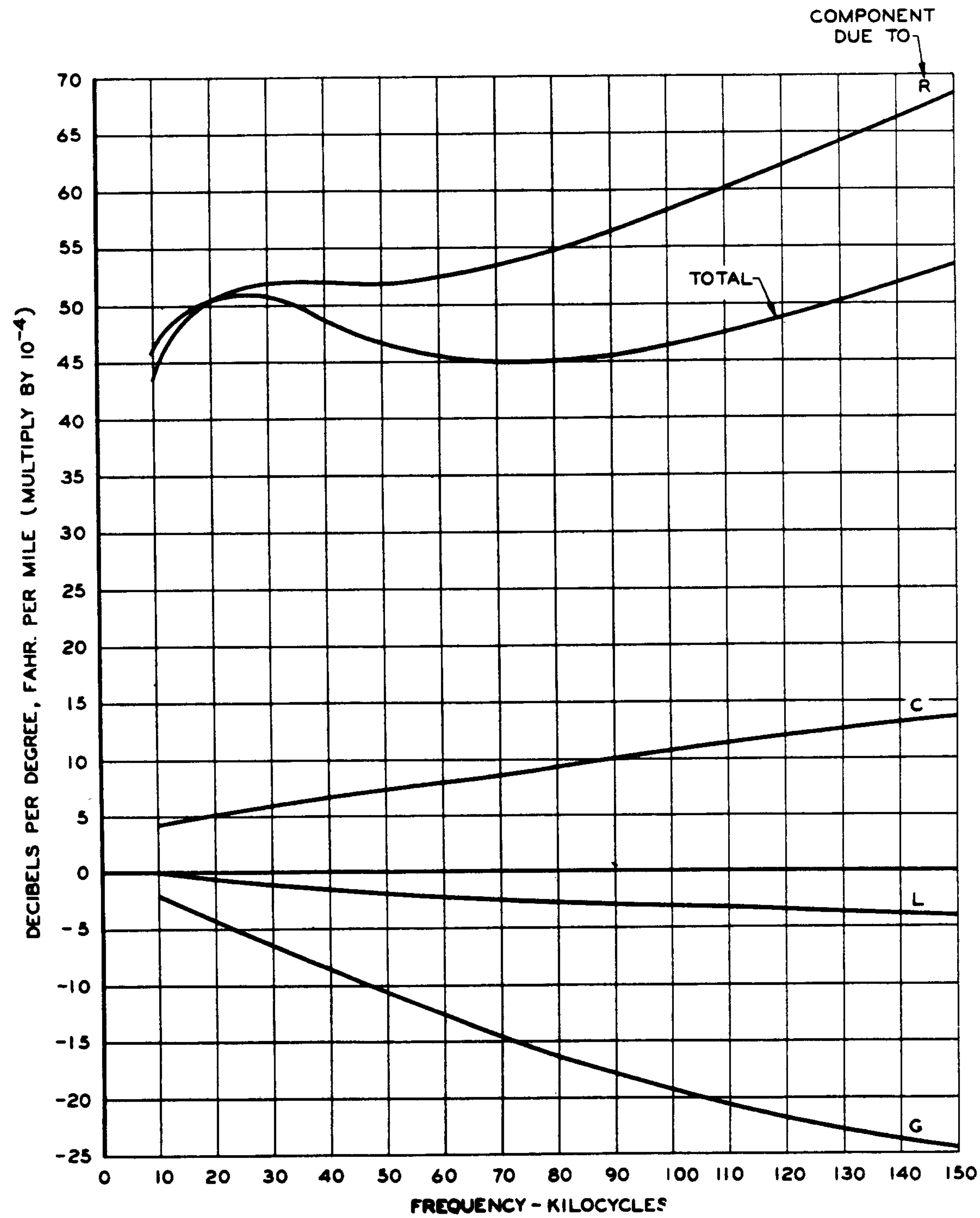
BELL TELEPHONE LABORATORIES, INC.

ES-855728
C.M.H. 4-30-41

TYPICAL VALUES OF COMPONENTS OF ATTENUATION-TEMPERATURE COEFFICIENT DUE TO R, L, G AND C

19 GAUGE CABLE PAIRS



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ES-855729
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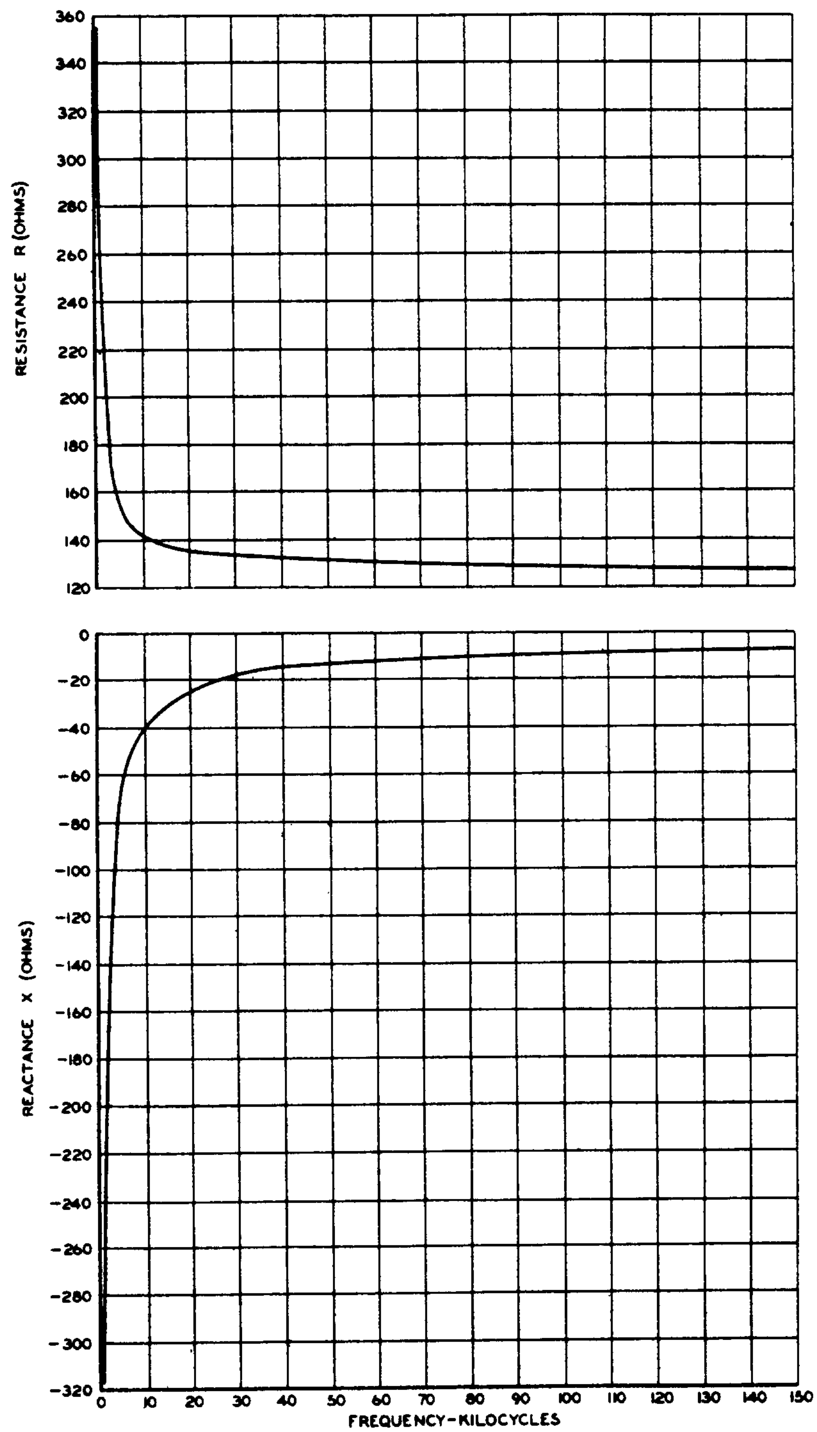
TYPICAL VALUES OF CHARACTERISTIC IMPEDANCE

$Z_o = R - jX$

TEMPERATURE 55° F

16 GAUGE PAIRS



BELL TELEPHONE LABORATORIES, INC.

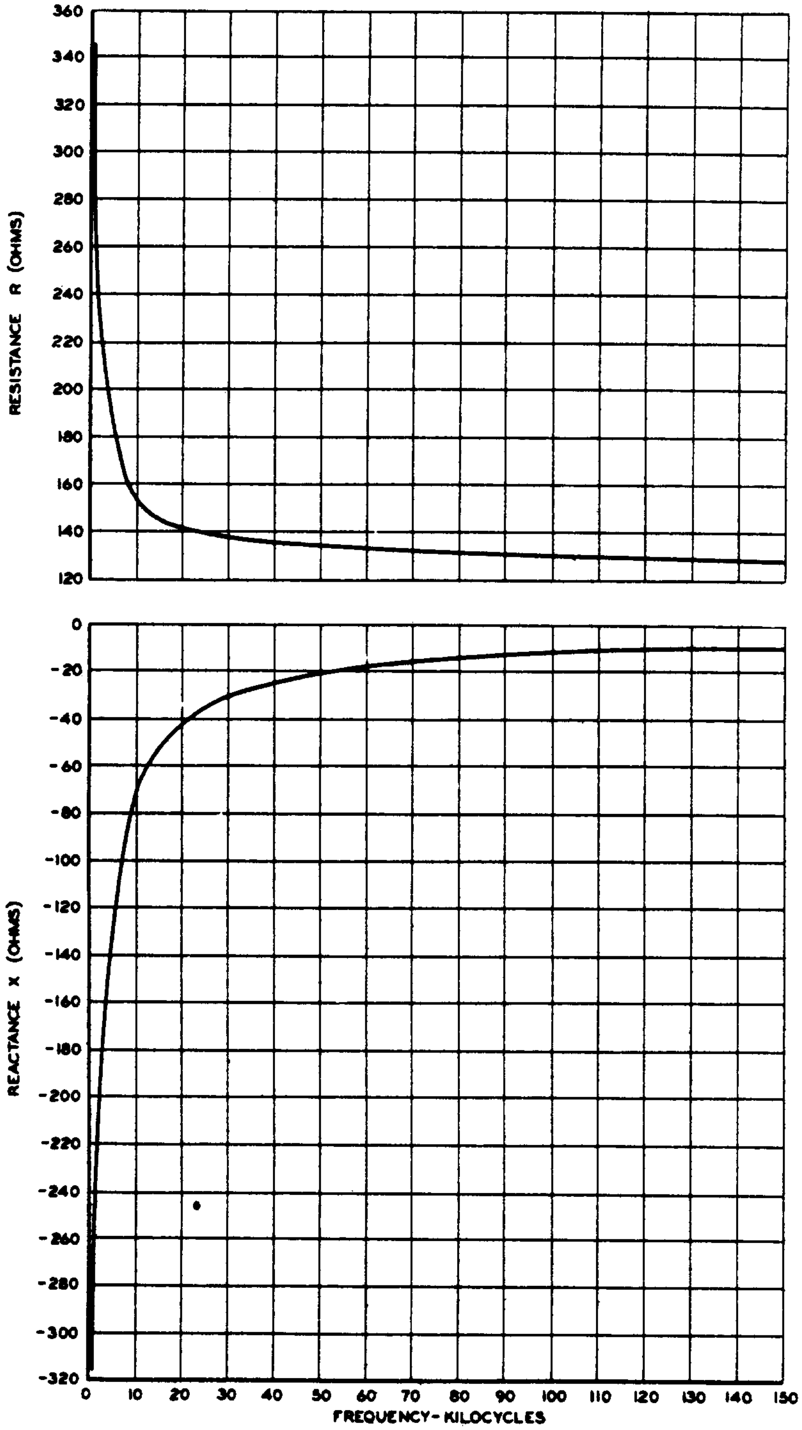
ES-855730
C.M.H. 4-30-41

TYPICAL VALUES OF CHARACTERISTIC IMPEDANCE

$Z_0 = R - jX$

TEMPERATURE 55° F

19 GAUGE PAIRS

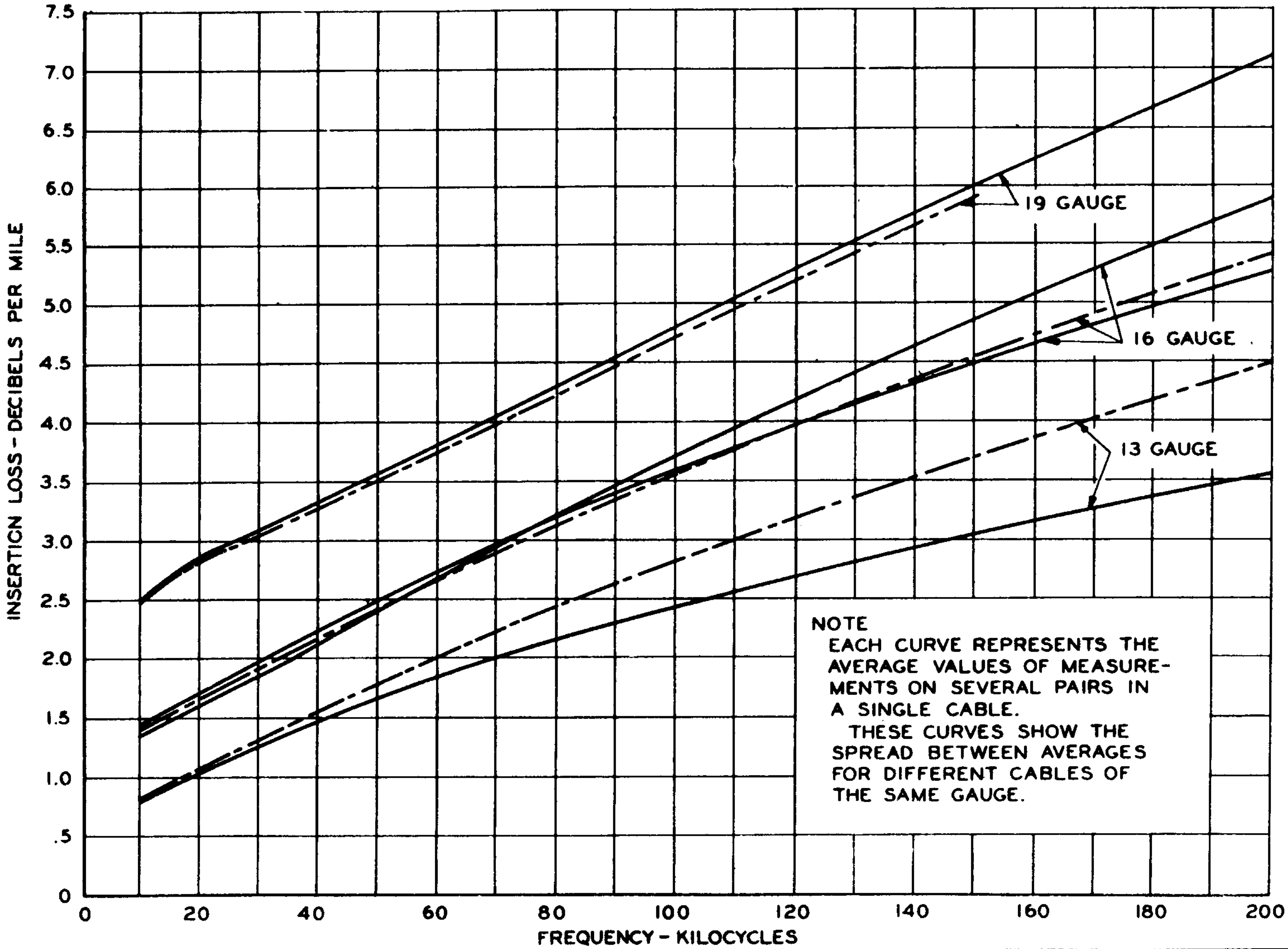


BELL TELEPHONE LABORATORIES, INC.

ES-855731
C.M.H. 4-30-41

CARRIER FREQUENCY LOSS* OF TOLL ENTRANCE CABLE

NON-LOADED, QUADDED TEMPERATURE 60 F., APPROX.
*INSERTION LOSS BETWEEN 125~ RESISTANCES
13, 16 AND 19 GAUGE



NOTE
EACH CURVE REPRESENTS THE AVERAGE VALUES OF MEASUREMENTS ON SEVERAL PAIRS IN A SINGLE CABLE.
THESE CURVES SHOW THE SPREAD BETWEEN AVERAGES FOR DIFFERENT CABLES OF THE SAME GAUGE.

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ES-855732
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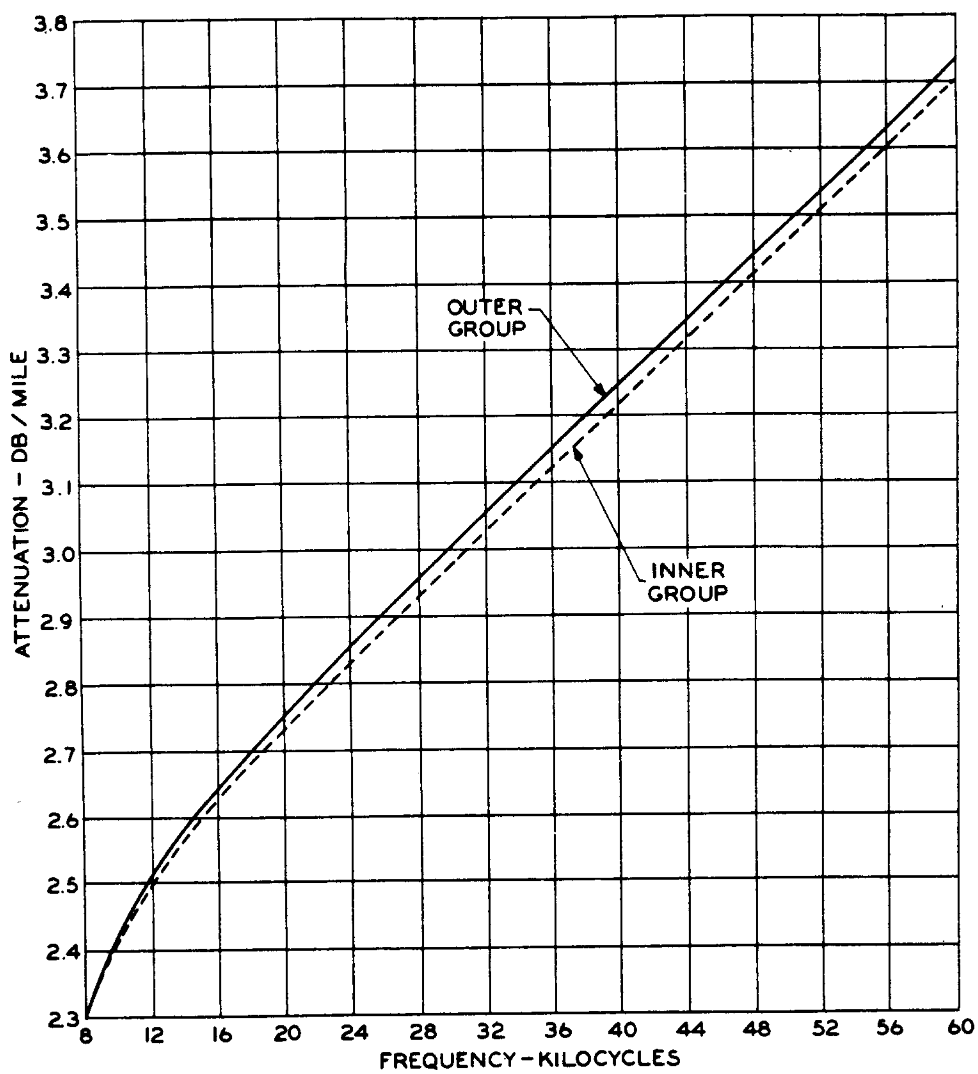
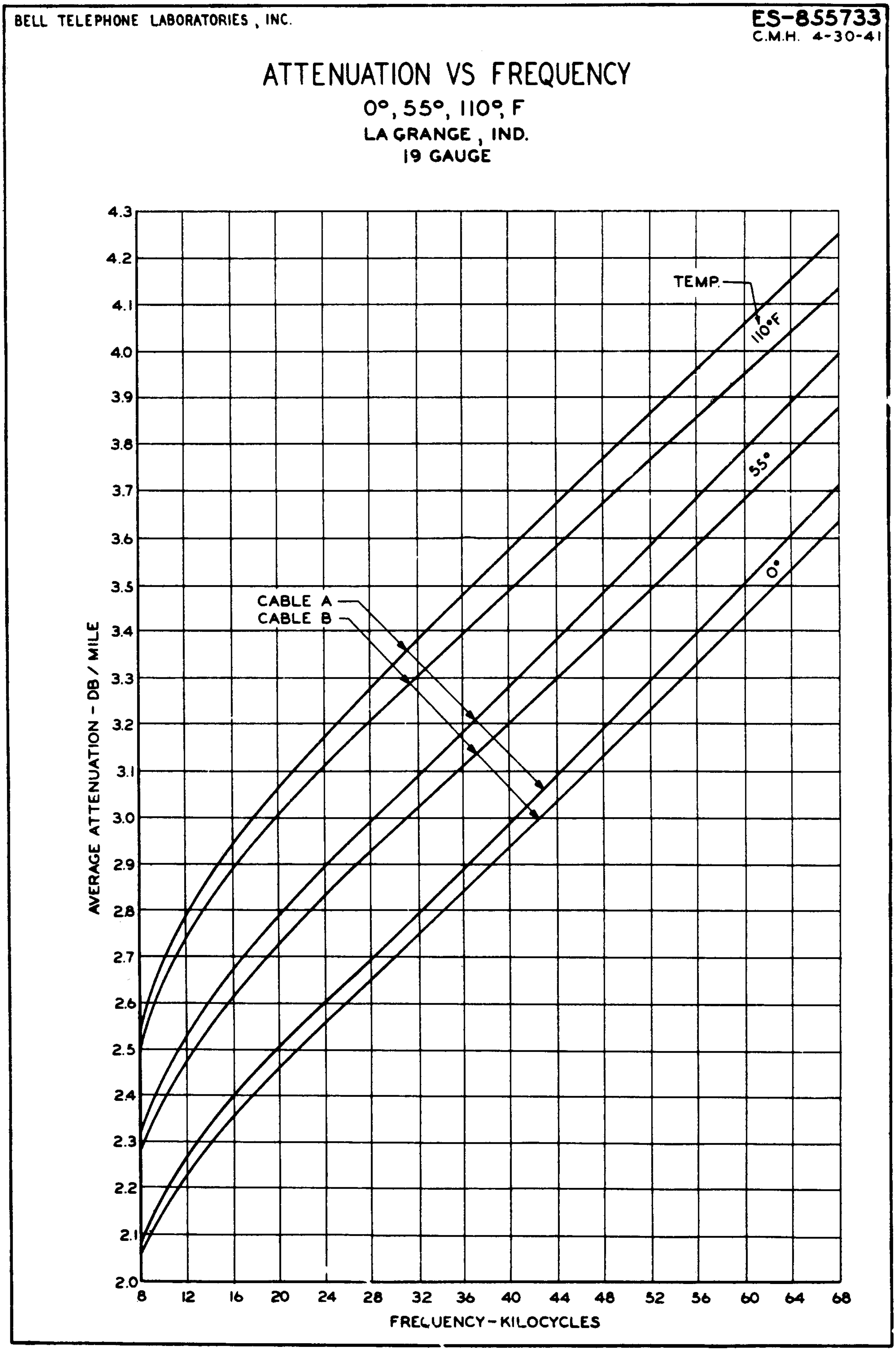
ATTENUATION VS FREQUENCY MEASURED ON MORRISTOWN - EASTON A CABLE

19 GAUGE PAIRS

TEMPERATURE 55°F





BELL TELEPHONE LABORATORIES, INC.
ES-855733
C.M.H. 4-30-41
ATTENUATION VS FREQUENCY
0°, 55°, 110°, F
LA GRANGE, IND.
19 GAUGE
TEMP.
110°F
55°
0°
CABLE A
CABLE B
AVERAGE ATTENUATION - DB / MILE
FREQUENCY - KILOCYCLES
4.3
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68

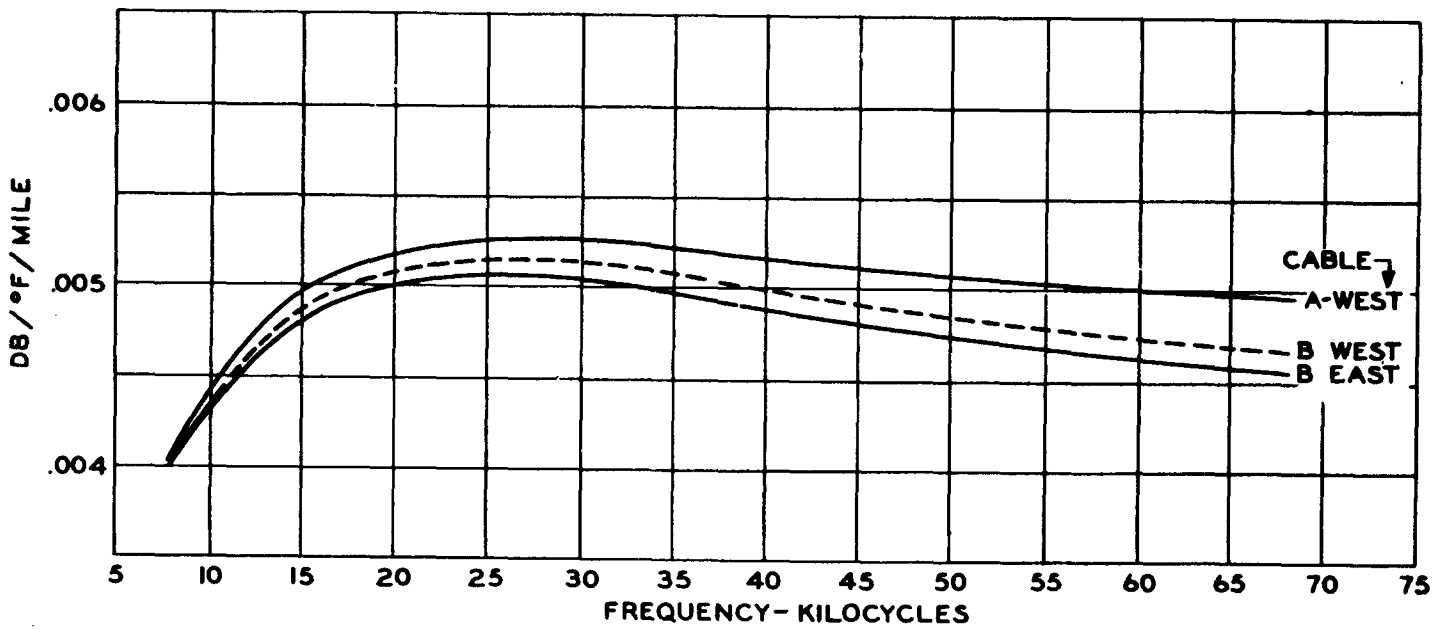
BELL TELEPHONE LABORATORIES, INC.

ES-855734
C.M.H. 4-30-41

ATTENUATION COEFFICIENT VS FREQUENCY

LA GRANGE, IND. MEASUREMENTS

AVERAGE VALUES



149

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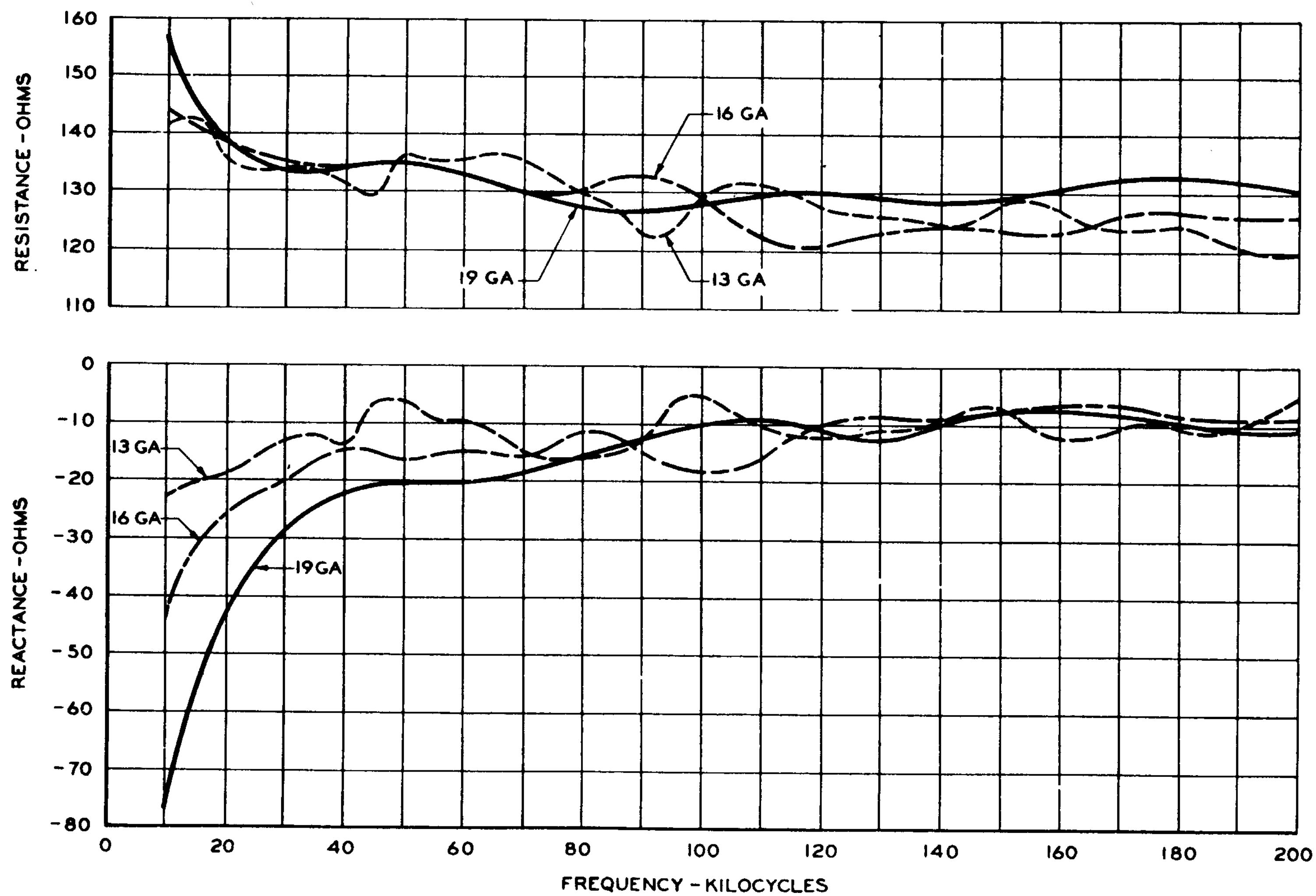
BELL TELEPHONE LABORATORIES, INC.

ES-855735
C.M.H. 4-30-41

CARRIER FREQUENCY IMPEDANCE OF TOLL ENTRANCE CABLE-DENVER, COLO.

NON-LOADED, QUADDED-TERMINATED IN 125 OHMS
13,16 AND 19 GAUGE
TYPICAL PAIRS



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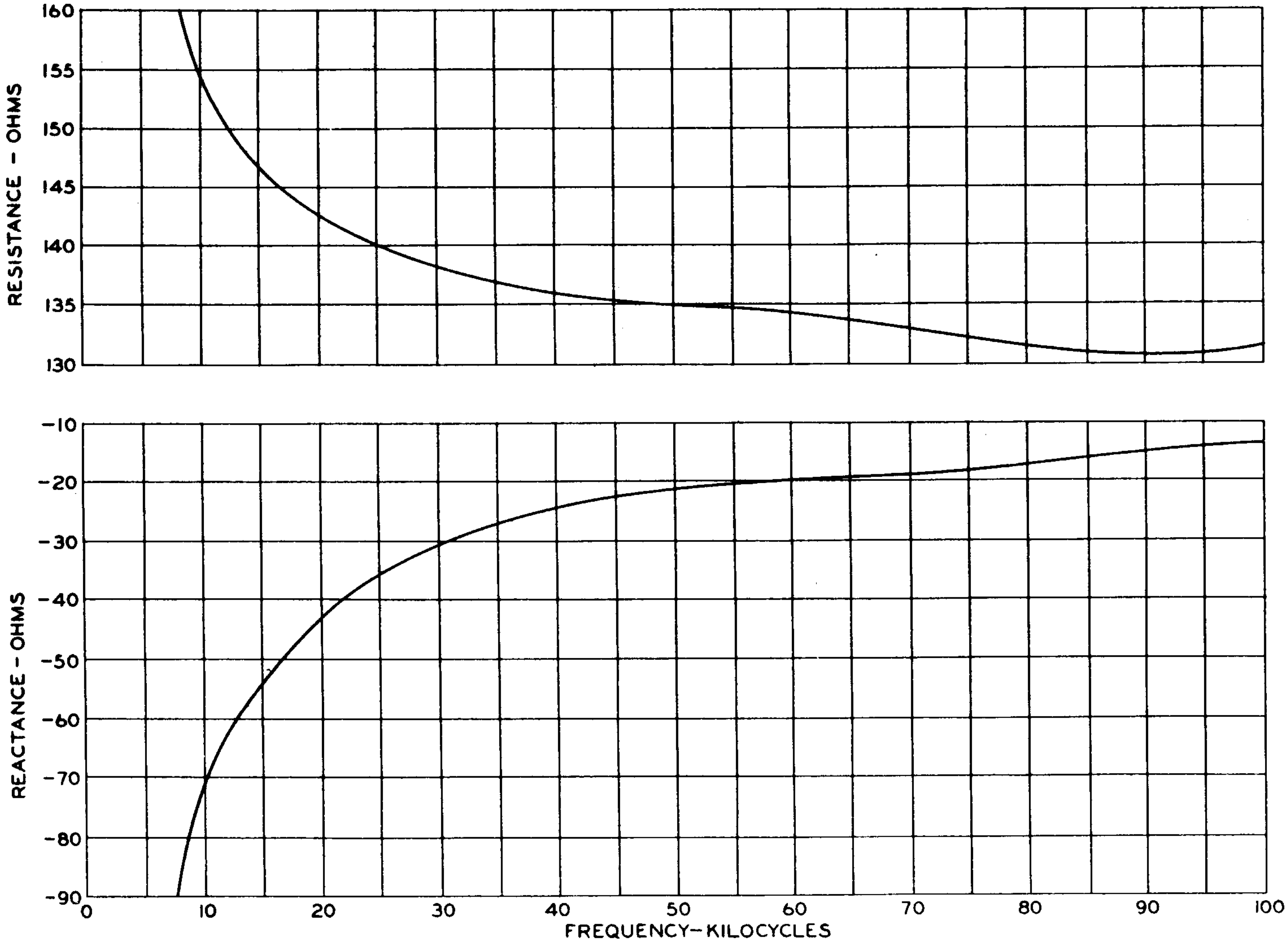
C.M.H. 4-30-41

CHARACTERISTIC IMPEDANCE OF B CABLE EAST - 10PR. AV.

LAGRANGE, IND.
19 GAUGE



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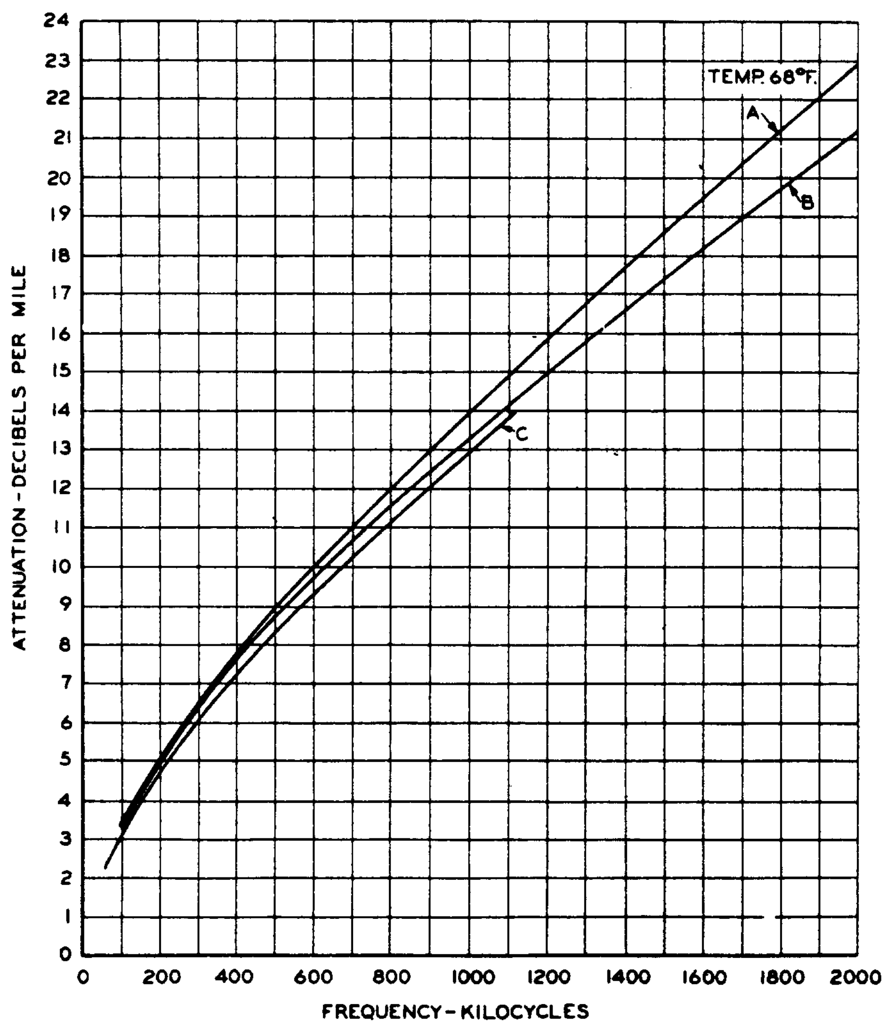
BELL TELEPHONE LABORATORIES, INC.

ES-855737
C.M.H. 4-30-41

ATTENUATION OF 16 GAUGE CABLE PAIRS

A- ON REEL, 247 FEET
B- FOURTEEN REELS, 1.3 MILES
C- AERIAL CABLE, 3.6 MILES, TICONDEROGA, N.Y.

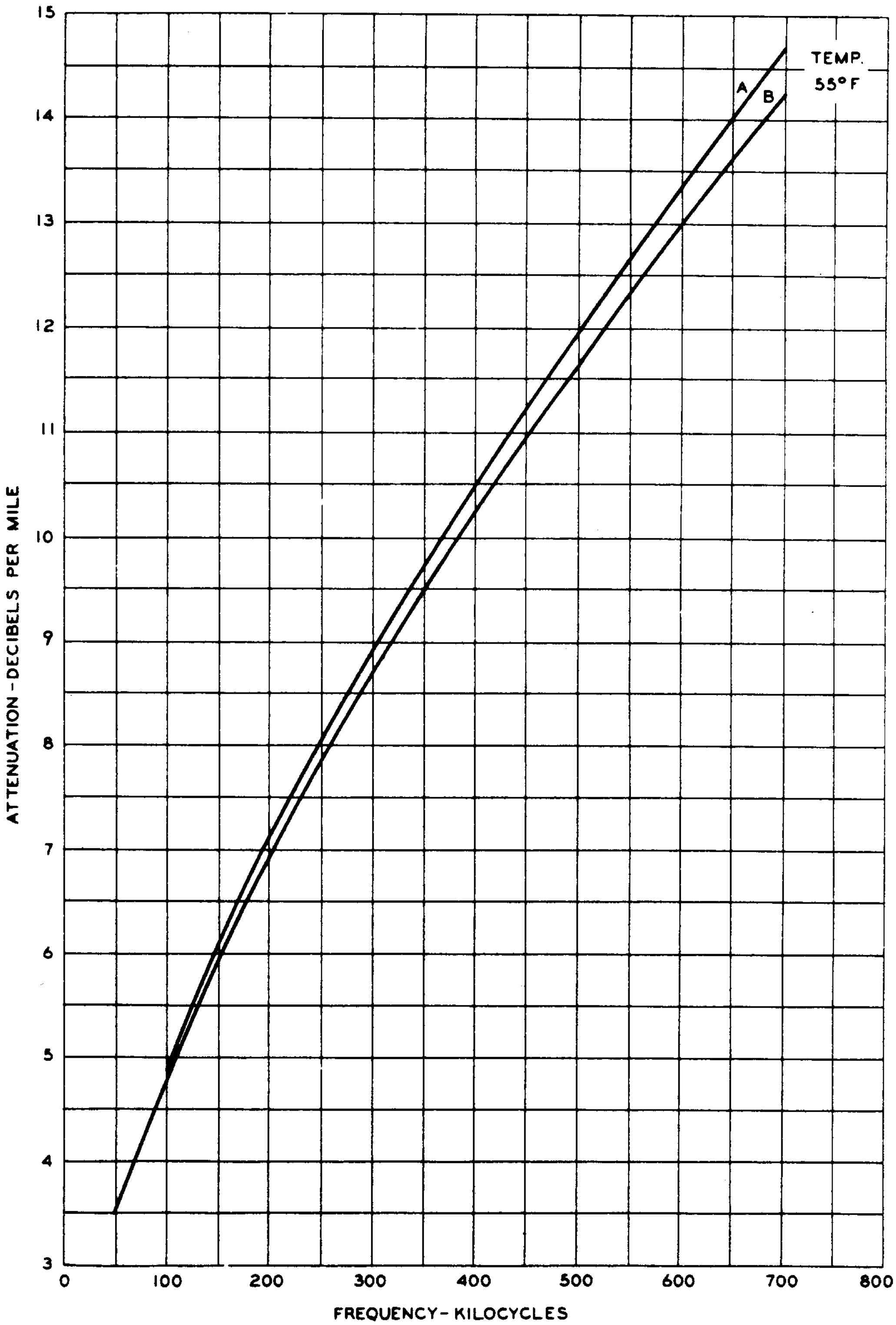


BELL TELEPHONE LABORATORIES, INC.

ES-855738
C.M.H. 4-30-41

ATTENUATION OF 19 GAUGE CABLE PAIRS

A- ON REEL, 247 FEET
B- AERIAL CABLE-3.6 MILES-TICONDEROGA, N.Y.
CURVES A AND B SHOW AVERAGE OF 10 PAIRS

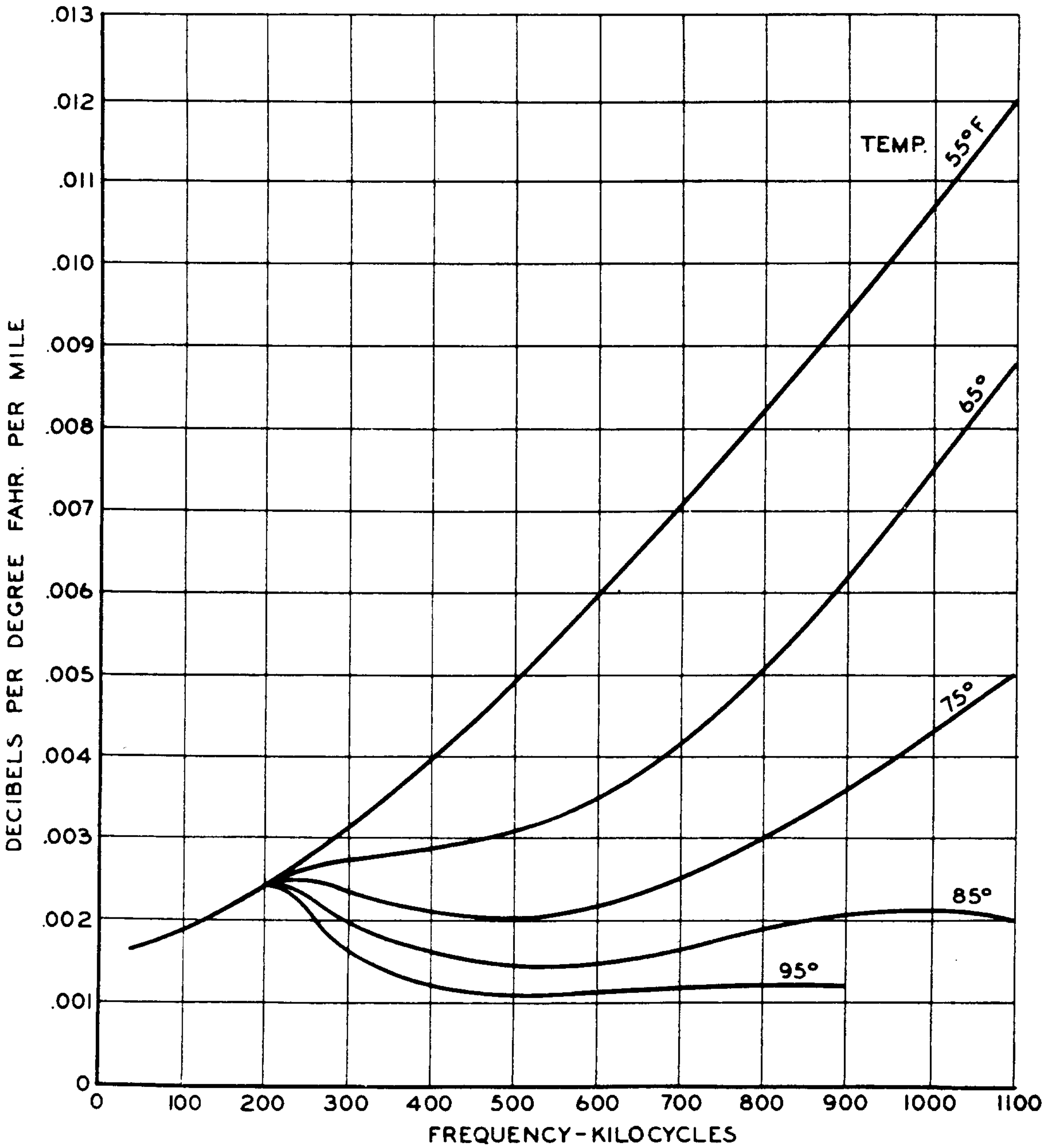


BELL TELEPHONE LABORATORIES, INC.

ES-855739
C.M.H. 4-30-41

TICONDEROGA MEASUREMENTS OF VARIATION IN ATTENUATION AT DIFFERENT TEMPERATURES FOR 1°F. CHANGE IN TEMPERATURE

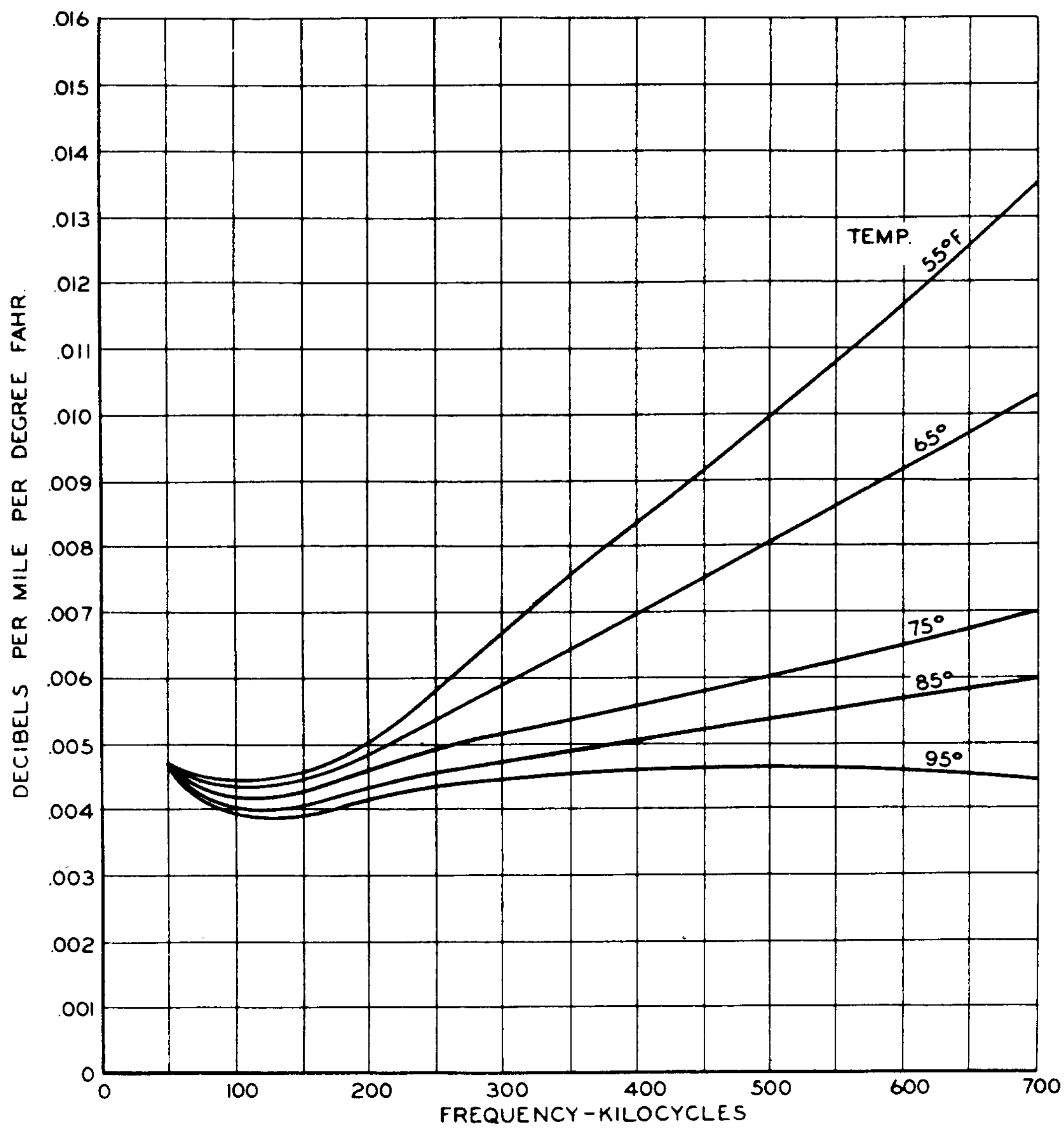
16 GAUGE AERIAL CABLE PAIRS



BELL TELEPHONE LABORATORIES, INC.

ES-855740
C.M.H. 4-30-41

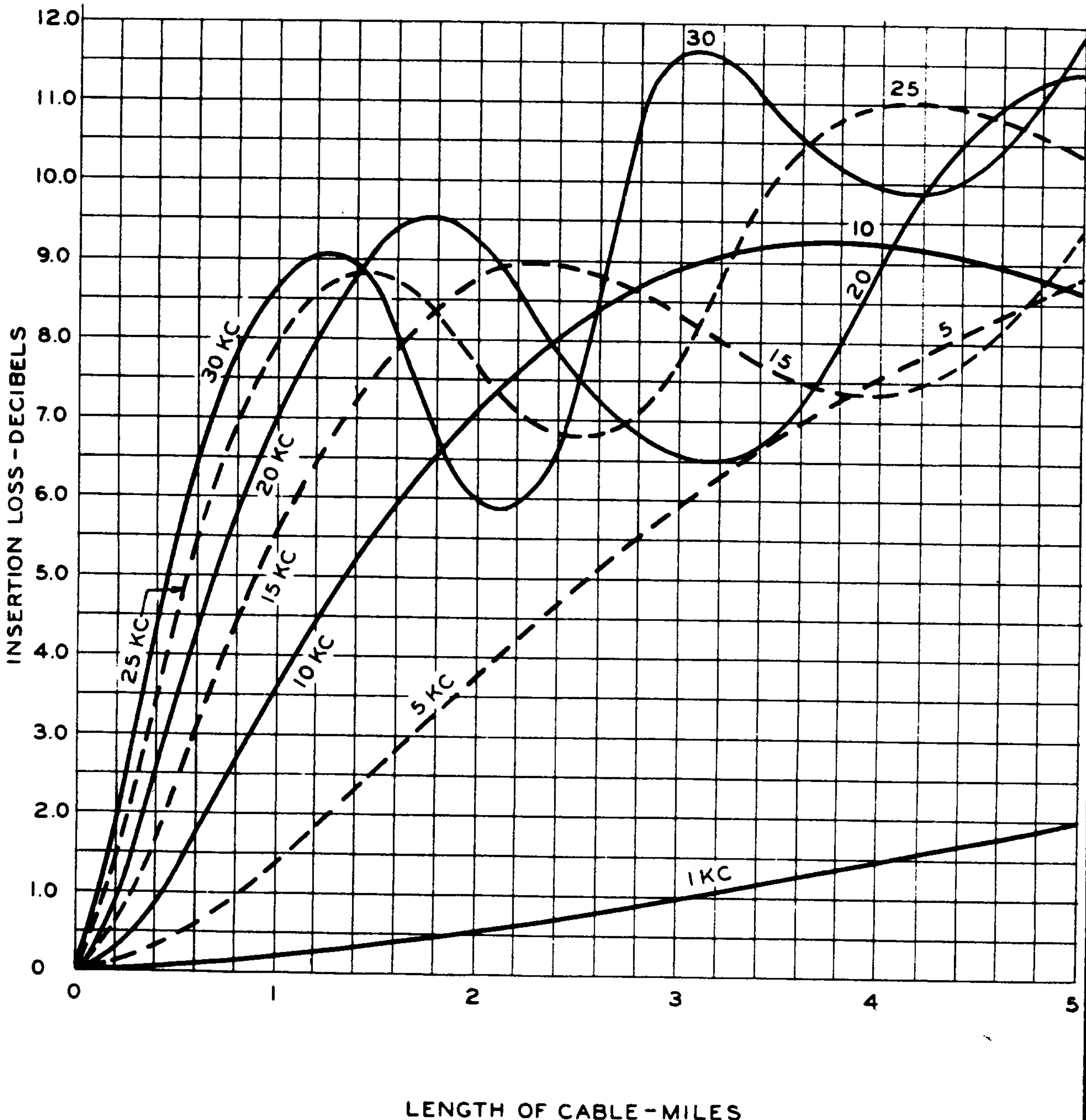
TICONDEROGA MEASUREMENTS OF
VARIATION IN ATTENUATION AT DIFFERENT TEMPERATURES FOR 1° F. CHANGE IN TEMPERATURE 19 GAUGE AERIAL CABLE PAIRS



BELL TELEPHONE LABORATORIES, INC.

ES-855741
C.M.H. 4-30-41

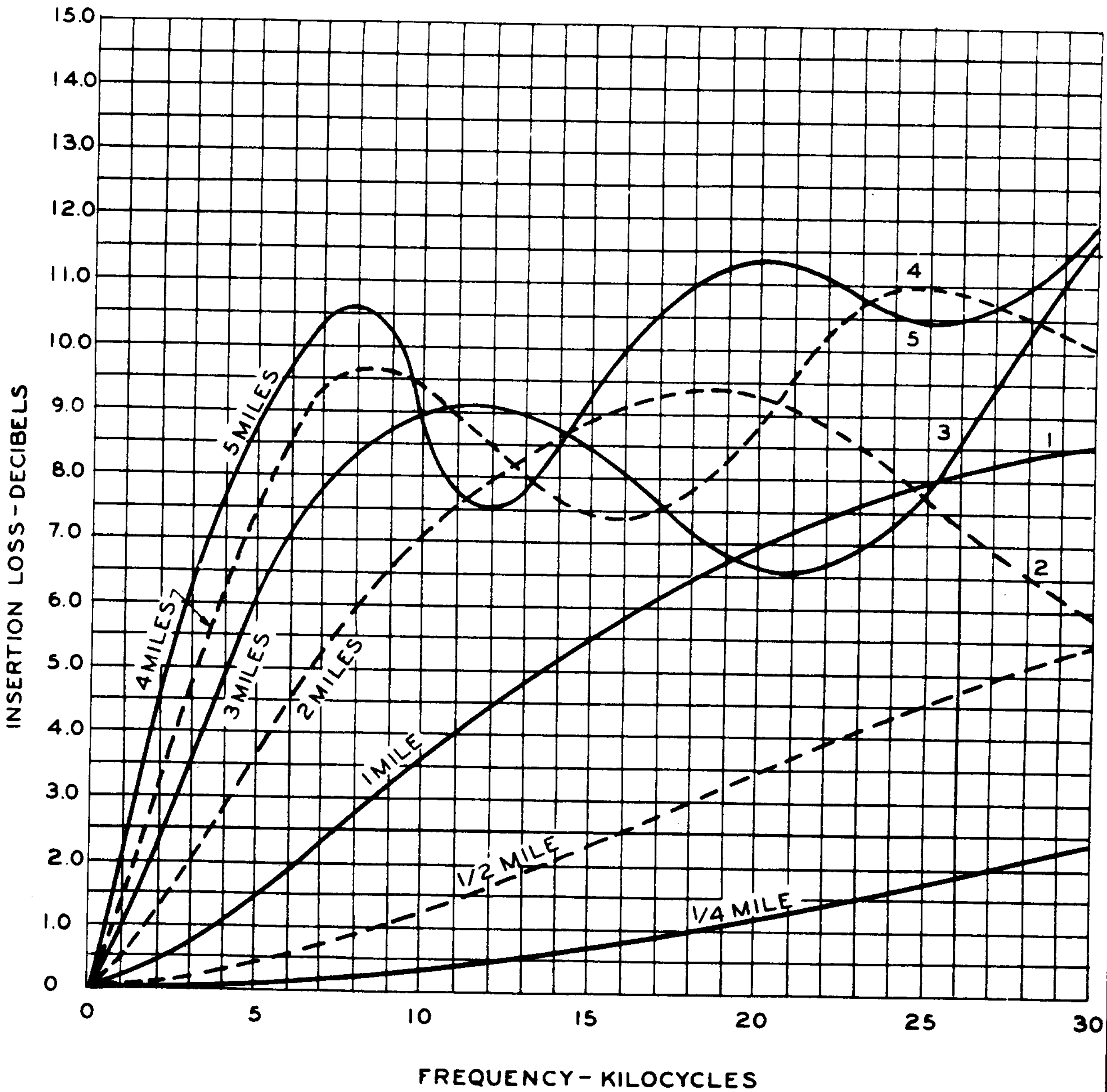
LOSS PRODUCED BY INSERTING SHORT LENGTHS OF 13 GA. CABLE BETWEEN 600 OHM RESISTANCES VS LENGTH OF CABLE



BELL TELEPHONE LABORATORIES, INC.

ES-855742
C.M.H. 4-30-41

LOSS PRODUCED BY INSERTING SHORT LENGTHS OF 13 GA. CABLE BETWEEN 600 OHM RESISTANCES VS FREQUENCY



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