Rural Electrification Administration
Telephone Engineering & Construction Manual

VOICE FREQUENCY LOADING FOR TRUNK CABLES

CONTENTS

1. GENERAL

1.01 This section is intended to provide REA borrowers, consulting engineers, contractors and other interested parties with information for use in the design and construction of REA borrowers' telephone systems. It discusses in particular the engineering and transmission considerations involved in the selection, layout and construction of trunk cable loading systems which, in combination with voice-frequency repeaters, are required in order to meet transmission objectives. This section also provides technical information for the correct interconnection of different types of loading systems when necessary. Quantitative information is also given in the tables contained herein for carrying out the required transmission computations. Though this section assumes the use of cable having twisted pairs insulated with polyethylene, information on paper insulated cables is included in Table I.

1.02 This section is reissued to reflect various changes in transmission practices necessitated by the conversion to direct distance dialing,[1] the operation of EAS trunks at lower losses, and the general trend toward improved transmission objectives. Economically priced transistorized voice frequency repeaters capable of high gain, more economical facilities and the improved characteristics of D-66 loading systems allow fuller utilization of finer gauge cables to make these objectives economically realizable. This section supersedes Section 431, Issue No. 1, dated May 1955 and all addenda thereto.

1.03 Importance of Loading System Uniformity

1.031 The successful operation of voice frequency repeaters in both extended area and toll trunk plant, requires that close attention be paid in design and construction to obtain nearly uniform spacing of loading points. Non-uniformity in the loading spacing lowers the structural return loss,[2] which in turn reduces the gain capability of the repeater. Non-uniformity in cable mutual capacitance in different cable reels also lowers the structural return loss. Cable mutual capacitance and loading coil uniformity are obtained in REA borrowers' plant by suitable cable and loading coil specifications.

---

1. Refer to "Notes on Distance Dialing" 1961, by the American Telephone and Telegraph Company, Engineering Department.

2. For the definition of "structural return loss" and a full discussion refer to REA TE & CM-445, "How to Make Structural Return Loss Measurements."

1.032 Over the past years the transmission losses to which trunk plant has been engineered have been constantly decreasing due to the growing trend toward improved and expanded services. Operation of trunks at increasingly lower net losses requires that voice frequency repeaters with increased gain capability be available and that the cable plant, including the type of loading system used, over which such equipment will operate be capable of effectively utilizing this increased gain. In turn, the ability of the cable plant to utilize to advantage the gain capability of the repeaters depends among other factors, not only on the type of loading system selected but on the care and methods used in spacing the loading points during the design, staking, and construction of the plant.

1.033 Because of the necessity for dealing with practical plant layout conditions due to conditions of terrain or other local factors, precise loading spacing is not usually attainable. Paragraphs 3.04 and 3.05 give the maximum loading spacing deviations which are considered tolerable. It should be kept in mind that the deviations discussed in these paragraphs are not design or target values, but the maximum which are allowable. For new construction where the terrain and other local factors permit, every effort should be made not only during the design stage but especially during staking and construction to improve the deviation limits of these paragraphs. Where these steps are taken the benefits of higher repeater gains, reduced repeater and plant maintenance and future flexibility should improvements or special services become necessary are more easily attainable.

1.034 Impedance irregularities with accompanying low return losses resulting from errors in loading spacing deviations, missing, reversed winding or doubled-up coils, incorrect value loading coil inductance, bridged taps or other causes, adversely affect the performance of repeaters operating over the cable. Of the different faults listed above, the irregularities resulting from incorrect load spacing may be the most difficult to correct due to the fact that they become manifest as minor or finite irregularities whereas the effect of the others is to produce major irregularities which totally disrupt the performance of voice frequency repeaters. Major irregularities as a result of missing, reversed, doubled-up or incorrect value loading coils or long bridged taps can be detected and located by using the measuring procedures set forth in REA TE & CM-408, "Facility Requirements for Voice Frequency Repeatered Trunks," paragraphs 10 and 11. This assumes that an impedance irregularity has a single cause. Where several causes are involved the detection procedures become more complex. However, once the major irregularities have been found and corrected, the final structural return loss will be reduced by the loading spacing deviations present. In general, detection and location of smaller impedance irregularities requires personnel skilled in the art and equipped with highly specialized test equipment. In addition, the procedures are invariably time consuming and for these reasons not readily adaptable to REA borrowers' plant. In buried plant construction the correction of load spacing deviations may not always be practical or economical due to the limited number of pedestal locations. For these reasons it is again to be emphasized that, due to the complexity, cost and highly specialized nature of the work involved in detecting, locating and correcting impedance irregularities the approach should be to prevent these irregularities from occurring rather than in trying to correct them afterwards. During the ACD* and construction stages this may be accomplished as follows:

(a) Consider the importance of uniform load spacing.

(b) Make the design somewhat more conservative than the maximum allowed.

(c) Use qualified personnel for staking plant.

(d) Provide proper and adequate supervision during construction.

(e) Utilize effectively the sequential marking of cables.

1.035 Since voice frequency repeaters are purchased on a guaranteed performance basis from contractors other than those which construct the outside plant facilities, measurements prior to repeater installation are

* Area Coverage Design

required on the as-built plant to determine its suitability to repeater application. REA Bulletin 383-2, "Acceptance Tests--Outside Plant," establishes the extent of required testing, and REA TE & CM-408, Figure 2, and REA TE & CM-445, Figures 11A and 11B, provide step-by-step procedures for making the actual measurements.

2. LOADING AND LOADING SYSTEMS

2.01 Theory of Loading

2.011 The primary[1] purpose of inductance coil loading is to improve the transmission of intelligence by substantially reducing the circuit attenuation, and by making the circuit attenuation approximately uniform throughout a predetermined frequency-band. These transmission benefits are obtained by serially inserting coils having uniform inductance values at regularly recurring intervals along the circuit, but are limited to a frequency-band below the loading cutoff frequency. Above the loading cutoff frequency, there is a substantial suppression of transmission.

2.012 The attenuation[2] improvement obtainable with loading corresponds somewhat to the increase in impedance that results from the increase in inductance. This can be understood from the fact that in the (low-impedance) non-loaded circuit, the series dissipation losses which are proportional to the square of the line current are ordinarily very large relative to the dielectric dissipation (i.e. shunt) losses which are proportional to the square of the line potential. When the line impedance is increased a suitable amount by the loading, the decrease in series losses is much greater than the increase in shunt losses. Economic considerations usually prevent the use of high loading impedances which would result in shunt losses becoming as great or greater than the series losses. As an illustration, an exchange type 22-gauge cable results in less loss when, for example, D-66 or H-88 loaded (approximately 0.8 db per mile at 1000 cps) than a similar

---

1, 2. "Inductive Loading for Bell System Telephone Circuits" by T. Shaw, Bell System Technical Journal, January 1951.

capacitance 19-gauge cable which is non-loaded (approximately 1.3 db per mile at 1000 cps). Therefore it becomes more economical to use loaded 22-gauge cable pairs than 19-gauge pairs non-loaded.

2.013 The inductance also offsets the effect of the cable capacitance which is always present between the wires of a cable. This results in a more natural sounding circuit since the effect of capacitance between wires is to cause more loss for the higher voice frequencies. The combination of the value of coil inductance, the spacing between loading coils and the mutual capacitance of the cable between loading points determine the attenuation, impedance and band pass characteristics of the particular loading system.

2.014 Another way of viewing inductive loading is by comparing it to a simple low pass filter where the inductance of the loading coil comprises the series arm while the cable mutual capacitance comprises the shunt arm. In a simple low pass filter and further, one where components have no losses, there is a frequency band where the attenuation is zero (passband) and another band where it is infinite (rejection band). The point where the two bands cross is termed "cutoff frequency." Unlike a simple one section low pass filter, a loaded cable behaves like a group of such filters in cascade with the capacitance and inductance of each loading section making up one filter section. The individual filters (loading sections) must be uniform in order to accomplish the purpose intended, that is, each loading section must look reasonably close to the others in spacing, capacitance and inductance.

2.015 If the above uniformity characteristics in any section in the multisection low pass filter (loaded cable) are altered, the performance characteristics of the filter are changed and the results are reflected in the entire loaded cable. Therefore, a change in the inductance or the capacitance of only one loading section degrades the band pass performance of the low pass filter action. Some common plant items which may bring this about are:

(a) Reversed, missing, doubled-up or incorrect value loading coils.

(b) Bridged taps between coils, doubled-up cable pairs or extra long or short loading sections.

(c) Irregular (non-uniform) loading spacing.

In summary, in order to effectively utilize the transmission advantages of loading, the loading must be properly designed, installed, and maintained.

2.016 A non-phantomed loading coil has two separate balanced windings coupled to the same magnetic core. The inductance of each winding of the loading coil, when the other winding is open circuited, has approximately the same value. The total inductance of a loading coil when both of its windings are connected series-aiding (this is the normal inductance which results when the coil is correctly wired to the cable pair), is approximately four times the inductance of the individual windings. Obviously, therefore, the additional inductance contribution of the individual windings by virtue of being coupled to a common core is approximately fifty percent of the total inductance. This additional inductance is known as "mutual inductance" and it acts to aid or negate the remaining inductance contributed by the individual windings. For this reason, reversing one winding with respect to the other must be avoided since this greatly reduces the total series inductance provided by the loading coil.

2.02 Designation of Loading Systems

2.021 Loading systems are designated by a letter signifying the full section length between loading points followed by a numeral denoting the inductance of the coil in millihenries. In voice frequency loading systems the full section lengths generally used are 6000 and 4500 feet with coil inductances of 88 and 66 millihenries. The following table covers some of these loading systems:

Designation	Coil Spacing-feet	Coil Inductance-mh
D-66	4500	66
H-88	6000	88
D-88	4500	88
B-88	3000	88
B-44	3000	44
H-44	6000	88

The cable mutual capacitance associated with the above loading systems usually has a nominal capacitance of 0.083 microfarads per mile. Such cable is referred to as "exchange type" and abbreviated "HC" in sections for convenience. Loading systems, however, may also be used with "low capacitance" (toll-grade) cable which has a capacitance of 0.062 or 0.066 microfarads per mile. To distinguish the application between loading systems of the exchange and the toll type, the designation of "LC" is usually attached after the loading system designation for the latter application. For example, the designation 19-H-88-LC refers to the application of H-88 loading on 19-gauge low capacitance cable.

2.022 The above designations refer to circuits from which no additional or "phantom" circuits are being derived. In situations where phantom circuits are being derived there is an additional designation of the loading system to denote the value of coil inductance for the phantom circuit. For example, the designation H-88-50 indicates that the side circuit is being loaded with 88 millihenry coils at every 6000' while the phantom circuit utilizes 50 millihenry coils spaced at the same intervals. Over the past years the practice of "phantoming" has gradually been discontinued.

2.03 Transmission Characteristics of Loading Systems

2.031 The most significant transmission characteristics of loading systems are:

(a) In the passband region, there is a reduction in the magnitude of the attenuation.

(b) The attenuation is reduced but not eliminated due to the cable and coil resistance and some cable conductance dissipation.

(c) There is a cutoff frequency by virtue of the lumped loading. (Distributed loading does not display this characteristic.)

(d) The impedance has been raised.

(e) At the cutoff frequency and beyond, the attenuation of the loaded cable is higher than that of non-loaded cable.

(f) Increasing the loading coil inductance or loading section cable mutual capacitance, or both, lowers the cutoff frequency.

(g) For a given loading spacing, increasing the loading coil inductance decreases the attenuation per mile while increasing the cable mutual capacitance increases this attenuation.

2.032 Quantitatively, the attenuation, impedance and cutoff frequency characteristics of loaded cable are given by the following simple expressions for the passband region where the loaded cable behaves almost exactly like a corresponding smooth line. The precise formulas for attenuation and impedance are much more complex than the ones shown. For 1000 cps computations, however, formulas (a) and (b) can be used to a very good approximation. In fact, formulas (a) and (b) are reasonably good up to 0.6 of the cutoff frequency. (See formula (c) and Figures 2 to 6.) The units are resistance in ohms, capacitance in farads and inductance in henries, and they must be expressed for the same unit length. A mile basis is normally used for formulas (a) and (b).

(a) The attenuation in db per mile is:

$$\left[a = 4.34R\sqrt{\frac{C}{L}} \right]$$

R includes both the cable and loading coil resistance.

(b) The magnitude of impedance in ohms is:

$$\left[Zo = \sqrt{\frac{L}{C}} \right]$$

(c) The cutoff frequency in cps is:

$$\left[Fc = \frac{1}{\pi\sqrt{LC}} \right]$$

In formula (c) both L and C must be expressed on a full loading section basis and in addition L includes the cable pair inductance of approximately one millihenry per mile. For an 0.083 microfarad per mile cable the cutoff frequency is about 3500 cps for H-88 and 4600 cps for D-66 loading.

2.033 Representative line constants for 19 gauge and 22 gauge exchange type and low capacitance plastic-insulated cable pairs are tabulated below. The unit of length is taken as one statute mile. These constants are practically independent of frequency in the passbands of D-66 and H-88 loading systems. The resistance per mile of the soft copper wires of the cable varies with temperature and the tabulated resistances are for 68°F. (20°C). In the voice frequency range, the resistance is about R (1 ± .0022 t) where R is the resistance at 68°F. and t is the change in temperature in degrees Fahrenheit. For t + ± 50 degrees, the resistance is R (1 ± .11).

Line Constants per Mile @ 68°F.

Gauge	HC or LC	Resistance Ohms	Inductance Millihenries	Conductance Micromhos	Nominal Capacitance in Microfarads
19	HC	85	1.0	1.0	.083
22	HC	171	1.0	1.0	.083
19	LC	85	1.0	1.0	.066

2.0331 Loading coils not only add series inductance in the cable pairs but series resistance as well. These resistances are tabulated below for a temperature of 68°F.

Typical Resistance of a Loading Coil in Ohms

Frequency-cps	Loading Coil Millihenries	
	66	88
100	6.2	7.9
300	6.4	8.1
500	6.6	8.3
1000	7.1	8.7
1500	7.5	9.2
2000	8.0	9.8
2500	8.6	10.6
3000	9.5	11.5
3500	10.4	12.6
4000	11.7	14.2

2.034 The above line constants were used to calculate the transmission loss in db per mile for the passbands of D-66, H-88 and other loading systems. These losses are plotted against frequency on attached Figures 2 to 6. For a given loading system such as 22 gauge D-66, the losses in db per mile vary approximately directly with the resistance per mile which, in turn, varies with temperature as discussed under Paragraph 2.033.

2.035 The characteristic impedance of a loaded circuit is theoretically the impedance as measured at a terminal of the circuit when it stretches to infinity. However, a circuit of finite length may be terminated in a proper precision balancing network at one end and then the characteristic impedance will almost be exactly as measured at the other end. The characteristic impedance depends upon the fraction of a loading section which the measuring instrument faces. As a reference, characteristic impedances for mid-section are quoted. Figure 6 shows mid-section characteristic impedances plotted against frequency for 22 and 19 gauge exchange type cables D-66 and H-88 loaded. It should be noticed that for exchange type cables the impedance for H-88 loading rises much more rapidly with increasing frequency than that for D-66 loading. A rapid rise with frequency is undesirable from both trunk and subscriber loop transmission considerations since this rise reduces available repeater gains and degrades voice frequency response characteristics.

2.04 Applications of Loading Systems

2.041 The D-66 loading system is the type of loading generally recommended for use in REA borrowers' plant with trunks over non-quadded cable pairs. This recommendation applies to repeatered and non-repeatered circuits.

2.042 For new construction where the facilities are completely within the REA borrower's territory, they should be D-66 loaded for the entire trunk length. The load spacing and end section requirements are discussed in Paragraphs 3 and 4, respectively. No junction impedance compensator is required where the entire facility is D-66 loaded.

2.043 For new construction where the REA borrower's facilities connect with those of another company, it is desirable that the entire trunk be D-66 loaded for exchange type cables. Where the D-66 loading is used for such applications for the entire facility it results in certain advantages for the companies involved. Some of the advantages for trunk applications are:

(a) Greater ease in meeting transmission objectives.

(b) Improvement in the circuit structural return loss.

(c) Elimination of impedance compensators at the toll center where toll trunks are involved.

(d) Elimination of junction impedance compensators.

(e) Improved circuit frequency response characteristics.

(f) More adaptable to some forms of data transmission or other special services.

(g) Improved crosstalk loss characteristics.

In addition to the above factors D-66 is compatible with H-88 loading inasmuch as their nominal 1000 cps attenuation and impedance for same gauge cables have been made to be the same by design. Therefore the use of D-66 loading does not introduce new or non-standard impedances in the telephone plant.

2.0431 Requests to connecting companies should be made at the earliest possible date during the ACD stage and all required technical information on D-66 loading requested by the connecting company should be provided.

2.044 For new construction where the REA borrower's facilities connect with those of another company which has existing H-88 loaded exchange type cable, it may not be practical for the connecting company to furnish D-66 loaded cables for its portion so as to meet the REA borrower's D-66 portion. Where the connecting company has so indicated, the resulting facility makeup will consist of D-66 loading for the REA borrower's portion and H-88 loading for the connecting company's portion. In order to minimize the reflection (low return loss at higher voice frequencies) which would exist at the junction of the two loading systems if the two were connected directly, an impedance compensator is required at the junction. The purpose of the junction compensator and how it is applied is further discussed in paragraph 7.0.

2.045 Existing cables which are H-88 loaded and are being extended may utilize D-66 loading for the extension portion. This treatment, however, will not improve the overall circuit due to the more restrictive cutoff characteristics of the existing H-88 loading, which will be controlling. Where, nevertheless, H-88 circuits are being extended with D-66 a junction compensator as discussed in paragraph 7.0 will be required.

2.046 From the transmission standpoint it is desirable to load additional circuits on a D-66 loading basis in a cable which contains H-88 loaded working cable pairs under the same sheath. However, this may not be attractive from the standpoint of having two different coil locations and two different values of loading coil inductance. The decision, therefore, whether the additions in the same cable sheath should be D-66 loaded should depend on such factors as:

(a) Whether normal or special transmission objectives can be met by the continuation of the existing type of loading.

(b) Availability of suitable pole, ready-access case or pedestal locations for 66 mh loading coil placement.

(c) Maintenance considerations.

(d) Other factors.

2.047 It is not generally recommended that H-88 working trunk routes which are H-88 loaded in their entirety be changed out to D-66 loading. In applications, however, where transmission objectives are not being met, or where it is necessary to meet special transmission objectives and where loading coil locations are or can be economically made available the use of D-66 loading should be considered. In situations where design changes are proposed affecting the entire system in a major way consideration should be given also to the feasibility of converting to D-66 loading.

2.048 As discussed in the above paragraphs the recommended loading system for REA borrowers' plant is D-66 for new construction and also for extensions or additions to existing plant which is H-88 loaded, where applicable. The D-66 loading will be adequate for all applications normally found in REA borrowers' plant. For this reason and also from the standpoints of plant flexibility and simplicity it is desirable to keep the number of loading systems to a minimum. Use should be made of other types of loading systems when:

(a) Normal transmission requirements cannot be met by the use of D-66 loading.

(b) Special applications where the use of D-66 loading is not suitable.

(c) Circumstances where existing situations may pose maintenance or other special problems.

3. LOAD SPACING REQUIREMENTS

3.01 As discussed in paragraph 1.03 the increasing application of electronic instrumentalities to voice frequency trunk plant as well as its successful operation requires that close attention be given to the design, staking and construction methods to obtain uniform loading spacing. Because of the necessity, however, of dealing with practical plant considerations precise loading spacings are not usually attainable. The paragraphs below discuss the extent of the loading spacing deviations which are permissible and also the type of deviations which are least objectionable from the transmission standpoint.

3.02 Loading spacing irregularities in trunk cables can be generally divided into two categories:

(a) The amount by which the average of all full loading sections depart from the standard spacing.

(b) The amount by which each full section length departs from the arithmetic average computed for all full sections.

Paragraphs 3.021 and 3.022 below discuss the specific effect which these deviations have on transmission.

3.021 Maintaining the average spacing close to the standard spacing (Paragraph 3.02 a) minimizes the chance of departure from standard attenuation, impedance characteristics and cutoff frequency. In addition when the different cable pairs in the same trunk group are also uniform in their capacitance characteristics this also results in uniform attenuation, impedance and cutoff frequency for all the circuits which is highly desirable. The reasons for maintaining the average spacing close to the standard are:

(a) To keep the measured losses close to the expected losses. For example, this is important during acceptance testing of plant and on a routine basis thereafter.

(b) To avoid special engineering of voice frequency repeaters which use standard network configurations.

(c) To avoid transmission contrasts between circuits in the same trunk group.

When the average spacing departs from the standard spacing, the structural return loss is also affected in addition to the factors discussed above. The amount of this impairment depends solely on the nominal frequency cutoff characteristics of the loading system in question. The lower the cutoff frequency of the loading system the greater will be the impairment (lower structural return loss). In a loading system such as H-88 this impairment is considerable, whereas in the D-66 loading system it is of less practical importance due to its naturally higher cutoff frequency.

3.022 Maintaining the individual sections close to the average spacing (Paragraph 3.02 b) reduces the amount of impedance irregularities which unequal sections introduce and results in good structural return losses. Since this item affects the structural return loss in a major way all efforts should be made to achieve uniform spacing to the greatest extent possible. To illustrate, consider a loaded trunk cable (A) whose average spacing length exceeds the standard spacing by 2% and in which, in addition, all individual sections are equal in their lengths. A cable having its loading points thus spaced will have substantially better structural return loss characteristics (actually the structural return loss theoretically will be infinite) than a loaded cable (B) where the average spacing length is the standard spacing but with individual sections longer and shorter than the average.

3.03 In summary, controlling the average spacing so it is close to the standard spacing results in attenuation, impedance and cutoff frequency uniformity, while controlling the individual spacing so it is close to the average spacing results in good structural return loss. However, it is not as important to adhere to standard spacing with D-66 loading as with H-88 loading. Therefore, with D-66 the average spacing may deviate from the standard spacing to the extent permitted in Paragraph 3.041 and the main effort to improve structural return loss should be in keeping the difference of the individual spacings from their average spacing to a value as low as practicable.

3.031 Examples 1 to 4 which are given in this section illustrate the procedure used for computing loading spacing deviations. A short analysis which is presented with each example on the relative importance of the type of spacing deviation in question will be found helpful in complementing the discussion of Paragraphs 3.02 and 3.03 above.

3.032 Where capacitance building-out is used to build out loading sections to normal the computation of the spacing deviation discussed in Paragraphs 3.04 and 3.05 below should include the equivalent of the amount of CBO used. The procedure for doing this is shown in Illustrative Example No. 6.

3.04 Loading Spacing Requirements - R.M.S. Method

3.041 The deviation of the average spacing from the standard spacing should be within ± 3%.

3.042 The R.M.S. value of all the deviations of the individual spacing lengths from the average spacing should not be more than 2%.

3.043 The loading spacing deviations outlined in Paragraph 3.042 above using the R.M.S. method of computation is not at this time a requirement. It is nevertheless recommended as an objective. From the transmission standpoint, control of spacing deviations on an R.M.S. basis is highly desirable as it results in the best possible utilization of the transmission capability of the loading system. It should also be noted that control limits on individual sections are not necessary by this method, due to the self-protecting characteristics of the method on maximum individual deviations.

3.044 Where it is possible to use the R.M.S. method of Paragraph 3.042 the computations should be made in accordance with the procedure shown in the Illustrative Examples 1 to 4 herein.

3.05 Loading Spacing Requirements - Arithmetic Method

3.051 Where the application of the R.M.S. method for determining spacing deviation requirements is not practical due to staking and/or construction or other local factors the method discussed below is considered acceptable.

3.052 The deviation of the average spacing from the standard spacing should be within ± 3%.

3.053 The average of the differences, with signs disregarded, between the individual spacings and the average spacing should be within 2.0%.

3.054 The deviation of the length of the longest individual sections from the average spacing should be within ± 3%.

3.055 Procedures for computing the above deviations when it becomes necessary to use the arithmetic method of this paragraph are shown in the Illustrative Examples 5 and 6.

4. END SECTION REQUIREMENTS

4.01 The objective for office end section length is one-half the length (0.5) of the normal full section. In cases where it is not practical to meet this objective, an end section length within 0.4 to 0.6 can be considered. The choice of the 0.4 length is preferable to the 0.6 end section. The published transmission information contained herein on loaded cables assumes 0.5 end sections.

4.02 The "end section" in loaded trunk cables refers to the length of cable between the central office and the first loading coil, including any cable in the central office leading to the main as well as intermediate distributing frame if existing. It is, however, the amount of capacitance associated with the end section which to a large extent determines, for a given type of loading, the degree of impedance variation across the voice frequency range. This variation is significant for different length end sections. REA TE & CM-444, Issue No. 2, Figure 2, illustrates the effect which the length of an end section has on impedance at various frequencies. In REA borrowers' projects, end section "length" and "capacitance" become synonymous since the same nominal capacitance cable is used for the entire trunk and since the wiring capacitance associated with the local office is not normally significant. For class four offices (toll centers) in REA borrowers' projects or for those of connecting companies the total end section should be considered. The total end section includes not only the physical length of the cable from the first loading point to the central office mainframe but any intervening cable inside the office up to the point of access to the switching equipment.

5. STAKING AND CONSTRUCTION CONSIDERATIONS

5.01 <u>To make possible the realization of the end section objectives outlined in Paragraph 4.02 above, the staking of the plant</u>

should start from each of the offices involved and proceed in the direction of the opposite office to the junction point. The resulting loading section, at the junction point, which in most instances will be shorter than the normal full section should be built-out to a full section by the use of building-out capacitors which are discussed in Paragraph 6.0. It is not necessary that the junction point (building-out point) be the geographical center between the two offices in question. From the standpoint of repeater application, it is preferable that the built-out section be as far away electrically as practicable from the repeater locations. Example 13 is illustrative of the building-out procedures used for new construction at the junction point.

5.012 It is recommended that at no time the plant be staked and/or constructed in a manner whose purpose is to eliminate the building-out capacitors at the junction, when doing this upsets the regularity of the load spacing which is possible when using building-out capacitors.

5.02 Where more than two offices are involved the procedures for staking are the same as those of Paragraph 5.01 by considering the trunk groups between offices separately. In cases where a portion of the cable facility trunk route is provided by a connecting company, staking should commence from the borrower's central office and proceed toward the boundary point. Example 14 is illustrative of the building-out procedures used for new construction at the junction point.

5.03 The requirements for loading subscriber loops are different from those for loading trunks and are outlined in REA TE & CM-430 "Subscriber Line Loading." In situations where both trunk and subscriber circuits are contained in the same cable sheath for a distance from the central office the plant should be staked to meet the applicable trunk spacing requirements, up to the point where they separate.

5.04 Normally, the construction of aerial cable plant should follow the staking sheet instructions fairly closely and the spacing of loading coils can be relatively precise. However, the lengths of buried cable during placement can vary substantially from those shown on the staking sheets. Additional footage of buried cable may be required to plow around culverts, install aerial inserts, etc., all of which will affect the location of the terminal housings planned for loading coils. For this reason, buried cable plant should be constructed from the central office out toward the extremities of the lead. This is especially important for loaded trunk circuits between two offices, in which case the cable should be installed starting at each office and proceeding toward the other. Construction of these leads should not commence until all of the material is on hand to permit the plowing of cable in the proper sequence. Plowing the cable in the proper sequence and using the sequential marking on the outside of the cable jacket is the most effective way to insure that the loading coils will be accurately spaced.

6. CAPACITANCE BUILDING-OUT (CBO) PROCEDURES

6.01 Capacitance building-out (referred to as CBO) as applied to loaded trunk cables offers a means of improving the transmission irregularities resulting from loading sections which depart from standard lengths. This may come about from abnormally short or long loading sections in comparison to standard. In new construction capacitance building-out will normally be necessary at the junction point in order to meet the end section objectives of Paragraph 4.01 and using the staking procedures of Paragraphs 5.01 and 5.02 above for making this possible.

6.02 Building-out procedures are particularly useful in applications involving existing loaded cable plant. Properly engineered new plant should not require their use, since building-out is essentially corrective in nature, and it is not a recommended practice when laying out the design of new systems. Correct staking and construction practices should be followed, thus entirely eliminating the need for building-out in all loading sections, except at the junction point as discussed in Paragraphs 5.01 and 5.02 and shown in Illustrative Examples 13, 14 and 15.

6.021 Another exception to the above procedure involves new plant in special applications such as when joining two dissimilar loading systems. This special case is described in Paragraph 8.

6.022 The method by which the attenuation of a loaded trunk cable using CBO is computed is discussed in Paragraph 9.023. The method for computing the spacing deviation when using CBO has been discussed in Paragraph 3.032.

6.03 Individual loading sections in existing cables having less than the standard length may be built-out by:

(a) Bridging capacitors (CBO) (without the need of opening up the cable pair).

(b) Bridging stub cable of the proper length.

(c) Series insertion of additional building-out cable (cable is physically opened and additional building-out cable inserted).

The use of building out capacitors of item (a) is usually the most economical procedure. Cases may arise, however, in which the series insertion of building-out cable of item (c) would provide a better solution, especially if the conductor involved is 24 gauge or finer in which case the resistance component must be also accounted for, and/or where the length of cable to be built-out is significant and where the particular application requires this added improvement on return loss. An illustration of the treatment of short sections with CBO and the method used to compute the amount required is shown in Illustrative Example 16.

6.04 Individual loading sections in existing plant which are longer than the standard length require, in addition, the use of a loading coil. This loading coil inserted in the section in question at a standard distance from its adjacent loading coil results in a standard loading section. The remaining short loading section is then treated as described in Paragraph 6.03. An example illustrative of the treatment of a long section with CBO and the method used to compute the amount required is shown in Illustrative Example 16.

6.05 End sections in existing plant which are shorter than normal may be built-out to their required value with CBO located at the office. Illustrative Example 16 shows how this is accomplished. End sections in existing plant which are longer than normal may be built-out to their required value by a loading coil and CBO treatment located at the office. Illustrative Example 16 shows how this is accomplished.

6.06 Building-out capacitors may be installed for both new or existing plant at loading coil locations. When installing the building-out capacitors at such loading coil terminal locations, it is imperative that steps be taken during installation to insure that the building-out capacitors are located on the correct side of the loading coil of the loading section which they will build-out. A good method for insuring this is by making actual continuity measurements with a d-c ohmmeter at the point of installation to the central office, rather than relying on cable directions, cable color markings or other such physical markings. If this is not done, the possibility exists that the building-out capacitors may be connected to the wrong loading section which will augment the irregularities and compound the difficulties. It will be found that designating the location for building-out to be consistent on either the office side of the loading coil or its field side for the entire route of the trunk, but not both, will reduce the possibility of errors.

6.061 From the transmission standpoint, the building-out capacitors can be installed at any point in the irregular section which they build-out. An installation point which does not entail the risks outlined in Paragraph 6.06 is to locate the building-out capacitors at a pedestal or pole where no loading coils are present.

6.07 When using capacitance building-out techniques for the purpose of treating the situations outlined above, the capacitors should be specified as per REA PE-30 Specification,*latest issue, thus assuring the required transmission, protection and physical construction performance.

7. THE D-66/H-88 JUNCTION IMPEDANCE COMPENSATOR AND APPLICATIONS

7.01 The device used to match the impedance of the H-88 loading system to that of the D-66 loading system when it is inserted at a point of interconnection (junction) of the two loading systems is termed a "D-66/H-88 junction impedance compensator," or simply "junction compensator."

7.02 The H-88 and D-66 loaded cables have, by design, the same nominal 1000 cps impedance, but as the cutoff frequency of the H-88 loaded cable is approached the impedances of the H-88 loaded trunk facilities increase in magnitude more rapidly than do the impedances of the D-66 loaded cables. Therefore, at frequencies higher than approximately 2500 cps the impedance match between the D-66 and H-88 loaded cable facilities becomes progressively poorer if the two systems are directly interconnected. Operation of voice frequency repeaters may be expected to be impaired due to the resulting poor return loss at the point of such direct interconnection. To obtain adequate return losses at these higher frequencies, it is necessary that the rising impedance of the H-88 be modified to match the flatter impedance of the D-66. The device which makes possible this matching, thereby improving the return loss, is the junction compensator.

7.03 The junction compensator consists of two capacitors in shunt with the tip and ring conductors of the cable pair, an intervening loading coil and two additional capacitors, each shunting one winding of the loading coil. For purposes of differentiation only, the former type capacitors are termed "shunt"

* PE-30 Specification, Building-Out Capacitors

while the latter are termed "series." The shunt capacitors each build-out the D-66 and H-88 natural cable end sections, respectively, to 0.8. This results in a 3600' effective end section for the D-66 and 4800' for the H-88 loading system. The characteristic impedances of both D-66 and H-88 loaded cables at 0.8 end-sections have nearly constant and approximately equal resistive components and negative reactive components non-linear with frequency. Since the desired result is to annul the non-linear negative reactances, the positive linear reactance of a simple loading coil in the compensator is not sufficient to annul the total of the negative reactances. Addition of the "series" capacitors to the loading coil helps in reducing this reactance disparity and the impedances of the D-66 and H-88 loaded systems become better matched.

7.04 The component makeup of the D-66/H-88 junction impedance compensator is shown in Figure 1. It should be noted that the loading coil and series capacitor components (capacitors C_3 and C_4 in Figure 1) are somewhat different for 19 and 22 gauge cables. The shunt or building-out capacitors, however, (capacitors C_1 and C_2 in Figure 1) are the same for either 19 or 22 gauge, since their value depends solely on the length of the cable at the end section. One or both shunt capacitors may be omitted if the natural cable end section on one or both sides of the compensator is 0.8 of its respective full section.

7.041 Where mixed gauges such as 19 and 22 gauge are used at the junction point, the configuration of the junction compensator should be computed for the gauge having the greater 1000 cps loss.

7.05 Illustrative examples pertaining to the application layouts of the junction compensator for various D-66 and H-88 natural end sections are shown in Illustrative Examples 17 to 20. It should be noted that it is not always necessary to place the junction compensator at the point where the D-66 and H-88 cable meet (boundary). From the transmission standpoint, the junction compensator may be physically located at any point within the cable section between the last H-88 and D-66 loading points, which results in reduction in the capacitance of the shunt capacitors in the compensator or in their partial or total elimination.

7.06 Junction compensators should be installed on both repeatered and non-repeatered trunk plant. When ordering the compensators, a sufficient number of compensator units should be specified for spares as part of the normal circuit requirements.

7.07 The D-66/H-88 junction impedance compensators and all application examples shown herein require the use of exchange type cables for both the connecting company and the REA borrowers' portions. It is the exchange type cable which makes interconnection of D-66 and H-88 loaded cables possible and further, for the reason discussed in Paragraph 7.03, requires the use of the impedance compensator. Where the connecting company provides 19 gauge H-88 loaded cable facilities using low capacitance cable, it is not possible for the REA borrower to use D-66 for connecting to it. In this situation the REA borrowers' portion must consist of D-88 loading. This special case is discussed in Paragraph 8.0.

7.08 To insure proper voice frequency repeater operation, it is imperative that the following steps be taken during the engineering, construction and installation of the junction compensator:

(a) Compute the building-out capacitance required (capacitors C_1 and C_2 in the compensator) only when the lengths of the natural D-66 and H-88 end sections at the junction are firmly known. Changes, if any, in the end sections due to re-staking, re-location or other factors which entail a change in shunt capacitors C_1 and C_2 should also be reflected in the REA PE-31 Specification,* latest issue.

(b) Ascertain through the color code of the completed assembly unit that it is spliced correctly, that is, the D-66 side of the unit is connected to the D-66 portion of the trunk and the H-88 side is connected to the H-88 portion of the trunk. A reversed compensator may adversely affect the performance of voice frequency repeaters operating over the circuit in question.

7.09 To assure proper compensator performance, the units should be ordered in accordance with REA Specification PE-31, latest issue, which covers all pertinent transmission, protection and physical characteristics. External protection for the compensator is not required.

*REA Specification PE-31, D66-H88 Junction Impedance Compensators

8. SPECIAL LOADING APPLICATIONS

8.01 Circumstances may arise in trunk applications where it may not be practical to maintain the same type of loading for the entire length of the trunk. This may come about as a result of the connecting company providing 19 gauge low capacitance cable, either paired or quadded and H-88 loading for its portion of the trunk route. In order to maintain the same mutual capacitance between loading points in the entire trunk, two approaches are technically possible:

(a) For the REA borrower to also provide low capacitance cable for his portion of the trunk so that the entire trunk is H-88 loaded on a low capacitance cable basis.

(b) For the REA borrower to provide exchange type cable and 88 mh loading coils for his portion of the trunk. Since the desired objective is to maintain the same capacitance between loading coils in the entire trunk, obviously the spacing between loading coils for the borrower's portion has to be shortened. This spacing is 4500 feet. This portion now becomes loaded every 4500 feet with 88 mh loading coils (D-88). Thus, the H-88 LC portion of trunk is matched to the D-88 HC portion for impedance and repeaters can properly operate over it.

Of the approaches (a) and (b) above, approach (b) is usually preferable for the REA borrower from the cost standpoint.

8.02 At the point of interconnection of H-88 LC and D-88 HC loading systems, the end section of each system must be 0.5; that is, the H-88 LC must have a 3000' end section and the D-88 HC a 2250' making the total full section at a junction 5250'. Where physical or staking considerations result in a junction section which is less than 5250', or greater than 6000', the building out procedures as outlined in Paragraph 6.0 must be used to maintain the total capacitance required for that junction section. Illustrative Example 21 shows how such a special case is handled.

8.021 Low capacitance 22 gauge cable is not manufactured as a standard cable. Therefore, the aspect of interconnection of the two loading systems applies only to 19 gauge cables.

9. PROCEDURE FOR COMPUTING LOADED TRUNK ATTENUATION

9.01 For purposes of transmission computations the attenuation of a loaded trunk cable is normally calculated at 1000 cps and 68°F. Table I provides attenuation information at 1000 cps and 68°F for various types of loading systems and cable gauges for both exchange and low capacitance type of cables for carrying out the required computations. The attenuation of the loaded cable must also include the transmission loss caused by reflections at the junction of facilities having dissimilar 1000 cps impedances and other incidental losses en route, such as the loss of junction impedance compensators. Table II provides the reflection loss information at 1000 cps; the loss of the junction compensator should be computed as discussed in Paragraph 9.022.

9.011 In cases where it becomes necessary to know the attenuation of a loaded trunk cable at frequencies other than 1000 cps, the information in Figures 2 through 5 can be used.

9.02 In general, the attenuation of a circuit consisting of various lengths of facility having conductors of the same or different gauges, with the same or dissimilar capacitance between conductors and having the same type of loading throughout or consisting of two dissimilar loading systems, is obtained by multiplying the applicable db loss per unit length for each type of facility in Table I by the corresponding length (in the same unit of length) of that facility and summing up all individual attenuations and adding to this reflections, losses of junction compensators or other incidental losses en route, where applicable.

9.021 The attenuation information of Table I is based on the mid-section impedance of the loading system for the particular gauge and mutual capacitance shown. Attenuation computations, therefore, involving circuits which consist of mixed gauges, dissimilar loading systems and dissimilar mutual capacitance will be rigorously correct only when computed on the basis that a change of gauge occurs at mid-section only. Due, however, mainly to the complexity in computation which the above procedure would entail in actual loading layouts, it will be sufficient to a first good approximation at 1000 cps to consider each gauge by simply multiplying its applicable db loss per unit length by the actual length, with no regard whether the change of gauge occurs at mid-section.

9.022 In computing the attenuation of a circuit consisting of D-66 and H-88 loading the loss of the D-66/H-88 junction compensator must be included in the computation. This loss, at 1000 cps, should be taken as 0.3 db regardless of the amount of CBO used in the compensator to build out the D-66 and H-88 sides for either 19 or 22 gauge cables.

9.023 As discussed in Paragraphs 6.01 and 6.02 capacitance building-out will be required to build out loading sections which are shorter than normal. The amount of building-out capacitance required will of course vary with the length of the section being built out. For purposes of transmission computations at 1000 cps it will not be necessary to consider the small dissipation loss caused by these capacitors as part of the circuit attenuation but only the amount of physical cable present as discussed in Paragraph 9.021 above. The above simplification in computation procedure is predicated on two conditions:

(a) That no resistance building-out (BOR) is used <u>in</u> the building-out capacitors.

(b) The capacitors are specified in accordance with REA Specification PE-30, which limits the amount of capacitor dissipation permissible.

All illustrative examples shown herein, using building-out capacitors assume <u>no</u> corresponding BOR.

In cases where, for return loss reasons, it becomes necessary to use resistance in addition to the capacitance of the building-out unit, for applications to cables consisting primarily of 24 gauge or finer, the 1000 cps attenuation should be computed to include the amount of capacitance building-out by converting this capacitance to an equivalent length of a physical cable having the same gauge as the section being built out and multiplying this equivalent length by the corresponding db loss per unit length for that gauge in Table I.

9.024 Regarding incidental entrance cables which are loaded, when the length of the loaded portion of the cable is such that the end section exceeds a half section, the length of the cable affected by the loading is multiplied by the applicable db loss per unit length for the gauge and the loading system used and the remainder of the cable is multiplied by the corresponding db loss per unit length for the nonloaded cable. The total loss for this portion of the circuit is obtained by adding together the loaded and nonloaded attenuations.

9.025 In connection with existing trunk plant, need will arise for computing the expected attenuation of trunk circuits consisting of combinations of loaded nonjacketed (older type) and nonloaded multipair shielded cables, loaded former type rural distribution wire and steel or copper-steel open wire conductors. The attenuation of nonloaded cable pairs and open wire conductors will be found in REA TE & CM-406, "Attenuation Data." The attenuation of loaded rural distribution types of cables, both for the former type and the Figure 8 type, is included in Table I herein. The reflection loss information pertaining to all dissimilar facilities, normally to be encountered, is given in Table II herein.

9.03 Examples 7 - 12 will be helpful in illustrating the computation procedures discussed in the above paragraphs.

Illustrative Example 1

To show how to compute the RMS spacing deviation of a D-66 loaded trunk cable, staked and constructed with the spacing shown below:

Loading Section Length	Average Spacing	Deviation of Loading Section from Average	Deviation Squared
4365	4365	0	0
4365	4365	0	0
4365	4365	0	0
4365	4365	0	0
4365	4365	0	0
4365	4365	0	0
Total 26,190			0

Avg. 26,190/6 = 4365'

RMS $= \sqrt{\frac{0}{6}}$ = zero feet

(a) Deviation of Average Spacing from Standard: $\frac{4365 - 4500}{4500} = -3\%$

(b) RMS Deviation from Average Spacing : $\frac{0}{4365} = 0\%$

Conformance to Requirements: The deviation requirements of paragraphs 3.041 and 3.042 are met in (a) and (b) above.

Analysis: Since the deviations of the loading spacings from the average spacing are zero (column 3), i.e., all the loading sections are alike, this load spacing will result in practically infinite structural return loss (assuming the cable capacitance also to be equally uniform).

Illustrative Example 2

To show how to compute the RMS spacing deviation of a D-66 loaded trunk cable, staked and constructed with the spacing shown below:

	Loading Section Length	Average Spacing	Deviation of Loading Section from Average	Deviation Squared
	4635	4635	0	0
	4635	4635	0	0
	4635	4635	0	0
	4635	4635	0	0
	4635	4635	0	0
	4635	4635	0	0
	4635	4635	0	0
	4635	4635	0	0
Total	37,080			0

Avg. 37,080/8 = 4635'

RMS $= \sqrt{\frac{0}{8}}$ = zero feet

(a) Deviation of Average Spacing from Standard: $\frac{4635 - 4500}{4500} = +3\%$

(b) RMS Deviation from Average Spacing : $\frac{0}{4635} = 0\%$

Conformance to Requirements: The deviation requirements of paragraphs 3.041 and 3.042 are met.

Analysis: (a) Since the deviations of the loading spacings from the average spacing are zero (column 3), i.e., all the loading sections are alike, this loading spacing will result in practically infinite structural return loss (assuming the cable capacitance also to be equally uniform).

(b) The spacings in this example and Example 1 will both result in equally good structural return loss. However, the spacing of Example 1 will result in somewhat lower attenuation and higher impedance and slightly higher cutoff frequency, since its average spacing is less than the standards (4500').

Illustrative Example 3

To show how to compute the RMS spacing deviation of a D-66 loaded trunk cable, staked and constructed with the spacing shown below:

	Loading Section Length	Average Spacing	Deviation of Loading Section from Average	Deviation Squared
	4590	4500	+ 90	8100
	4464	4500	- 36	1296
	4680	4500	+180	32,400
	4518	4500	+ 18	324
	4410	4500	- 90	8100
	4428	4500	- 72	5184
	4464	4500	- 36	1296
	4572	4500	+ 72	5184
	4320	4500	-180	32,400
	4536	4500	+ 36	1296
	4482	4500	- 18	324
	4536	4500	+ 36	1296
Total	54,000			97,200

Avg. 54,000/12 = 4500' RMS $= \sqrt{\frac{97,200}{12}}$ = 90 feet

(a) Deviation of Average Spacing from Standard: $\frac{4500 - 4500}{4500}$ = 0%

(b) RMS Deviation from Average Spacing : $\frac{90}{4500}$ = 2%

Conformance to Requirements: The deviation requirements of paragraphs 3.041 and 3.042 are met in (a) and (b) above.

Analysis: (a) The structural return loss in this example will not be as good as that of either Examples 1 or 2, because the individual loading sections are unequal, i.e., larger or shorter than the average, despite the perfect average spacing (4500').

(b) If only two large deviations of 180' existed, the RMS deviation would have been 73.5' as compared to 90' for all the deviations. The two deviations of 180' and the two deviations of 90' account for 82.2' of the total RMS deviation of 90'. In this example it is, therefore, particularly desirable to reduce the large deviations.

(c) If there were only two deviations of +110' and -110', the RMS deviation would be only about 1%.

Illustrative Example 4

To show how to compute the effect of one large deviation in loading spacing on the RMS deviation. The remaining deviations are assumed to be small in comparison with the one large deviation:

Solution: The one large spacing deviation which can be tolerated on an RMS basis is given by the following expression to a good approximation:

$$D = RMS\sqrt{n}$$

Where "D" is the one large load spacing deviation in feet,
"n" is the number of loading sections, and
RMS is the 2% of 4500 allowable or 90'

As an example, if a loaded trunk cable has 12 loading sections and is aimed at an average spacing of 4450', one large deviation, D, can be tolerated if necessary:

$$D = RMS\ \sqrt{n} = 90\sqrt{12} = 312'$$

Therefore, the loading section can be: 4450 + 312 = 4762' long.

The following example illustrates the computation method for justifying this 4762'* loading section:

Loading Section Length	Average Spacing	Deviation of Loading Section from Average	Deviation Squared
4451	4478	27	729
4454	4478	24	576
4449	4478	29	841
4461	4478	17	289
4452	4478	26	676
4450	4478	28	784
4762*	4478	284*	80,656
4453	4478	25	625
4451	4478	27	729
4453	4478	25	625
4447	4478	31	961
4453	4478	25	625
Total 53,736			88,116

Avg. 53,736/12 = 4478

$$RMS = \sqrt{\frac{88,116}{12}} = 85.7 \text{ feet}$$

(a) Deviation of Average Spacing from Standard: $\frac{4478 - 4500}{4500} = -0.5\%$

(b) RMS Deviation from Average Spacing : $\frac{85.7}{4478} = 1.9\%$

Conformance to Requirements: The deviation requirements of paragraphs 3.041 and 3.042 are met in (a) and (b) above.

Analysis: (a) If all the individual deviations but one are kept small, it is possible to meet the RMS deviation requirements.

(b) Had this layout been considered on the basis of paragraph 3.05, the large 284' deviation would not meet the requirements of paragraph 3.054 since this paragraph permits a maximum deviation from average spacing of 3% and 3% of 4478' is 134'.

NOTE: IF TWO LARGE BUT EQUAL DEVIATIONS ONLY ARE NECESSARY, THE FORMULA BECOMES:

$$D = RMS\sqrt{\frac{n}{2}}$$

FOR THREE EQUAL DEVIATIONS:

$$D = RMS\sqrt{\frac{n}{3}}$$

Illustrative Example 5 To show how to compute the spacing deviation using the arithmetic method of a D-66 loaded trunk cable having the load spacing shown below.

	Loading Section Length	Average Spacing	Deviation of Loading Section from Average
	4635	4501	134
	4511	4501	10
	4374	4501	127
	4590	4501	89
	4365	4501	136
	4410	4501	91
	4613	4501	112
	4626	4501	125
	4522	4501	21
	4500	4501	1
	4387	4501	114
	4478	4501	23
Total	54,011		983

Avg. Spacing: 54,011/12 = 4501'   Avg. Dev.: 983/12 = 82'

(a) Deviation of Avg. Spacing from Standard: $\frac{4501 - 4500}{4500}$ = 0.02%
(Paragraph 3.052)

(b) Deviation of Avg. of Differences from Avg. Spacing: $\frac{82}{4501}$ = 1.8%
(Paragraph 3.053)

(c) Maximum Individual Spacing Dev. from Avg. Spacing: $\frac{4365 - 4501}{4501}$ = -3%
(Paragraph 3.054)

Illustrative Example 6 To show how to compute the spacing deviation on an existing H-88 loaded trunk cable using the arithmetic method.

(Note: In this particular layout, the length of loading sections Nos. 7 and 22 are 1305' and 4251', respectively. Building-out capacitors of 0.073 and 0.025 microfarads have, however, been used at sections Nos. 7 and 22, respectively, to build out sections to normal. In the computations below, the equivalent length of the CBO is included as part of the section length as discussed in Paragraph 3.032.)

Loading Section Number	Loading Section Length	Average Spacing	Deviation of Loading Section from Average
1	6012	6014	2
2	5904	"	110
3	5835	"	179
4	6236	"	222
5	5989	"	25
6	5991	"	23
7	1305 + .073 µf = 5949	"	65
8	5996	"	18
9	6033	"	19
10	5967	"	47
11	6000	"	14
12	6296	"	282
13	5996	"	18
14	6000	"	14
15	6000	"	14
16	6069	"	55
17	6018	"	4
18	6033	"	19
19	6105	"	91
20	6048	"	34
21	5996	"	18
22	4251 + .025 µf = 5841	"	173
Total	132,314		1446

Avg. Spacing: 132,314/22 = 6014' Avg. Dev.: 1446/22 = 22'

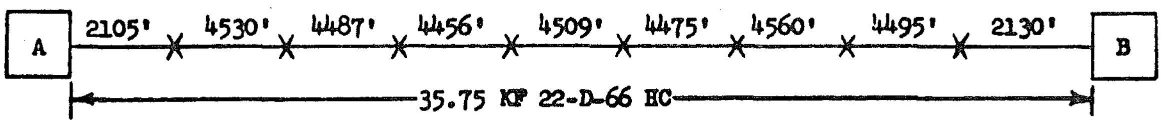
(a) Deviation of Avg. Spacing from Standard: $\frac{6014 - 6000}{6000} = 0.2\%$
(Paragraph 3.052)

(b) Deviation of Avg. of Differences from Avg. Spacing: $\frac{66}{6014} = 1.1\%$
(Paragraph 3.053)

(c) Maximum Individual Spacing Dev. from Avg. Spacing: $\frac{6296 - 6014}{6014} = 4.7\%$
(Paragraph 3.054)

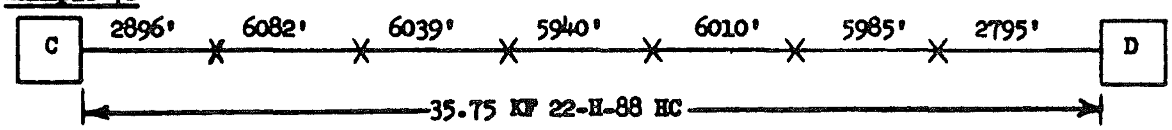
Illustrative Example 7 To show how to compute the attenuation of a loaded trunk cable similar to the ones shown below, at 1000 cps and 68°F.

Example 7a



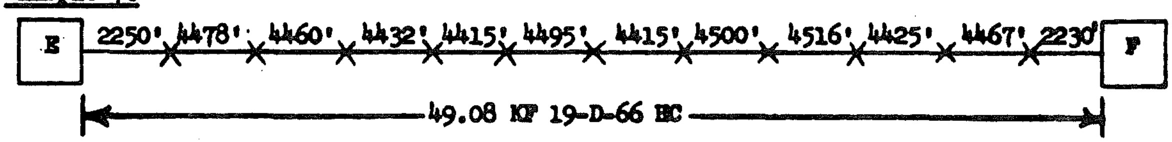
Procedure	Answer
35.75 KF x 0.15 db/KF	5.36 db

Example 7b



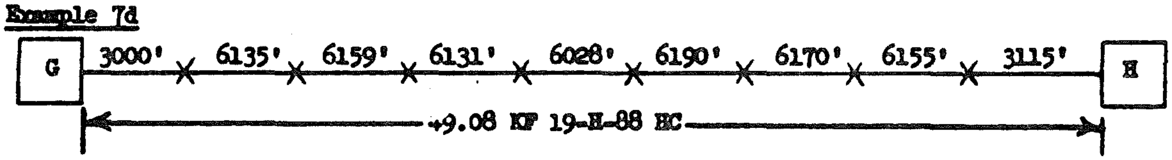
35.75 KF x 0.15 db/KF	5.36 db

Example 7c



49.08 KF x 0.081 db/KF	3.98 db

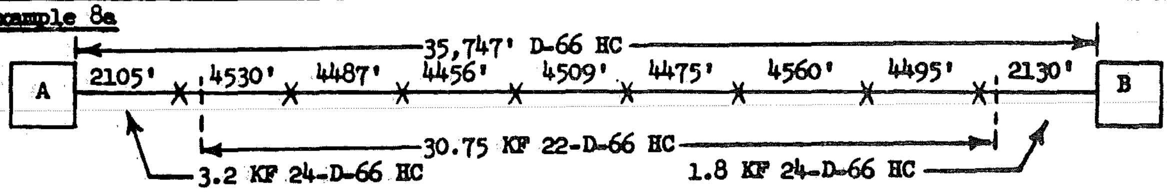
Example 7d



49.08 KF x 0.081 db/KF	3.98 db

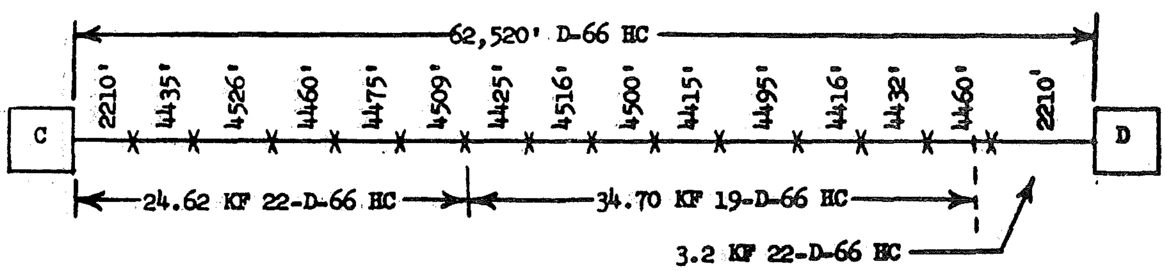
Illustrative Example 8 To show how to compute the attenuation of a loaded trunk cable similar to the ones shown below at 1000 cps and 68°F.

Example 8a



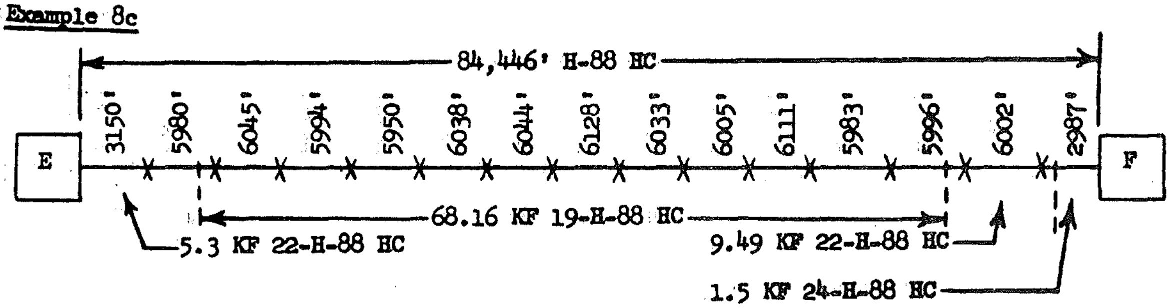
Procedure	Answer
(3.2 + 1.8) x 0.23 + 30.75 x 0.15	5.76 db

Example 8b



(24.62 + 3.2) x 0.15 + 34.70 x 0.081	6.98 db

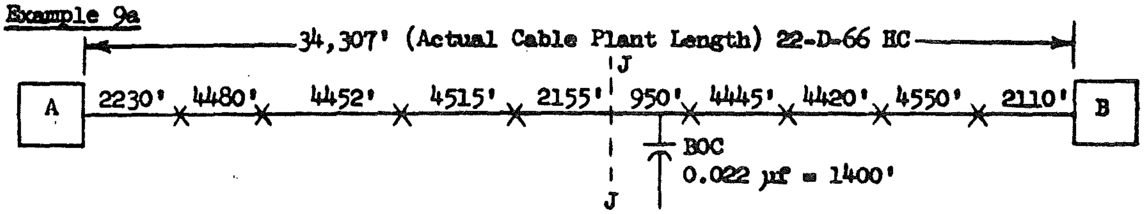
Example 8c



1.5 x 0.23 + (9.49 + 5.3) x 0.15 + 68.16 x 0.081	8.09 db

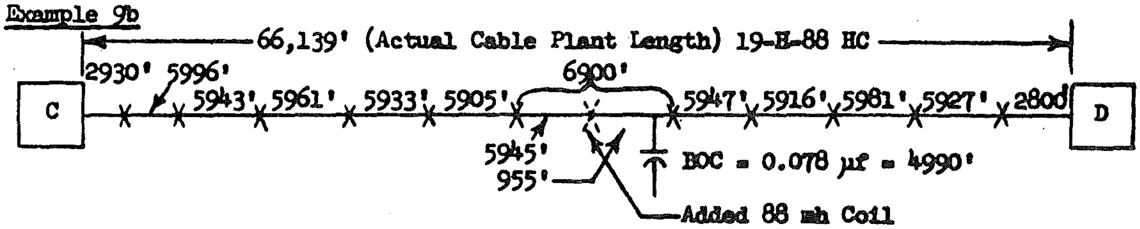
Illustrative Example 9 To show how to compute the attenuation of a loaded trunk cable similar to the ones shown below, at 1000 cps and 68°F.

Example 9a



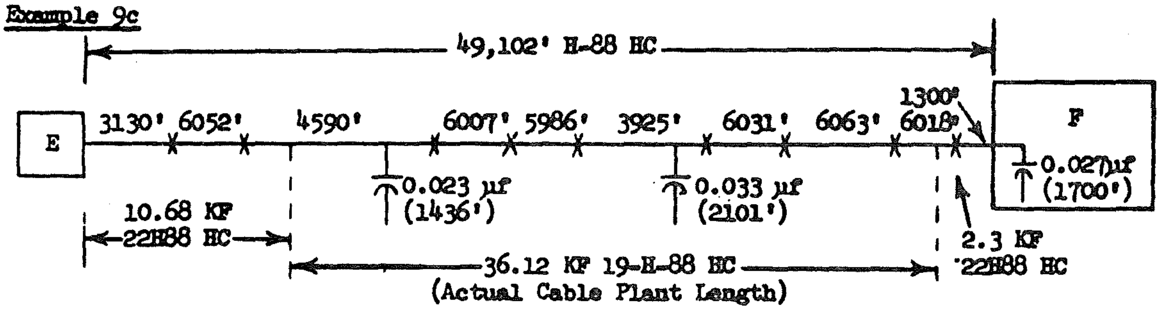
Procedure	Answer
34.31 KF x 0.15 db/KF	5.15 db

Example 9b



66.14 KF x 0.081 db/KF	5.36 db

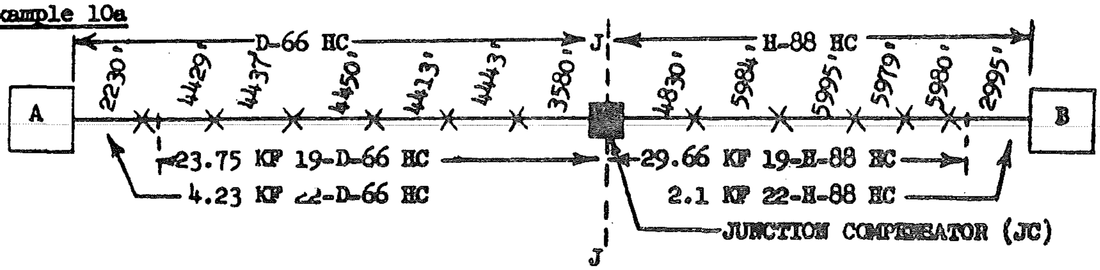
Example 9c



(10.68 + 2.3) x 0.15 + 36.12 x 0.081	4.88 db

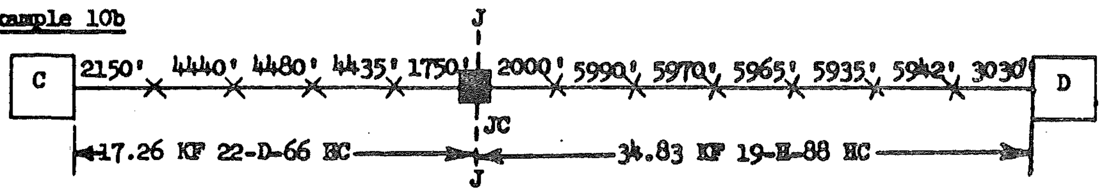
Illustrative Example 10 To show how to compute the attenuation of a loaded trunk cable similar to the one shown below at 1000 cps and 68°F.

Example 10a



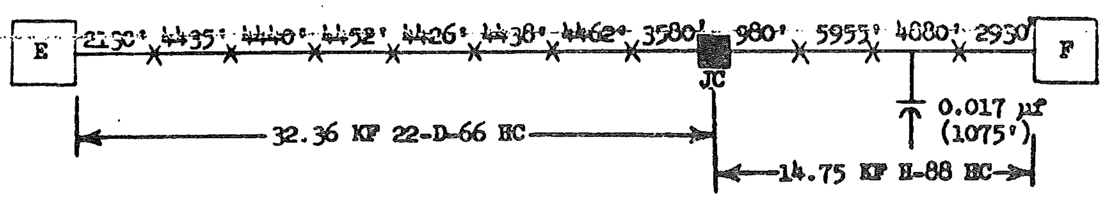
Procedure	Answer
Cable Attenuation + JC Loss (4.23 + 2.1) x 0.15 + (23.75 + 29.66) x 0.081 + 0.3	5.58 db

Example 10b



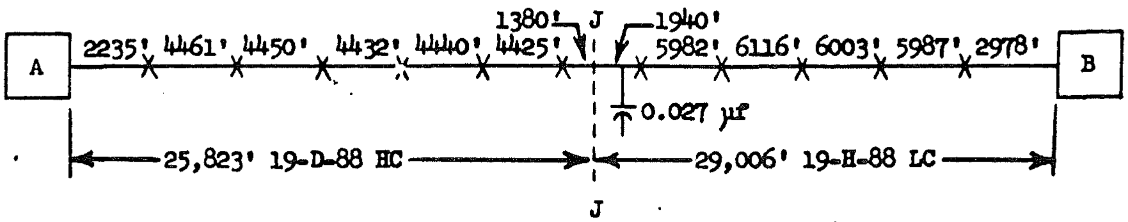
(17.26 x 0.15) + (34.83 x 0.081) + 0.3	5.71 db

Example 10c



47.11 KF x 0.15 db/KF + 0.3	7.37 db

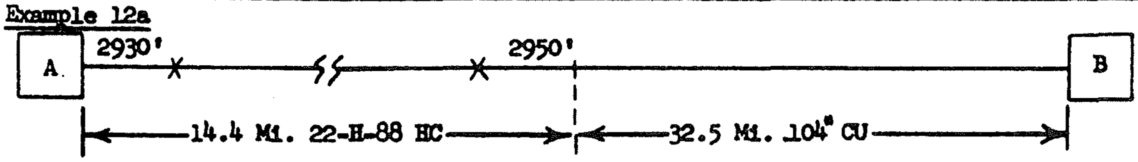
Illustrative Example 11 To show how to compute the attenuation of a loaded trunk cable similar to the one shown below at 1000 cps and 68°F.



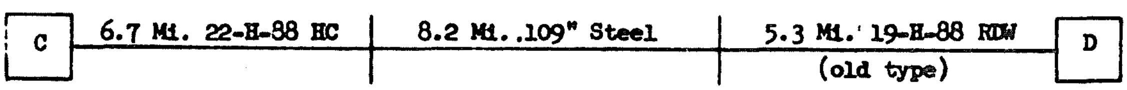
Computation	Answer
54.83 KF x 0.071 db/KF	3.89 db

Illustrative Example 12 To show how to compute the attenuation of a loaded trunk cable similar to the one shown below at 1000 cps and 68°F.

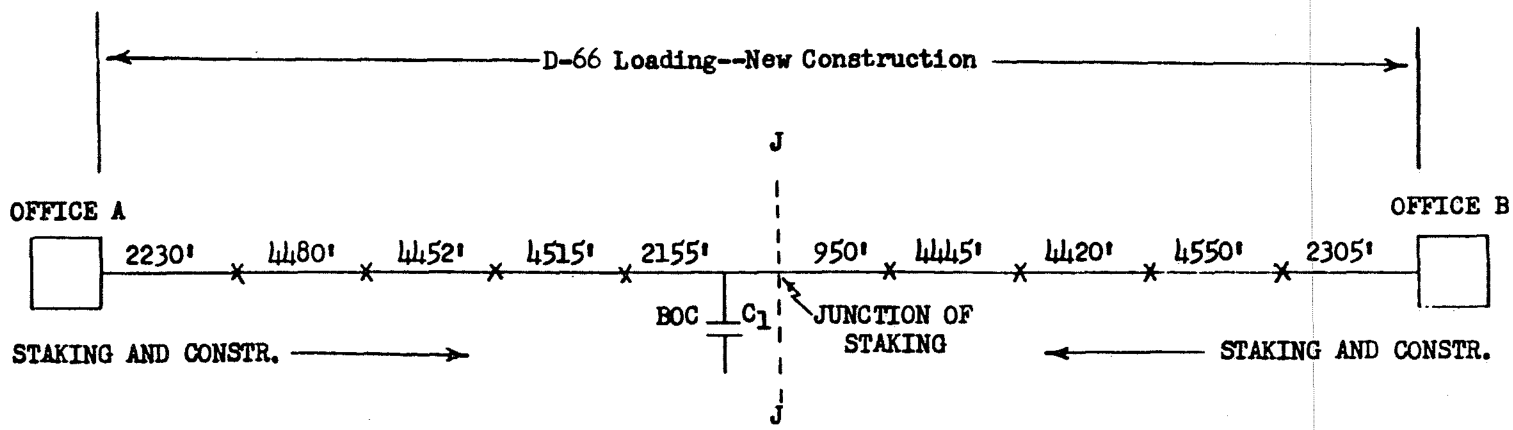
Example 12a



Procedure	Answer
Attenuation + Reflection (14.4 x 0.792) + (32.5 x 0.078) + (0.2)	14.13 db



(6.7 x 0.792) + (8.2 x 0.31) + (5.3 x 0.514) + (0) + (0) Reflections	10.57 db



(1) Average full load spacing is:

$$\frac{4480' + 4452' + 4515' + 4445' + 4420' + 4550'}{6} = 4477'$$

(2) Amount of building-out capacitance required at junction is:

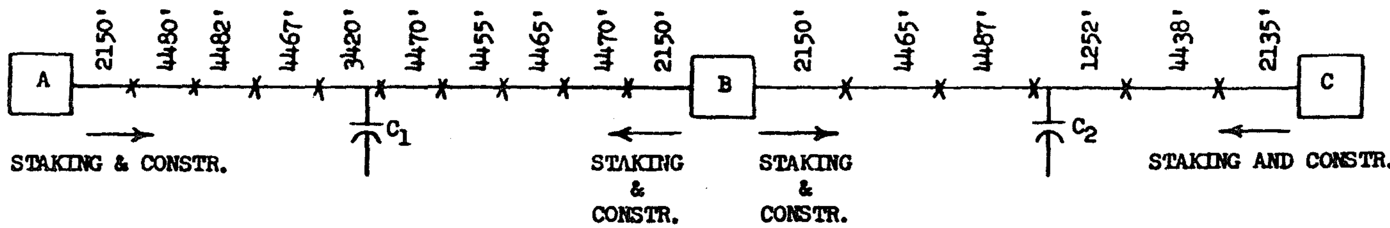
$$\frac{[4477' - (2155' + 950')]}{5280} \times 0.083 = \frac{1372}{5280} \times 0.083 = .022\ \mu f = C_1$$

Therefore, the value of capacitor C_1 is .022 µf and should be ordered in accordance with PE-30.

Notes: 1. All cable PE-22 or PE-23.
2. Both offices in REA borrowers' system.

ILLUSTRATIVE EXAMPLE 13

CBO COMPUTATION FOR NEW CONSTRUCTION AT JUNCTION POINT OF STAKING



OFFICE A - B

Avg. Spacing = (4480' + 4482' + 4467' + 4470' + 4455' + 4465' + 4470')/7 = 4470'

$$C_1 = \frac{4470' - 3420'}{5280'} \times 0.083 = 0.017\ \mu f$$ (ORDER PER PE-30)

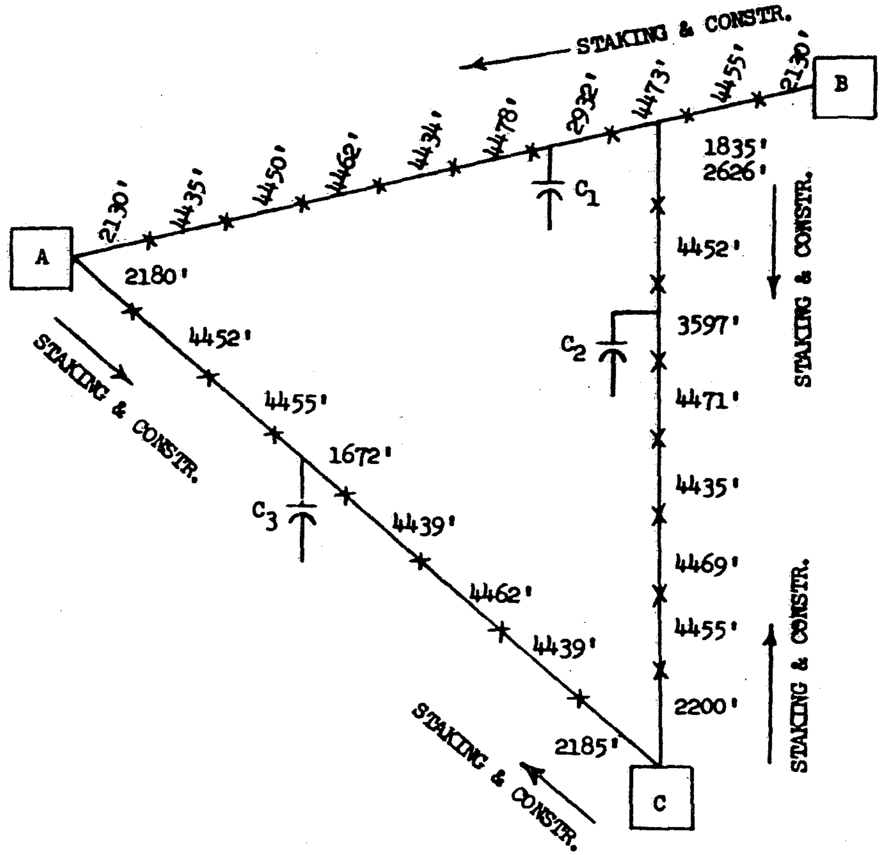
OFFICE B - C

Avg. Spacing = (4465' + 4487' + 4438')/3 = 4463'

$$C_2 = \frac{4463' - 1252'}{5280'} \times 0.083 = 0.051\ \mu f$$ (ORDER PER PE-30)

ILLUSTRATIVE EXAMPLE 14

CBO COMPUTATION FOR NEW CONSTRUCTION AT THE JUNCTION POINT



OFFICE A-B

Avg. Spac. = (4435' + 4450' + 4462' + 4434' + 4478' + 4473' + 4455')/7 = 4455'

$$C_1 = \frac{4455' - 2932'}{5280'} \times 0.083 = 0.024\mu f$$

OFFICE B - C

Avg. Spac. = (4455' + 4461' + 4452' + 4471' + 4435' + 4469' + 4455')/7 = 4457'

$$C_2 = \frac{4457' - 3597'}{5280'} \times 0.083 = 0.014\mu f$$

OFFICE A - C

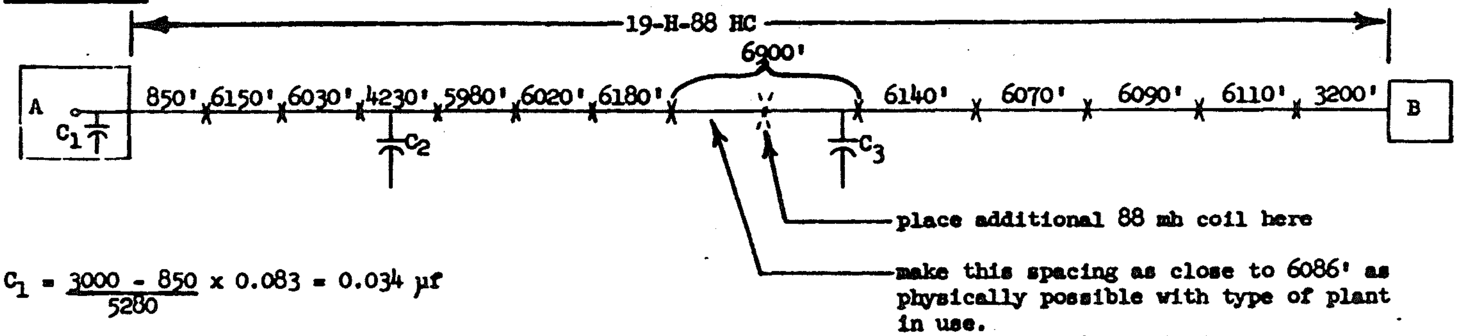
Avg. Spac. = (4452' + 4455' + 4439' + 4462' + 4439')/5 = 4449'

$$C_3 = \frac{4449' - 1672'}{5280'} \times 0.083 = 0.044\mu f$$

ILLUSTRATIVE EXAMPLE 15

CBO COMPUTATION FOR NEW CONSTRUCTION AT THE JUNCTION POINT

Example 16a



$C_1 = \frac{3000 - 850}{5280} \times 0.083 = 0.034\ \mu f$

Avg. Spac. = (6150' + 6030' + 5980' + 6020' + 6180' + 6140' + 6070' + 6090' + 6110')/9 = 6086'

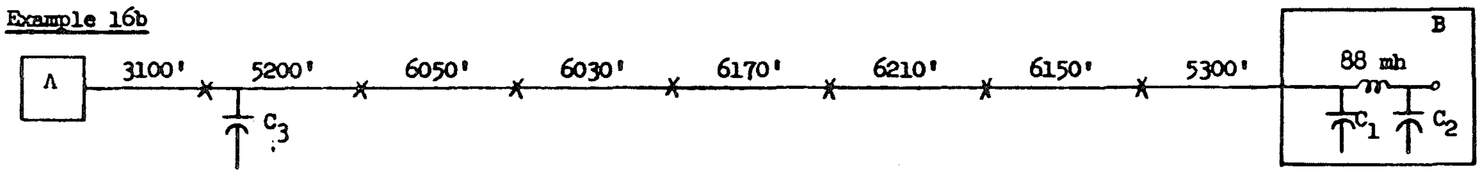
$C_2 = \frac{6086 - 4230}{5280} \times 0.083 = 0.029\ \mu f$

Loading Section No. 7 (Office A) = 6086'

$C_3 = \frac{2\ (6086) - 6900}{5280} \times 0.083 = 0.083\ \mu f$

ORDER ALL BUILDING-OUT CAPACITORS PER REA SPECIFICATION PE-30

Example 16b



Avg. Spac. = (6050 + 6030 + 6170 + 6210 + 6150)/5 = 6122'

$C_3 = \frac{6122 - 5200}{5280} \times 0.083 = 0.015\ \mu f$

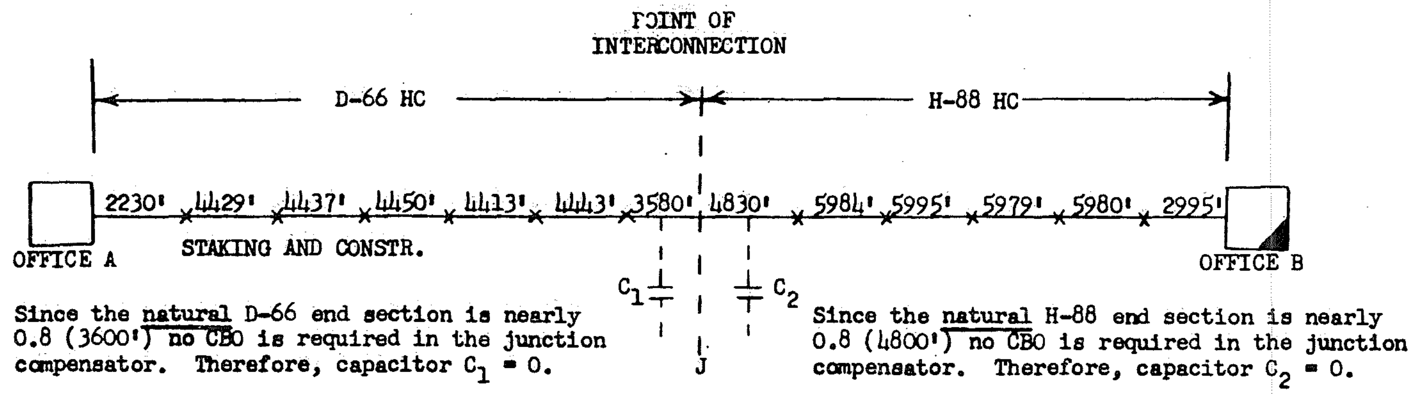
Coil — CBO Unit

$$\begin{cases} C_1 = \frac{6122 - 5300}{5280} \times 0.083 = 0.013\ \mu f \\ C_2 = \frac{3000 - 0}{5280} \times 0.083 = 0.047\ \mu f \end{cases}$$

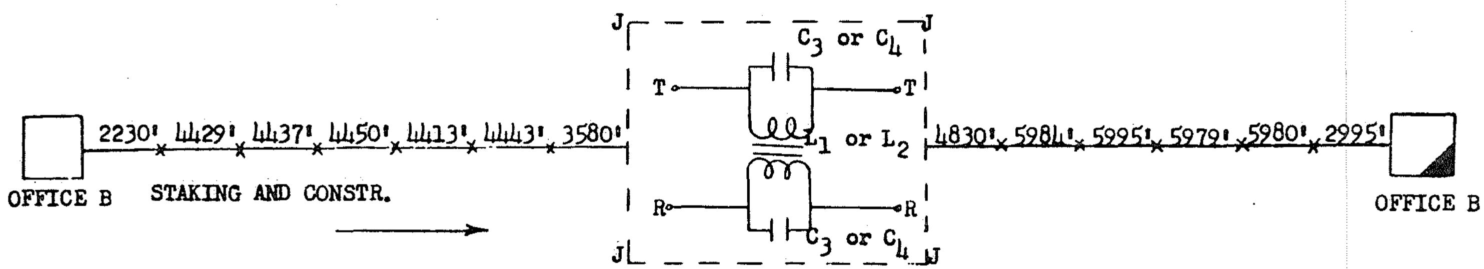
a. ORDER C_3 CBO AS PER REA SPECIFICATION PE-30.
b. ORDER COIL-CBO UNIT AS ONE ASSEMBLY UNIT FOR EASE OF MOUNTING.

ILLUSTRATIVE EXAMPLE 16

CBO AND COIL COMPUTATIONS FOR EXISTING PLANT



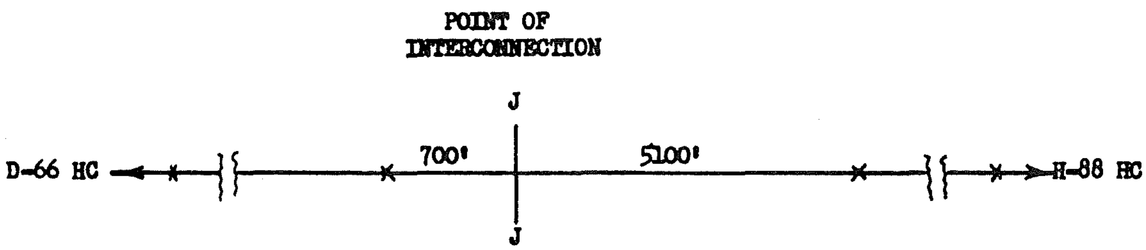
A. CABLE LAYOUT UNDER CONSIDERATION



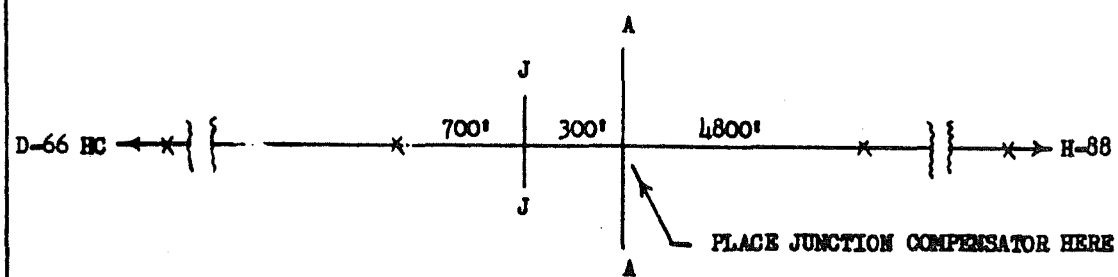
B. RESULTING APPLICATION OF JUNCTION COMPENSATOR

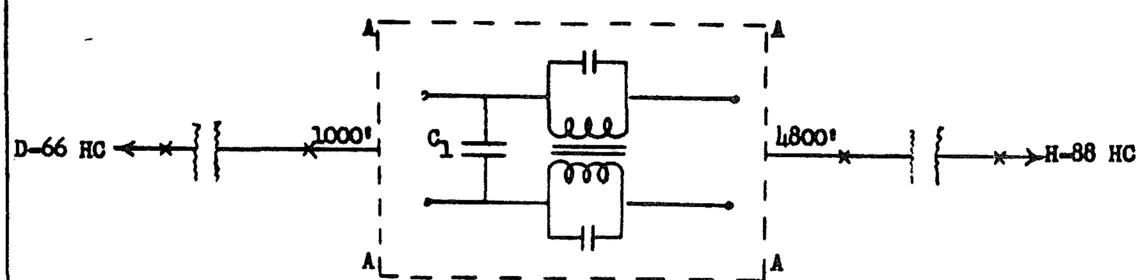
Notes:
1. In Examples 17 to 20, refer to Figure 1 for values of L_1 or L_2 of loading coil inductance and values of capacitance for C_3 or C_4 "series" capacitors in the compensator.
2. "T" and "R" designations in compensator refer to tip and ring conductor identification.
3. Office B is office of the connecting company.

ILLUSTRATIVE EXAMPLE 17
APPLICATION OF THE JUNCTION COMPENSATOR



A. CABLE LAYOUT UNDER CONSIDERATION





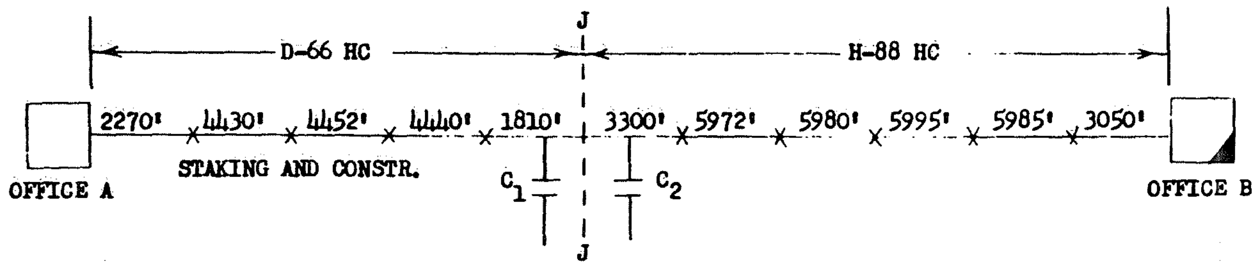
$$C_1 = \frac{(3600' - 1000')}{5280} \times 0.083 = 0.041\ \mu f$$

$$C_2 = 0$$

B. RESULTING APPLICATION OF JUNCTION COMPENSATOR

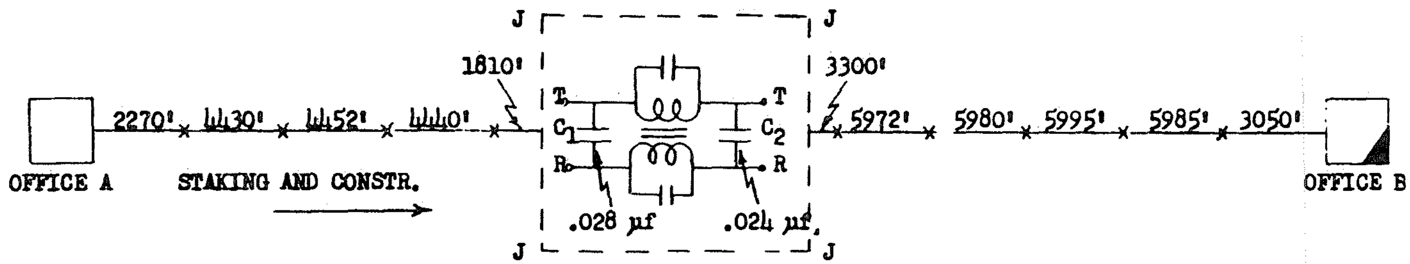
ILLUSTRATIVE EXAMPLE 18

APPLICATION OF THE JUNCTION COMPENSATOR



$$C_1 = \frac{(3600' - 1810')}{5280} \times 0.083 = 0.028 \ \mu f \qquad C_2 = \frac{(4800' - 3300')}{5280} \times 0.083 = 0.024 \ \mu f$$

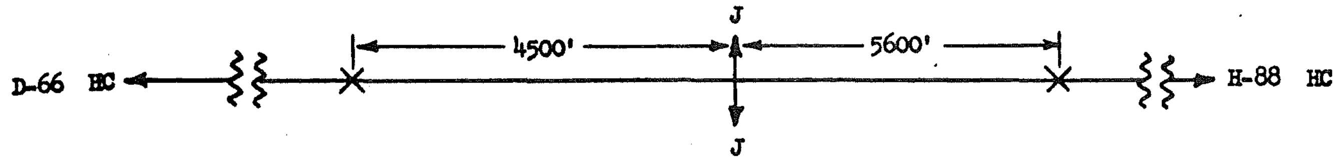
A. CABLE LAYOUT UNDER CONSIDERATION



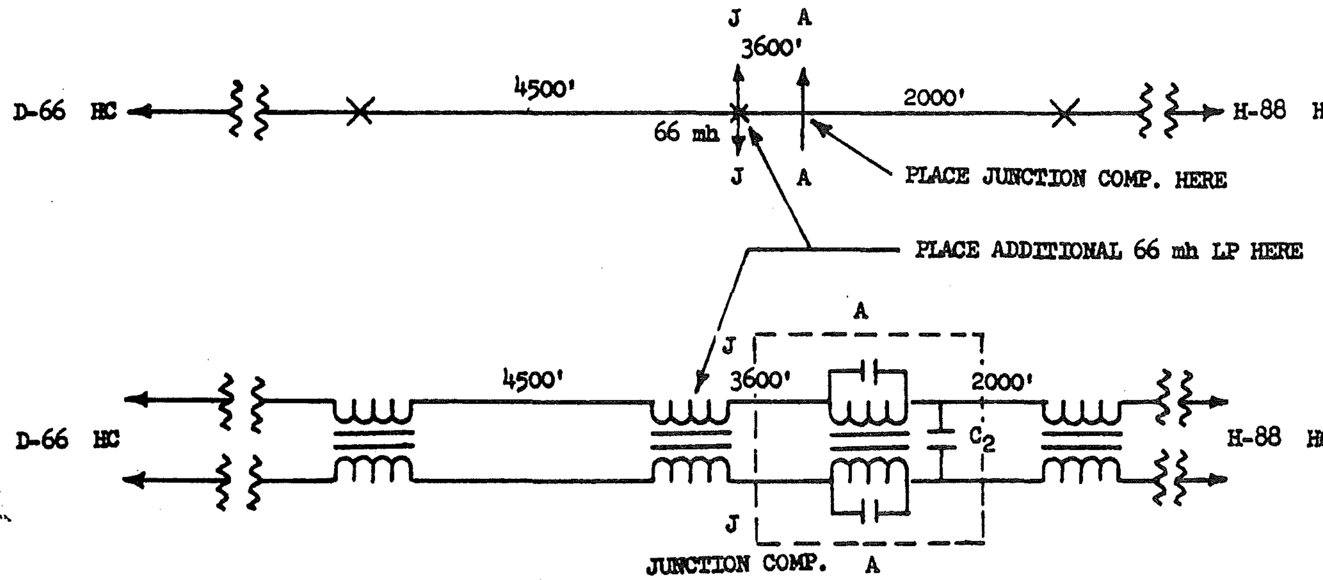
B. RESULTING APPLICATION OF JUNCTION COMPENSATOR

ILLUSTRATIVE EXAMPLE 19
APPLICATION OF THE JUNCTION COMPENSATOR

ILLUSTRATIVE EXAMPLE 20
APPLICATION OF THE JUNCTION COMPENSATOR



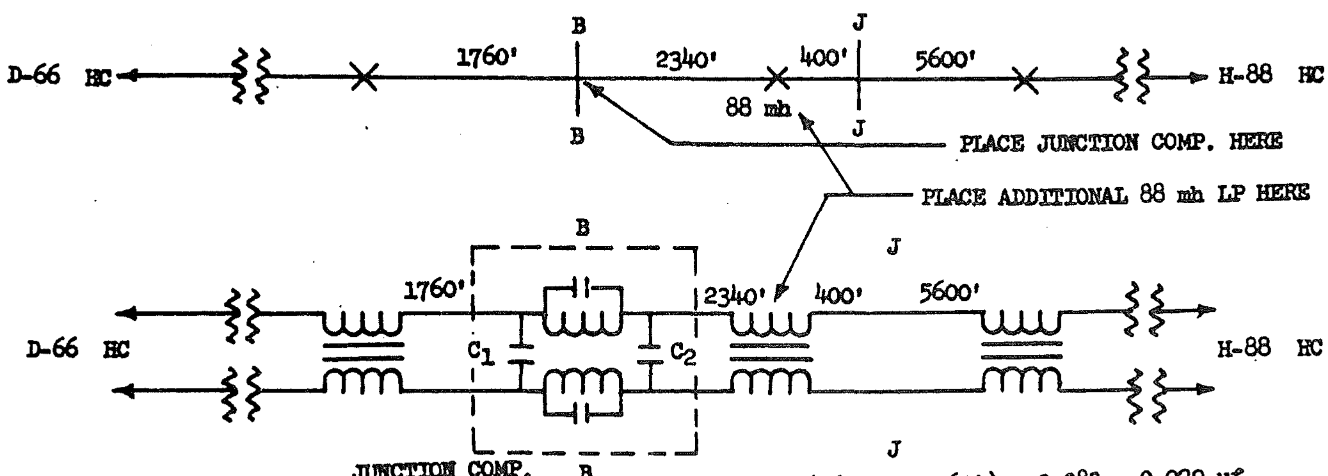
A. CABLE LAYOUT UNDER CONSIDERATION



$C_1 = 0$

$$C_2 = \frac{(4800' - 2000')}{5280} \times 0.083 = 0.044 \text{ uf}$$

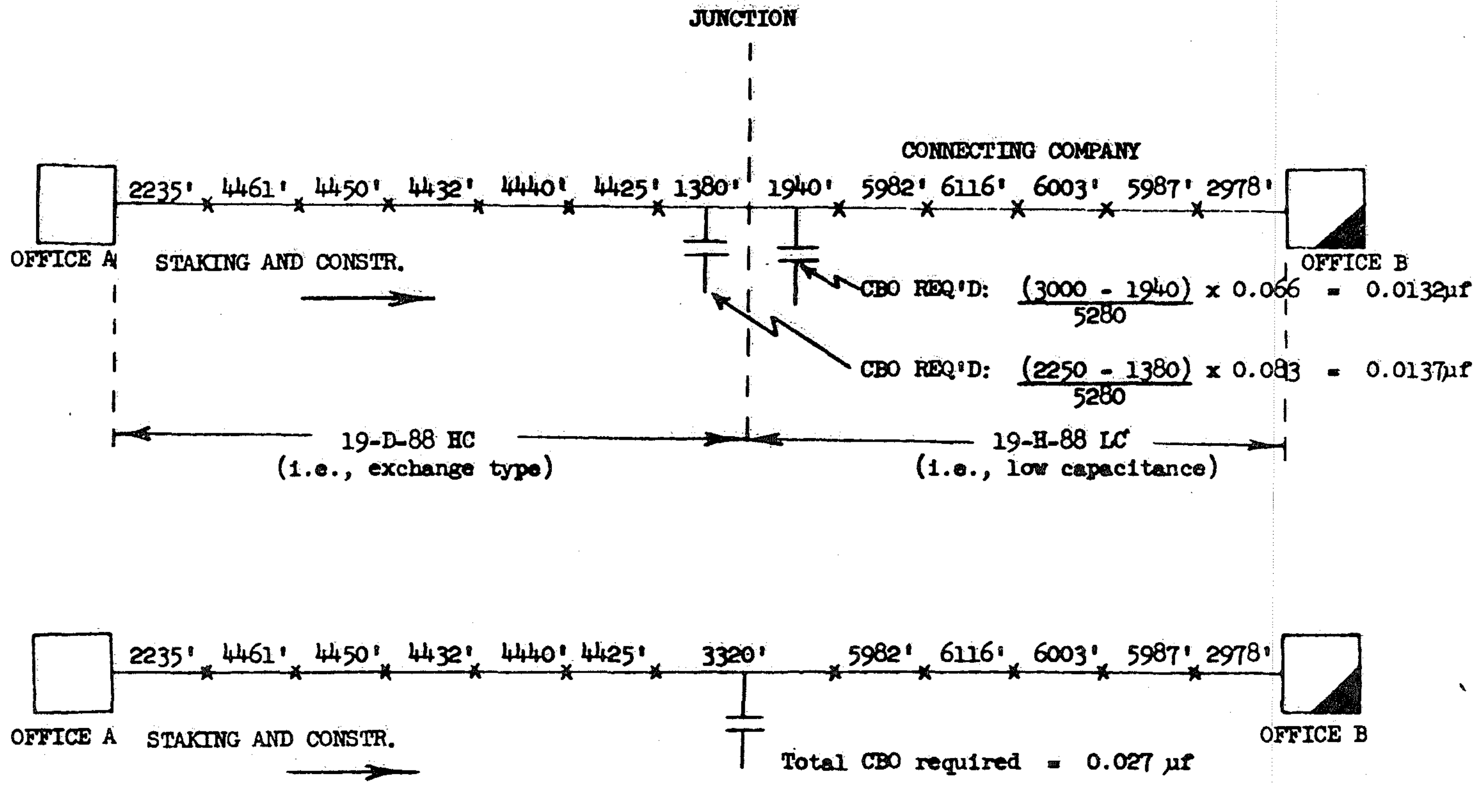
B. ONE POSSIBLE SOLUTION AND RESULTING JUNCTION COMP. CONFIGURATION



$$C_1 = \frac{(3600' - 1760')}{5280} \times 0.083 = 0.029 \text{ uf}$$

$$C_2 = \frac{(4800' - 2340')}{5280} \times 0.083 = 0.039 \text{ uf}$$

C. ANOTHER POSSIBLE SOLUTION AND RESULTING JUNCTION COMP. CONFIGURATION



ILLUSTRATIVE EXAMPLE 21

CBO COMPUTATION AT JUNCTION OF 19D-88HC AND 19H-88 LC

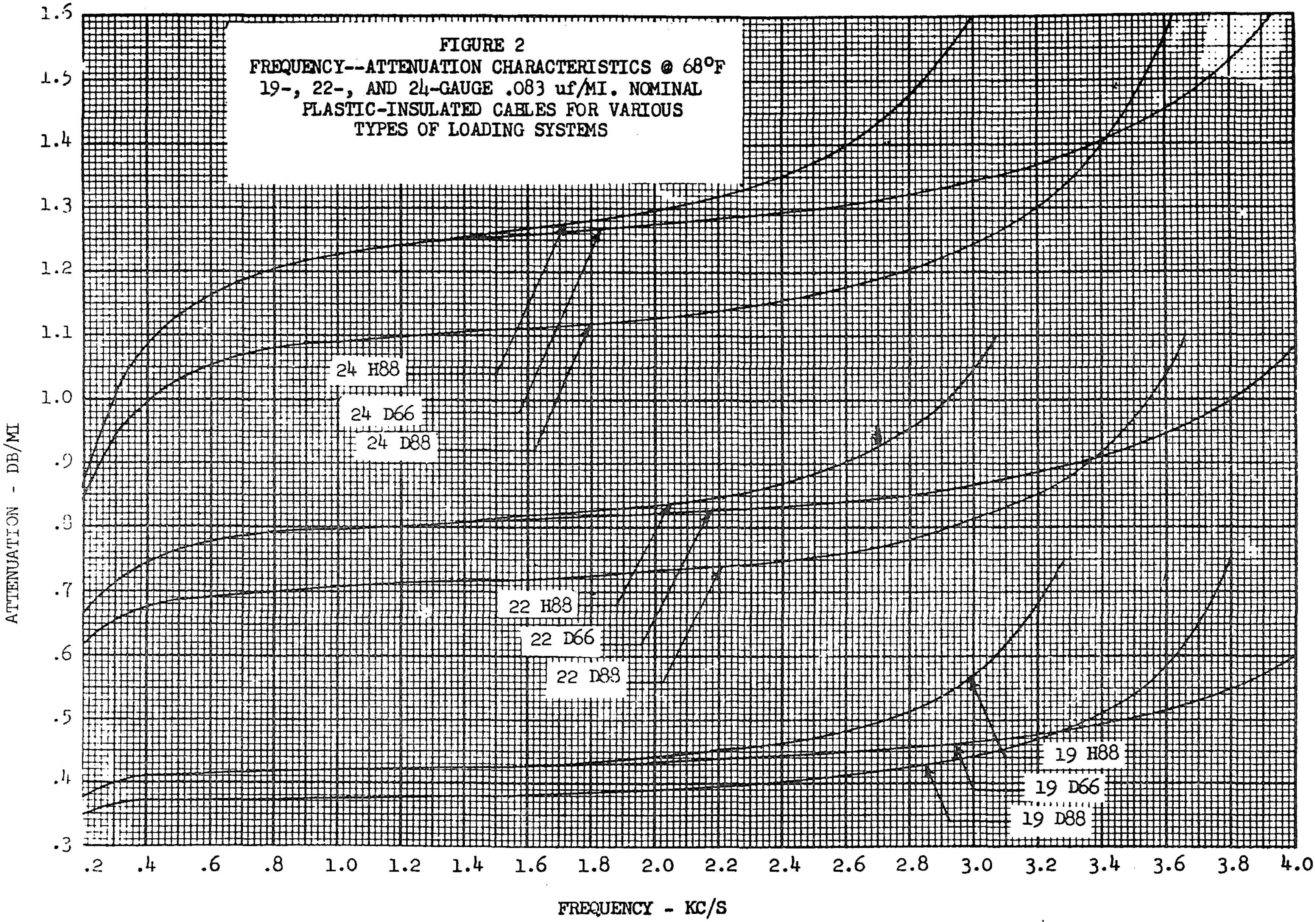


FIGURE 2
FREQUENCY--ATTENUATION CHARACTERISTICS @ 68°F
19-, 22-, AND 24-GAUGE .083 uf/MI. NOMINAL
PLASTIC-INSULATED CABLES FOR VARIOUS
TYPES OF LOADING SYSTEMS
24 H88
24 D66
24 D88
22 H88
22 D66
22 D88
19 H88
19 D66
19 D88
ATTENUATION - DB/MI
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
FREQUENCY - KC/S

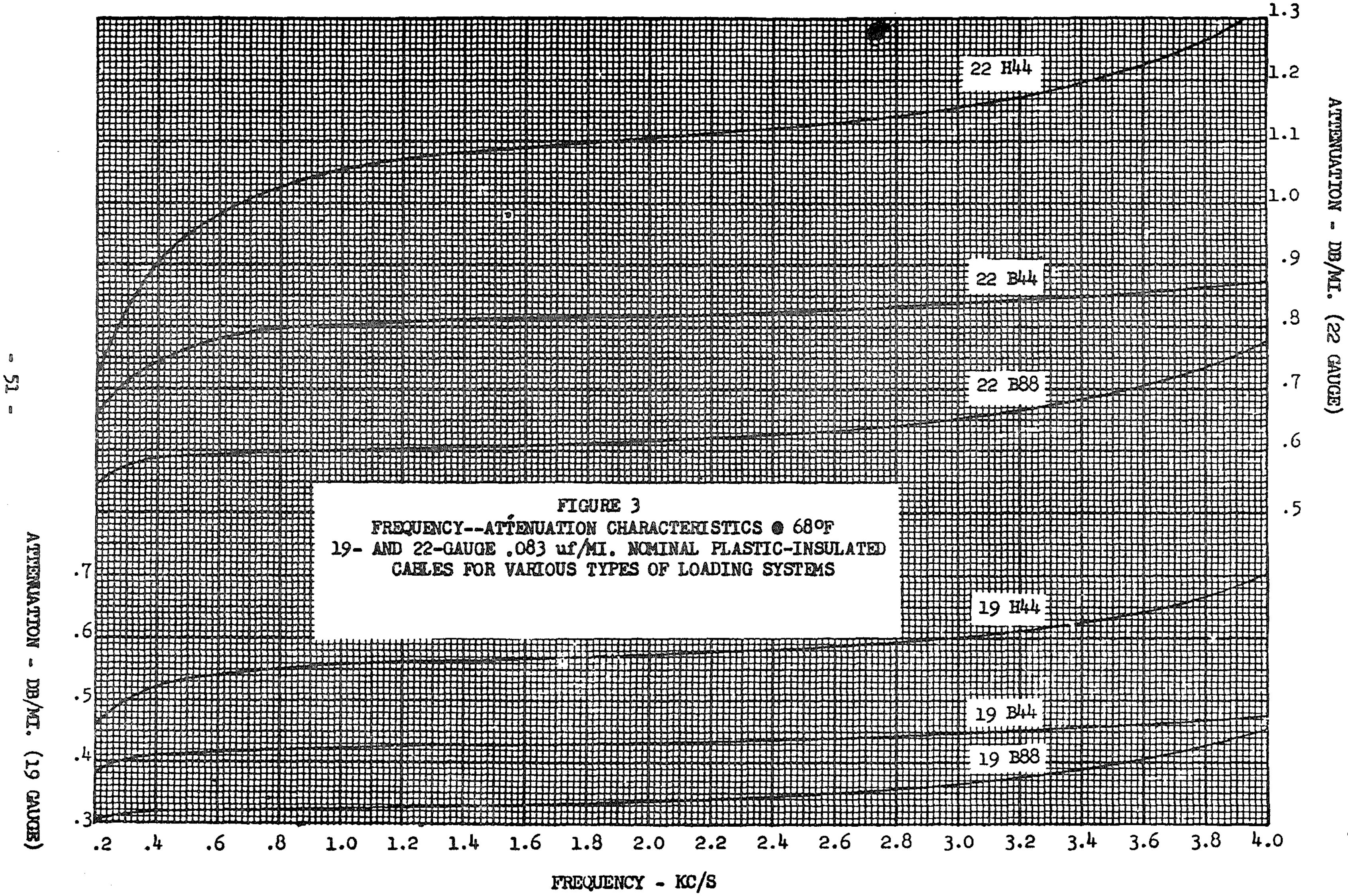


FIGURE 3
FREQUENCY--ATTENUATION CHARACTERISTICS @ 68°F
19- AND 22-GAUGE .083 uf/MI. NOMINAL PLASTIC-INSULATED
CABLES FOR VARIOUS TYPES OF LOADING SYSTEMS

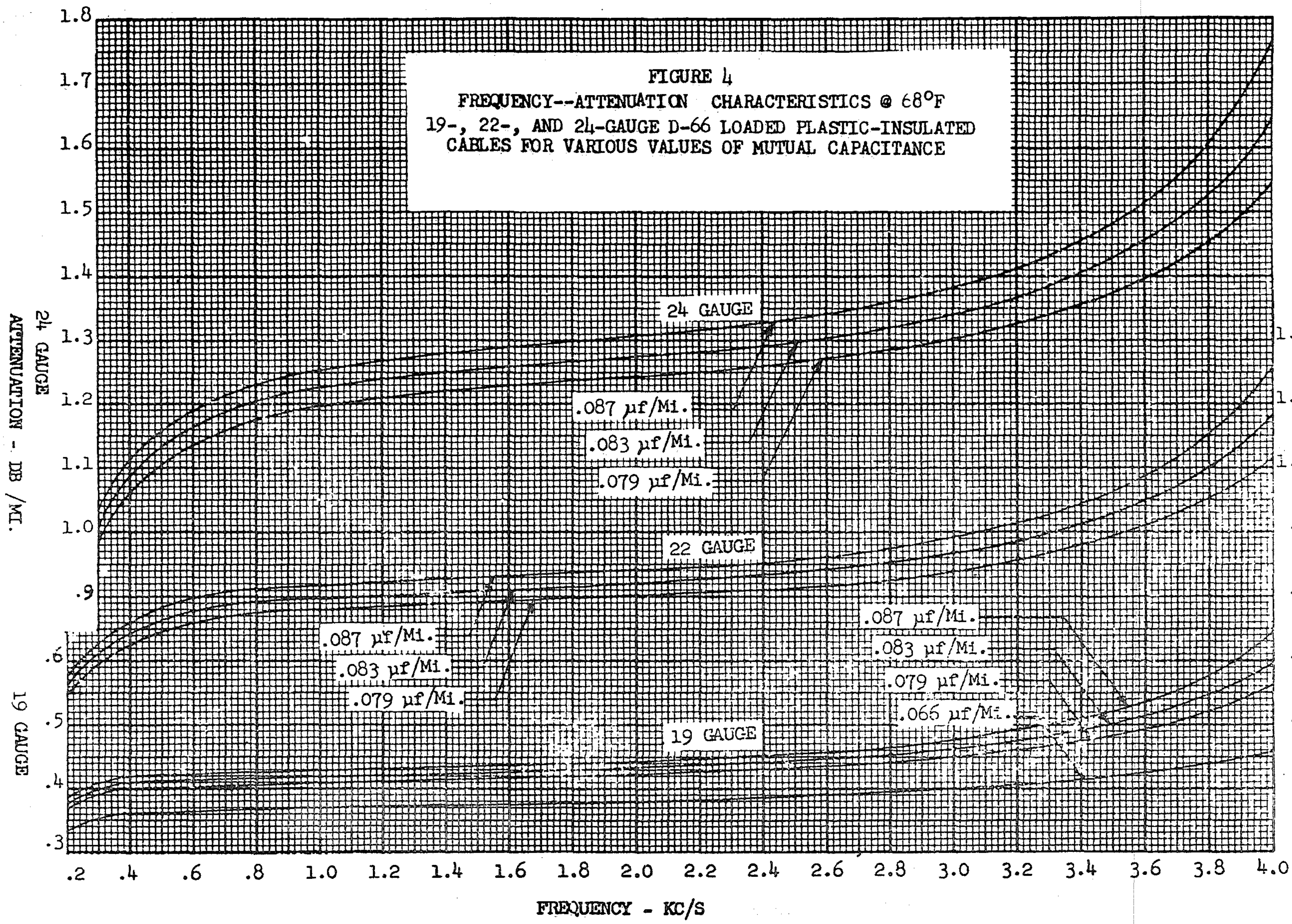


FIGURE 4
FREQUENCY--ATTENUATION CHARACTERISTICS @ 68°F
19-, 22-, AND 24-GAUGE D-66 LOADED PLASTIC-INSULATED CABLES FOR VARIOUS VALUES OF MUTUAL CAPACITANCE
24 GAUGE
.087 µf/Mi.
.083 µf/Mi.
.079 µf/Mi.
22 GAUGE
.087 µf/Mi.
.083 µf/Mi.
.079 µf/Mi.
19 GAUGE
.087 µf/Mi.
.083 µf/Mi.
.079 µf/Mi.
.066 µf/Mi.
24 GAUGE ATTENUATION - DB /MI.
19 GAUGE
ATTENUATION - DB/MI. (22 GAUGE)
FREQUENCY - KC/S
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.6
.5
.4
.3
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0

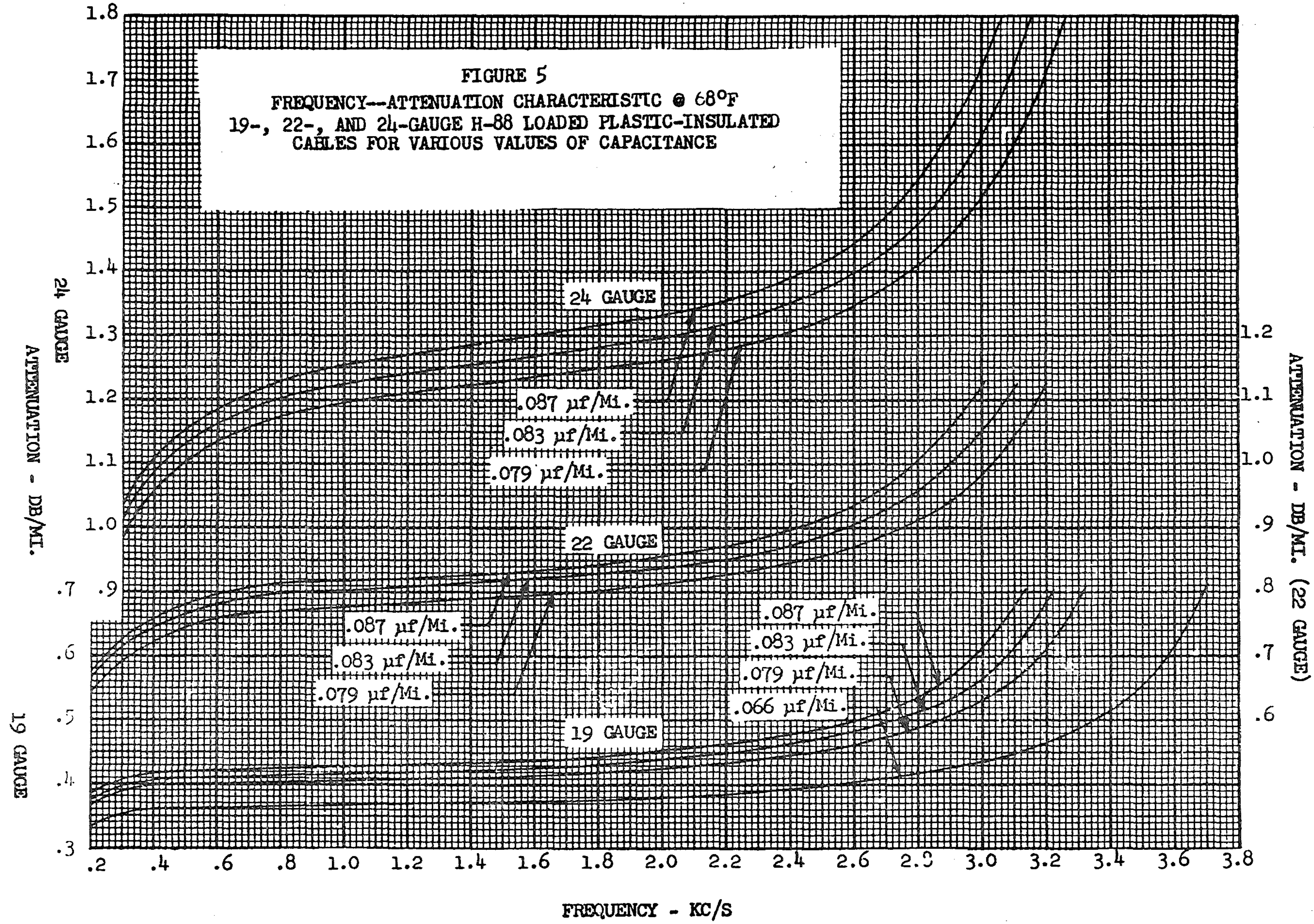


FIGURE 5
FREQUENCY--ATTENUATION CHARACTERISTIC @ 68°F
19-, 22-, AND 24-GAUGE H-88 LOADED PLASTIC-INSULATED CABLES FOR VARIOUS VALUES OF CAPACITANCE

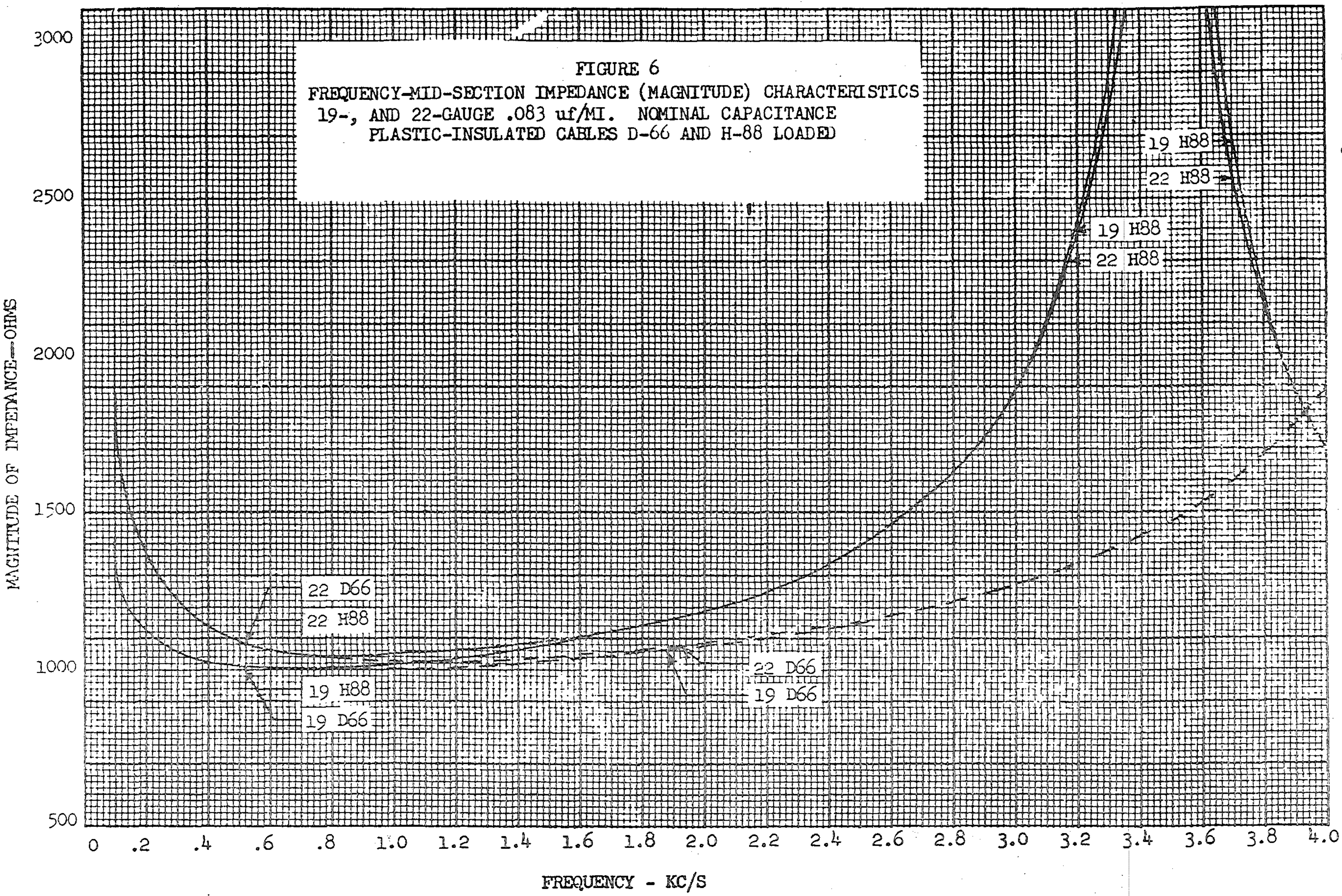


FIGURE 6
FREQUENCY-MID-SECTION IMPEDANCE (MAGNITUDE) CHARACTERISTICS
19-, AND 22-GAUGE .083 uf/MI. NOMINAL CAPACITANCE
PLASTIC-INSULATED CABLES D-66 AND H-88 LOADED
MAGNITUDE OF IMPEDANCE—OHMS
3000
2500
2000
1500
1000
500
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
FREQUENCY - KC/S
19 H88
22 H88
19 H88
22 H88
22 D66
22 H88
19 H88
19 D66
22 D66
19 D66

TABLE I

ATTENUATION AT 1000 CPS AND 68°F[1]
LOADED, POLYETHYLENE AND PAPER[2] INSULATED TRUNK CABLES
PAIRED OR QUADDED

1. PAIRED, MULTIPAIR SHIELDED CABLES

Type of Facility	Attenuation DB/Mi.	Attenuation DB/KF
24-D-66 HC	1.21	0.23
22-D-66 HC	0.792	0.15
19-D-66 HC	0.428	0.081
26-H-88 HC	1.79	0.34
24-H-88 HC	1.21	0.23
22-H-88 HC	0.798	0.15
19-H-88 HC	0.428	0.081
24-B-88	0.921	0.174
22-B-88	0.601	0.114
19-B-88	0.320	0.606
19-D-88 HC	0.375	0.071
19-H-88 LC (Paired or Quadded)	0.375	0.071

2. PAIRED, MULTIPAIR NON-SHIELDED CABLES (RDW TYPE)

Type of Facility	DB/Mi.	DB/KF
19-D-66 (Figure 8)	0.49	0.093
19-H-88 "	0.49	0.093
22-D-66 (Former Type)	1.0	0.181
22-H-88 "	1.0	0.181
19-D-66 "	0.6	0.114
19-H-66 "	0.6	0.114

3. TOLL QUADDED CABLE—19 GAUGE

	Side Circuit		Phantom Circuit	
	DB/Mi.	DB/KF	DB/Mi.	DB/KF
H-31-18	0.549	0.104	0.459	0.087
H-44-25	0.470	0.089	0.391	0.074
H-88-50	0.349	0.066	0.301	0.057
B-88-50	0.259	0.049	0.232	0.044

NOTES:

1. For temperatures other than those shown above, change attenuation shown by ± 1 percent for each change in temperature of ± 5°F.
2. Western Electric Company types DNB, BSA, and DSM for 19-, 22-, and 24-gauge, respectively.

TABLE II

REFLECTION LOSSES IN DB AT 1000 CPS FOR DISSIMILAR FACILITIES

	FACILITY	CABLE AND FIGURE "8" RDW															OPEN WIRE							RDW (FORMER TYPE)						600 OHMS
		26 GAUGE			24 GAUGE				22 GAUGE				19 GAUGE				109 STEEL		COPPER-STEEL				104 COPPER	22 GAUGE			19 GAUGE			
		D66 H88	B88	H44	N.L.	D66 H88	B88	H44	N.L.	D66 H88	B88	H44	N.L.	D66 H88	B88	H44	85-135	190	30% 104	40% 104	30% 080	40% 080		N.L.	D66 H88	H44	N.L.	D66 H88	H44	
CABLE AND FIGURE "8" RDW	26 N.L.	-0.2	-0.1	-0.1	0.1	-0.3	-0.2	-0.1	0.3	-0.4	-0.4	-0.2	0.9	-0.5	-0.5	-0.3	0	0.1	-0.1	-0.1	0	-0.1	-0.2	0.4	-0.4	-0.1	1.0	-0.6	-0.3	-0.4
	26 D66 or H88	X	0	0	0.1	0	0	0.1	0.5	0	-0.1	0.2	1.2	0	-0.1	0.3	0	0	0.2	0.2	0	0.1	0.4	0.7	0.1	0.2	1.5	0	0.3	0.4
	26 B88		X	0	0.2	0.1	0	0.3	0.8	0.2	0	0.5	1.8	0.2	0	0.6	0	-0.1	0.3	0.5	0	0.2	0.7	1.0	0.3	0.6	2.0	0.2	0.7	0.9
	26 H44			X	0	-0.1	0	0	0.4	-0.2	-0.2	0.1	1.0	0.2	-0.2	0	0.1	0.1	0	0.1	0	0	0.1	0.5	0.1	0.1	1.2	-0.2	0.1	0.1
	24 N.L.				X	-0.1	0.1	-0.1	0.1	-0.3	-0.1	-0.2	0.5	-0.5	-0.2	-0.4	0.2	0.4	-0.2	-0.2	0.2	-0.1	-0.3	0.2	-0.3	-0.2	0.6	-0.5	-0.4	-0.6
	24 D66 or H88					X	0.1	0	0.2	0	0	0.2	1.0	0	0	0.2	0	0	0.1	0.1	0	0	0.3	0.6	0.1	0.3	1.2	0	0.3	0.4
	24 B88						X	0.2	0.6	0.2	0	0.4	0.6	0.2	0	0.6	-0.1	-0.1	0.2	0.4	0	0.1	0.6	1.1	0.3	0.7	1.8	0.2	0.7	0.9
	24 H44							X	0.1	-0.1	0.1	0	0.6	-0.1	0	0	0.2	0.3	0	0	0	0	0	0.3	-0.1	0.1	0.8	-0.1	0	0
	22 N.L.								X	0	0.4	-0.1	0.1	-0.2	0.4	-0.3	0.8	0.9	0	0	0.5	0.2	-0.3	0	-0.2	-0.2	0,3	-0.2	-0.4	-0.6
	22 D66 or H88									X	0.1	0.1	0.7	0	0.1	0.2	0	0	0	0	-0.2	-0.1	0.2	0.3	0.1	0.2	0.9	0	0.2	0.3
	22 B88										X	0.3	1.3	0.1	0	0.5	-0.2	-0.2	0.1	0.3	-0.2	0	0.5	0.8	0.2	0.5	1.6	0.2	0.6	0.7
	22 H44											X	0.3	0	0.3	0	0.3	0.4	0	0	0.1	0	0	0	0	0	0.4	0	0	0
	19 N.L.												X	0.5	1.2	0	1.5	1.8	0.5	0.4	1.1	0.7	0	0	0.3	0.1	0	0.4	-0.1	-0.4
	19 D66 or H88													X	0.1	0.1	0	0	-0.1	0	-0.3	-0.1	0.1	0.2	0	0.1	0.8	0	0.2	0.3
	19 B88														X	0.4	-0.2	-0.2	0.1	0.2	-0.3	0	0.5	0.7	0.2	0.5	1.5	0.2	0.5	0.7
	19 H44															X	0.4	0.5	0	-0.1	0	0	0	-0.1	0	0	0.2	0.1	0.1	0
OPEN WIRE	109 Steel (85 or 135)																X	0	0.2	0.3	0.1	0.2	0.4	1.1	0.1	0.6	1.8	0	0.5	0.6
	109 Steel (190)																	X	0.3	0.4	0.1	0.2	0.6	1.3	0.2	0.7	2.0	0	0.6	0.7
	104 C.S. 30%																		X	0	0.2	0	0	0.3	-0.1	0.1	0.7	-0.2	0	0
	104 C.S. 40%																			X	0.2	0.1	0	0.1	0	0.1	0.6	-0.1	0	-0.1
	080 C.S. 30%																				X	0	0.2	0.7	-0.1	0.2	1.3	-0.2	0.1	0.1
	080 C.S. 40%																					X	0.1	0.4	-0.1	0.1	1.0	-0.2	0	0
	104 CU																						X	-0.2	0.1	0	0.2	0.2	0	0
RDW (FORMER TYPE)	22 N.L.																							X	0	-0.1	0.1	0	-0.3	-0.6
	22 D66 or H88																								X	0.1	0.6	0	0.1	0.2
	22 H44																									X	0.2	0.1	0	-0.1
	19 N.L.																										X	0.6	0	-0.3
	19 D66 or H88																											X	0.1	0.2
	19 H44																												X	0