Section 431
Issue No. 1
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VOICE-FREQUENCY LOADING FOR TRUNK CABLES

CONTENTS

1. GENERAL

1.1 This section is intended to provide Rural Electrification Administration borrowers, consulting engineers, contractors and other interested parties with technical information for use in the design and construction of REA-financed telephone systems. It discusses in particular the application of loading to trunk cable plant carrying voice-frequency circuits. The trunks referred to are those defined in Section 401 of this manual.

1.2 Loading is the insertion of inductance coils or inductors in series with the line at approximately equal intervals along the line usually used for the purpose of reducing attenuation through a given frequency range. Loading a line always increases its characteristic impedance over the voice frequencies of interest. This may be desirable as nonloaded cable generally has a smaller characteristic impedance than open wire. In such cases, loading helps to reduce reflection losses at junctions by reducing this difference in impedance where a circuit consists of both facilities. Repeatered circuits particularly benefit from such an arrangement, since the return loss[1] is improved and a higher repeater gain can be realized.

1.3 Since the primary purpose of loading is to reduce cable attenuation, loading should be considered where a nonloaded trunk cable does not meet the criteria specified in Section 415 of this manual. It should be borne in mind that this is not the only method of reducing attenuation, or that, in itself, loading may be inadequate; it may be necessary to both load a cable and apply one or more voice frequency repeaters to obtain satisfactory transmission. Situations are possible where the over-all cost of trunks in cable does not compare favorably with that of other facilities, such as carrier on cable pairs, open wire pairs (voice frequency or carrier) or radio, because of the cost of coarse gauge cable, loading systems and repeatering necessary to obtain satisfactory transmission in loaded trunk cables. Comparative annual charge studies[2] may therefore be necessary in order to determine whether interoffice trunking should be obtained by means of loaded cable in the first place.

1.4 The loading discussed in this section is confined to loading on cable pairs for use at voice frequencies. It is theoretically possible to effect some decrease in attenuation on open wire lines through loading, and, in fact, this was practiced for a few years but was discontinued about 30 years ago. Today where necessary, far more satisfactory methods of decreasing open wire trunk voice-frequency attenuation are available through the use of voice frequency repeaters.

1.5 It is possible to use "light" loading on cable pairs (coils of low inductance at short intervals) to reduce attenuation and to increase the line characteristic impedance in order to avoid reflection at an open wire junction for carrier applications, but such applications are beyond the scope of this section.

1.6 Loading coils are designated by a letter signifying the section length and with the inductance of the coil in millihenrys. In voice-frequency loading systems the section lengths generally used are the 6,000-ft. (H system) and the 3,000-ft. (B system). When "standard spacing" is used

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[1]Return loss is a measure of the impedance match between any two impedances. Realizable repeater gains are a function of return loss between the balancing networks and corresponding line impedance.

[2]See Section 218 REA Telephone Engineering and Construction Manual entitled "Plant Annual Cost Data for System Design Purposes."

hereinafter it will refer to these lengths. The "series-aiding" inductances of the coils generally used are 44 millihenry and 88 millihenry. Thus a loading coil having a 44 millihenry inductance and used in a 6000-ft. section is coded as H-44. Phantom group loading, for example H-88-50, with a 6000-ft. section introduces 88 millihenrys inductance in the side circuits and 50 millihenrys inductance in the phantom circuit.

1.7 Loading systems and methods of application discussed are for use in entrance cables[1], intermediate cables[2] in open wire lines, "short haul" and medium length trunks, and repeatered and nonrepeatered trunks using either quadded or nonquadded cables.

1.8 On the average, the use of loading will reduce the attenuation of a nonloaded trunk circuit by about one-third to two-thirds depending on the type of conductor and the loading system employed. This is true in the voice ranges up to frequencies of about 3 kc. At higher frequencies there is a sharp increase in attenuation and the attenuation of a loaded cable above voice frequencies becomes greater than that of a nonloaded cable. Therefore no carrier can be used on voice-frequency loaded cables. The frequency where this sharp increase in attenuation begins is called the cutoff frequency. Cutoff frequencies for the loading systems discussed herein (Paragraph 2) are included in Table I.

1.9 Reference to Figure 1 shows that a loading "coil" for a nonphantomed circuit actually consists of two equal separate windings wound on a toroidal core. The coil offers equal (series) impedance to each line wire. Side circuit coils (Figure 2) also have two distinct windings, but are manufactured with the added precaution of having each winding equally divided between inside and outside layers on the core to hold the impedance of each coil to a close tolerance. A phantom circuit coil consists of four windings (Figure 2) balanced in accordance with the above principles to maintain balance and minimize phantom-to-side and side-to-side crosstalk.

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[1]An entrance cable is a cable or several lengths of cable in tandem which connects to the main distributing frame of a central office at one end and to open wire at the other.

[2]An intermediate cable is a cable or several lengths of cable in tandem which connect to open wire at either end.

TABLE I

Cable	System	Circuit	Cable capacitance per mile in mfd [1]	Cutoff frequency in cycles/sec. (all gauges)
Nonquadded	H-44	-	.082	5000
	H-88	-	.082	3500
	B-88	-	.082	5000
Quadded	H-44-25	Side	.062	5600
		Phantom	.100	6000
	H-88-50	Side	.062	4200
		Phantom	.100	5700
	B-88-50	Side	.062	5700
		Phantom	.100	6000

[1] Capacitances shown are typical. The cutoff frequency varies inversely as the square root of the capacitance.

2. LOADING SYSTEMS

2.1 The loading systems which are generally used for voice-frequency trunks and which are recommended in this section are H-88 and B-88 for trunks contained in nonquadded cable, and H-88-50 and B-88-50 for trunks in quadded cable. The H-44 system may be employed for nonquadded trunks where an individual situation indicates that over-all service and economy requirements favor its use over H-88. Similar principles apply to the use of H-44-25 with relation to H-88-50 where quadded pairs are involved.

2.2 There are other types of loading systems that are used at voice frequencies but most of them are designed for special purposes which do not apply to problems discussed in this section. Some of the more important of these special applications which should receive special study are:

2.21 Impedance-matching loading for use on incidental cables with open wire lines.

2.22 Terminal or intermediate cables occuring in open wire lines that have carrier systems working at frequencies above the voice range.

2.23 Loading systems for cable circuits which transmit radio broadcasting.

2.24 Four-wire telephone cable circuits operated in conjunction with telephone repeaters.

3. APPLICATION OF LOADING SYSTEMS

3.1 Nonquadded cable

3.11 The H-88 loading system is the type of loading generally recommended for use with trunks over nonquadded cable pairs. This recommendation applies to repeatered and nonrepeatered circuits.

3.12 The H-88 loading system should be resorted to only when the length of cable is such that:

3.121 The trunk attenuation would be excessive if the H-88 system were applied.

3.122 There is a need for loading additional pairs in a cable where the B-88 system is already employed.

3.2 Quadded cable

3.21 The H-88-50 loading system should be used for loading quadded cable. Cable with the H-88-50 loading gives a more satisfactory impedance match than any other system specified in this section when terminating in .109 grade 85 or grade 135 steel open wire and .104 or .080 copperweld 30 or 40 percent conductivity open wire using 12-inch pin spacing. This type of loading is recommended for general use and should be applied in all cases except those of specific requirement where the B-88-50 system is especially suitable.

3.22 The B-88-50 loading system should be used for trunk quadded cable where conditions similar to those in Paragraph 3.12 apply. This system may be used on nonrepeatered or repeatered circuits.

3.23 The B-88-50 loading system should be used for loading trunk quadded cable where:

3.231 Trunk attenuation would be excessive applying the H-88-50 system, or

3.232 The B-88-50 system is already employed. This system may be used for nonrepeatered or repeatered circuits.

3.3 The minimum length of cable considered practical to load for the system discussed is 12 kilofeet.

4. LOADING SECTION LENGTH (Spacing)

4.1 The standard section lengths controlling loading point location for the loading systems listed in Paragraph 2.1 are as follows:

Loading systems	Section length (feet)	End section length (feet)
H-44	6,000	3,000
H-44-25	6,000	3,000
H-88	6,000	3,000
H-88-50	6,000	3,000
B-88	3,000	1,500
B-88-50	3,000	1,500

4.2 The layout of trunk plant should be arranged in such a manner as to locate loading coils as near to the specified spacing as is economically and physically possible.

4.3 Nonrepeatered trunks. For nonrepeatered trunks, deviations may be made from the regular loading coil spacings without causing an appreciable reduction in the optimum transmission improvement obtained by loading. The deviations from the regular spacing should meet the criteria given in Paragraphs 4.31 and 4.32.

4.31 The deviation of average spacing from standard spacing (D_a) should not exceed ±180 feet for the H System and ±90 feet for the B System.

4.32 The deviation of any individual section from the average spacing (D_n) should not exceed ±300 feet for the H System and ±150 feet for the B system.

4.4 Repeatered trunks. For repeatered trunks, tolerances on individual loading section deviations are smaller than those permitted on non-repeatered circuits. The criteria for deviations for repeatered cable circuits are given in Paragraphs 4.41, 4.42 and 4.43.

4.41 The deviation of average spacing from standard spacing (D_a) should not exceed ±180 feet for the H System and ±90 feet for the B System.

4.42 The deviation of any individual loading section from the average spacing in the lead (D_n) should not exceed ±120 feet for the H System or ±60 feet for the B System.

4.43 Disregarding the signs of the differences between all loading sections and the average spacing (D_{aa}), the average deviation should not exceed ±30 feet for the H System or ±15 feet for the B System.

4.5 End Sections

4.51 The cable in the central office leading to the main distributing frame or intermediate distributing frame is considered as part of an end section.

4.52 The central office end section should lie between 1,800 and 6,000 feet for H systems and between 900 and 3,000 feet for B systems.

4.53 It is desirable to have the central office end section and the outer end section of the same length. Any alternative decision as to long- or short-end sections should generally be in favor of whort sections since this will provide maximum loading.

4.6 The above guide may be formulated as follows. Let:

L_a - Average Loading spacing in feet (excluding end sections)

L_n - Length of nth loading section in feet (excluding end sections)

N - Total number of loading sections (excluding end sections)

n - Number of loading section (excluding end sections)

D_a - Deviation of average spacing from standard spacing, in feet (sign taken as positive) (Paragraph 4.31 and 4.41)

La - Standard section length (Paragraph 4.1)

D_n - Deviation of nth loading section in feet from average spacing (sign taken as positive) (Paragraphs 4.32 and 4.42)

D_{aa} - Average deviation from the average spacing in feet (sign taken as positive) (Paragraph 4.43)

Then,

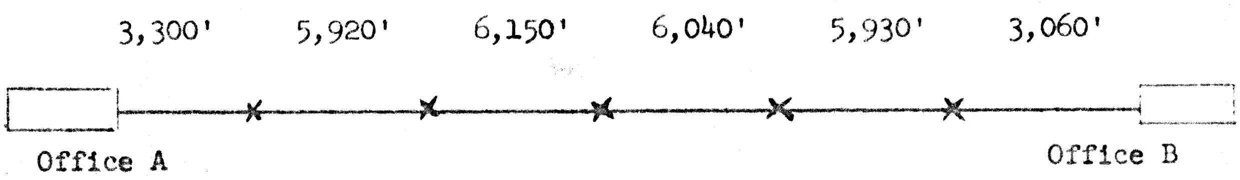
$$L_a = \frac{L_1 + L_2 + L_3 + \cdots + L_n}{N}$$

$$D_a = (L_s - L_a) \text{ or } (L_a - L_s)$$

$$D_n = (L_a - L_n) \text{ or } (L_n - L_a)$$

$$D_{aa} = \frac{D_1 + D_2 + D_3 + \cdots + D_N}{N}$$

4.7 Example 1. The following is a proposed H-88 loading coil layout for nonrepeatered trunks.



Is spacing within desirable limits?

4.71 Solution

$$L_a = \frac{L_1 + L_2 + L_3 + L_4}{N}$$

$$L_a = \frac{5,920 + 6,150 + 6,040 + 5,930}{4}$$

$$L_a = 6,010 \text{ feet}$$

$$D_a = L_a - L_s = 6,010 - 6,000 = 10 \text{ feet}$$

$$D_n = L_a - L_n \text{ or } L_n - L_a$$

$$D_1 = 6,010 - 5,920 = 90$$

$$D_2 = 6,150 - 6,010 = 140$$

$$D_3 = 6,040 - 6,010 = 30$$

$$D_4 = 6,010 - 5,930 = 80$$

4.72 D_a is less than 180 feet (Paragraph 4.31) and any D_n is less than 300 feet (Paragraph 4.32). By inspection it is seen that the end sections lie within the limits established in Paragraph 4.52. Spacing is therefore within desirable limits. ANS.

4.73 Note that if these trunks were to be repeatered, D_2 would exceed the 120-foot limit established in Paragraph 4.42.

5. LOADING LAYOUT

5.1 The spacing limits given in Paragraph 4.4 are important in obtaining smooth impedance characteristics in the loaded cable to match the repeater balancing network in installations where substantial repeater gains are required without introducing objectionable impairments because of "singing".

However, where excessive expense might be entailed in meeting the spacing deviation limits in an occasional loading section, it may be more desirable for the loading to be regular in the loading section adjacent to the repeater points than in those sections which are electrically remote from the repeaters. Where there is a choice in the location of an irregular loading section it should be as far away from the repeater as possible. Where a very irregular spacing must be employed, the spacing irregularity effects may be substantially reduced or eliminated by the building-out capacitor procedures. This procedure is effective in making an under-length section approximately a normal loading section. When an irregular section is over-length, the irregularity may be corrected by dividing it into two sections and building out one or both new sections to approximate a normal section.

5.2 There are two methods of building-out a cable pair to obtain a capacitance equal to the capacitance of a cable pair having the length of a normal loading section. The first method is that of using a section of cable having the required length in tandem with the main cable or a section of cable shunted across the main cable. The second method is that of using building-out capacitors. Of the two methods the use of building-out capacitors seems to be the more economical procedure to use on REA-financed systems.

5.3 The use of fractional inductance loading coils, that is, coils having smaller inductance than that specified for each section of a loading system, in connection with short end-sections and regular loading sections is to be avoided because of the detailed engineering required to determine the proper inductance of the coil; however, if an alternate means of adjusting the layout to correct the irregularity cannot be found, it may be necessary to use fractional inductance coils to meet transmission criteria.

5.31 Departures from equality in length of the order of 600-1,200 feet for the H system and 300-600 feet for the B system may occur without seriously increasing the excess loss (refer to Paragraph 6.51 for definition) above the values given in Paragraph 6.5. If one of two adjacent short sections should be only slightly below normal length, the aggregate excess loss would be approximately that contributed by the shorter section, acting as a single irregularity. When the aggregate length of two adjacent short sections is less than about 1.6 times a normal section, a reduction of excess attenuation can usually be secured by using a fractional inductance loading coil at the junction of the short sections in place of a full inductance coil. The excess attenuation that results from irregularities are due principally to changes in frequency response resulting from the irregular loading sections.

5.4 In view of the stringent requirements applying to the location of loading coils for repeatered circuits, it is recommended that in planning the loading of a cable containing trunk circuits, the location of the loading coils should be determined as the first step. The information may be used in designing underground conduit systems to select the optimum manhole locations or the information may be used in the staking of a pole line to place a pole at the proper point for mounting loading coil cases on the pole or to provide access to strand-mounted loading coil cases or to splice-enclosed loading coils. Two lengths of cable having conductors of different gauges, with the same capacitance between conductors and using the same loading system may be connected to each other without regard to the half section points of each length of cable. The loading system would be laid out without regard to where the cables are spliced together. This principle is illustrated in Figure 3.

5.5 In the case where the two lengths of cable to be connected are dissimilar either as to capacitance between conductors or as to the loading systems used on each cable, the two lengths of cable should be spliced together at the half-section loading point for each of the cables. The method of arranging a cable layout of this type is given in Figure 4.

6. METHODS OF CALCULATING TRANSMISSION OVER LOADED FACILITIES

6.1 Transmission over a loaded cable facility is determined by referring to Table I, Paragraph 7.1 of this section for the attenuation per kilofoot of the facility used and multiplying the attenuation by the number of kilofeet used. The method is shown in Example 2, Paragraph 8.

6.2 Where open wire facilities are involved in a calculation, the db loss given in Table I, Section 423, is per mile of circuit length. The method is shown in Example 3.

6.3 The transmission loss for a circuit consisting of two lengths of loaded cable having similar capacitance per unit length between conductors as discussed in Paragraph 5.4, and using the same loading systems is calculated by multiplying the db loss per kilofoot for each type of cable by the length of that cable. Example 4 demonstrates the application of this method of calculation.[1]

6.4 In the case where two reasonable long (electrically) lengths of cable of different capacitance per unit length are spliced together to form

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[1]A rigorous method would consider reflection losses, but these are so near zero for the loading systems considered that they can be disregarded.

a circuit and both pieces are loaded, as described in Paragraph 5.5, it is necessary to calculate the loss of each length of cable separately and total these losses with the reflection loss between the lengths of cable. The application of this method is demonstrated in Example 5. When the length of loaded cable is such that the end section exceeds a half-section, the length of cable affected by the loading is multiplied by the db loss per kilofoot for the loading system used and the remainder of the cable is multiplied by the db loss per kilofoot for the nonloaded cable. The loss for the loaded section and the loss for the nonloaded section are added together. The reflection loss (Table III, Section 422) between the two sections is then added to give the total loss if the nonloaded cable is of significant electrical length. The application of this method is demonstrated in Example 6.

6.5 Loading irregularities in nonrepeatered loaded circuits increase the over-all loss caused by the internal reflection effects at the irregularities. Precise appraisals of such increment losses are difficult because of secondary effects due to the position of the irregularity in the circuit. For practical purposes it will be satisfactory to use the curves in Figure 5 as a basis for estimating the values of the resulting loss. These data apply specifically to single irregularities in intermediate loading sections and it is recognized that to a close degree of approximation the transmission impairment caused by a given percentage difference in a loading section length from the normal length is equal to that caused by an excess length of similar magnitude. The approximations involved are such that the loss values read from the curves should be read to the nearest 0.1 db.

6.51 The loss data in Figure 5 are given as excess or increment losses which should be added to the loss of the circuit that would apply if the circuit had regular loading spacing throughout its entire length. The total loss in a loaded circuit having an intermediate loading section of subnormal or abnormal length is thus given by the expression.

$$n L + b = db$$

in which L is the loss per unit length in the regularly loaded line, n is the number of unit lengths, and b is the <u>excess loss</u> caused by the spacing irregularity. On this basis, <u>the numerical</u> values of the excess losses are substantially independent of the size of the loaded conductor involved. These data apply specifically to spacing irregularities, i.e., the loading coil inductances are assumed to be substantially uniform, as is usually the case, except when manufacturing or installation errors cause inductance irregularities.

6.52 Data in Figure 5 apply to a single-spacing irregularity. Where irregularities are separated by one or more loading sections of normal length, the total impairment is approximately the sum of the excess losses due to the individual irregularities. This approximation applies also when irregularities of opposite signs occur in adjacent loading sections, i.e., when one has an excess length and the other a deficiency in length relative to a normal loading section. The approximation is closest when these departures from normal spacing are of equal magnitude.

6.53 When each of two adjacent loading sections is longer than normal, a rough approximation for the aggregate excess attenuation may be obtained by assuming that it is equal to the excess attenuation which would be contributed by a single abnormal loading section having an excess length equal to the sum of the excess lengths of the two adjacent sections. The increment attenuation obtained by this procedure is greater than the true aggregate increment attenuation by an amount which depends principally upon the sum of the excess lengths in the approximate relations given in Table A.

6.54 When each of two adjacent sections is shorter than normal, the excess attenuation due to the double irregularity is considerably less than that which would result in a single short section having a deficiency in length equal to the sum of the deficiencies in the adjacent short sections. The aggregate excess attenuation is a minimum when the adjacent short sections have equal deficiencies from normal length. The equivalent sum of excess lengths is given in Table B as a function of the aggregate length of the adjacent short sections, and is expressed as an equivalent single section irregularity. In other words, the excess attenuation is equal to the attenuation obtained from Table A using the equivalent single section irregularity obtained from Table B as the "excess length."

Table A.--Attenuation Corrections

Sum of excess lengths (normal sections)	Correction to be subtracted (db)
0 to .3	0
.3 to .6	.1
.6 to .8	.2
.8 to 1.0	.3

Total length - two short loading sections	Equivalent single section irregularity
(normal sections)	(normal sections)
1.8	.05
1.5	.15
1.2	.30

7. TRANSMISSION LOSSES FOR LOADED FACILITIES

7.1 Although the attenuations for loaded facilities are given in Section 423, Table I of this manual, the same information is repeated here for convenience. These attenuation data are presented in the form of the attenuation per kilofoot of circuit.

Table II. --Nonquadded cable attenuation

(db per kf)

Gauge	26	24	22	19	
Capacitance Group	H	H	H	H	L
Nonloaded	.54	.44	.34	.24	.21
B-88	.26	.18	.11	.063	.056
H-88	.34	.23	.15	.081	.071
H-44	.42	.30	.20	.11	.098

Notes:

1. Line constants at 1000 cycles, 68°F, assumed as follows:

Gauge	Capacitance[1] "High or low"	R (ohms/mi.)	L (mh/mi.)	C (mfd/mi.)	G (micromho/mi.)
26	H	440	.832	.079	1.2
24	H	274	.783	.084	1.3
22	H	171	.798	.082	1.2
19	L	85	.989	.066	.96
19	H	85	.777	.084	1.3

2. Loading coil constants at 1000 cycles assumed as follows:

Loading system	L Millihenrys	R Ohms
B-88 or H-88	88	9.8
H-44	44	8.1

[1] The actual values of capacitance used in calculating the values of attenuation in Table II are as shown in Note 1. However, for most applications, all cables may be assumed to fall into one of two categories.

a) The "High" or H group, including all cable having a capacitance equal to or greater than .075 micorfarad per mile (for example, Western Electric Types BST, DSM, DSA and ENB, or

b) The "Low" or L group, including all cables having a capacitance less than .075 microfarad per mile (for example, Western Electric type DNB.

CABLE 19-GAUGE QUADDED[1]

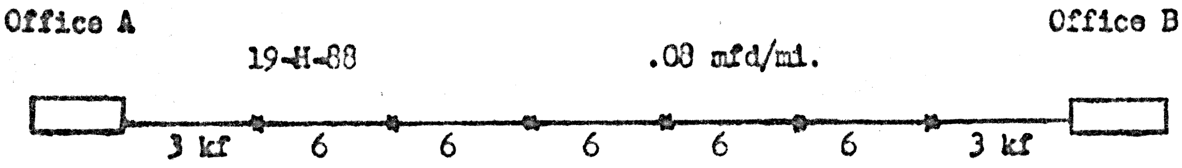
Loading	Side	Phantom
NL	.21	.18
H-44-25	.093	.076
H-88-50	.068	.057
B-88-50	.053	.045

[1]Line and load-coil constants at 1000 cycles, 68°F, assumed as follows:

Type of circuit	Side or phantom	R (ohms/mi.)	L (mh/mi.)	C (mfd/mi.)	G (micromho/mi.)	Load-coil constants R (ohms)	Load-coil constants L (henry)
NL	S	85.8	.001	.062	1.5	-	-
NL	Ph	42.9	.0007	.100	2.4	-	-
H-44	S	89.4	.039	.062	1.5	4.1	.043
H-25	Ph	44.7	.023	.100	2.4	2.1	.025
H-88	S	92.2	.078	.062	1.5	7.3	.088
H-50	Ph	46.2	.045	.100	2.4	3.7	.050
B-88	S	98.7	.156	.062	1.5	7.3	.088
B-50	Ph	49.4	.089	.100	2.4	3.7	.050

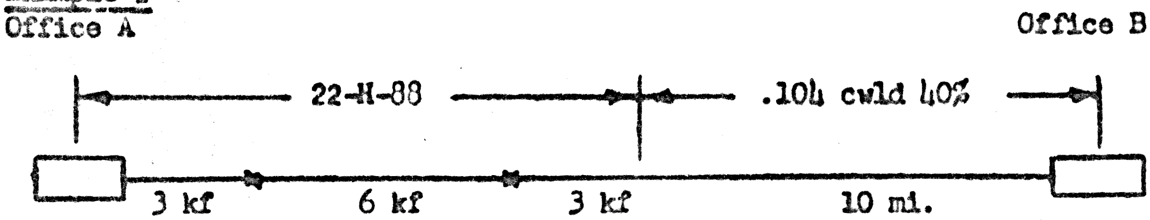
8. EXAMPLES OF LOADED TRUNK CABLE TRANSMISSION CALCULATIONS

Example 2



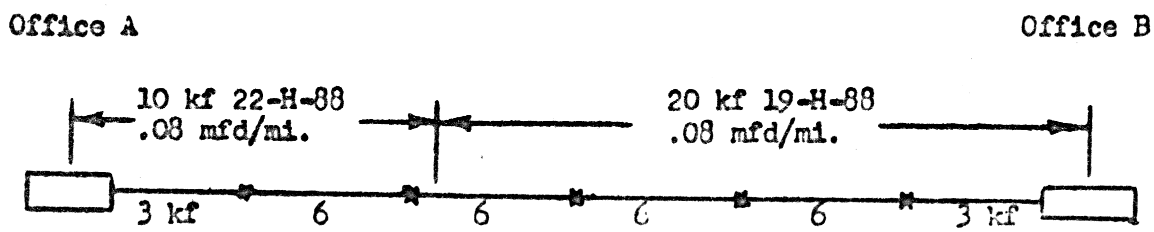
36 kf 19-H-88	@	.081 db/kf	= 2.9
2 C. O. entrances	@	.5	= 1.0
			3.9 db

Example 3



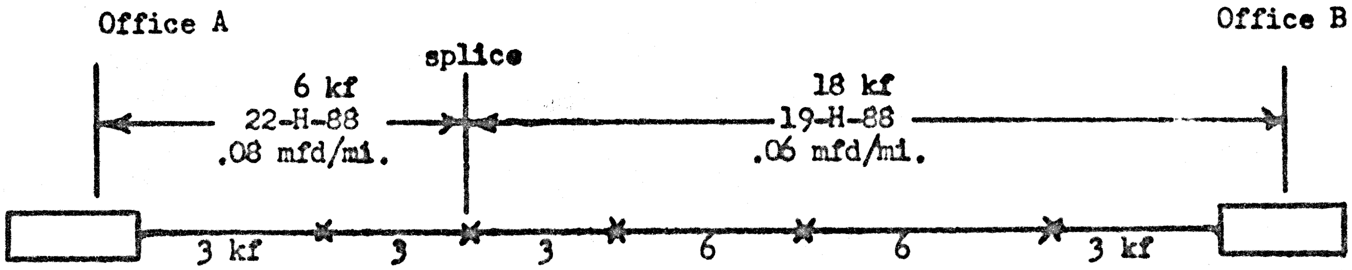
12 kf	@	.15 db/mi.	= 1.8
10 mi. .104 cwld (40%)	@	.152 db/mi.	= 1.5
C. O. entrances	@	.5	= 1.0
			4.3 db

Example 4



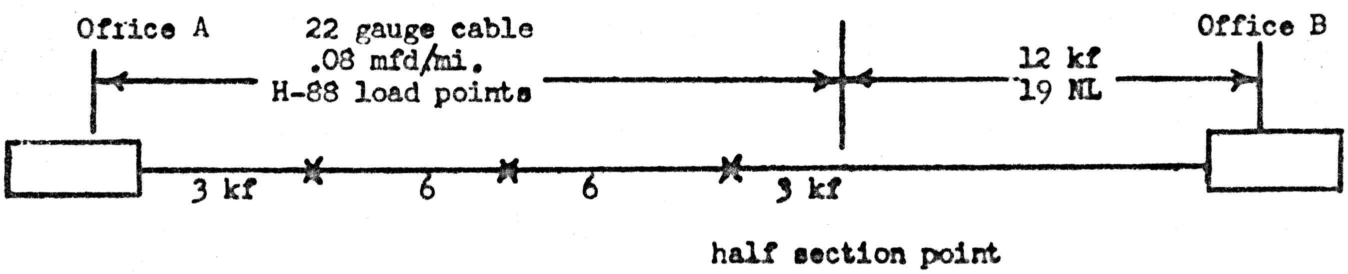
10 kf 22-H-88	@	.15 db/kf	= 1.5
20 kf 19-H-88	@	.081 db/kf	= 1.6
2 C. O. entrances	@	.5	= 1.0
			4.1 db

Example 5



6 kf	22-H-88	@	.15 db/kf	=	0.9
18 kf	19-H-88	@	.071 db/kf	=	1.3
2 C. O. entrances		@	.5	=	1.0
					3.2 db

Example 6



18 kf	19-H-88	@	.081 db/kf	=	1.5
12 kf	19 NL	@	.24	=	2.9
Reflection:	19-H-88 - 19 NL			=	0.5
				=	1.0
					5.9 db

H-88 Loading Points

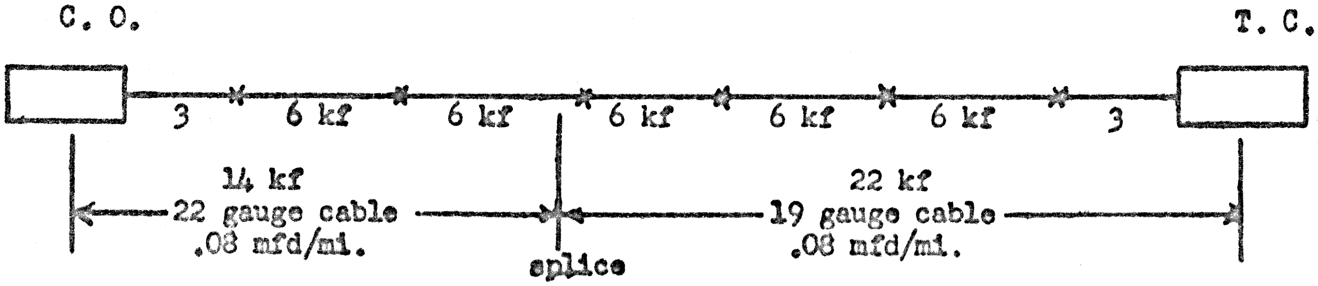


Figure 3.--Example of location of load points on circuits consisting of two cable gauges - cables of equal capacitance per unit length.

H-88 Loading Points

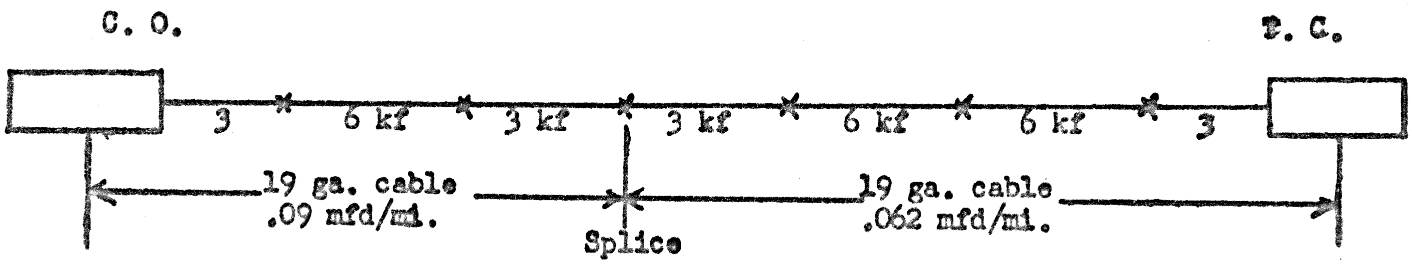
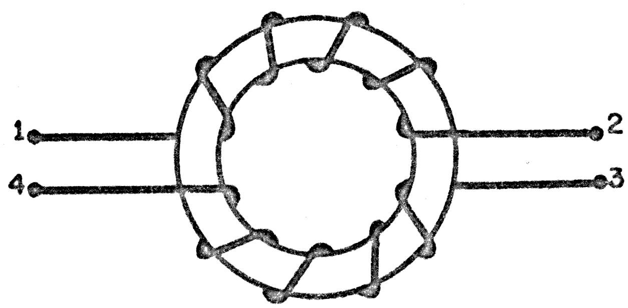
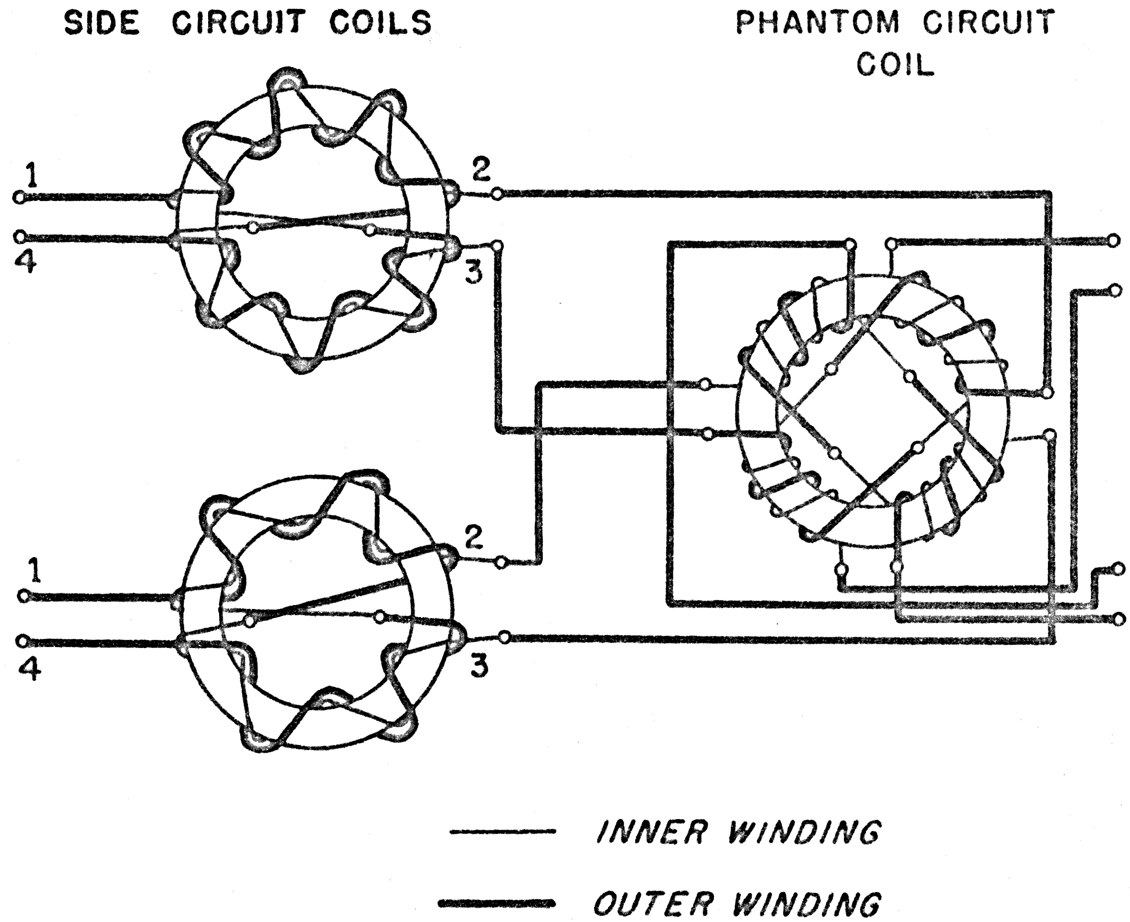


Figure 4.--Example of location of load points on circuits consisting of cable of same gauge but of different capacitance per unit length.



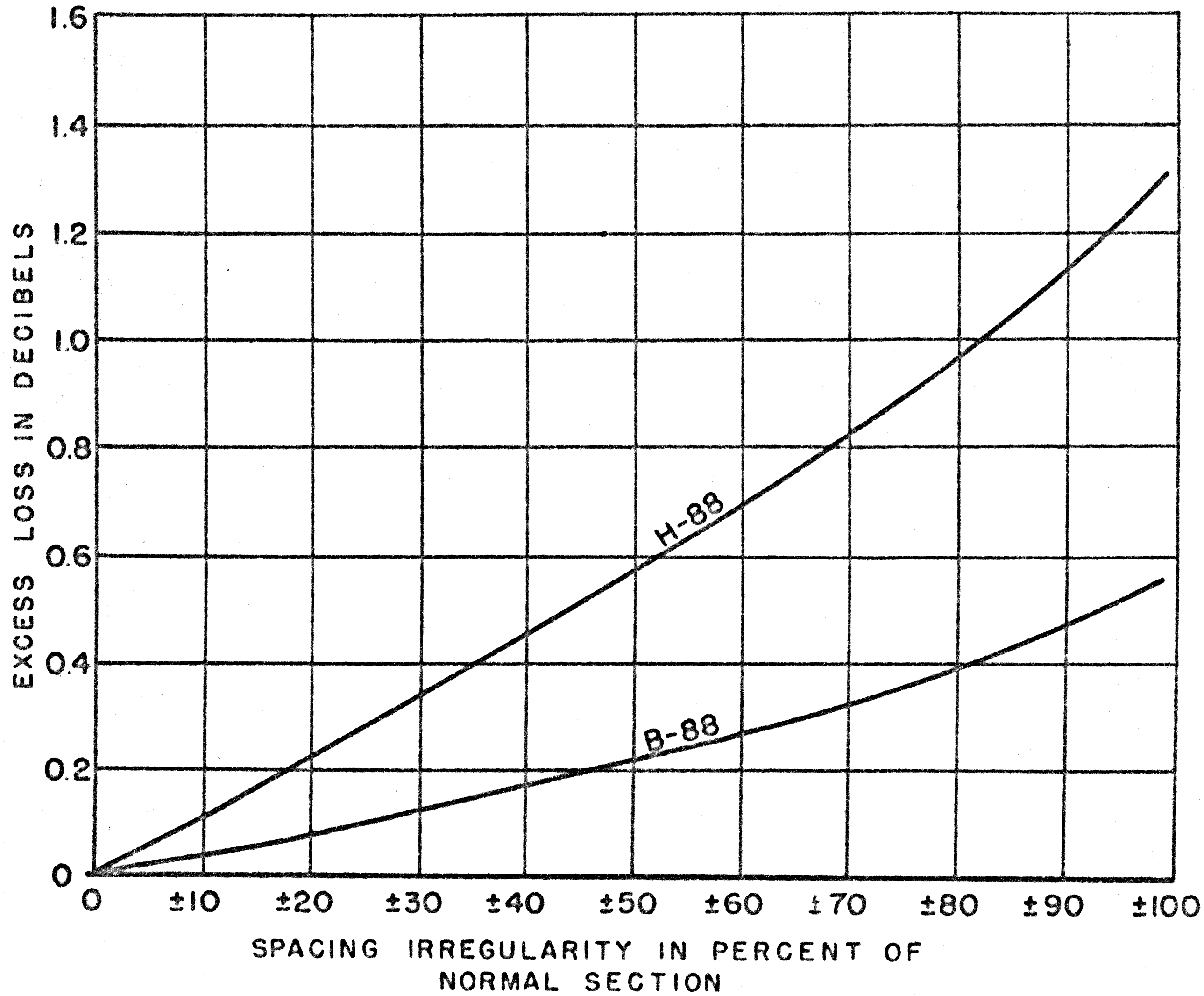
WIRING DIAGRAM FOR NON-PHANTOMED
CIRCUIT LOADING COIL

Figure 1



WIRING DIAGRAM FOR SIDE AND PHANTOM CIRCUIT LOADING COILS

Figure 2



TRANSMISSION IMPAIRMENT DUE TO ONE ABNORMALLY
LONG OR SHORT LOADING SECTION IN A LONG LOADED CABLE
(ALL GAUGES)

Figure 5