NEGATIVE IMPEDANCE REPEATERS

SERIES TYPE—NETWORK DESIGN AND SELECTION

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1. GENERAL

1.01 This practice amplifies the information given in Section 852-305-102 relating to the selection of networks for series-type negative impedance repeaters using the standard strapping charts included in Section 332-200-107.

1.02 In addition, the following supplementary information, which will be particularly useful for special service line design, is provided:

(a) Methods for determining the effective gain of the repeater from loss-frequency measurements

(b) Methods for shaping the loss-frequency characteristic of the repeater by adjustment of the network

(c) Methods for determining the network required to provide specific gains when the repeater is inserted between loaded and nonloaded line sections

(d) Information on network selection to provide specific gains when terminal return losses are better than 0 db

(e) Information on the addition of components in the network to account for equipment between the repeater and a nonloaded line section

(f) Procedures for selecting the network building-out capacitor when loaded facilities are involved

(g) Formulas from which may be computed the network constants required to produce specific gains when the repeater is used between unusual types of loaded facilities for which no networks have been provided in the standard charts.

1.03 As covered in Section 852-305-102, the general design method for circuits with series-type negative impedance is based on the fact that the most critical circuit condition from a stability standpoint is the idle condition and, therefore, in determining the maximum insertion gain that can be obtained, the terminal return losses are taken as 0 db. However, as also pointed out under the part of Section 852-305-102 dealing with special services, it is frequently possible with these kinds of lines to provide idle circuit terminations which may increase the terminal return losses in the idle condition to a point where they are no longer controlling.

1.04 When the circuits are designed on the basis of 0-db terminal return losses, and the repeater is to be inserted between two loaded line sections or between two nonloaded line sections, the network strappings required to produce the gain determined from the information in Section 852-305-102 can be obtained directly from the standard strapping charts of Section 332-200-107. This is also true when the terminal return losses are better than 0 db and loaded facilities are involved on each side of the repeater.

1.05 For the case of a repeater inserted between loaded and nonloaded facilities for any terminal return loss condition and when the repeater is inserted between nonloaded facilities and the terminal return losses are not 0, the networks required must be determined by the methods given in this practice.

1.06 For quick reference, the following table shows the source of the network strappings for the various combinations discussed above:

	Repeater Inserted Between:		
	Loaded Facilities	Nonloaded Facilities	Loaded and Nonloaded Facilities
Terminal RL = 0 db	Standard Charts	Standard Charts	This Practice
Terminal RL Greater than 0 db	Standard Charts	This Practice	This Practice

1.07 For convenience in following the network design and selection procedures given in this practice, the standard strapping charts of Section 332-200-107 are discussed briefly in Part 2.

2. DISCUSSION OF STANDARD NETWORK STRAPPING CHARTS

A. General

2.01 The standard strapping charts for loaded facilities given in Section 332-200-107 were determined by computing the values of the network elements required by means of the formula given in Part 7 of this practice and then working out the strappings that would provide them as accurately as possible. In some cases the theoretical values could not be obtained exactly in the network and this, along with the fact that certain compromises were made in the interest of reducing the number of charts required for similar facilities, explains any differences that may be noted between theoretical values and those provided by the strappings given in the charts. The networks for nonloaded facilities are not readily susceptible to computation and the strappings given in the charts are based largely on empirical data.

B. X Networks for Loaded Facilities

2.02 For loaded facilities (X-type network), Section 332-200-107 gives one chart for each group of facilities in general use having similar impedance and cutoff characteristics. For convenience in use and in order to minimize the number of network strapping charts required, the strappings on each chart are given as a function of nominal gain. This nominal gain is defined as the insertion gain which would be obtained between two uniform line sections of the same type of facility and end section. Methods for converting the desired insertion gain into nominal gain are discussed later in this section.

2.03 The strapping information is given for nominal gains of 1 to 8 db in 0.5-db steps. There are a few facilities for which networks are not shown for gains greater than 6 or 7 db. In these cases, the required network impedance is extreme and critical, and the network does not provide the elements which would be needed.

2.04 In the case of repeaters at the junctions of loaded and nonloaded facilities, as discussed later in this section, strappings are selected on the basis of return loss of the loaded line at the repeater and the resistance and gauge of the nonloaded line; therefore, corresponding values of return loss are also included along with the nominal gain steps.

C. Y Networks for Nonloaded Facilities

2.05 The networks for use with nonloaded facilities are given on chart 1Y of Section 332-200-107. The setup differs from the loaded case in that no gain figures are associated with the networks and their constants are determined only by the dc loop resistance and gauge of the facilities. When the repeater is inserted between nonloaded lines, the networks will provide effective gains equal to the "maximum obtainable gain" given by Fig. 1 of Section 852-305-102 when the return losses in the two directions (RLA and RLB) are taken as twice the effective line losses between the repeater and the circuit terminals, which is equivalent to 0-db terminal return losses. Methods for determining the network when the terminal return losses are not 0 and for the case where the repeater is inserted between loaded and nonloaded facilities are given later in this practice.

3. GAIN CONSIDERATIONS AND MEASUREMENTS

A. General Considerations

3.01 When the repeatered circuit is designed on the basis of 0-db terminal return losses, following the methods given in Section 852-305-102 and the proper networks are selected from the standard charts, the computed effective insertion gains will be closely approached. Also, as long as the circuits are free from important irregularities, they should be stable under all terminal conditions so that it is generally not necessary to make special gain tests or network adjustments. When other than standard networks are used or where the circuits are designed on the basis of higher than 0-db terminal return losses, gain and stability tests should be made to be sure that the expected gain is obtained and that the circuit is stable. The stability tests should be made with the terminations that were assumed in determining the terminal return losses used for the circuit design.

3.02 It will generally be found, with loaded circuits particularly, that the insertion gain-frequency characteristic will vary by several db or more in the voice-frequency range, due to circuit impedance variations. When special gain tests as described above are made on a single repeater, the maximum insertion gain at any frequency between 200 cycles and the cutoff frequency of the higher cutoff facility (3500 cycles for the nonloaded case) should not be allowed to exceed 26 db in order to assure stability. Where a group of circuits using the same facility layouts are involved, it is usually only necessary to test, and if necessary adjust, one and apply the same network strappings to the others. In this case, however, the 26-db maximum gain figure should be reduced to 20 db to allow for inherent variations between repeaters and networks.

3.03 Detailed methods for making insertion gain tests are given in sections in the 332 Division, and procedures for adjusting the overall gain or the gain in particular frequency ranges are given elsewhere in this section.

3.04 In some unusual circumstances where networks are adjusted to produce maximum gains with irregular facility layouts, singing may occur at some point beyond cutoff frequency. This condition will adversely affect the performance of the repeater with respect to over-loading and may not always be detected by monitoring tests at the repeater or at the circuit terminals because it may be outside of the audible range or not transmitted over the circuit. It can be detected, however, during gain measurements by disconnecting the test oscillator and checking to see if a deflection still exists on the instrument used as a detector. If such a condition is found, it will be necessary to reduce the gain at the higher frequencies within the voiceband.

3.05 Where multifrequency or single-frequency signaling pulses must pass over E repeatered trunks, the gain should be checked at and near the pulsing frequencies to insure that the limitation of the signal receiving equipment with respect to differences in level between the various tones is met. This gain check should be made with the signaling terminations on the trunk.

B. Effective Gain

3.06 Although the existence of alternate gain peaks and valleys in the gain-frequency characteristic makes it difficult to judge the effective gain of a repeater where it is operating with loaded facilities on one or both sides, it has been found reasonable to take the average of the value of the peak and valley above and below 1400 cps, measured between normal talking circuit terminations, as the effective gain. If, however, no well defined peaks and valleys exist between 900 and 1900 cps, the gain at 1400 cps may be taken as the effective gain.

3.07 In the case of repeaters between loaded and nonloaded line sections, the measured insertion gain frequency response with normal talking circuit terminations should have a rising characteristic to at least 2000 cps, in order to compensate partially for the frequency characteristic of the nonloaded line section. On this rising characteristic there will be superimposed small variations caused by variations in the impedance of the loaded facility particularly, as seen at the repeater. The effective gain may be approximated, however, in the same manner as covered in 3.06.

3.08 For the case of repeaters between nonloaded facilities, or at the end of a nonloaded facility, provided that the gain-frequency characteristic is free from pronounced peaks and valleys, as is to be expected, the effective gain may be taken as the average of values measured every 500 cps from 500 to 3500 cps. Normal talking circuit terminations are assumed.

4. NETWORKS FOR REPEATER BETWEEN LOADED FACILITIES

A. Type of Network

4.01 For loaded facilities the network is of the X type shown in Fig. 1. The complete specification for strapping consists of a basic strapping (column 3 of strapping charts) and a supplemental strapping (column 4 of strapping charts) for providing the appropriate value of C_2 to correspond to the end sections of the facilities at the repeater.

4.02 The procedure for specifying network strapping to give the desired insertion gains with the types of facilities used is described in the following paragraphs. If a chart is not available for the facility or combination of facilities in question, the network constants can be computed as described in Part 7 and the strapping selected to provide these constants.

B. Facilities of Similar Impedance on Opposite Sides of the Repeater

4.03 Where the repeater is to be inserted between two facilities of the same type or between facilities of types which fall into the same group as indicated on the master chart (Section 332-200-107), the gain provided will be the nominal gain shown opposite the strapping on the appropriate chart.

C. Facilities of Dissimilar Impedance on Opposite Sides of the Repeater

4.04 When the repeater is to be operated between two different types of loaded facilities and these facilities do not fall in the same group on the master chart, the insertion gain provided by the network strapping obtained from the charts will not be the nominal gain shown in the chart. The true insertion gain can be taken from Fig. 2, in which Z_1 equals the characteristic impedance of the facility for which the network is selected (usually the lower cutoff facility) and Z_2 equals the impedance of the other facility. If, for example, $Z_2/Z_1 = 1.3$ and the desired insertion gain is 6.4 db, the proper network will be tabulated opposite a nominal gain of 8 db.

D. Terminal Repeater on Loaded Facilities

4.05 In the case of terminal repeaters on loaded facilities, the nominal gain may be assumed as an approximation to be the insertion gain and Fig. 2 need not be consulted. This approximation is necessary because the terminal side of the repeater may connect to a variety of facilities, resulting in a different insertion gain.

E. Supplemental Strapping for Loading End Sections

4.06 If the end sections of the line facilities on the two sides of the repeater are equal in terms of tenths of full section, the end section for strapping purposes is the same as the cable end section on one side. Likewise, if only one end section is involved, as in the case of a terminal repeater, the end section for strapping purposes is the same as the cable end section.

4.07 If the end sections of the line facilities on the two sides of the repeater are different, but both their characteristic impedances and their cutoff frequencies are within 13 percent of the smaller value, Table 1 should be used to determine the required end section for network selection. Table 1 is also to be used when the loading systems are the same regardless of gauges.

4.08 When the repeater is inserted between facilities having either cutoff frequencies or characteristic impedances which differ by more than 13 percent, the longer end section (in terms of tenths of full section) adjacent to the repeater should be taken as the end section for the network. In this case, the gain of the repeater is likely to differ significantly from the nominal value, making it necessary to check the gain and perhaps to adjust the network. Table 2 provides a convenient means for determining whether or not a case falls into this category.

4.09 If one of the end sections is less than 0.3 of a full section in length, it is necessary to build it out as discussed in Section 852-305-102. For the purpose of building out, a 0.01-μF or 0.02-μF tubular, pigtail-type capacitor may be connected across the appropriate line terminals of the repeater, or equivalent building out applied at some other point in the central office.

F. Equipment Between Repeaters and Line Facilities

4.10 Where central office equipment including inductive elements such as retard or repeating coils is placed at the repeater location on the side facing a loaded facility, or in the loaded facility section some distance from the repeater, it is not possible to compensate for this inductance by adding an element in the network. In either case the effect of this equipment on obtainable gain should be reflected in the computation of the return loss of the loaded line by referring the 10- to 15-db return loss of the coil back to the repeater (Section 852-305-102). In some cases the added loss of the equipment in this path will approximately compensate for the decrease in overall return loss caused by the coil. Where equipment of this type is placed between a repeater and a nonloaded line, however, compensation in the network for this inductance is possible and this condition should be treated as covered in 6.12.

G. Network Adjustment

4.11 In the usual case the only adjustment to X-type networks that need be made in the field may be a change in the value of the network building-out capacitance, C_2. The supplemental strappings tabulated for various end sections provide values of capacitance C_2 which are convenient for adjustment purposes. Strappings are tabulated on the charts for 0.3 to 1.2 sections, which will generally provide small enough steps for any adjustments that need be made, so it is not usually necessary to determine new strappings from the network wiring diagram.

4.12 If the measured gain of the repeater falls off at the higher voice frequencies, this gain may be increased by decreasing the value of C_2 (i.e., reducing the capacitance of the supplementary strapping by 0.1-section steps).

4.13 If the measured gain of the repeater is too high at high frequencies, or if the repeater sings at high frequencies, the gain can be decreased by increasing the value of C_2 by 0.1-section steps.

4.14 If the repeater sings at frequencies of 0.6 of cutoff or below, with any circuit condition, the network should be changed to one having the next lower nominal gain.

5. NETWORKS FOR REPEATER BETWEEN LOADED AND NONLOADED FACILITIES

A. Type of Network

5.01 When the series-type repeater is connected between loaded and nonloaded facilities, the network consists of two parts connected in series, one for the loaded and one for the nonloaded facility. For the loaded facility the same X networks as covered above for the case of a repeater between loaded facilities are used. For the nonloaded side, Z networks are used, making a combination known as the XZ network. The Z networks are similar in configuration to the Y networks used when the repeater is inserted between nonloaded facilities (Part 6), but the constants are not determined in the same way and must be computed as covered in 5.02. Since two networks are involved, the gain of the repeater becomes a function of the sum of the two network impedances, and the gain figures associated with the X network charts in Section 332-200-107 therefore have no significance as far as total gain is concerned, and this must be determined as discussed in 5.11.

5.02 The Z-type network has either two or three elements, depending on the end section of the loaded line on the other side of the repeater and the circuits used, along with information for selecting their constants, are shown in Fig. 3A and 3B. To show the manner in which the X and Z networks are connected together to form the complete XZ network, the X network is also shown within a dashed box. Generally, the 3-element Z network will result in more gain than provided by the 2-element arrangement. For some instances, this added gain may be sufficient to more than off-set the loss occasioned by building out the short end section to permit the use of a 3-element network, and this possibility should be considered. The added gain provided may be detemined from Fig. 3 of Section 852-305-102.

5.03 Because of the many combinations of loaded and nonloaded facilities that may exist on either side of the repeater, it has not been practicable to set up standard charts for this case, and the required networks must therefore be worked out and specified by the engineer. This involves the selection of a standard X network based on the return loss looking into the loaded facility and its end section and the computation of a Z network based on the dc resistance and gauge of the nonloaded section in accordance with Fig. 3.

B. Selection of X Part of the XZ Network

5.04 The X part of the XZ network is determined by the return loss on the loaded side of the repeater and by the end section of the loaded facility facing the repeater. The same standard charts as for the loaded-loaded case are used, the only difference being that the appropriate network is selected on the basis of return loss instead of gain. For this use, the standard charts are tabulated in terms of return loss as well as gain and the network may be specified from the charts using the return loss column. When the return loss falls between values given on the chart, the next lower return loss should be used.

C. Selection of Z Part of XZ Network

5.05 The Z part of the XZ network is determined from the information given in Fig. 3. After the constants have been determined, the strappings required to produce the network, bearing in mind that the X network elements can not be used, must be worked out and specified.

5.06 As indicated in Fig. 3, two forms of Z network are used, depending on the end section of the loaded facility involved. When the end section is less then 0.9, a 2-element network is used; when the end section is 0.9 or greater, a 3-element network is used. To aid in the selection of available values of resistance and capacitance, 5.07 and 5.08 discuss the makeup of the resistor and capacitor strings provided in the network.

5.07 The components for the X part of the combination have been selected so as to make available for the Z network the resistor string ending in the 510-ohm resistor (terminal No. 22). Thus, for the case of the 2-element Z network, the resistance can be adjusted to the nearest 510 ohms when the resistors are taken in series; also, the combinations in Table 4 can be used to give finer steps. For the case of the 3-element Z network, however, two resistances are required, one of which is fixed at 510 ohms; the other resistance can then only be adjusted to the nearest 1000 ohms.

5.08 The capacitance used in the Z part of the XZ network can be made up of parts of the 2-capacitor banks which are not used to make up the X network. When the return loss of the loaded line is less than 7 db, and a 2-element is desired, it may be found that the values of capacitance required become so large that insufficient capacitance is available. Where this is the case, the 2-element Z network must be used, regardless of end section, with some sacrifice in gain.

5.09 If the nonloaded facility has one bridged tap of less than a mile in length, located more than one mile from the repeater, the tap can be disregarded in the network design. For other bridged tap combinations on the nonloaded facility, the network should be selected as if they did not exist. This will result in lower gain, but it may be possible to increase the gain by cut-and-try adjustment of the capacitance in the Z portion following the procedure given in 5.15.

D. The Complete XZ Network

5.10 Having selected the X and Y portions of the network as described above, it is necessary to connect them in series as indicated in Fig. 3. This is done by opening the strap normally shown between terminals 7 and 36 for the X networks and inserting the selected Z network in the circuit between these terminals.

E. Gain

5.11 When the XZ network has been selected as described above, the insertion gain obtained will be closely the same as the allowable gain indicated by Fig. 3 of Section 852-305-102, which gives the highest gain that can be obtained with adequate stability margins plotted against return loss of the loaded line section and the effective loss of the nonloaded line section. In this it is assumed that the terminal return loss on the nonloaded facility is 0, which is the usual design assumption, as covered in Section 852-305-102. However, in some cases, and particularly on special service lines, terminations which give better return losses may exist, and it is therefore possible to obtain higher gains.

5.12 When this is the case, and the improved return loss is on the loaded side, Fig. 3 may be used to obtain the gain since return loss on the loaded side is one of coordinates and the X part of the network is selected, as described above, on the basis of this return loss. When the return loss on the nonloaded side is better than 0 db, the gain can not be read directly from Fig. 3 of Section 852-305-102 but must be estimated as described therein, using the actual return losses on each side of the repeater.

5.13 To find the Z part of the XZ network that will produce this estimated gain, it is necessary to determine a "fictitious" resistance for the nonloaded line section. This is done by finding from Fig. 3A or 3B of Section 852-305-102, as appropriate, an effective line loss for nonloaded line section corresponding to the actual return loss of the loaded line section involved and the estimated gain. From this information a "fictitious" line resistance, based on the predominant gauge of the nonloaded cable, can be computed. This "fictitious" resistance is then used to compute Z network as described in Part 5C.

5.14 The network selected on this basis should give an effective gain closely approaching that estimated if the nonloaded facilities are reasonably uniform with respect to gauge. In any case, however, it is advisable to check the gain by measurement and to make adjustments as described in Part 5F to insure stability.

F. Network Adjustment

5.15 The adjustments given here are primarily intended for use when networks have been computed as described in 5.13 but may be applied in other cases if gain adjustment is necessary. The adjustments and associated gain checks should be carried out with the circuit in the condition under which the terminal return losses used for estimating the gain exist. (See Part 3A.)

5.16 If the insertion gain-frequency characteristic with the XZ network selected falls within the general objectives given in Part 3A, it may be possible to obtain higher gain. Conversely, if the objectives are not met, the gain must be reduced. The overall gain can be changed by using the next higher or lower gain X network selected from the standard charts which provides approximately 0.5-db steps. The gain in particular frequency ranges may be adjusted by the same changes as given for Y networks in Part 6E.

G. Equipment Between Repeater and Line Facilities

5.17 If equipment, such as long line circuits, is connected in the circuit at points remote from the repeater on either the loaded or nonloaded side, the return losses arising from its use must be included when the maximum permissible gain figure is determined. This is true also when the equipment is immediately adjacent to the repeater on the loaded side. When the equipment is on the nonloaded side and immediately adjacent to the repeater, its return loss can be neglected if an element to account for is included in the Z network. This may be done in the same manner as described in Part 6F, except that the inductive element must be connected across the Z portion of the XZ network (Terminals 7 and 36).

5.18 From the above, it is apparent that more gain can usually be obtained when the long line equipment is placed immediately adjacent to the repeater and on the nonloaded facility side. If the equipment involved is substantially open circuited at voice frequencies on one side in the idle condition, the open side should face the repeater to insure stability in the idle circuit condition.

6. NETWORKS FOR REPEATER BETWEEN NONLOADED FACILITIES

A. Type of Network

6.01 As in the case of a repeater between loaded and nonloaded facilities, covered in 5.01, the network used when the repeater is connected between nonloaded facilities consists of two parts connected in series, each of which takes care of the facility on one side of the repeater. These parts are known as Y networks, and the complete network is called a YY network. The Y networks may consist of two or three elements, depending upon the gauge of cable involved, as indicated in Fig. 5, which shows the circuit used. The 2000-ohm resistor shown in series with the two Y networks is included to compensate for losses in the repeater and is fixed for all cases.

B. Selection of Y Networks

6.02 Chart 1Y of Section 332-200-107 gives strapping information for Y networks, based on the gauges and the dc resistance ranges of the nonloaded cables involved. Since two Y networks are required to make the complete YY network, Chart 1Y contains two strapping columns (2 and 3) for each gauge and resistance range which give strappings that have been chosen to provide two independent networks. Thus, if the strapping for a Y network for a particular facility on one side of the repeater is selected from column 2, the strapping for the Y network for the facility on the other side must be taken from column 3. The 2000-ohm fixed resistor is always included in the strapping given in column 3.

6.03 In some cases it may be that the line resistance in one direction is lower than provided for in the standard charts. When this occurs, special strappings using a lower resistance for R2 (or R4) may be worked out. This is best done by adjustment of the network after the repeater has been placed in service and found to be stable with the lowest resistance strapping provided in the charts.

6.04 For causes involving mixed gauges, the predominant facility nearest to the repeater should be used as the basis for determining the network from the charts. The resistance, however, should be taken for the entire length of line. For cases where gauges are about equally divided, the coarsest gauge should be used for network determination. For example, for a mixture of 22- and 24-gauge cable where the gauges have about equal dc resistance, the table for 22 gauge should be used and a network chosen on the basis of the total dc resistance.

C. The Complete YY Network

6.05 When the strappings for two Y networks are selected from columns 2 and 3 of the standard charts, as described in Part 6B, the resulting network consists of two Y networks and a 2000-ohm resistor in series which forms the complete YY network.

D. Gain

6.06 When the YY network is selected as described above, the insertion gain will closely approach the maximum obtainable gain given in Fig. 1 of Section 852-305-102 if the return losses of the two line sections (RL_A and RL_B) are obtained by assuming the terminal return losses to be 0 db, which, as mentioned earlier, is the usual design procedure. When this is the case, the circuits should be stable under all terminal conditions, and the repeater can generally be placed in service without tests.

6.07 When the terminal return losses are not 0, as may be the case, particularly for some special service lines (1.03), the maximum stable gain may be estimated by the method given for special service lines in Section 852-305-102. To obtain this higher gain, it is necessary to select the YY network as described in 6.02, but using "fictitious" resistances for the cable pairs. These "fictitious" resistances may be determined as described in 6.08.

6.08 Determine the maximum stable gain by the method given in Section 852-305-102, which involves the determination of the combined return losses on the two sides of the repeater, using actual expected terminal return losses; and, with this gain figure, find, from Fig. 1 of Section 852-305-102, a combination of two return losses (RL_A and RL_B) that correspond to this gain. The return losses chosen should be in the same general region as the actual return losses. Divide these return losses by two to obtain fictitious circuit losses on each side of the repeater, and from this information, using the predominant type of facility, compute the dc resistances for equivalent circuits on the two sides of the repeater. Using these "fictitious" resistances, select a YY network from the standard charts as covered in 6.02.

6.09 The YY network selected by this procedure should give an effective gain closely approaching the gain estimated from Section 852-305-102, if the line sections are reasonably uniform and are free from repeating coils. Where this is not the case, it is usually necessary to make adjustments and additions to the networks after the repeater has been placed in service as described in Part 6E and F, if the maximum gain is to be obtained. In any case, gain measurements should be made to see that the general objectives for maximum gain given in 3.01 are met.

E. Network Adjustment

6.10 The following adjustments may be made to change the gain in particular frequency ranges:

(a) To reduce the gain at frequencies above 1500 cycles, increase the value of the capacitance (C_1 or C_2) in the YY network. This may be done in either Y section or in both. Conversely, to increase the gain, decrease the capacitances.

(b) To reduce the gain at frequencies below 1500 cycles, decrease the value of the resistances shunted by the capacitances in the YY network (R_2 and R_4). Conversely, to increase the gain, increase the value of these resistances.

6.11 In the above, it is assumed that the measurements and adjustments are made with the circuit in the condition for which the terminal return losses used for estimating the maximum gain exist. (See Part 3A.)

F. Equipment Between Repeater and Nonloaded Line Section

6.12 When equipment, such as long line circuits as used on some special service lines, is placed between a series-type repeater and a nonloaded line section, the network selected as described in Part 6B must be modified to include an element to account for the voice-frequency impedance of the coil. In the usual case, this modification amounts to the addition of an inductance in parallel with the Y section representing the facility on the side of the repeater to which the equipment is connected. The connection points are therefore between network terminal 36 and either 22 or 35. When a 94N coil is involved, an inductance of 1.25H (terminals 8 and 16) has been found satisfactory. For higher inductance coils (such as the 94E, 120CS, or 120C), 3H may be used (terminals 4 and 8 will strap between 5-20 and 28-16). An example of the use of this modification is included in the illustrative example given in Part 6H.

G. Network Strapping for Terminal Repeater on Nonloaded Facilities

6.13 In the case of a terminal repeater, only one Y section is required and this is selected in the same way as described for the intermediate repeater. It is necessary, of course, to place a strap between terminals 35 and 36 which would otherwise connect to a Y section for the facility on the other side of the repeater.

H. Illustrative Example for Series Repeater Between Nonloaded Facilities

6.14 Figure 6 shows a series-type repeater connected between two nonloaded line sections. On one side the facilities are of mixed gauges while the other side is entirely 19 gauge. The dc resistances and effective losses are indicated for the facilities on each side of the repeater. The nonrepeatered loss of the facilities is 13.67 db.

6.15 Assume first that the circuit is to be used for an interoffice trunk. In this case, to find the maximum obtainable gain, the terminal return losses are taken as 0 and Fig. 1 of Section 852-305-102 is entered with twice the effective line losses on each side of the repeater as RL_A and RL_B. These are 18.36 and 13.74, respectively. Using these figures, Fig. 1 gives the maximum obtainable gain as slightly over 9.0 db. Since the predominant facility nearest the repeater on the mixed gauge side is 24 gauge, the 1Y Chart of Section 332-200-107 for 24 gauge is used to find the Y network for this side. The total dc resistance is 943 ohms which falls in the range of 841 to 1200 ohms given on the chart. For the 19-gauge side, where the resistance is 386 ohms, the Y network is taken from column 3 of Chart 1Y for 19 gauge for the resistance range of 351 to 480 ohms. The circuit of the resulting YY network is shown in Fig. 6 as Net. 1. Figure 7 shows the insertion gain-frequency characteristic of the repeater using this network, measured with a subset termination at one end and a 900-ohm termination at the other. The equivalent effective gain, using the method covered 3.05, is 8.5 db which is close to that expected.

6.16 To illustrate the effect of network adjustment, the adjustment procedure given in 6.10 was carried out in the idle circuit condition. The resulting network and the gain-frequency characteristic after adjustment are also shown in Fig. 7. It will be noted that the effective gain was increased to 10 db, an increase of 1.5 db.

6.17 Figure 8 shows the same circuit layout with the exception that a 94E repeating coil is inserted between the repeater and the nonloaded line. The selection of the YY network is carried out exactly as before; but, as covered in 6.12, an inductance of 3H must be added to the network on the 19-gauge side to account for the repeating coil. The resulting network, after adjustment for maximum gain, as covered in 6.10, is also shown in Fig. 8. Figure 9 shows the measured insertion gain-frequency characteristic from which the effective gain is found to be close to 8.5 db, which checks with that obtained with the original circuit without a coil, illustrating that the coil can be compensated for by network modification and adjustment.

7. DETERMINATION OF NETWORK COMPONENTS BY COMPUTATION

7.01 In some cases where unusual combinations of loaded facilities are involved, it may be necessary to compute the values of the network components by the methods given in the following paragraphs. These apply to the case of loaded facilities on each side of the repeater and to the case of loaded facilities on one side and nonloaded facilities on the other.

A. Loaded Facilities on Each Side of Repeater

7.02 The following formulas give the values of the network elements R, L_1, L_2, C_1, and C_2 in terms of the characteristic midsection impedance of the facility at 1000 cycles, the cutoff frequency of the facility, and the nominal insertion gain required:

$$R = 19 \frac{G-1}{G} Z_o \quad (1)$$

$$L_2 = \frac{1.16 R}{6.28 (f_c - 750)} \quad (2)$$

$$C_2 = \frac{1}{7.3 R (f_c - 750)} \quad (3)$$

$$C_1 = 0.55 C_2 \quad (4)$$

$$L_1 = \frac{1}{C_1 \left[11.65 (f_c - 750)^2\right]} \quad (5)$$

(The effect of end section is covered in 7.06)

Where:

G = voltage ratio corresponding to required gain in db.

Z_0 = characteristic midsection impedance of facility at 1000 cycles.

f_c = cutoff frequency of facility.

R is in ohms, L_1 and L_2 in henries, and C_1 and C_2 in farads.

7.03 For convenience, the following table gives G and G−1/G for values of gain from one to 10 db.

Gain (db)	G	$\frac{G-1}{G}$
1.0	1.122	0.1087
1.5	1.189	0.1590
2.0	1.259	0.2057
2.5	1.334	0.2504
3.0	1.413	0.2923
3.5	1.496	0.3316
4.0	1.585	0.3691
4.5	1.679	0.4044
5.0	1.778	0.4376
5.5	1.884	0.4692
6.0	1.995	0.4987
6.5	2.113	0.5267
7.0	2.239	0.5534
7.5	2.371	0.5782
8.0	2.512	0.6019
8.5	2.661	0.6242
9.0	2.818	0.6451
9.5	2.985	0.6650
10.0	3.162	0.6837

7.04 In general, it will not be possible to select network strappings that will exactly match the computed values. The values selected, however, should conform as closely as practicable to the following check ratios:

(a) $\frac{1}{6.28 \sqrt{L_2 C_2}}$ should lie between $f_c - 900$ and $f_c - 600$

(b) $\frac{1}{R} \sqrt{\frac{L_2}{C_2}}$ should lie between 1.12 and 1.20

(c) $\frac{C_1}{C_2}$ should lie between .48 and .62

(d) $\sqrt{\frac{L_2 C_2}{L_1 C_1}}$ should lie between 1.75 and 2.1

7.05 If the selected values do not meet these objectives, the elements should be changed until compromise values are found that are satisfactory.

7.06 The formulas in 7.02 are for 0.5 end sections. Where the actual end sections are not half sections, Table 1 should be consulted to determine the equivalent end section and the value of C_2 multiplied by the ratio of the equivalent end section to 0.5.

7.07 When the loaded facilities on each side of the repeater are not the same, the computations should be made using the constants of the facility having the lower cutoff frequency. If the characteristic impedances are not the same, the network thus determined will not provide the assigned nominal gain corresponding to the ratio G in formula (1). The insertion gain can be determined, however, from Fig. 2.

B. Loaded Facilities on One Side of Repeater, Nonloaded on the Other

7.08 For this combination an XZ network is required. The constants of the Z part of the network can be determined readily by the procedures given in 5.05. To find the constants of the X position the formulas of 7.01 may be used but, since the insertion gain is now a function of both parts of the network, it is necessary first to find an appropriate gain figure on which to base the value of G.

7.09 Assuming that the network to be designed is to provide the maximum gain that the return losses on each side of the repeater will support, find from any X-type network chart a gain figure corresponding to the return loss on the loaded side of the repeater. For instance, if the return loss on the loaded side is 15 db, the nearest corresponding gain figure from any of the standard charts is 3.5 db. Use the gain figure found in this manner to determine G, and compute the network constants for the X portion of the network from the formulas. As before, the value of C_2 should be corrected if the end section of the loaded facility differs from 0.5. (See 7.06.)

7.10 When the ZX network is designed as described above, the insertion gain should be close to that indicated by Fig. 3 of Section 852-305-102.

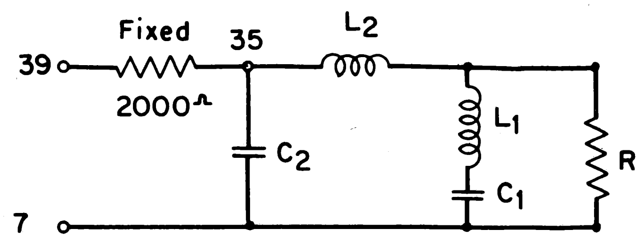


Fig. 1—X-Type Network for Loaded Facilities

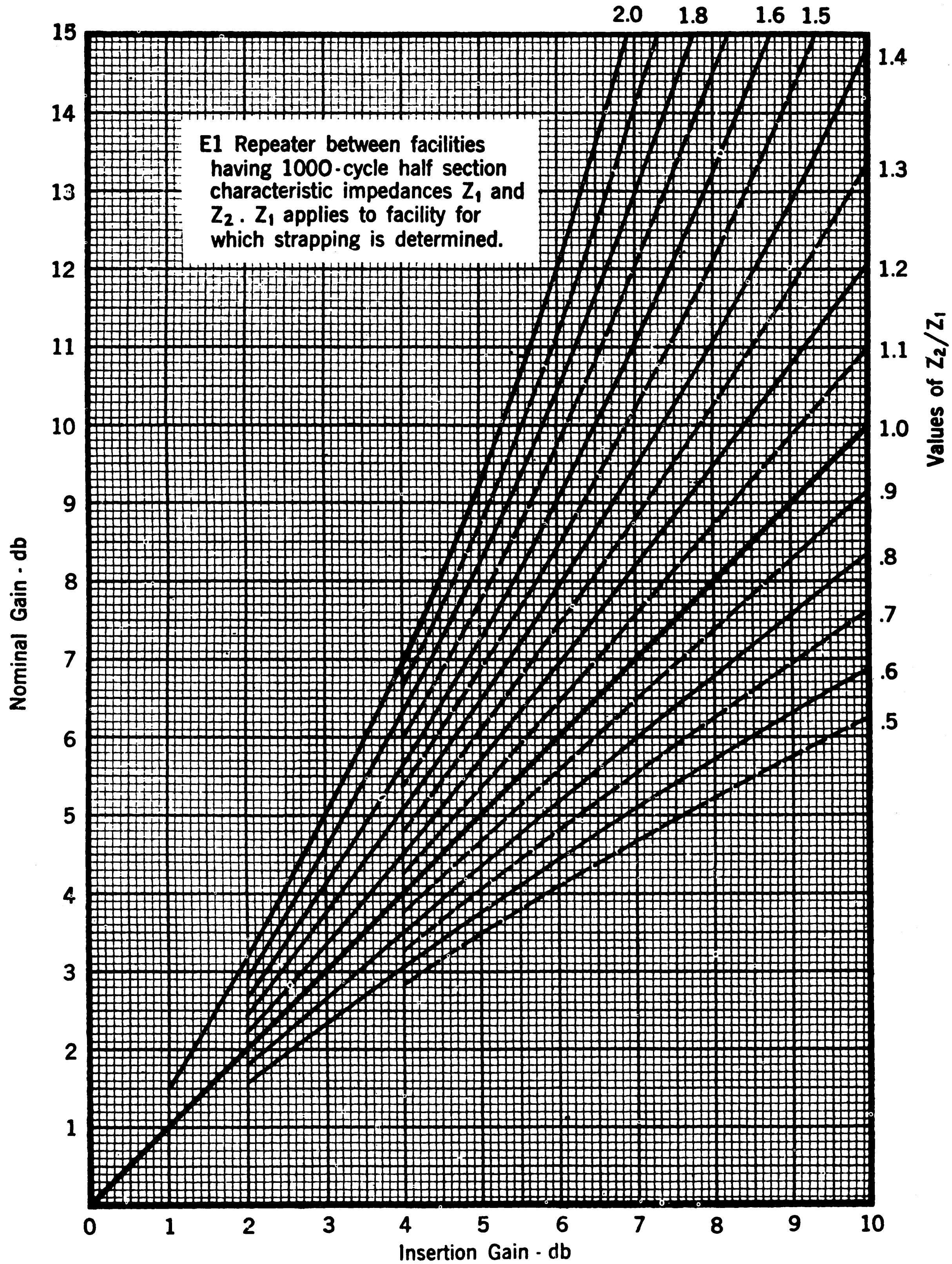
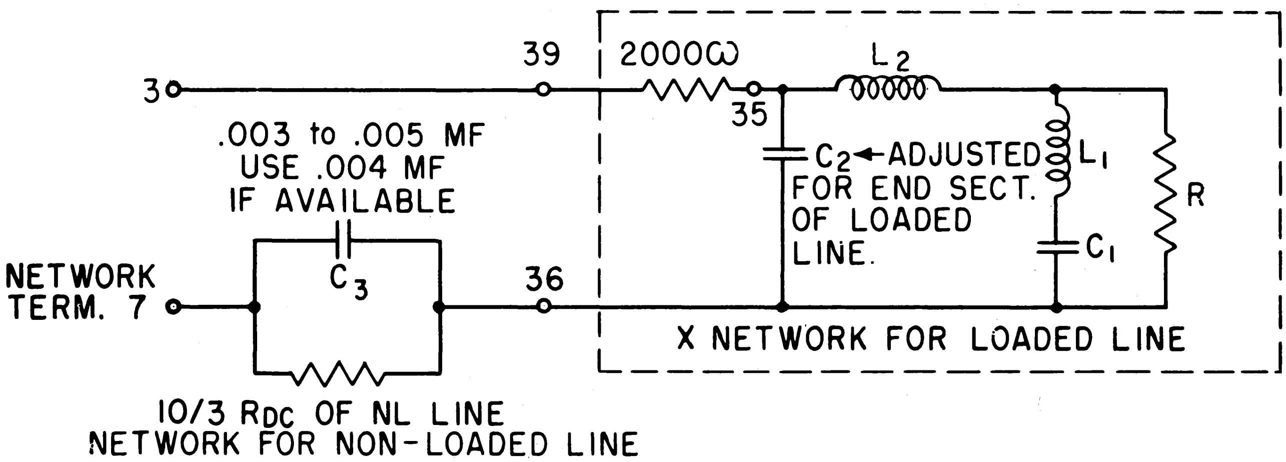
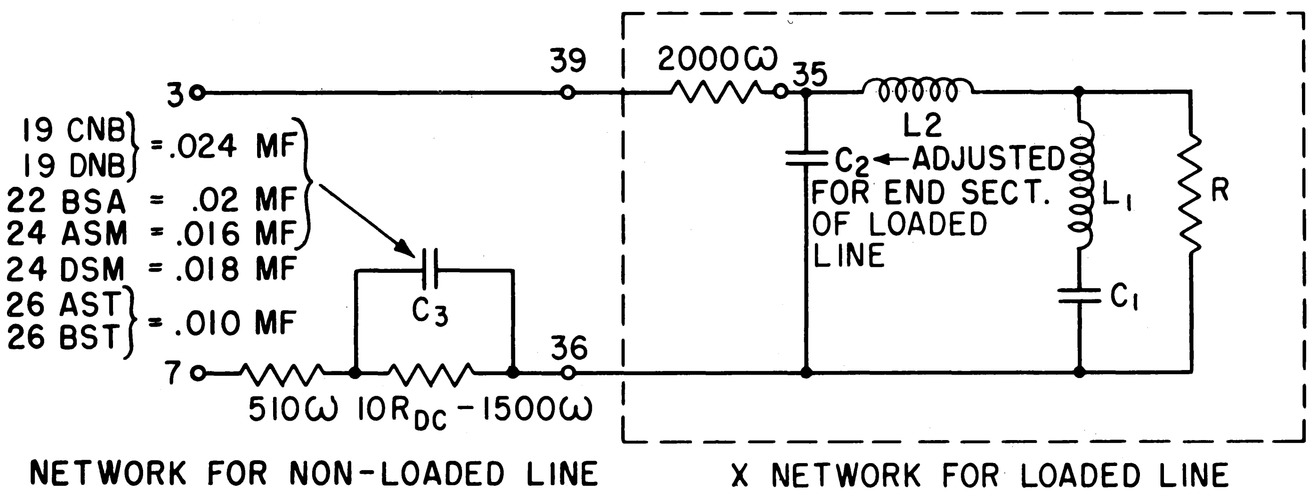


Fig. 2—Relation of Nominal Gain to Insertion Gain



A - WHERE END SECTION OF LOADED LINE IS LESS THAN .9



B - WHERE END SECTION OF LOADED LINE IS .9 OR GREATER

Fig. 3—XZ-Type Networks for Use With Repeaters Between Loaded and Nonloaded Lines

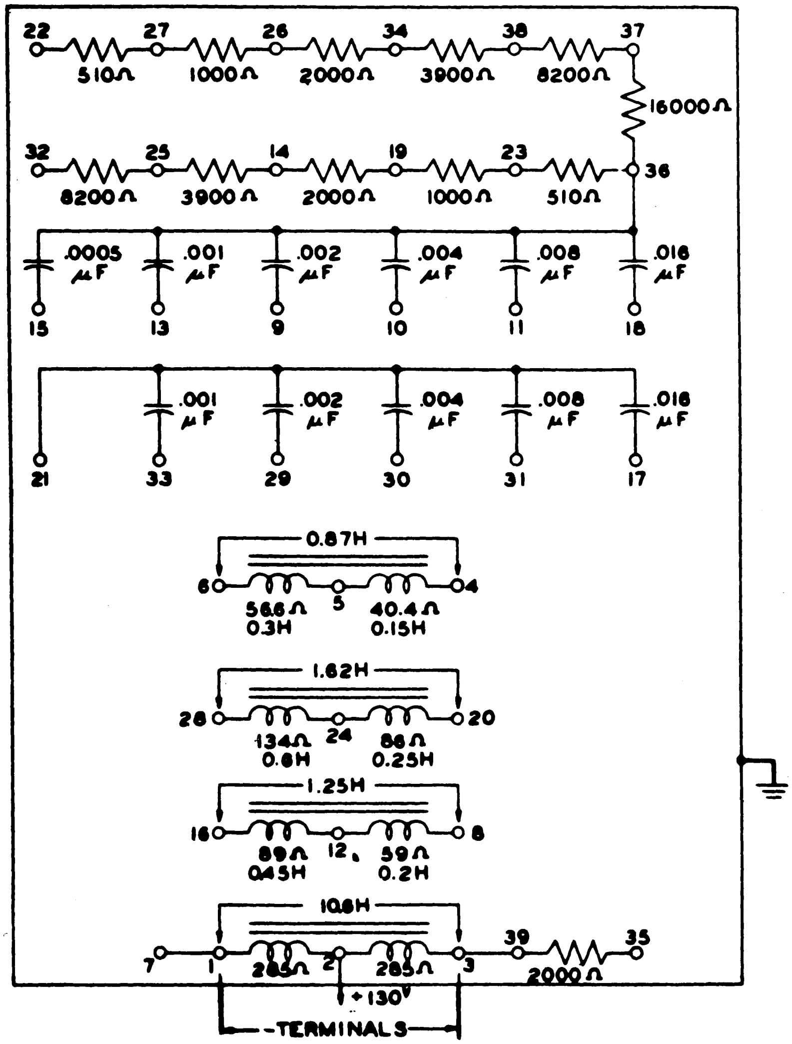
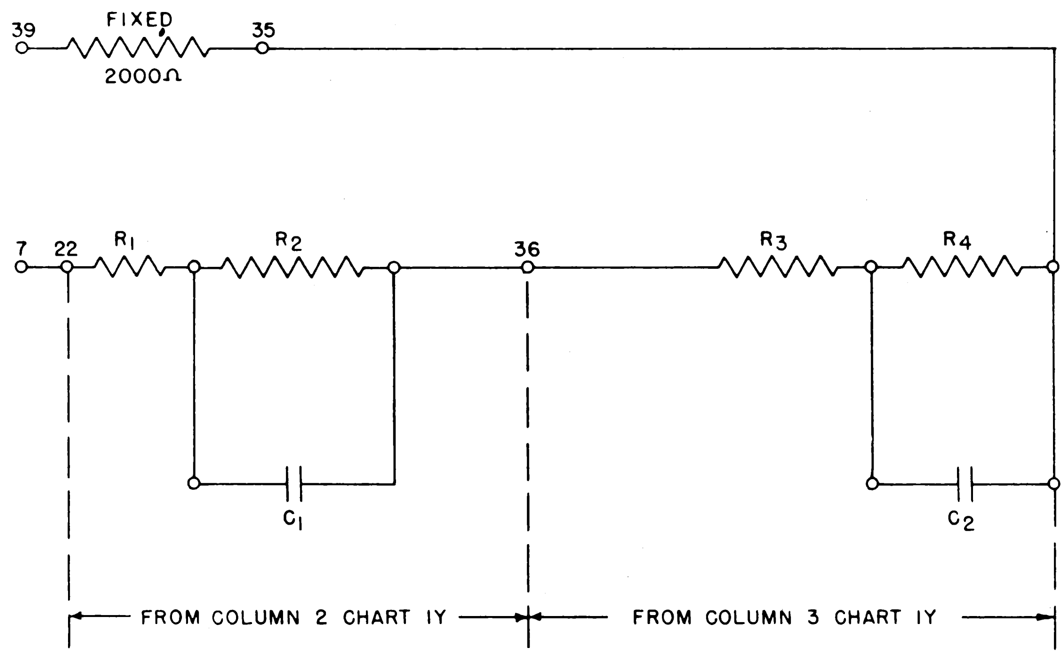
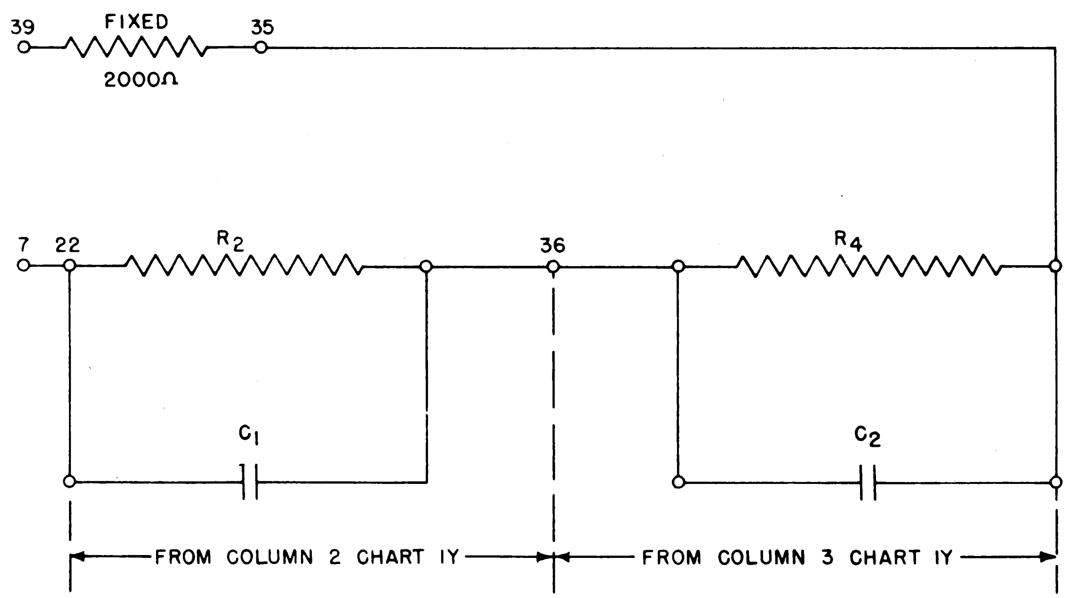


Fig. 4—Gain Adjusting Network



NETWORK FOR 22, 24 AND 26 GAUGES



NETWORK FOR 19 GAUGE

Fig. 5—YY-Type Network for Nonloaded Lines on Both Sides of Repeater

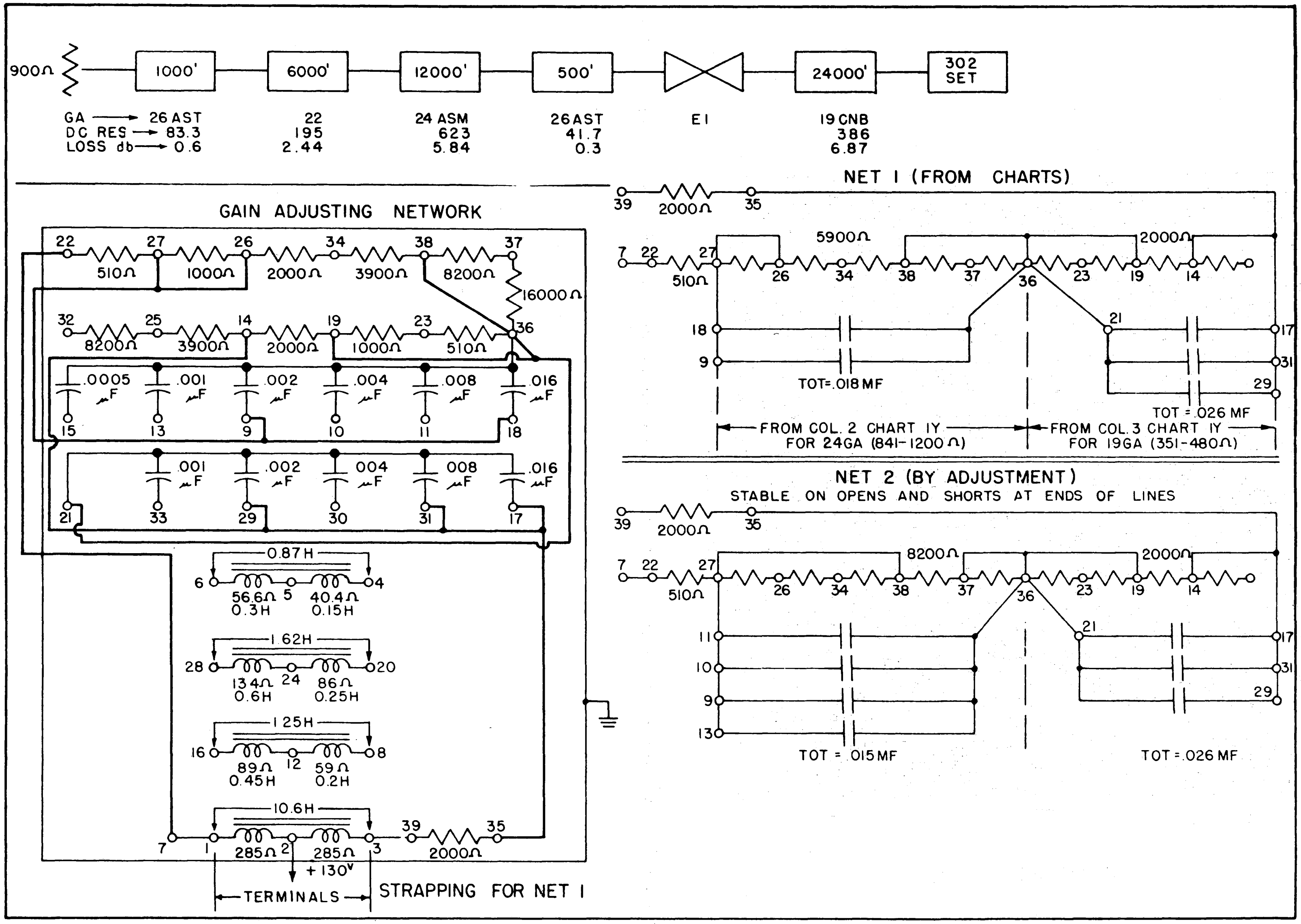


Fig. 6—Network Strapping on Gain Adjusting Network for Example of Nonloaded Lines on Both Sides of Repeater

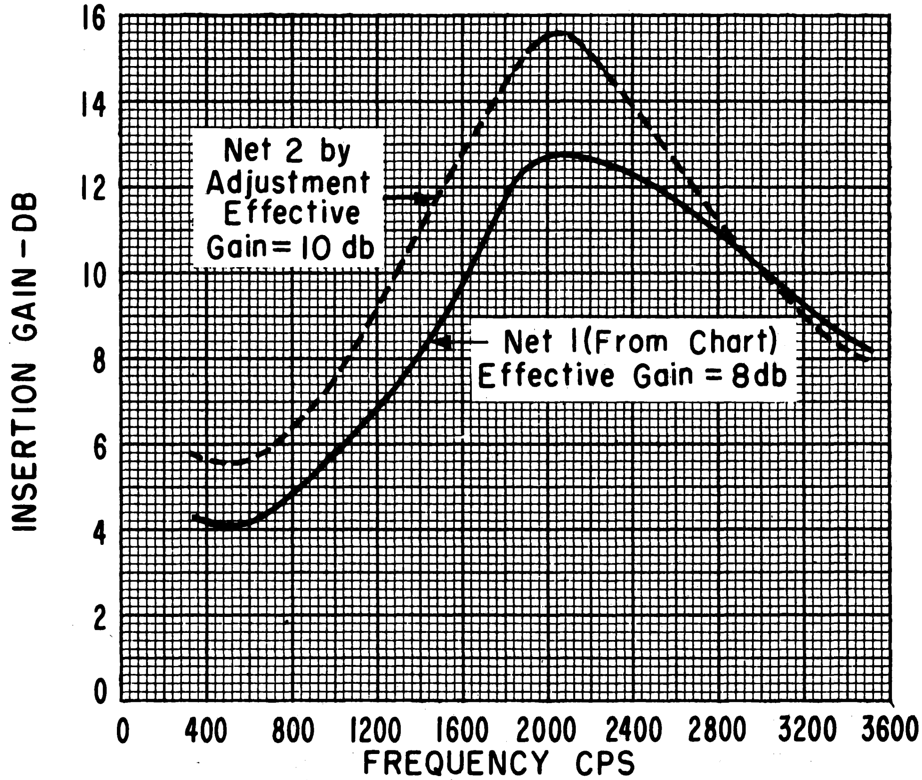


Fig. 7—Insertion Gain Characteristics—Network Adjustment for Maximum Gain (See Example in 6.14)

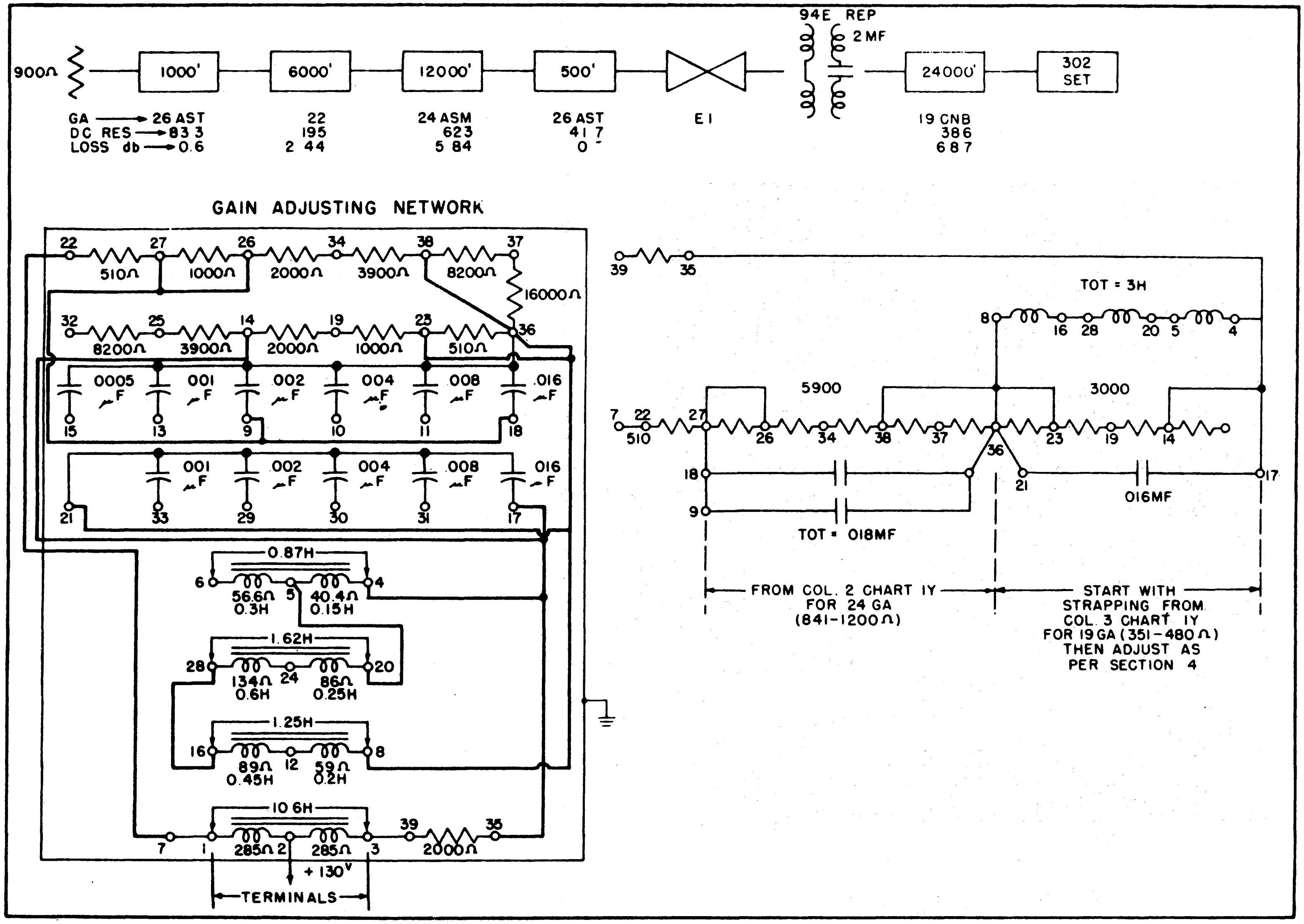


Fig. 8—Network Strapping on Gain Adjusting Network for Example for Nonloaded Lines on Both Sides of Repeater With a 94E Repeating Coil at Repeater Coil at Repeater on One Side

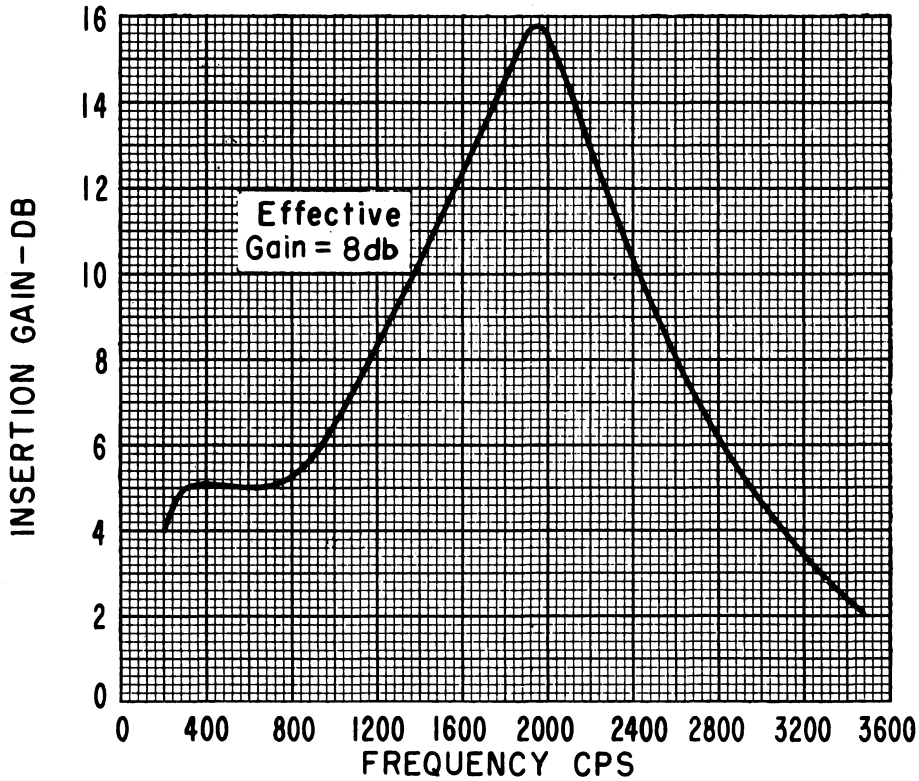


Fig. 9—Insertion Gain Characteristics—Repeater Between Nonloaded Lines—94E Coil at Repeater (See Example in 6.16)

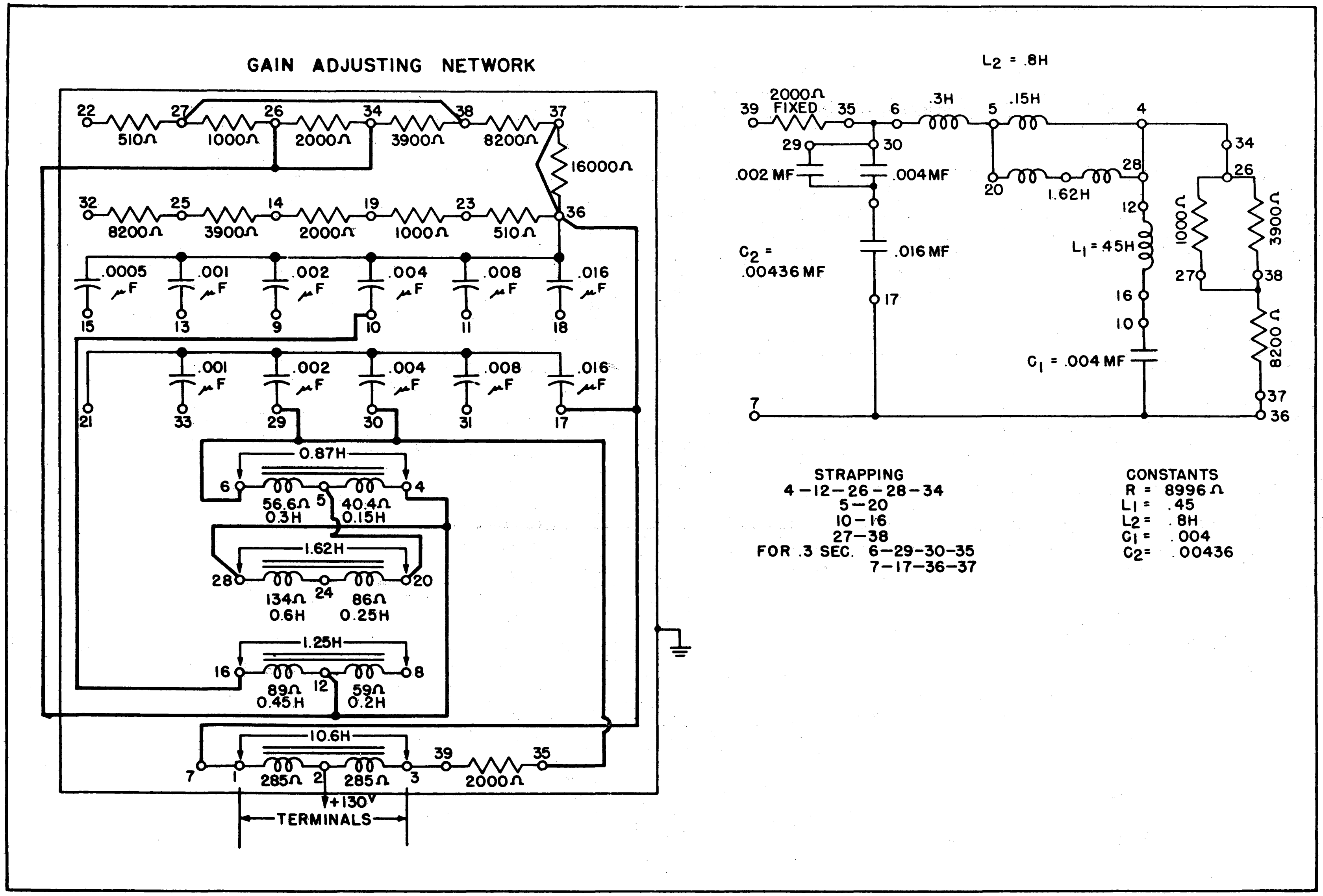


Fig. 10—Sample Strapping Layout

TABLE 1

NETWORK END SECTION FOR LOADED LINES

End Section of Line A	End Section of Line B 1.2	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3
0.3	-	-	-	-	-	-	-	0.4	0.4	0.3
0.4	0.9	0.8	0.8	0.7	0.7	0.6	0.5	0.5	0.4	0.4
0.5	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.4
0.6	0.9	0.9	0.8	0.7	0.7	0.7	0.6	0.6	0.5	-
0.7	0.9	0.9	0.8	0.8	0.8	0.7	0.6	0.6	0.5	-
0.8	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	-
0.9	1.1	1.0	1.0	0.9	0.9	0.8	0.7	0.7	0.7	-
1.0	1.1	1.1	1.0	1.0	0.9	0.8	0.8	0.8	0.8	-
1.1	1.2	1.1	1.1	1.0	0.9	0.9	0.9	0.8	0.8	-
1.2	1.2	1.2	1.1	1.1	1.0	0.9	0.9	0.9	0.9	-

Equivalent end section for the network of the E-type series repeater when it is between two loaded lines (A and B) fulfilling one of the following conditions:

(a) Both lines having the same type of loading regardless of gauge.

(b) The characteristic impedance and cutoff frequency of one line within 13% of the characteristic impedance and cutoff of the other. (The 13% being applied to the lesser value.)

TABLE 2

SIMILARITY OF EXCHANGE FACILITIES

"X" indicates that both midsection characteristic impedance and nominal cutoff frequency are within 13% of the lesser value.

FACILITY		B88					D88					H88					M88					H135					B135			H175	B175
		19 CNB	19 DNB	22	24 CSM	24 DSM	19 CNB	19 DNB	22	24 CSM	24 DSM	19 CNB	19 DNB	22	24 CSM	24 DSM	19 CNB	19 DNB	22	24 CSM	24 DSM	19 CNB	19 DNB	22	24 CSM	24 DSM	19 CNB	19 DNB	22	19 DNB	19 DNB
B88	19 CNB	X	X	X	X	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	19 DNB	X	X	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	22	X	X	X	X	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	24 CSM	X	X	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	24 DSM	X	X	X	X	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D88	19 CNB	-	-	-	-	-	X	X	X	X	X	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	19 DNB	X	-	X	-	X	X	X	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	22	-	-	-	-	-	X	X	X	X	X	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	24 CSM	-	-	-	-	-	X	X	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	24 DSM	-	-	-	-	-	X	X	X	X	X	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H88	19 CNB	-	-	-	-	-	-	-	-	-	-	X	X	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	19 DNB	-	-	-	-	-	X	-	X	-	X	X	X	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	22	-	-	-	-	-	-	-	-	-	-	X	X	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	24 CSM	-	-	-	-	-	X	-	X	-	X	-	X	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	24 DSM	-	-	-	-	-	-	-	-	-	-	X	X	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M88	19 CNB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	-	X	-	-	-	-	-	-	-	-	-	-
	19 DNB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	-	-	-	-	-	-	-	-	-	-	-
	22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X	X	-	-	-	-	-	-	-	-	-	-
	24 CSM	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X	-	-	-	-	-	-	-	-	-	-
	24 DSM	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	X	X	-	-	-	-	-	-	-	-	-	-
H135	19 CNB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X	X	-	-	-	-	-
	19 DNB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X	X	-	-	-	-	-
	22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X	X	-	-	-	-	-
	24 CSM	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X	X	-	-	-	-	-
	24 DSM	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X	X	-	-	-	-	-
B135	19 CNB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	-	-
	19 DNB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	-	-
	22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	-	-
H175	19 DNB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
B175	19 DNB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X

Note: 24 ASM and 24 CSM may be assumed identical for network computations.

TABLE 3

CHARACTERISTIC IMPEDANCES AT 1000 CYCLES AND NOMINAL CUTOFF
FREQUENCY OF EXCHANGE AREA LOADED FACILITIES
AT MIDSECTION TERMINATION

GA	C MF/Mile	C MF/1000 Ft	Loading	Half-section Char Imp	Cutoff Frequency
26 AST	.069	.0131	-	-	-
26 BST	.079	.0150	-	-	-
24 ASM) CSM) ESML)	.072	.0136	H-44	923 ohms	5250 cps
			M-88	1028 "	3060 "
			H-88	1159 "	3725 "
			D-88	1290 "	4330 "
			H-135	1407 "	3030 "
			B-88	1530 "	5300 "
			B-135	1888 "	4280 "
24 DSM	.084	.0159	H-44	857 "	4850 "
			M-88	960 "	2800 "
			H-88	1080 "	3450 "
			D-88	1199 "	4000 "
			H-135	1303 "	2800 "
			B-88	1416 "	4910 "
			B-135	1748 "	3970 "
22 BSA) CSA)	.082	.0155	H-44	783 "	4900 "
			M-88	905 "	2850 "
			H-88	1050 "	3500 "
			D-88	1184 "	4050 "
			H-135	1308 "	2825 "
			B-88	1419 "	4950 "
			B-135	1767 "	4000 "
			H-175	1512 "	2475 "
19 CNB	.084	.0159	H-44	723 "	4850 "
			M-88	860 "	2800 "
			H-88	1017 "	3500 "
			D-88	1157 "	4000 "
			H-135	1283 "	2800 "
			B-88	1395 "	4900 "
			B-135	1743 "	3950 "
19 DNB	.066	.0125	H-44	811 "	5475 "
			M-88	955 "	3175 "
			H-88	1137 "	3920 "
			D-88	1294 "	4510 "
			H-135	1424 "	3150 "
			B-88	1565 "	5525 "
			H-175	1645 "	2780 "
			B-135	1952 "	4470 "
			B-175	2238 "	3930 "
16 TH	.066	.0125	B-88	1565 "	5520 "
			H-175	1649 "	2760 "
			B-135	1951 "	4450 "
			B-175	2238 "	3910 "

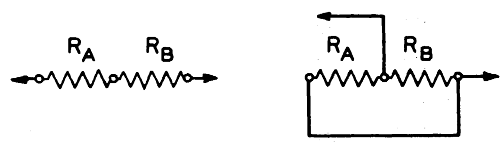
TABLE 4

Available Values of Resistance in Network
Using Resistor String Including 16,000 Ohms
Terminals 22, 26, 27, 34, 36, 37, 38

Suitable for X-Type Networks

Sheet 1

In Series   In Parallel



$R_O = R_A + R_B$

$R_O = R_A$ in Parallel with R_B

$= R_A \; P \; R_B$

$= \frac{R_A - R_B}{R_A + R_B}$

R_O		R_A		R_B	R_A	R_B
338	=	510	P	1000	510	1000
406	=	510	P	2000	510	2000
436	=	510	P	3000	510	1000 + 2000
451	=	510	P	3900	510	3900
462	=	510	P	4900	510	1000 + 3900
469	=	510	P	5900	510	2000 + 3900
475	=	510	P	6900	510	1000 + 2000 + 3900
480	=	510	P	8200	510	8200
491	=	510	P	13100	510	2000 + 3900 + 8200
500	=	510	P	25200	510	1000 + 8200 + 16000
510	=	510			510	-
667	=	1000	P	2000	1000	2000
796	=	1000	P	3900	1000	3900
860	=	1510	P	2000	510 + 1000	2000
891	=	1000	P	8200	1000	8200
911	=	1000	P	10200	1000	2000 + 8200
924	=	1000	P	12100	1000	3900 + 8200
934	=	1000	P	14100	1000	2000 + 3900 + 8200
941	=	1000	P	16000	1000	16000
952	=	1000	P	19900	1000	3900 + 16000
960	=	1000	P	24200	1000	8200 + 16000
1000	=	1000			1000	-
1089	=	1510	P	3900	510 + 1000	3900
1202	=	1510	P	5900	510 + 1000	2000 + 3900
1275	=	1510	P	8200	510 + 1000	8200
1322	=	2000	P	3900	2000	3900
1342	=	1510	P	12100	510 + 1000	3900 + 8200
1380	=	1510	P	16000	510 + 1000	16000
1393	=	1510	P	18000	510 + 1000	2000 + 16000
1404	=	1510	P	19900	510 + 1000	3900 + 16000

TABLE 4

Available Values of Resistance in Network
Using Resistor String Including 16,000 Ohms
Terminals 22, 26, 27, 34, 36, 37, 38

Suitable for X-Type Networks

Sheet 2

R_O R_A R_B	R_A	R_B
1413 = 1510 P 21900	510 + 1000	2000 + 3900 + 16000
1421 = 1510 P 24200	510 + 1000	8200 + 16000
1510 = 510 + 1000	510	1000
1608 = 2000 P 8200	2000	8200
1696 = 3000 P 3900	1000 + 2000	3900
1716 = 2000 P 12100	2000	3900 + 8200
1778 = 2000 P 16000	2000	16000
1817 = 2000 P 19900	2000	3900 + 16000
1847 = 3510 P 3900	510 + 1000 + 2000	3900
1867 = 2000 P 28100	2000	3900 + 8200 + 16000
1922 = 2510 P 8200	510 + 2000	8200
2000 = 2000	2000	
2079 = 2510 P 12100	510 + 2000	3900 + 8200
2170 = 2510 P 16000	510 + 2000	16000
2196 = 3000 P 8200	1000 + 2000	8200
2229 = 2510 P 19900	510 + 2000	3900 + 16000
2274 = 2510 P 24200	510 + 2000	8200 + 16000
2304 = 2510 P 28100	510 + 2000	3900 + 8200 + 16000
2338 = 338 + 2000	510 P 1000	2000
2404 = 3000 P 12100	1000 + 2000	3900 + 8200
2458 = 3510 P 8200	510 + 1000 + 2000	8200
2510 = 510 + 2000	510	2000
2526 = 3000 P 16000	1000 + 2000	16000
2607 = 3000 P 19900	1000 + 2000	3900 + 16000
2643 = 3900 P 8200	3900	8200
2669 = 3000 P 24200	1000 + 2000	8200 + 16000
2711 = 3000 P 28100	1000 + 2000	3900 + 8200 + 16000
2720 = 3510 P 12100	510 + 1000 + 2000	3900 + 8200
2868 = 4410 P 8200	510 + 3900	8200
2984 = 3510 P 19900	510 + 1000 + 2000	3900 + 16000
3000 = 1000 + 2000	1000	2000
3067 = 8200 P 4900	8200	1000 + 3900
3120 = 3510 P 28100	510 + 1000 + 2000	3900 + 8200 + 16000
3136 = 3900 P 16000	3900	16000
3259 = 8200 P 5410	8200	510 + 1000 + 3900
3359 = 3900 P 24200	3900	8200 + 16000
3431 = 8200 P 5900	8200	2000 + 3900
3457 = 4410 P 16000	510 + 3900	16000
3510 = 510 + 3000	510	1000 + 2000
3598 = 8200 P 6410	8200	510 + 2000 + 3900

TABLE 4

Available Values of Resistance in Network
Using Resistor String Including 16,000 Ohms
Terminals 22, 26, 27, 34, 36, 37, 38

Suitable for X-Type Networks

Sheet 3

R_O R_A R_B	R_A	R_B
3730 = 4410 P 24200	510 + 3900	8200 + 16000
3751 = 16000 P 4900	16000	1000 + 3900
3893 = 8200 P 7410	8200	510 + 1000 + 2000 + 3900
3900 = 3900	3900	-
4043 = 16000 P 5410	16000	510 + 1000 + 3900
4075 = 24200 P 4900	8200 + 16000	1000 + 3900
4238 = 3900 + 338	3900	510 P 1000
4306 = 3900 + 406	3900	510 P 2000
4311 = 16000 P 5900	16000	2000 + 3900
4336 = 3900 + 436	3900	510 P (1000 + 2000)
4410 = 510 + 3900	510	3900
4422 = 24200 P 5410	8200 + 16000	510 + 1000 + 3900
4567 = 3900 + 667	3900	1000 P 2000
4577 = 16000 P 6410	16000	510 + 2000 + 3900
4744 = 24200 + 5900	8200 + 16000	2000 + 3900
4760 = 3900 + 860	3900	(510 + 1000) P 2000
4821 = 16000 P 6900	16000	1000 + 2000 + 3900
4900 = 1000 + 3900	1000	3900
5065 = 16000 P 7410	16000	510 + 1000 + 2000 + 3900
5369 = 24200 P 6900	8200 + 16000	1000 + 2000 + 3900
5410 = 510 + 4900	510	1000 + 3900
5421 = 16000 P 8200	16000	8200
5640 = 16000 P 8710	16000	510 + 8200
5673 = 24200 P 7410	8200 + 16000	510 + 1000 + 2000 + 3900
5841 = 16000 P 9200	16000	1000 + 8200
5900 = 2000 + 3900	2000	3900
6043 = 16000 P 9710	16000	510 + 1000 + 8200
6229 = 16000 P 10200	16000	2000 + 8200
6410 = 510 + 5900	510	2000 + 3900
6416 = 16000 P 10710	16000	510 + 2000 + 8200
6588 = 16000 P 11200	16000	3000 + 8200
6890 = 16000 P 12100	16000	3900 + 8200
6900 = 1000 + 5900	1000	2000 + 3900
7052 = 16000 P 12610	16000	510 + 3900 + 8200
7203 = 16000 P 13100	16000	1000 + 3900 + 8200
7354 = 16000 P 13610	16000	510 + 1000 + 3900 + 8200
7410 = 510 + 6900	510	1000 + 2000 + 3900
7495 = 16000 P 14100	16000	2000 + 3900 + 8200

TABLE 4

Available Values of Resistance in Network
Using Resistor String Including 16,000 Ohms
Terminals 22, 26, 27, 34, 36, 37, 38

Suitable for X-Type Networks

Sheet 4

R_0		R_A		R_B	R_A	R_B
7637	=	16000	P	14610	16000	510 + 2000 + 3900 + 8200
7768	=	16000	P	15100	16000	1000 + 2000 + 3900 + 8200
7901	=	16000	P	15610	16000	510 + 1000 + 2000 + 3900 + 8200
8200	=	8200			8200	
8538	=	8200	+	338	8200	510 P 1000
8606	=	8200	+	406	8200	510 P 2000
8636	=	8200	+	436	8200	510 P 3000
8662	=	8200	+	462	8200	510 P 4900
8675	=	8200	+	475	8200	510 P 6900
8710	=	510	+	8200	510	8200
8867	=	8200	+	667	8200	1000 P 2000
8996	=	8200	+	796	8200	1000 P 3900
9060	=	8200	+	860	8200	(510 + 1000) P 2000
9200	=	8200	+	1000	8200	1000
9289	=	8200	+	1089	8200	(510 + 1000) P 3900
9402	=	8200	+	1202	8200	(510 + 1000) P 5900
9522	=	8200	+	1322	8200	2000 P 3900
9710	=	510	+	9200	510	1000 + 8200
9896	=	8200	+	1696	8200	(1000 + 2000) P 3900
10047	=	8200	+	1847	8200	(510 + 1000 + 2000) P 3900
10200	=	2000	+	8200	2000	8200
10710	=	510	+	10200	510	2000 + 8200
11200	=	1000	+	10200	1000	2000 + 8200
11710	=	510	+	11200	510	1000 + 2000 + 8200
12100	=	3900	+	8200	3900	8200
12610	=	4410	+	8200	510 + 3900	8200
13100	=	4900	+	8200	1000 + 3900	8200
13610	=	5410	+	8200	510 + 1000 + 3900	8200
14100	=	2000	+	12100	2000	3900 + 8200
14610	=	2510	+	12100	510 + 2000	3900 + 8200
15100	=	3000	+	12100	1000 + 2000	3900 + 8200
15610	=	1510	+	14100	510 + 1000	2000 + 3900 + 8200
16000	=	16000			16000	-
16510	=	510	+	16000	510	16000
17000	=	1000	+	16000	1000	16000
17510	=	510	+	17000	510	16000 + 1000
18000	=	2000	+	16000	2000	16000
18510	=	510	+	18000	510	2000 + 16000
19000	=	1000	+	18000	1000	2000 + 16000
19510	=	510	+	19000	510	1000 + 2000 + 16000
19900	=	3900	+	16000	3900	16000
20410	=	510	+	19900	510	3900 + 16000
20900	=	1000	+	19900	1000	3900 + 16000
21410	=	510	+	20900	510	1000 + 3900 + 16000
21900	=	2000	+	19900	2000	3900 + 16000
22410	=	510	+	21900	510	2000 + 3900 + 16000

TABLE 5

Available Values of Resistance in Network
Using Resistor String Without 16,000ω
Terminals 14, 19, 23, 25, 32 and 36

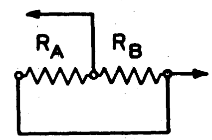
Suitable for X-Type Networks

Sheet 1

In Series

$$R_O = R_A + R_B$$

In Parallel



$R_O = R_A$ in Parallel with R_B

$$= R_A \, P \, R_B$$

$$= \frac{R_A - R_B}{R_A + R_B}$$

R_O	R_A R_B	R_A	R_B
338	= 510 P 1000	510	1000
406	= 510 P 2000	510	2000
436	= 510 P 3000	510	1000 + 2000
451	= 510 P 3900	510	3900
462	= 510 P 4900	510	1000 + 3900
469	= 510 P 5900	510	2000 + 3900
475	= 510 P 6900	510	1000 + 2000 + 3900
480	= 510 P 8200	510	8200
491	= 510 P 13100	510	1000 + 3900 + 8200
510	= 510	510	
667	= 1000 P 2000	1000	2000
796	= 1000 P 3900	1000	3900
860	= 1510 P 2000	510 + 1000	2000
891	= 1000 P 8200	1000	8200
911	= 1000 P 10200	1000	2000 + 8200
924	= 1000 P 12100	1000	3900 + 8200
934	= 1000 P 14100	1000	2000 + 3900 + 8200
1000	= 1000	1000	-
1089	= 1510 P 3900	510 + 1000	3900
1202	= 1510 P 5900	510 + 1000	2000 + 3900
1275	= 1510 P 8200	510 + 1000	8200
1322	= 2000 P 3900	2000	3900
1342	= 1510 P 12100	510 + 1000	3900 + 8200
1510	= 510 + 1000	510	1000
1608	= 2000 P 8200	2000	8200
1696	= 3000 P 3900	1000 + 2000	3900
1716	= 2000 P 12100	2000	3900 + 8200
1847	= 3510 P 3900	510 + 1000 + 2000	3900
1922	= 2510 P 8200	510 + 2000	8200
2000	= 2000	2000	-

TABLE 5

Available Values of Resistance in Network
Using Resistor String Without 16,000ω
Terminals 14, 19, 23, 25, 32 and 36

Suitable for X-Type Networks

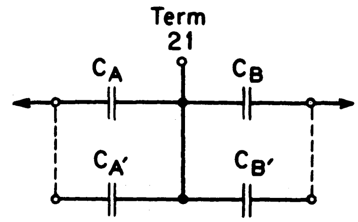
Sheet 2

R_O		R_A		R_B	R_A	R_B
2079	=	2510	P	12100	510 + 2000	3900 + 8200
2196	=	3000	P	8200	1000 + 2000	8200
2404	=	3000	P	12100	1000 + 2000	3900 + 8200
2458	=	3510	P	8200	510 + 1000 + 2000	8200
2510	=	510	+	2000	510	2000
2643	=	3900	P	8200	3900	8200
2720	=	3510	P	12100	510 + 1000 + 2000	3900 + 8200
2868	=	4410	P	8200	510 + 3900	8200
3000	=	1000	+	2000	1000	2000
3067	=	8200	P	4900	1000 + 3900	8200
3259	=	8200	P	5410	8200	510 + 1000 + 3900
3431	=	8200	P	5900	8200	2000 + 3900
3510	=	510	+	3000	510	1000 + 2000
3598	=	8200	P	6410	8200	510 + 2000 + 3900
3893	=	8200	P	7410	8200	510 + 1000 + 2000 + 3900
3900	=	3900			3900	-
4410	=	510	+	3900	510	3900
4900	=	1000	+	3900	1000	3900
5410	=	510	+	4900	510	1000 + 3900
5900	=	2000	+	3900	2000	3900
6410	=	510	+	5900	510	2000 + 3900
6900	=	1000	+	5900	1000	2000 + 3900
7410	=	510	+	6900	510	1000 + 2000 + 3900
8200	=	8200			8200	-
8710	=	510	+	8200	510	8200
9200	=	1000	+	8200	1000	8200
9710	=	510	+	9200	510	1000 + 8200
10200	=	2000	+	8200	2000	8200
10710	=	510	+	10200	510	2000 + 8200
11200	=	1000	+	10200	1000	2000 + 8200
11710	=	1510	+	10200	510 + 1000	2000 + 8200
12100	=	3900	+	8200	3900	8200
12610	=	4410	+	8200	510 + 3900	8200
13100	=	4900	+	8200	1000 + 3900	8200
13610	=	5410	+	8200	510 + 1000 + 3900	8200
14100	=	2000	+	12100	2000	3900 + 8200
14610	=	2510	+	12100	510 + 2000	3900 + 8200
15100	=	3000	+	12100	1000 + 2000	3900 + 8200
15610	=	1510	+	14100	510 + 1000	2000 + 3900 + 8200

TABLE 6

Available Values of Capacitance with Network Units in Series*
(Using Detached String which does not include .0005 MF
Terminals 17, 29, 30, 31, 33 with common 21)

Suitable for X-Type Networks



Where C_A in series with $C_B = C_0 = \frac{C_A - C_B}{C_A + C_B}$

and where C_A may be C_A in parallel with $C_{A'}$, P etc.

and where C_B may be C_B P $C_{B'}$, P etc.

C_0	C_A	C_B	C_A	C_B
.00067	.002	.001	-	-
.00080	.004	.001	-	-
.00086	.006	.001	.002 P .004	-
.00133	.002	.004	-	-
.00143	.002	.005	-	.001 P .004
.00160	.002	.008	-	-
.00164	.002	.009	-	.001 P .008
.00171	.002	.012	-	.004 P .008
.00171	.003	.004	.002 P .001	-
.00178	.002	.016	-	-
.00218	.003	.008	.002 P .001	-
.00240	.003	.012	.002 P .001	.004 P .008
.00253	.003	.016	.002 P .001	
.00261	.003	.020	.002 P .001	.004 P .016
.00267	.004	.008	-	-
.00277	.004	.009	-	.001 P .008
.00286	.004	.010	-	.002 P .008
.00293	.004	.011	-	.001 P .002 P .008
.00308	.005	.008	.001 P .004	-
.00320	.004	.016	-	-
.00324	.004	.017	-	.001 P .016
.00327	.004	.018	-	.002 P .016
.00330	.004	.019	-	.001 P .002 P .016
.00343	.006	.008	.002 P .004	-
.00360	.006	.009	.002 P .004	.001 P .008
.00373	.008	.007	.002 P .004	.001 P .002 P .004
.00381	.005	.016	.001 P .004	-
.00436	.006	.016	.002 P .004	-
.00444	.006	.017	.002 P .004	.001 P .016
.00487	.007	.016	.001 P .002 P .004	-
.00533	.008	.016	-	-
.00542	.007	.024	.001 P .002 P .004	.008 P .016
.00576	.009	.016	.001 P .008	-
.00594	.008	.023	-	.001 P .002 P .004 P .016
.00615	.010	.016	.002 P .008	-
.00630	.010	.017	.002 P .008	.001 P .016
.00652	.011	.016	.001 P .002 P .008	-
.00667	.010	.020	.002 P .008	.004 P .016
.00686	.012	.016	.004 P .008	-
.00703	.012	.017	.004 P .008	.001 P .016
.00710	.011	.020	.001 P .002 P .008	.004 P .016
.00717	.013	.016	.001 P .004 P .008	-
.00720	.012	.018	.004 P .008	.002 P .016
.00747	.014	.016	.002 P .004 P .008	-
.00755	.013	.018	.001 P .004 P .008	.002 P .016
.00768	.014	.017	.002 P .004 P .008	.001 P .016
.00774	.015	.016	.001 P .002 P .004) P .008)	

* This string of condensers may also be connected in parallel giving values from .001 MF to .031 MF in steps of .001

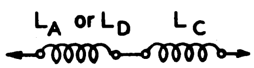
TABLE 7

Available Values of Inductance
with Network Units in Series and Parallel

Suitable for X-Type Networks Requiring 2 Inductances

Sheet 1

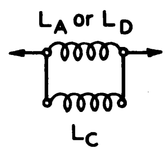
Series



$L_O = L_A + L_C$

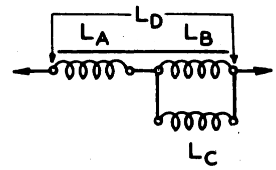
Where L_A and L_C are separate coils.

Parallel



$$L_O = \frac{L_A - L_C}{L_A + L_C}$$

Combination



$$L_O = \frac{L_D - L_C}{L_B + L_C}$$

L_D = Inductance of 2 Windings on same core

L_O	Single Component	Series		Parallel		Combination L_A	L_B	L_C	L_D
.0857	-			.15	.20				
.0938	-			.15	.25				
.1111	-			.20	.25				
.1125	-			.15	.45				
.12	-			.15	.60				
.12	-			.20	.30				
.1339	-			.15	1.25				
.1364	-			.25	.30				
.1373	-			.15	1.62				
.15	.15			-	-				
.15	-			.20	.60				
.1607	-			.25	.45				
.1628	-			.20	.874				
.178	-			.20	1.62				
.18	-			.30	.45				
.1949	-			.25	.874				
.20	.20			-	-				
.20	-			.30	.60				
.2083	-			.25	1.25				
.2419	-			.30	1.25				
.25	.25			-	-				
.2516	-			.30	1.62				
.2571	-			.45	.60				
.2971	-			.45	.874				
.30	.30			-	-				
.35	-	.15	.20	-	-				
.3522	-	-	-	.45	1.62				
.3558	-	-	-	.60	.874				
.40	-	.15	.25	-	-				
.4054	-	-	-	.60	1.25				

TABLE 7

Available Values of Inductance
with Network Units in Series and Parallel

Suitable for X-Type Networks Requiring 2 Inductances

Sheet 2

L_O	Single Component	Series		Parallel		Combination L_A	L_B	L_C	L_D
.45	.45	-	-	-	-	-			
.45	-	.20	.25	-	-	-			
.4994	-	-	-	-	-	.30	.15	.20	.874
.50	-	.20	.30	-	-	-			
.5144	-	-	-	.874	1.25	-			
.5244	-	-	-	-	-	.15	.30	.45	.874
.5463	-	-	-	-	-	.30	.15	.25	.874
.55	-	.25	.30	-	-	-			
.5677	-	-	-	.874	1.62	-			
.5827	-	-	-	-	-	.15	.30	.6	.874
.60	.60	-	-	-	-	-			
.60	-	.15	.45	-	-	-			
.6555	-	-	-	-	-	.30	.15	.45	.874
.6949	-	-	-	-	-	.45	.20	.25	1.25
.6992	-	-	-	-	-	.30	.15	.60	.874
.70	-	.25	.45	-	-	-	-	-	-
.7048	-	-	-	-	-	.15	.30	1.25	.874
.7056	-	-	-	1.25	1.62	-	-	-	-
.7143	-	-	-	-	-	.20	.45	.60	1.25
.7374	-	-	-	-	-	.15	.30	1.62	.874
.75	-	.15	.60	-		-	-	-	-
.75	-	-	-	-		.45	.20	.30	1.25
.75	-	.30	.45	-		-	-	-	-
.7804	-	-	-	-		.30	.15	1.25	.874
.7999	-	-	-	-		.30	.15	1.62	.874
.80	-	.20	.60	-		-	-	-	-
.8252	-	-	-	-		.20	.45	.874	1.25
.874	.874	-	-	-		-	-	-	-
.8836	-	-	-	-		.60	.25	.30	1.62
.90	-	.30	.60	-		-	-	-	-
.9375	-	-	-	-		.45	.20	.60	1.25
.9606	-	-	-	-		.25	.60	.874	1.62
.9783	-	-	-	-		.20	.45	1.62	1.25
1.0172	-	-	-	-		.45	.20	.874	1.25
1.0414	-	-	-	-		.60	.25	.45	1.62
1.05	-	.45	.60			-			
1.074	-	.20	.874			-			
1.0946	-	-	-			.25	.60	1.25	1.62
1.1126	-	-	-			.45	.20	1.62	1.25
1.124	-	.25	.874			-			

TABLE 7

Available Values of Inductance
with Network Units in Series and Parallel

Suitable for X-Type Networks Requiring 2 Inductances

Sheet 3

L_O	Single Component	Series		Parallel	Combination L_A	L_B	L_C	L_D
1.25	1.25	-	-		-	-	-	-
1.2597	-	-	-		.60	.25	.874	1.62
1.324	-	.45	.874		-	-	-	-
1.35	-	-	-		.60	.25	1.25	1.62
1.4	-	.15	1.25		-	-	-	-
1.474	-	.60	.874					
1.5	-	.25	1.25					
1.55	-	.30	1.25					
1.62	1.62	-	-					
1.77	-	.15	1.62					
1.82	-	.20	1.62					
1.85	-	.60	1.25					
1.92	-	.30	1.62					
2.07	-	.45	1.62					
2.124	-	.874	1.25					
2.494	-	.874	1.62					
2.87	-	1.25	1.62					