NEGATIVE IMPEDANCE REPEATERS

DESIGN OF CIRCUITS USING SERIES TYPE

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1. GENERAL

1.01 This section discusses the considerations involved in the use of series type negative impedance repeaters (E1 and E2 types) on exchange area trunks and special service lines. The more general engineering considerations involved in the use of these repeaters, such as return loss computations and other transmission data, are covered in other sections of this series. The use of these series elements in combination with shunt elements in L and T configurations is covered in other sections.

1.02 As with other repeaters the use of these negative impedance series elements requires that suitable practices be followed to secure desired gains and at the same time limit the likelihood of objectionable reactions due to instability, echo, overloading or crosstalk.

1.03 To simplify the design work, curves are included which indicate the maximum gains that may usually be obtained for the expected range of return losses on either side of the repeater. These curves are based on the assumption that the return losses at the critical frequency on both sides of the repeater may combine in phase. Since this will not occur in all cases, there may be some margin in specific cases but this can not readily be determined in advance. Allowance is also made in the curves for departure of the network and other components from their optimum values as well as for tube aging and power supply variations. This allowance, expressed as a return loss, is about 26 db and is assumed to combine in phase (on a current basis) with other return losses on each side of the repeater. This is equivalent to about a 10 per cent reduction in impedance. It would therefore be possible, by measurements and special adjustments on a specific repeater, to obtain gains in the order of 0.5 db greater than indicated by the curves. However, this is not an advisable procedure since tube replacements, aging, or other subsequent changes may reintroduce the variation and cause instability.

1.04 The series element affords a transmission gain by introducing a negative impedance into the line. The magnitude of this negative impedance is adjustable by strappings on the repeater network. The gain is therefore an insertion gain which is equal in the two directions and its magnitude determined by the network strappings and the line impedances in the two directions. As these impedances may be different for the idle and talking conditions the nominal gain is defined as the insertion gain produced between characteristic impedances. These gains are therefore approximately the same as exist under talking conditions though there will be some variations particularly where a circuit with a terminal repeater is switched at that terminal to facilities with a variety of impedances.

1.05 In the case of nonloaded circuits, on one or both sides of the repeater, the gains noted on the curves in this section also contain an allowance for the improvement in transmission frequency characteristics and are therefore of the nature of effective gains. These are from 1 to 2 db higher than the average single-frequency gain near 1000 cycles.

1.06 Gains up to a maximum of about 8 to 10 db are obtainable under the limitations of return losses and other factors. The gains can usually be predetermined by estimates as discussed in this section and preselection of the network strappings.

1.07 As outlined below the proper strappings can in most cases be obtained from the strapping charts. (Section A304.486). Strappings for combinations of facilities not shown in that section may be determined by methods outlined in Section AB22.152.1.

2. CIRCUIT DESIGN FACTORS

(A) Required Gain

2.01 The gain required in a particular circuit is determined by the transmission objectives and other general engineering considerations. This gain required is one of the design factors which will determine the type of repeater to be used. Gain as computed in this section is the maximum obtainable gain with the series type repeater under given circuit conditions.

(B) Repeater Location

2.02 In the selection of a series repeater location consideration should be given to the following:

(a) The most favorable location on loaded facilities with 6 or more loading coils is near the middle of the circuit (not less than 3 coils on either side of the repeater) while for shorter lines a terminal location is preferable because of a more uniform gain frequency characteristic even though slightly higher gains may be indicated for a midpoint location. For nonloaded circuits the preferable location of a single repeater is at the midpoint regardless of the loss.

(b) For a circuit made up of two sections of unlike facilities a location at the junction will be preferable. This is particularly desirable for junctions between nonloaded and loaded facilities.

(c) For a line made up of sections of more than two unlike facilities the preferable location will be at a junction which gives the most favorable line return losses. The calculation of return losses is discussed in Section AB22.150.2.

(C) Maximum Usable Gain

2.03 The maximum usable repeater gain from the standpoint of singing is determined from the return losses of the fixed line sections on both sides of the repeater as outlined below.

2.04 Intermediate Repeater:

(a) Loaded Facilities on Both Sides - Similar Impedances: Fig. 1 gives the maximum usable gain as a function of the return losses of the two fixed lines.

(b) Loaded Facilities on Both Sides - Dissimilar Impedances: When loaded facilities with unlike impedances are involved, corrections read from Fig. 2, based on the difference between the two return losses and the ratio of line impedances are added algebraically to the gain determined from Fig. 1 to give the maximum insertion gain obtainable. The 1000-cycle half-section characteristic impedances may be used in determining the impedance ratio. For purposes of network selection the nominal gain should be determined in accordance with Section AB22.152.1. As an example let the line east have a return loss of 14 db and the line west 8 db. Assume an impedance ratio of east to west of 0.6. Fig. 1 indicates an obtainable gain of 6.0 db. Add to this a correction of -0.4 db from Fig. 2 to obtain the maximum obtainable insertion gain of 5.6 db. The actual network strapping to obtain this gain may be obtained as follows. The network should be selected for the lower cutoff facility (or by the master chart Page 3 of Section A304.486). This facility is the Z_1 of Fig. 2 of Section AB22.152.1. Using this chart for the example above the 5.6 db insertion gain will be obtained by the 4.0 db strapping if the west facility network is used ($Z_2/Z_1 = 0.6$) or by the 8.5 db strapping ($Z_2/Z_1 = 1.66$) if the east facility network is used.

(c) Nonloaded Facilities on Both Sides: As in the case of loaded facilities Fig. 1 may be used to determine gain as discussed in Section AB22.152.1.

(d) Loaded Facilities on One Side - Nonloaded on Other: Gains are given by Figs. 3A and 3B.

2.05 Terminal Repeaters: For all types of facilities use Fig. 1 (as discussed in Section AB22.152.1) and assume 0 db return loss on the switched side. Where more gain is required than this would indicate and in applications where repeating coils may be used at the circuit terminal, consideration should be given to the matched impedance method discussed in Section AB22.151.2.

(D) Basis for Redesign

2.06 If the obtainable gain is not high enough to meet design requirements changes in the circuit layout may be considered such as:

(a) Selection of another repeater location.

(b) Installation of additional loading.

(c) Improvement of return loss such as the correction of loading irregularities.

(d) Use of facilities with higher structural return loss.

(e) Assignment to facilities with lower loss.

(E) Consideration of Loading End Sections

General

2.07 In general the repeater network can be adjusted to give the gains indicated in Fig. 1, 3A, or 3B. When loaded facilities are involved on one or both sides of the repeater the end sections adjacent to the repeater should be determined within 5 per cent of a loading section. There are three conditions of these end sections which are of concern in applications of E1 and E2 repeaters. These conditions determine whether the strapping of the repeater network can be determined entirely from the charts, whether field adjustments will be required or if building-out procedures will be needed and are discussed below and summarized in Table 1.

(a) (Column 1.) When the end sections are within the ranges for which predetermined network strappings can be used to secure the gains indicated in Figs. 1, 3A, and 3B.

(b) (Column 2.) When the end sections are outside of the ranges covered by the predetermined network strappings but which are still within ranges for which the gains indicated in Figs. 1, 3A, and 3B can be realized by gain tests and network strapping selection on the job.

(c) (Column 3.) When the end sections are so short that it would generally be impossible to obtain the gains indicated in Figs. 1, 3A, and 3B even with tests on the job.

2.08 Since building-out capacitors are now available both in the repeater and in inexpensive form for external use, it will in most cases be preferable to build out the end sections to be within the limits of (a) above rather than to require gain tests and network selection in the field. When building out is used, the end sections should be adjusted to from 0.4 to 0.6 section whenever possible.

2.09 When building-out capacitors are used the effect of the additional capacitance on the line loss should be considered. In determining this effect consider the total built-out length between the adjacent loading points on the two sides of the repeater to be a loading section. Where the added building-out capacitance tends to correct a short section no transmission penalty should be added. Where the building-out capacitance results in a longer than average section a penalty should be added appropriate to the irregularity created.

Table 1

END SECTION TREATMENT

Line Conditions	End Sections for Which Gains Indicated in Fig. 1, 3A, or 3B: Can be Obtained by Predetermined Network Strappings	Can be Obtained by Network Adjustment on Job	Can Not Usually be Obtained
1. Terminal Repeaters			
(a) Low cutoff facilities	0.4 to 1.25 1.25 to 1.5 when return loss is 7 db or more	0.3 to 0.4 1.25 to 1.5 when return loss is less than 7 db 1.5 or more	0 to 0.3
(b) High cutoff facilities	0.3 to 1.25 1.25 to 1.5 when return loss is 7 db or more	1.25 to 1.5 when return loss is less than 7 db 1.5 or more	0 to 0.3
2. Intermediate Repeaters			
(a) Similar loading systems on both sides of repeater	0.3 to 0.5 for both 0.4 to 1.25 for both	0.3 to 0.5 for one, over 0.5 for other, 0.4 to 1.25 for one, over 1.25 for other	0 to 0.3
(b) Repeater between dissimilar loading systems	0.4 to 1.25 for both	0.4 to 1.25 for one, over 1.25 for other	0 to 0.4
(c) Loaded facility one side, nonloaded on other	0.3 to 0.9 Fig. 3A 0.9 to 1.5 Fig. 3B	1.5 to 2	0 to 0.3

Note: If building-out capacitors are used the preferable end sections after correction are:

For cases 1(a), 1(b), 2(b) - 0.4 to 0.6 section.

For case 2(a) - 0.4 to 0.5 section.

For case 2(c) - An end section of 0.3 section is generally desirable but as indicated by Figs. 3A and 3B higher gains may be possible with certain facilities with end sections of 0.9 to 1.5 section.

(F) Crosstalk Considerations

2.10 Trunks: The most severe location for repeaters from a crosstalk standpoint is at the end of a trunk where connection is made to subscriber loops (i.e., local office end of tandem and toll connecting trunks, or either end of direct interlocal trunks). If the gains of such terminal repeaters are kept within the values shown in the table below for various types of facilities, a crosstalk index of "GOOD" should be realized. (A more complete discussion of crosstalk index is contained in the AB61 series of practices.) These gain values are based on typical rms couplings for the various types of trunk facilities. In the case of nonstaggered twist cable the coupling distribution is such that "POOR" crosstalk conditions may result even with small gains.

Type of Trunk Facility	Gain of Terminal Repeater
NL	11 db
H175	3 db
H135	5 db
B135	3 db
H88	6 db
D88	5 db
B88	4 db

For intermediate repeaters the above gains may be increased by the amount of the trunk loss between the repeater location and the circuit terminal at the subscriber end. It should be noted, however, that in both the above table for terminal repeaters and for intermediate repeaters, gains permitted by crosstalk may in certain cases exceed the maximum working gains from other design standpoints.

2.11 Special Service Lines: The gain values given in the table of Paragraph 2.10 assume a distribution of subscriber loops for which the 1000-cycle loss of the average line is 4 db. In the assignment of repeater gains on special service lines, the values in the above table may be decreased or increased accordingly as the 1000-cycle loss to the station terminal is less or greater than 4 db, with a resultant index of "GOOD."

2.12 If it is known that in a given splicing group or color group in a trunk cable, only a small fraction of the lines (less than 10%) are to be repeatered, the gains given above may be as much as doubled and an index of "GOOD" still be obtainable.

2.13 The use of equalized 500-type sets properly zoned in subscriber loops should not affect the crosstalk index for repeatered trunks leaving that area, since the set gain is achieved only on longer loops, where crosstalk conditions are in general better than the index. However, on special service lines, where unequalized 500-type sets are used, the crosstalk susceptivity will be further increased by the 5 db additional receiving gain of the 500-type set, and a crosstalk index of "GOOD" will not be achieved using the gains determined in Paragraph 2.11. This principle of course applies to any other station equipment with higher receiving efficiency than the F1A-HA1 instrument.

(G) Other Factors

Repeater Overloading

2.14 The E1 or E2 series repeater will handle putput levels up to +14 dbm before significant gain compression takes place. For this reason these repeaters may be placed at any location on a line and operated at any gain permitted by other design limitations without danger of overloading.

Effect on Signaling Range

2.15 The series repeater is coupled into a circuit by means of two separate transformer windings and introduces a loop dc resistance of about 40 ohms. In simplex signaling applications it introduces a series noninductive resistance of 10 ohms.

2.16 The repeater introduces a series impedance at 20 cycles which may vary from 150 to 250 ohms depending upon the gain and associated type of line. The series impedance will approach the lower value for lower gains. In general for applications on cable circuits the series impedance will affect the signaling range by an amount less than would otherwise be expected because of a favorable combination of the reactances of the line and of the repeater. For general design work a 20-cycle ringing penalty of 150 ohms should be assumed for one series repeater and 250 ohms for two repeaters. No penalty need be assumed to the pulsing ranges on PC1, revertive or dial pulsing trunks other than the dc resistance added by the repeater.

2.17 The repeater is designed to withstand the maximum pulsing and ringing currents which occur in normal telephone usage. It will maintain stable repeater gain with dc loop currents up to 100 milliamperes.

Echo and Sidetone Effects

2.18 In general, if the repeater is adjusted to avoid singing or near singing conditions, echo and sidetone effects will not generally be controlling factors, in the design of all trunks other than toll connecting trunks and most special service lines. Echo considerations in toll connecting trunks are discussed in Section AB22.150.4.

3. REPEATERS IN SERIES

(A) General

3.01 There will be no transmission advantage in using two repeaters in series at one location rather than a single repeater at the same location. However, this condition may occur when two circuits equipped with terminal repeaters are switched together. In such cases different gains will be obtained for the switched connections than for other connections as discussed below. When E1 or E2 repeaters separated by line facilities are operated in series, the additional gains which may be obtained compared to the use of a single repeater depend on the loss and other characteristics of the intervening facilities as discussed below.

(B) Intermediate Repeaters

3.02 In cases where two or more intermediate series repeaters are used on one circuit, computations to determine the maximum obtainable gain should be made as follows. Between any two repeaters a 0 db return loss is assumed at a point 0.55 of the total section loss away from each repeater. A return loss of 0 db should also be assumed at each circuit terminal. The gain of each repeater is computed separately and the sum of these gains will give the maximum circuit gain obtainable. Where junctions of unlike facilities or other major irregularities exist these points will generally be preferable repeater locations and result in higher total gains than those obtainable if the irregularity occurred between repeaters.

(C) Terminal Repeaters on the Same Circuit

3.03 The maximum obtainable gain for two terminal repeaters is computed in the same manner as for intermediate repeaters above. In general there will be a small transmission advantage in the use of two terminal repeaters rather than a single repeater at a midpoint location.

(D) Terminal Repeaters on Switched Circuits

3.04 When two lines with terminal repeaters are switched together the total gain obtained will be greater than the sum of individual gains. In such cases the usable gain for each repeater will be determined by the return loss of its associated fixed line section as previously described. The gain which will then be obtained for switched connections may be determined by reading Fig. 1 using the return losses of the two fixed line sections associated with the terminal repeaters on the two switched lines. The curves are read in the same manner as though a single intermediate repeater were involved as described earlier.

3.05 If two terminal repeaters are operated with gains which differ from the usable gains which were assumed in Paragraph 3.04 above, the resulting gain for the series combination may also be determined from Fig. 1. Assuming RL_B is 0 db locate a point corresponding to each repeater gain on the RL_A scale and read the resulting return loss values for RL_A. Use Fig. 1 in the normal manner to obtain the allowable gain for a single repeater with return losses equal to the two return loss values just determined. This gain will be that obtained when the two terminal repeaters occur between circuits of approximately equal impedance.

4. SPECIAL SERVICE LINE CONSIDERATIONS

(A) General

4.01 In many special service line applications it is possible to take advantage of specific terminating or equipment conditions to obtain a somewhat greater gain than would be obtainable in the case of switched circuits where the design usually requires stability in all terminal conditions. When idle circuit terminations can be used or when auxiliary equipment adjacent to the repeater is so arranged as to open the line in the idle condition (series repeater elements are basically open circuit stable), the idle condition can be made less restrictive than the talking condition. In the case of idle circuit terminations or a fixed instrument termination the idle circuit terminal return loss will be greater than zero and should be computed to determine the allowable idle circuit gain. When this terminal return loss is greater than zero the maximum gain may be estimated in the case of loaded facilities from the curves in this section. For nonloaded facilities or for the case of the repeater between loaded and nonloaded facilities reference should be made to Section AB22.152.1. When the auxiliary equipment effectively opens the line at the repeater in the idle condition the idle condition may be neglected as limiting the design and stability computations based on the talking condition as discussed below.

4.02 In either of the above cases the talking condition of the line will usually be limiting and the attainable gain computed on that basis. A 6 db return loss should be assumed at the point where the circuit is switched to trunks, loops, PBX stations or connected to a telephone instrument. The terminal return loss and intermediate return losses, after correction for line loss, should be combined with the structural return loss on a power basis in the usual manner. However, a 26 db return loss should be assumed on each side of the repeater to take care of variations in the network and other repeater characteristics. This should be added on a current summation basis to the other return losses on each side of the repeater. These return losses should be added arithmetically and 10 db deducted from the sum. One-half of the remainder represents the estimated usable repeater gain under the talking condition. The 10 db is included here to allow for variations from the assumed conditions.

4.03 In general, the results obtained by the above estimates will indicate repeater gains of 1 to 5 db greater for intermediate repeaters than would be indicated where the idle circuit condition is controlling and zero return losses apply at the terminals. In addition, should the special service line under consideration be connected to other repeatered circuits the requirements for operating repeaters in series should be met.

4.04 In all instances where the above method of preselecting the usable repeater gain is followed it will be desirable to make gain tests and adjustments in the network strapping when the circuit is lined up. This should include both the idle condition and the talking condition based on representative connections at the circuit terminals. Talking tests should also be made.

4.05 Where idle circuit terminations are not provided or are impracticable and it is desired to obtain higher gains it would be advisable in all instances to make gain tests and to select the network strapping on the basis of the test results. It is probable that, in some cases, the return losses under the idle circuit condition may combine in a more favorable manner and higher gains may be obtained than indicated by the curves. Where this is done the measurements under the talking condition should be supplemented by talking tests on representative connections.

(B) Intermediate Signaling Equipment

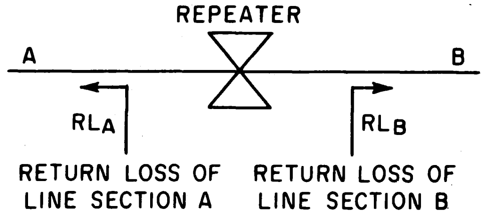
4.06 In cases where intermediate signaling equipment is used its presence in the line will have an effect not only on the maximum gain obtainable but also in some cases on the selection of the proper network strapping. As discussed above if the intermediate equipment is so arranged as to open the line in the idle circuit condition this usually eliminates the idle condition as controlling. In general where such equipment is at the repeater location and the impedance presented by it under the idle condition is higher than the line impedance the effect will be to decrease the relative importance of the idle condition and its effect on repeater gain. Where the signaling equipment is not near the repeater particularly where loading facilities intervene, such equipment may increase or decrease the impedance as seen from the repeater. The effect of this intermediate equipment on the proper network selection for the cases of loaded, nonloaded and combination facilities is discussed in Section AB22.152.1.

(C) Bridged Taps

4.07 On special service lines where loop facilities are used adjacent to a repeater as a part of the fixed line, bridged taps are sometimes encountered. Where predetermined network strappings are to be used the effect of such bridged taps on line loss should be neglected in using Fig. 3A or 3B to obtain the estimated usable repeater gain. In estimating the over-all loss, however, the line loss caused by the bridged tap should be taken into account. For the situations where network adjustments are to be made during the circuit line-up it can be assumed that approximately one-half of the added line loss due to the bridged tap can be compensated for by gains over the estimated values from Figs. 3A and 3B.

(D) AC Operation of Repeaters

4.08 In some special service applications it may be desired to install these repeaters in locations where standard repeater power supply is not available and in such small numbers that the provision of such a supply is not warranted. In such cases the repeaters may be operated on 110V ac power by means of a modified J68638A power supply unit. Each such unit will supply four series repeaters. Such use requires replacement of the 407A-type vacuum tube in the repeater with a type 396A tube to obtain 6.3-volt heater operation and requires strapping changes in both the power supply and the repeater. The details of these modifications are discussed in other sections of these practices.



NOTE: GAINS ARE BASED ON THE RETURN LOSS OF THE TWO LINE SECTIONS CONNECTED TO THE REPEATER.
WHEN THE CHARACTERISTIC IMPEDANCE OF LINE SECTION A DOES NOT EQUAL THAT OR LINE SECTION B, A GAIN CORRECTION, SHOWN ON FIG. 2, MUST BE ADDED.

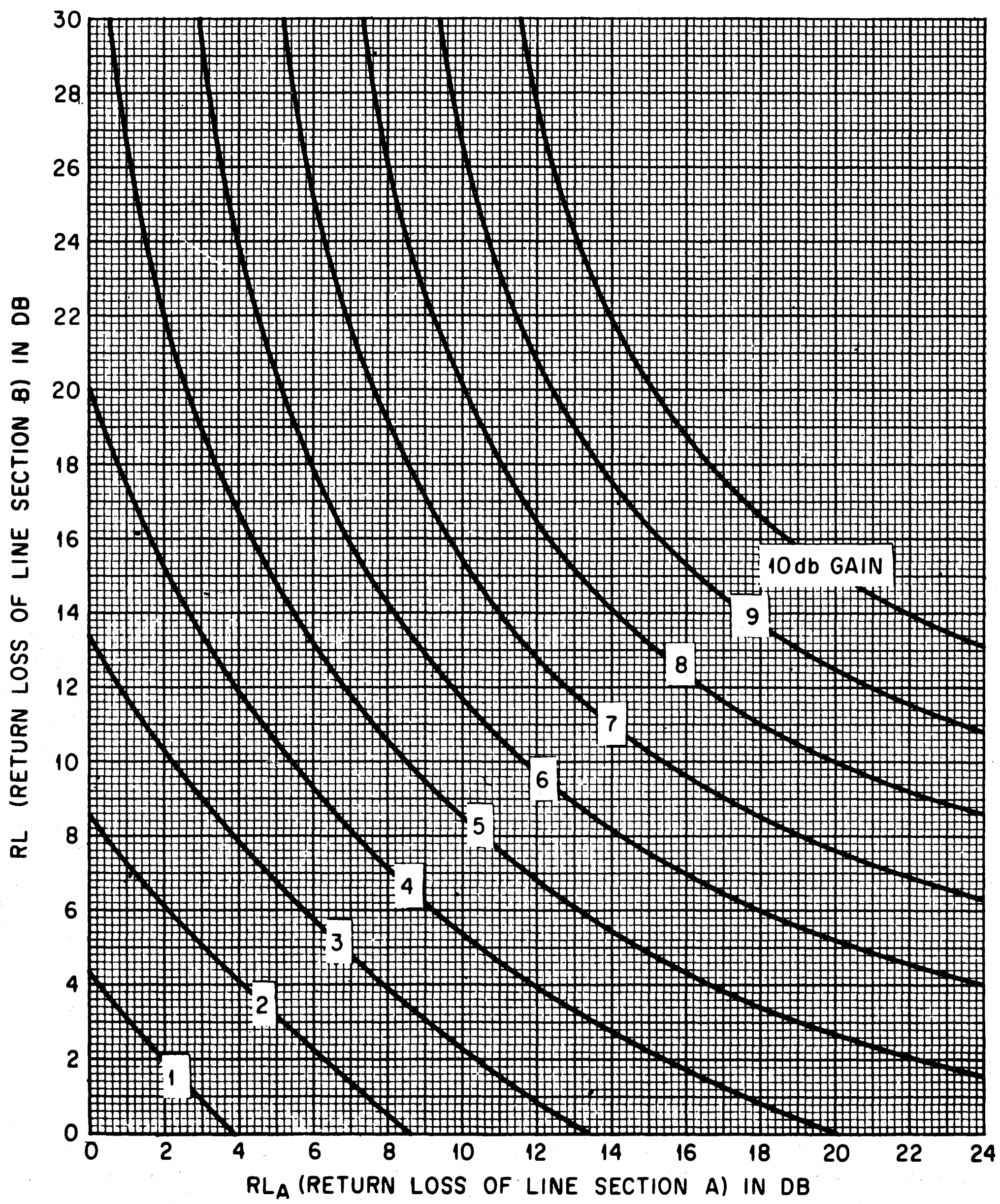


Fig. 1 - Maximum Nominal Repeater Gain

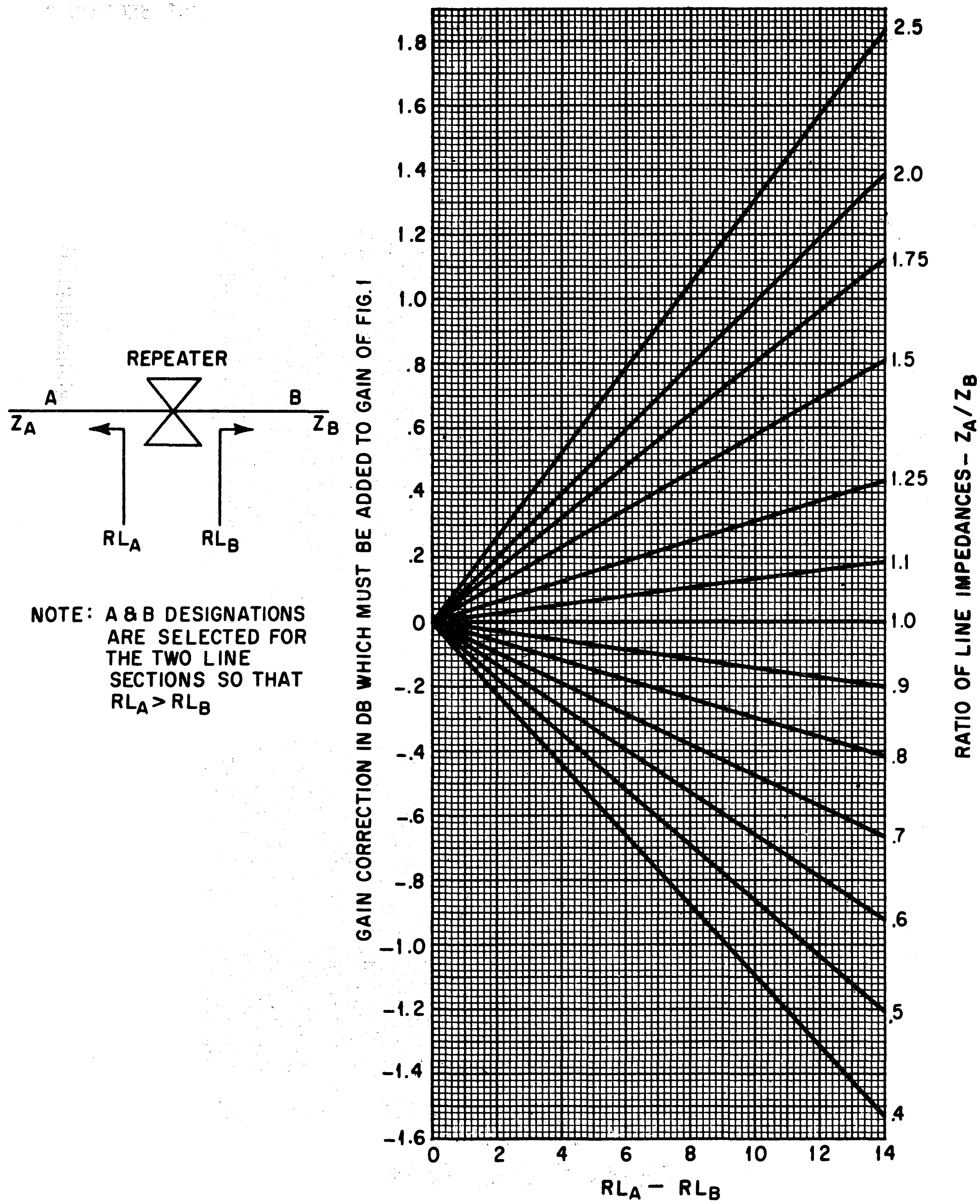
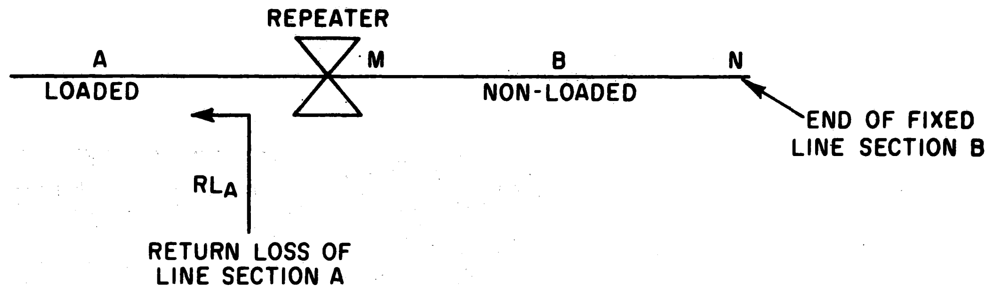


Fig. 2 - Gain Correction for Unlike Line Impedances



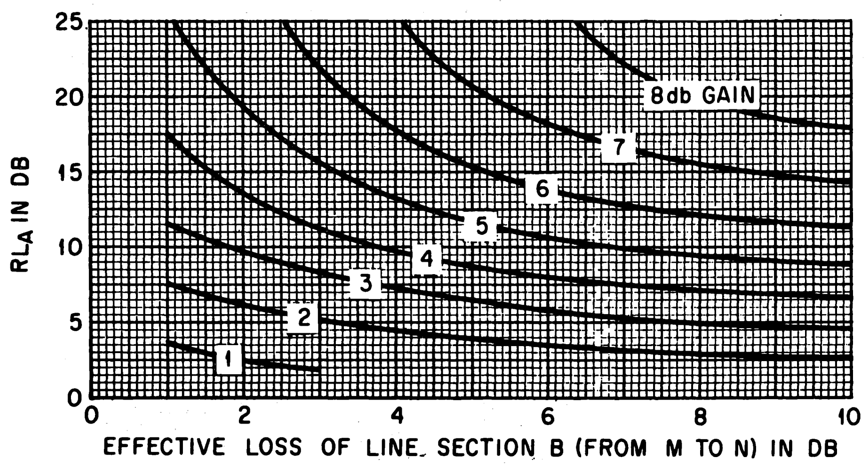


FIG. 3A
END SECTION 0.3 TO 0.9

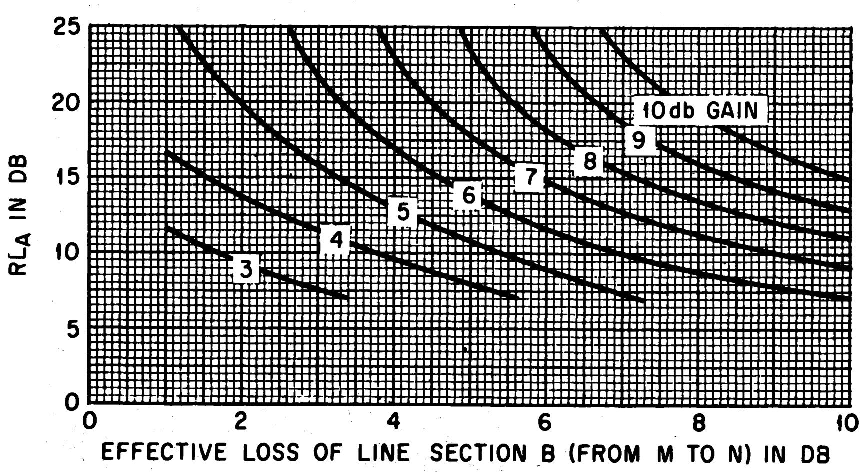


FIG. 3B
END SECTION 0.9 TO 1.5

Fig. 3 - Maximum Gain for Repeater between Loaded and Nonloaded Lines