BELL SYSTEM PRACTICES
Transmission Engineering and Data
Exchange Area Transmission Practices

SECTION AB22.151.3
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AT&TCo Standard

NEGATIVE IMPEDANCE REPEATERS

DESIGN OF CIRCUITS USING THE ET REPEATER ON LOADED FACILITIES

1. GENERAL

1.01 This section outlines the various aspects of circuit design involved in the use of the ET repeater. The determination of maximum usable gain is discussed in detail except with respect to the effect of echo limitations on toll connecting trunk design.

1.02 The ET repeater discussed in this section consists of two negative impedance elements. One is a series type which is connected into the line by means of two transformer windings in the same manner as if it were to be used alone. The other is a shunt type element connected to the center taps of the line windings associated with the series element to form a symmetrical arrangement. The following standard repeater elements may be used to provide this combination:

(1) Series element.

   (a) E2 repeater or

   (b) E1 repeater with center tapped coil.

(2) Shunt element.

   (a) E3 repeater unit.

The symmetrical combination of E1 and E3 elements is known as an E13 repeater and the symmetrical combination of E2 and E3 elements is known as an E23 repeater.

1.03 Other sections of the appropriate series of Bell System Practices will cover the following types of information:

(1) Equipment features.

(2) Operating principles.

(3) Network selection and strappings.

(4) Installation and maintenance procedures.

(5) Gain measurements.

(6) Return loss information.

(7) Echo considerations.

(8) Designations and symbols for layout purposes.

1.04 During the period of development, pilot Section AB22.150.0 will summarize the status of the various sections.

2. TRANSMISSION FEATURES OF THE ET REPEATER

2.01 Both the series element and the shunt element of the ET repeater include sets of network components from which a wide variety

of network designs may be obtained by the strapping of terminals. The network strappings determine both the gain and the image impedance of the ET repeater. In order to obtain maximum stability the match between the image impedance of the ET repeater and the characteristic impedance of the line is taken into consideration in the network designs not only in the frequency range for which gain is needed but up to and beyond the cutoff frequency of the facility.

2.02 The network designs for the series and shunt elements of the ET repeater are classified on the basis of the following considerations:

(1) Permissible value of gain based on the gain steps indicated in Table 3.

(2) Proper type of loading system, gauge of conductors and loading end section.

(3) Type of location:

  (a) Terminal repeater on loaded facilities.

  (b) Intermediate repeater between similar loaded facilities.

  (c) Intermediate repeater between unlike loaded facilities.

  (d) Intermediate repeater between loaded and nonloaded facilities.

  (e) Intermediate repeater between sections of nonloaded facilities. (Information for this type of application will be covered in another section.)

2.03 The ET repeater has two major advantages over the series type E repeater:

(1) More gain can be obtained.

(2) Close impedance matches are obtained between line and repeater.

2.04 Since the ET repeater is a symmetrical arrangement its image impedance is the same at both sides. If unlike facilities are connected to the two sides, the repeater can be made to match only one of them. In practice the repeater is made to match the lower cutoff facility. The design procedures cover methods for taking into account the mismatch between the repeater and the other facility. Such a mismatch limits the maximum allowable gain in much the same way as an irregularity in the line.

2.05 The gain obtained with a particular network strapping is not increased or decreased by the presence of an adjacent mismatch. This is true because a similar mismatch would exist even if the repeater were not present in the line.

2.06 The ET repeater is like any other 2-way gain producing device in that it will sing if the basic requirements for stability are not met. If the repeater were terminated on at least one side by an impedance exactly equal to the image impedance of the repeater, singing could not occur, since a signal traveling in the direction toward such a termination would be completely absorbed. In practice both lines present impedances which differ somewhat from that of the repeater and singing will occur if the gain is high enough, with a resulting limitation on the maximum usable gain. For circuit design purposes the variations of the line impedances from their characteristic impedance values are expressed in terms of the line return losses, with higher values indicating the smaller variations. The degree of mismatch between an ET repeater and a facility unlike the one for which the networks are designed is also expressed as a return loss, with higher values indicating smaller degrees of mismatch.

2.07 The ET repeater is not a perfect device and allowance must be made for possible variations of the repeater components and for the effects of unavoidable changes in operating conditions. As a result the recommended maximum usable gains are generally a little less than the highest stable gains which can be obtained by test and adjustment at the time of installation.

2.08 Unlike the series type negative impedance repeater the ET repeater is not open circuit stable. It is not feasible, therefore, to use circuit design methods that depend on opening the circuit adjacent to the repeater in order to maintain idle circuit stability.

2.09 From an effective transmission point of view the intermediate junction loss for the combination of two unlike facilities is applicable at the junction between the repeater and the unlike facility.

3. EFFECT OF ET REPEATERS ON PLANT ENGINEERING PRACTICES

3.01 The use of telephone repeaters in the design of exchange plant offers important advantages with respect to both transmission

and cost. The maximum benefits will be obtained, however, only if considerable attention is given to the achievement of smooth facility layouts. It is important, therefore, to aim toward uniform layouts and good load spacings in general plant engineering practices.

3.02 The transmission capabilities and the effect on signaling limits of the ET repeater should be given early consideration in each specific case.

4. CIRCUIT DESIGN PRINCIPLES

(A) Stability Design of Circuits Using ET Repeaters

4.01 The method of design for circuits using ET repeaters with which this section is primarily concerned is that which produces stable (nonsinging) circuits in the idle condition without idle line terminations. Stability is also required, of course, during any combination of circumstances which may occur during normal switching and signaling operations. For this reason this design method has been called the "stability design method." A line meeting the design objective may be described as being "passive" in the sense that it will not sing when connected to other passive lines or to terminations which are not negative impedances. This type of design applies to all exchange type trunks and from a singing standpoint is usually adequate for toll connecting and tributary trunks designed to a value of via net loss + 2.0 db (VNL + 2.0). However, its effect on echo return loss may require consideration as discussed in Paragraph 4.11.

4.02 Trunks using ET repeaters, requiring a via net loss (VNL) design, such as those between two crossbar tandem offices, or other 2-wire toll switching centers in a metropolitan area, will require idle circuit terminations at one or both ends. For such trunks the gain required is determined as the difference between the actual facility loss and the via net loss (VNL), usually 1 db or less. For such trunks a check for idle circuit stability only is made by assuming a 9.0 db return loss at the end or ends where terminations are provided and establishing that the permissible gain determined on this basis is greater than the actual gain assigned to the repeater to meet the VNL design.

4.03 The following steps indicate the usual procedure involved in the stability design of circuits using ET repeaters:

(1) Select a trial layout of facilities and a location for the ET repeater. The most favorable results will be obtained for intermediate locations in loaded facilities of uniform type with accurate coil spacing and with no major irregularities. For less desirable layouts the maximum usable gains indicated by the following steps will be a fair measure of their usefulness.

(2) Estimate the line return loss on each side of the repeater. For a single repeater line each line section will extend from the repeater to the end of the circuit. Assume a 0 db return loss at the remote end of each line section. For a terminal location the line return loss on the terminal side of the repeater will be simply 0 db. For other line sections refer the 0 db return loss to the repeater location by adding twice the loss of the line section. The return losses of any major load spacing irregularities, junctions between unlike facilities or intermediate equipment are also to be referred to the repeater location by adding to each twice the loss from the irregularity to the repeater. The structural return loss of the loaded facility adjacent to the repeater is obtained from data based on the type of facility and on the accuracy of the load spacing as measured by the reference deviation of the loading system. The referred return losses and the structural return loss are combined on a power summation basis to obtain the line return loss. The procedure just outlined and the method by which the return losses are combined are described in more detail in the section of this series on return losses. For some special service lines intermediate equipment may open the transmission path at a point closer to the repeater than the end of the circuit. In such instances the 0 db return loss point should be taken at the location of this equipment which is considered to be the end of the line section.

(3) If an ET repeater is located at the junction of two unlike loaded facilities the repeater networks, and hence the image impedance of the repeater, are based on the facility with the lower cutoff frequency. The junction return loss between the repeater and the other facility should be combined with the line return loss on that side of the repeater, on the current or in-phase basis. The combined value is then used in the same manner as a line return loss in obtaining the maximum usable gain in Step (5).

(4) If an ET repeater is located at a junction between a loaded and a nonloaded facility the network designs are based on the type of loaded facility. The junction return loss between the repeater and the nonloaded

facility should be combined with the line
return loss on that side of the repeater on
the current or in-phase basis. Typical
values of junction return losses are given in
Table 2. The resulting combined value is
used in the same manner as a line return loss in
obtaining the maximum usable gain in Step (5).
It should be noted that the usable gain of
the ET repeater at junctions between loaded
and nonloaded facilities is relatively low.

(5) From the line return losses use Fig. 1 to
obtain the maximum usable gain for the ET
repeater. In Table 3 are given values of
gain steps for which ET repeater networks
have been designed. If the reading of Fig. 1
indicates a value of gain which is not the
same as one of the gain steps of Table 3 the
next lower gain step represents the highest
available gain which will meet the stability
requirement.

4.04 The scope of this section is limited to
applications with at least one line sec-
tion which includes a loaded facility adjacent
to the repeater. For special service applica-
tions a line section may be considered to ex-
tend beyond the loaded facility into a nonloaded
section if the latter remains connected in the
idle condition. The procedure for estimating
line return losses in such cases is similar to
that for other repeaters and is covered in the
section of this series on return losses.

4.05 In laying out circuits which require the
use of more than one ET repeater the great-
est total gain will be obtainable for a uniform
facility if the loss between each end of the
circuit and the nearest repeater is in the
order of 4 to 5 db and also if the spacing be-
tween repeaters is in the general range of 7 to
9 db. In practice, of course, less favorable
arrangements will be necessary for various
reasons.

4.06 One way to design a line having more than
one repeater is to divide the line arbi-
trarily into several sections, each containing
one repeater, and to design each section as if
it were a separate line in itself. Such a
design method, however, restricts the gains
unnecessarily, since all the arbitrary sections
are permanently connected together. It has
been found empirically that the maximum gains
permissible for over-all stability may be
computed as follows:

Actual Layout

Treatment
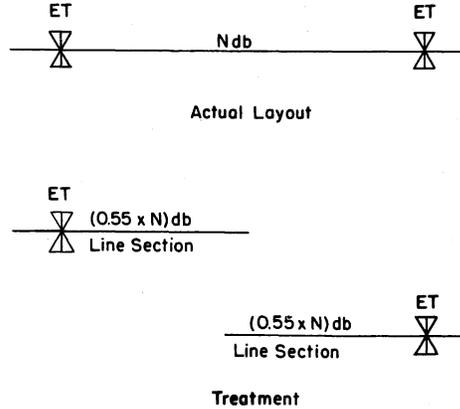
In estimating return losses the portion of a
line between two ET repeaters may be treated as
though its loss were 1.1 times its actual loss.
Normally this extended section will then be
split into two equal parts. This results in a
fictitious line section for each of the ad-
joining repeaters with a loss equal to 0.55
times the actual loss between the repeaters.
For example, if the loss between two ET repeaters
is 8.0 db each line section can be treated as
having a loss of $(8.0 \times 1.1) \div 2 = 4.4$ db.
This means that a 0 db return loss when re-
ferred to each of the repeaters results in a
value of 8.8 db to be combined with the struc-
tural return loss. See Paragraphs 6.05 and
6.06 for other examples. It is evident that
the computed permissible gain of each repeater
on a multirepeatered line may fall short of a
specific gain step by a small amount. As a
practical matter a gain step higher than the
maximum usable gain may be selected for one
repeater provided that the excess does not ex-
ceed the total margin at one or more other re-
peaters on the line.

4.07 If a series type repeater such as an E2
is to be operated in tandem with an ET-
type repeater it is desirable to assign to the
ET repeater more than 0.55 times the loss be-
tween the two repeaters, and to the E2 repeater
less, so that the total assigned to both is
still 1.1 times that amount. This is so be-
cause for each db added to the ET's line sec-
tion more additional gain can be obtained from
the ET than is lost to the E2. up to a certain
point. The line section for the ET repeater
may be extended beyond 0.55 times the loss be-
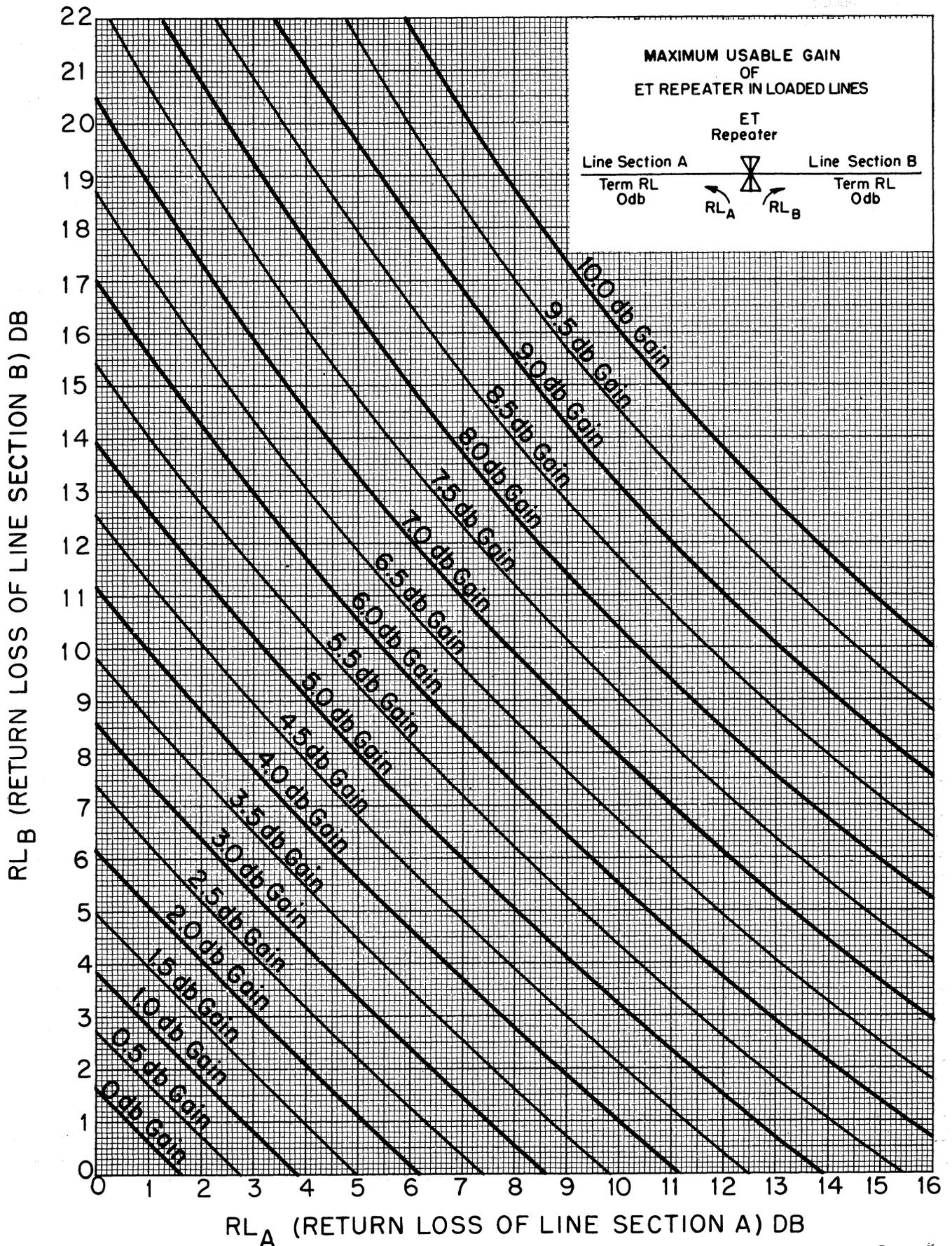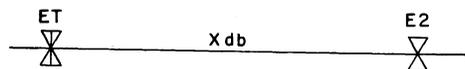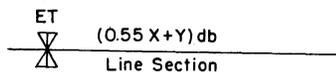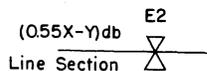tween repeaters up to the point where either

MAXIMUM USABLE GAIN OF ET REPEATER IN LOADED LINES

Fig. 1

ET   X db   E2

Actual Layout

ET   (0.55 X + Y) db
Line Section

(0.55 X − Y) db   E2
Line Section

Treatment

Y Should be as large as possible (up to 0.55 X db)
provided that the resulting usable gain for the ET
repeater is not higher than 9.8 db or highest feasible
gain step.

(1) the highest ET **repeater** gain step shown in Table 3 is used or (2) until the loss of the line section for the ET repeater becomes equal to 1.1 times the loss between the two repeaters. The loss of the line section for the series repeater should be reduced to a value which is less than 0.55 times the loss between repeaters by the same amount that the line section of the ET repeater exceeds this value. The extent to which the highest ET gain step permits the ET repeater line section to be extended can be arrived at by a cut and try process by assuming a series of trial values for the loss of the line section. See Paragraph 6.07 for an illustration of the procedure.

4.08 In Table 3 the 6.5 db gain step is indicated as the highest available for a terminal ET repeater. Network designs for gains higher than this will not be provided because of the crosstalk and stability limitations associated with terminal locations.

4.09 In referring return losses to the repeater location, this section assumes that facility losses at 68° F as given in Section AB43.175, will normally be used. A drop in temperature from 68° F to about 0° F may lower the transmission loss of loaded facilities in aerial cable by as much as 15 per cent. For underground cable a seasonal drop in transmission loss of about 7 per cent below the design value may be experienced. The effect of such loss variations is to temporarily reduce the return losses which determine the maximum usable gain of the repeaters. In areas where temperatures as low as 0° F can be expected it is

recommended that the loss of the aerial portion of a circuit be reduced by about 8 per cent in the process of estimating return losses. This treatment is based on the assumption that normal design procedures include sufficient margin against singing for layouts which are entirely in underground cable.

(B) Effect of the ET Repeater on Echo Return Losses

4.10 As previously discussed in Paragraph 4.01 if circuits using ET repeaters are designed in accordance with the methods described in this section they should meet the requirements for being passive. Even if the design method is extended to circuits of considerable length or if several circuits are operated in tandem, excessive talker echo should not occur. As a result no special consideration need be given to echo design for exchange area trunks which do not carry intertoll traffic.

4.11 Toll connecting plant must be designed with proper consideration of talker echo effects at both ends of intertoll connections. Since the design considerations are covered in detail in other sections this section will merely outline the recommended treatment of the ET repeater in the process of referring echo return losses to the toll switching center. Other steps in the procedure for estimating the echo return loss at the toll switching center and the proper interpretation of the result are covered in the sections which deal with toll connecting trunk design.

4.12 For a trunk with an intermediate ET repeater the echo return loss should be estimated for the portion of the circuit on the side of the ET repeater furthest from the toll switching center. This return loss is then combined with 26 db on a power basis as an allowance for the residual mismatch between the repeater and a facility of the type for which the repeater networks are designed. If the facility on the side of the repeater remote from the toll switching center is of a mismatched type an additional return loss from Table 1 should be combined on a power basis with the result. The combined value is then referred through the repeater by subtracting twice the gain. If a facility mismatch occurs on the side of the repeater nearest to the toll switching center a return loss from Table 1 should be combined on a power basis with the echo return loss at that point. The final result is then further referred to the toll switching center in the same manner as other echo return losses. Table 4 illustrates this procedure on a step-by-step basis.

4.13 For an ET repeater at a terminal location 26 db should be combined on a power basis with the echo return loss at the side of the repeater furthest from the toll switching center. The combined value is referred to the near side of the repeater by subtracting twice the gain. The result is then referred to the toll switching center in the same manner as other echo return losses.

(C) Avoidance of Overloading Effects

4.14 If an ET repeater is operated at excessively high output levels the result is a volume limiting effect on steady tones and some degree of volume compression on speech. This effect is quite different from the high harmonic production, distortion and blocking effects typical of nonlimiting amplifiers.

4.15 It is desirable as a general rule to design circuits using ET repeaters so that the repeater output level relative to a 0 db transmitting level at either circuit terminal will not exceed +8 db. This precaution will avoid appreciable limiting action on testing or signaling tones which are transmitted at levels which are no higher than 0 dbm and will limit possible interference with other services. In the case of special services for which speech volumes are regulated or controlled a maximum repeater output level of +8 vu is permissible. Any other maximum level restrictions based on other considerations which are applicable should also be observed.

(D) Crosstalk Considerations

4.16 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., at the local office end of tandem and toll connecting trunks, or at either end of direct interlocal trunks). If the gains of such terminal repeaters do not exceed 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 and do not, therefore, constitute firm limits but may be exceeded under certain conditions.

Type of Trunk Facility (Staggered Twist Cable)	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

In the case of nonstaggered twist cable the coupling distribution is such that "POOR" crosstalk conditions may result even with small gains. For intermediate repeaters the gains shown in the table 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 crosstalk considerations may not be controlling in the selection of repeater gain steps.

4.17 Special Service Lines: The gain values given in the table of Paragraph 4.16 assume that a trunk connects to a typical distribution of subscriber loops for which the 1000-cycle loss of the average loop is 4 db. In the assignment of repeater gains on special service lines the values given in the table may be decreased or increased by the amount that the 1000-cycle loss to the station terminal is less than or greater than 4 db with a resultant index of "GOOD."

4.18 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 per cent) are to be repeatered, the gains given in the table may be as much as doubled and an index of "GOOD" still be obtainable.

4.19 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 be obtained by applying a reduction of the same amount to the gains determined in Paragraph 4.16. This principle applies, of course, to any other station equipment with higher receiving efficiency than the F1A-HA1 instrument.

(E) Signaling and Supervision Considerations

4.20 The series element of the ET repeater is coupled into a line by means of two separate windings of a transformer which together introduce a total loop dc resistance of about 40 ohms. In simplex signaling applications these windings introduce about 10 ohms of noninductive resistance in the signaling path.

4.21 Studies which are under way to determine the effects of the ET repeater on signaling ranges have not been completed. In the meantime the following recommendations will

provide a guide for current engineering. It is expected that replacing information will be included in the standard signaling range charts when available. In all the following cases the actual dc resistance of the repeater should be considered part of the trunk conductor loop except that when a resistance penalty is given, as in Paragraphs 4.25 and 4.26, this allowance is included in the penalty and should not be separately applied.

4.22 PCI Trunks: On PCI trunks which terminate in crossbar tandem or panel sender tandem, including CAMA equipped offices, a maximum of two ET repeaters may be used. On PCI trunks from panel equipment to manual offices a maximum of one ET repeater may be used. On PCI trunks from crossbar equipment to manual offices a maximum of two ET repeaters may be used.

4.23 Revertive Trunks: On revertive signaling trunks terminating in crossbar type offices a maximum of two ET repeaters may be used. On revertive trunks terminating in battery cutoff panel offices one ET repeater may be used provided that the trunk length does not exceed 16 miles. For revertive trunks terminating in ground cutoff panel offices the use of ET repeaters is not recommended either for nonrepeating or repeating incoming circuits.

4.24 Dial Pulsing Trunks Terminating in Crossbar Offices: On dial pulsing type trunks originating at manual or sender type offices and terminating in crossbar tandem offices other than CAMA no penalty other than the dc resistance effect is required for the use of one or two ET repeaters. Dial pulsing trunks from step-by-step offices to No. 5 crossbar offices which operate on a bylink basis fall into two general classes. (1) Short range bylink trunks with published ranges of 2000 ohms and 23 miles may be equipped with one or two ET repeaters without penalty other than the dc resistance effect. (2) Long range bylink trunks with a published range of 4200 ohms and 24 miles in 22 gauge or 32 miles in 19 gauge may be equipped with one ET repeater if the cable length does not exceed 20 miles. The use of two ET repeaters is not recommended. Trunks from step-by-step offices to CAMA equipped tandem offices may be equipped with one ET repeater with no penalty other than the dc resistance effect, but the use of two ET repeaters is not recommended.

4.25 Dial Pulsing Trunks Terminating in Step-by-Step Equipment: On dial pulsing trunks with battery and ground signaling from SD-31779, SD-31929, SD-32008 or SD-31147 outgoing DP repeaters at the originating end and terminating in typical step-by-step incoming selector and connector switch trains one or two ET repeaters may be used. With SD-31648 outgoing DP repeaters the cable length should be limited to 20 miles if two ET repeaters are used. The addition of

ET repeaters to working trunks may necessitate an adjustment of the pulse relay of the outgoing DP repeaters to meet the specified pulse repeating requirements. On dial pulsing trunks which use battery and ground pulsing from senders at the originating end and which terminate in step-by-step equipment or in SD-31779 out repeaters at step-by-step tandem a maximum of two ET repeaters may be used. For dial pulsing trunks using loop pulsing either from senders or from manual SD-15346 out trunks equipment and terminating in step-by-step equipment one or two ET repeaters may be used except that the cable length should not exceed 20 miles for two ET repeaters when the SD-31648 incoming repeater is used. Toll trunks (nonintertoll) using SD-55255 or SD-55346 outgoing circuits may be equipped with one or two ET repeaters. Intertoll trunks using SD-55301 or SD-64473 outgoing circuits may be equipped with one ET repeater, only, if the conductor loop is limited to 1700 ohms.

4.26 20-Cycle Ringing Ranges: The effect of the ET repeater on 20-cycle ringing ranges will be to reduce the maximum loop resistance by 400 ohms for one repeater and by 750 ohms for two repeaters.

5. LOADING END SECTION TREATMENT AT ET REPEATERS

(A) Terminal Location (See Table 5)

5.01 The maximum usable gain will be obtainable if the loading end section falls within the range of 0.4 to 0.6 section, inclusive, with the reference spacing being the average, on a capacitance basis, for the loaded facility. End section values should include an allowance for office cabling for situations where appreciable lengths are involved. For end sections shorter than 0.4 section, capacitance building-out should be used with 0.5 section being the objective value within the precision of available units. The E2 repeater includes three capacitance units, one 0.01 mf and two 0.02 mf, which have a common terminal and may be used in the various possible combinations for building-out purposes on either side but not on both sides of the repeater. To correct an end section longer than 0.6 section requires: (1) precision capacitance building-out of the existing end section to a full section, (2) a full weight loading coil and, (3) capacitance building-out to the 0.4 to 0.6 section range using the capacitance units included in the repeater.

5.02 For a loading end section longer than 0.6 section a penalty of 0.2 db for each 0.1 section above 0.6 must be applied to the gain of a terminal ET repeater if the cost of building-out to eliminate this penalty can not be justified. For example, if the end section is 0.8 the gain obtained will be (2 x 0.2) = 0.4 db less than the nominal gain step value. The

application of this penalty does not affect the choice of gain step on which the network designs are based. Because of increasing response-frequency distortion it is generally advisable not to permit the end section to exceed 0.8 section. When necessary, however, satisfactory operation for end sections up to about 1.2 sections can be obtained by means of field tests and special network adjustments.

(B) Intermediate Location between Loaded Facilities of the Same Type (See Table 6)

5.03 The end sections adjacent to an intermediate repeater should preferably fall within the range of 0.4 to 0.6 section with the reference spacing being the average, on a capacitance basis, for the loading system involved. Allowance should be made for office cabling if appreciable lengths are involved. In any case, the sum of the two end sections should be at least 1.0 section. An end section less than 0.4 section should be built out with capacitance to fall in the 0.4 to 0.6 range, considering also that the sum of the two end sections should be at least 1.0 section. If either or both of the end sections exceeds 0.6 section a penalty must be applied to the gain of the ET repeater. The amount of the penalty is based on the excess of the larger fractional end section over 0.6 section and on the gain of the repeater. It may be found by multiplying one half the gain of the repeater by the excess of the larger end section over 0.6. For example, if the repeater gain is 8.0 db and the larger fractional end section is 0.8 section the penalty will be (8.0 ÷ 2) 0.2 = 0.8 db. Since this penalty is essentially an allowance for response-frequency distortion, it is not advisable to permit either end section to exceed 0.8 section. To correct a section larger than 0.6 requires: (1) precision capacitance building-out of the existing section to a full section, (2) a full weight loading coil and, (3) capacitance building-out to the 0.4 to 0.6 section range. The sum of the two resulting end sections should be at least 1.0 section.

(C) Intermediate Location between Unlike Facilities (See Table 6)

5.04 The treatment of end sections adjacent to an intermediate ET repeater operating between unlike loaded facilities is the same as for similar loaded facilities. The only difference is that the basis of reference for the fractional length of each of the two end sections is the average load spacing for the loading system of that particular facility.

6. EXAMPLES

6.01 The following typical examples show the methods by which maximum usable gains are computed in each case.

6.02 Terminal Location on a Loaded Facility.

EXAMPLE 1
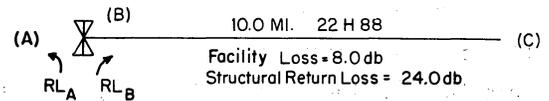
Terminal R.L. at (C) = 0 db

Term. R.L. referred to (B) 0 + (2x8.0) = 16.0 db

Structural Return Loss = 24.0 db

Difference 24.0 - 16.0 = 8.0 db
     Comb. Term = 0.6 db (Section AB47.872)

Line Return Loss at (B) 16.0 - 0.6 = 15.4 db

Max. Usable Gain (Fig. 1, RL_A = 0 db, RL_B = 15.4 db) = 5.5 db

Gain Step (Table 3) = 5.0 db

Overloading (Paragraph 4.14) - Repeater output level at (B) is +5.0 db relative to 0 db at (A).

This is well under +8 db.

Crosstalk Rating (Paragraph 4.16) - "GOOD" or better since gain from (B) to (A) is 5.0 db which is under 6.0 db (H88 facility beyond repeater).

6.03 Intermediate Location in a Loaded Facility.

EXAMPLE 2

Terminal R.L. at (A) or (D) = 0 db

Term. R.L. referred to (B) or (C) 0 + (2x4.0) = 8.0 db

Structural Return Loss = 24.0 db

Difference 24.0 - 8.0 = 16.0 db
    Comb. Term = 0.1 db (Section AB47.872)

Line Return Loss at (B) or
    (C) 8.0 - 0.1 = 7.9 db

Max. Usable Gain (Fig. 1, RL_A = 7.9 db,
    RL_B = 7.9 db) = 6.2 db
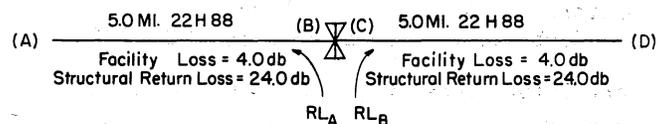
    Gain Step (Table 3) = 5.8 db

    Overloading (Paragraph 4.14) - Repeater
    output level at (C) or (B) relative to 0 db
    at (A) or (D) is +1.8 db.

    This is well under +8 db.

    Crosstalk Rating (Paragraph 4.16) - "GOOD"
    or better since net gain from (C) to (A) or
    (B) to (D) is 5.8 - 4.0 = 1.8 db which is
    under 6.0 db (H88 facility beyond repeater).

6.04 Intermediate Location between Unlike Loaded Facilities.

EXAMPLE 3
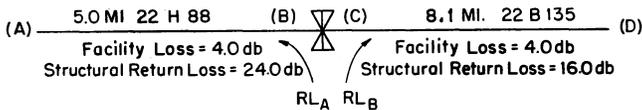
Terminal R.L. at (A) = 0 db

Term. R.L. referred to (B) 0 + (2x4.0) = 8.0 db

    Structural R.L. = 24.0 db

Difference 24.0 - 8.0 = 16.0 db
    Comb. Term = 0.1 db (Section AB47.872)

Line Return Loss at (B) 8.0 - 0.1 = 7.9 db

    RL_A = 7.9 db

    Term. R.L. at (D) = 0 db

Term. R.L. referred to (C) 0 + (2x4.0) = 8.0 db

    Structural R.L. = 16 db

Difference 16.0 - 8.0 = 8.0 db
    Comb. Term = 0.6 db (Section AB47.872)

Line Return Loss at (C) 8.0 - 0.6 = 7.4 db

HC B135 is the higher cutoff facility (Table 1)

Junction Return Loss at (C) (Table 1) = 11.8 db

Difference 11.8 - 7.4 = 4.4 db
    Comb. Term = 4.1 db (Section AB47.872)

    RL_B = 7.4 - 4.1 = 3.3 db

Max. Usable Gain (Fig. 1, RL_A = 7.9 db
    RL_B = 3.3 db) = 4.2 db

   Gain Step (Table 3) = 3.5 db

    Overloading (Paragraph 4.14) - Repeater
    output level at (C) or (B) relative to 0 db
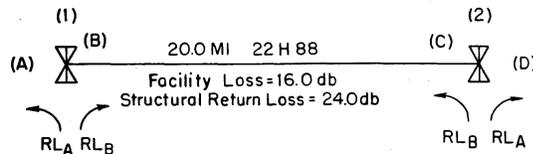   at (A) or (D) is -0.5 db.

    This is well under +8 db.

    Crosstalk Rating (Paragraph 4.16) - "GOOD"
    or better since net gain from (C) to (A) is
    3.5 - 4.0 = -0.5 db which is under 3.0 db
    (B135 facility beyond repeater) and net
    gain from (B) to (D) is 3.5 - 4.0 = -0.5 db
    which is under 6.0 db (H88 facility beyond
    repeater).

Effective Intermediate Junction Loss at (C) =
    0.4 db (Section AB43.176)

6.05 Two Terminal Repeaters on a Loaded Facility.

EXAMPLE 4

Each line section between (B) and (C)
16.0 x 0.55 = 8.8 db (Paragraph 4.06)

0 db referred to (B) or (C)
                0 + (2x8.8) = 17.6 db

    Structural R.L. = 24 db

Difference 24.0 - 17.6 = 6.4 db
    Comb. Term = 0.9 db (Section AB47.872)

Line Return Loss at (B) or (C) 17.6 - 0.9 =
    16.7 db

Gain at (1) or (2) (Fig. 1, RL_A = 0,
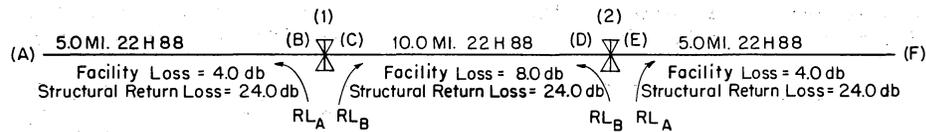 RL_B = 16.7) = 5.9 db

    Gain Step (Table 3) = 5.8 db

    Total Gain = 11.6 db

    Overloading (Paragraph 4.14) - Repeater
    output level at (B) or (C) relative to 0 db
    at (A) or (D) is +5.8 db which is well
    under +8 db.

    Crosstalk Rating (Paragraph 4.16) - "GOOD"
    since net gain from (B) to (A) or (C) to
    (D) is 5.8 db which is under 6.0 db (H88
    facility beyond repeater).

EXAMPLE 5

6.06 **Two Intermediate Repeaters in a Loaded Facility.**
See sketch for Example 5.

0 db at (A) or (F) referred to (B) or (E)
    0 + (2x4.0) = 8.0 db

    Structural R.L. = 24 db

Difference 24.0 - 8.0 = 16 db
    Comb. Term = 0.1 db (Section AB47.872)

Line Return Loss at (B) or (E) 8.0 - 0.1 = 7.9 db

Each Line Section between (C) and (D) 8.0 x
    0.55 = 4.4 db (Paragraph 4.06)

0 db referred to (C) or (D) 0 + (2x4.4) = 8.8 db

    Structural R.L. = 24 db

Difference 24.0 - 8.8 = 15.2 db
    Comb. Term = 0.1 db (Section AB47.872)

Line Return Loss at (C) or (D) 8.8 - 0.1 = 8.7 db

Gain at (1) or (2) (Fig. 1, RL_A = 7.9 db,
    RL_B = 8.7 db) = 6.5 db

    Gain Step (Table 3) = 6.5 db

    Total Gain = 13.0 db

    Overloading (Paragraph 4.14) - Repeater
    output level at (C) or (D) relative to 0 db
    at (A) or (F) is +2.5 db. This is well
    under +8.0 db.

Crosstalk Rating (Paragraph 4.16) - "GOOD" or
better since net gain from (C) to (A) or (D) to
(F) is 2.5 db which is well under 6.0 db (H88
facility beyond repeater).

6.07 **ET Repeater in Tandem with a Series Type Repeater.**
See sketch for Example 6.

Line Return Loss at (B) or (E) = 7.9 db
(Paragraph 6.06, Example 5)

ET Repeater Gain

Trial 1

Assume that 1.1 times the line section loss
between (C) and (D) is all associated with
the ET repeater.

    Line Section at (C) = 8.8 db

    0 db referred to (C) 0 + (2x8.8) = 17.6 db

Structural Return Loss = 24 db

Difference 24.0 - 17.6 = 6.4 db

Comb. Term = 0.9 db (Section AB47.872)

Line Return Loss at (C) 17.6 - 0.9 = 16.7 db

Maximum Usable Gain of ET (Fig. 1, RL_A =
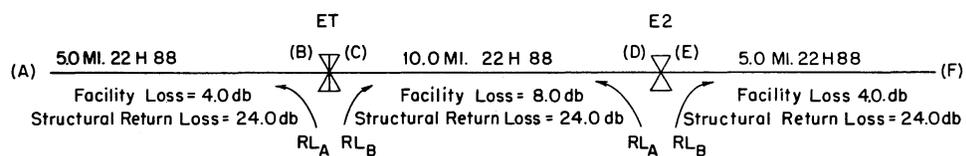   7.9 db, RL_B = 16.7 db) = 9.3 db

Gain Step (Table 3) = 9.2 db

Trial 2

Reduce Trial 1 ET repeater line section to
    8.5 db

    0 db referred to (C) 0 + (2x8.5) = 17.0 db

    Structural Return Loss = 24 db

    Difference 24.0 - 17.0 = 7.0 db

EXAMPLE 6

Comb. Term = 0.8 db (Section AB47.872)

Line Return Loss at (C) 17.0 - 0.8 = 16.2 db

Maximum Usable Gain of ET (Fig. 1, RL_A = 7.9 db, RL_B = 16.2 db) = 9.2 db

Gain Step for ET (Table 3) = 9.2 db

Although in this case the second trial resulted in the same gain step for the ET repeater as the first trial, the line section remaining for the E2 repeater was increased slightly.

E2 Repeater Gain

Line Section at (D) 4.4 - (8.5 - 4.4) = 0.3 db (Paragraph 4.07)

0 db referred to (D) 0 + (2x0.3) = 0.6 db

Structural Return Loss = 24 db

Difference 24.0 - 0.6 = 23.4 db

Comb. Term = 0 db (Section AB47.872)

Line Return Loss at (D) (0.6 - 0.0) = 0.6 db

Maximum Usable Gain of E2 Repeater (RL_A = 0.6 db, RL_B = 7.9 db) = 2.0 db (Section AB22.151.1, Fig. 1)

Gain Step for E2 (Table 3) = 2.0 db
    Total Gain (9.2 + 2.0) = 11.2 db

For comparison, the total gain with an equal division between the two line sections between (C) and (D) may also be obtained.

ET repeater gain   6.5 db (Paragraph 6.06)
E2   "   "   3.5 db (Section AB22.151.1)

Total Gain   =   10.0 db

7. LIST OF ATTACHMENTS

(A) Table 1 - Junction Return Losses for Use at ET Repeaters for Combinations of Unlike Loaded Facilities

(B) Table 2 - Junction Return Losses for Use at ET Repeaters When One Facility Is Nonloaded

(C) Table 3 - Network Gain Steps for ET Repeaters - In Loaded Facilities

(D) Table 4 - Echo Return Loss Treatment at an Intermediate ET Repeater

(E) Table 5 - Terminal ET Repeater - Loading End Section Treatment

(F) Table 6 - Intermediate ET Repeater - Loading End Section Treatment

Attached:
    Tables 1 to 6

TABLE 1

JUNCTION RETURN LOSSES

FOR USE AT ET REPEATERS

FOR COMBINATIONS OF UNLIKE LOADED FACILITIES

(Note 1)

Higher Cutoff Facility (Notes 2 and 3)	Lower Cutoff Facility (Notes 2 and 3)														
	LC H175	HC H135	HC M88	LC H135	LC M88	HC H88	LC H88	LC B175	HC B135	HC D88	LC B135	LC D88	HC H44	HC B88	LC H44
HC H135	17.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HC M88	9.6	13.3	-	-	-	-	-	-	-	-	-	-	-	-	-
LC H135	18.4	29.3	12.3	-	-	-	-	-	-	-	-	-	-	-	-
LC M88	9.9	14.1	19.8	13.6	-	-	-	-	-	-	-	-	-	-	-
HC H88	10.4	14.8	22.4	14.4	21.0	-	-	-	-	-	-	-	-	-	-
LC H88	10.9	15.8	19.7	15.4	18.9	29.5	-	-	-	-	-	-	-	-	-
LC B175	16.2	11.2	7.3	12.9	7.8	8.3	9.3	-	-	-	-	-	-	-	-
HC B135	23.8	16.3	9.6	19.5	10.5	11.8	12.7	17.8	-	-	-	-	-	-	-
HC D88	11.6	17.0	17.5	16.5	18.5	24.2	28.4	9.6	13.7	-	-	-	-	-	-
LC B135	21.0	13.7	8.5	15.9	9.1	10.2	11.0	19.7	24.9	12.0	-	-	-	-	-
LC D88	13.0	20.2	15.5	19.3	16.2	20.3	23.4	10.3	14.7	22.0	13.6	-	-	-	-
HC H44	6.2	8.5	14.8	8.3	14.0	13.6	11.8	5.1	6.8	11.2	6.2	10.0	-	-	-
HC B88	14.2	23.1	12.5	22.0	14.4	15.7	17.3	11.0	15.9	19.4	14.0	27.2	9.7	-	-
LC H44	6.8	9.1	16.5	9.0	15.2	15.0	12.5	5.5	7.1	12.0	6.5	10.5	28.4	10.2	-
LC B88	15.8	20.5	12.0	25.3	12.6	14.8	16.3	12.0	17.8	18.2	14.8	20.8	9.3	23.7	9.7

Note 1: The return loss values in this table are based on midsection impedances of typical grades of plant at either 1000 cycles or at a frequency near the critical frequency of the lower cutoff facility according to which return loss is lower.

Note 2: The designation HC indicates cable pairs with a capacitance of 0.075 mf per mile or greater (Section AB42.027).

Note 3: The designation LC indicates cable pairs with a capacitance less than 0.075 mf per mile (Section AB42.027).

TABLE 2

JUNCTION RETURN LOSSES FOR USE AT ET REPEATERS

WHEN ONE FACILITY IS NONLOADED

(Note 1)

Loaded Facility (Notes 2 and 3)	Nonloaded (Notes 2 and 3)						
	26LC	26HC	24LC	24HC	22C	19LC	19HC
26LC-H88	5.6	5.3	4.5	4.1	3.4	2.7	2.5
26HC-H88	6.4	6.0	5.0	4.5	3.8	3.1	2.7
24LC-B88	3.2	3.0	2.6	2.4	2.0	1.6	1.5
24LC-H88	5.6	5.3	4.4	4.1	3.4	2.7	2.5
24HC-B88	3.6	3.4	2.9	2.7	2.2	1.8	1.6
24HC-H88	6.3	5.8	5.0	4.6	3.8	3.1	2.7
22 -B88	3.5	3.3	2.8	2.6	2.1	1.8	1.6
22 -H88	5.9	5.6	4.7	4.4	3.6	3.0	2.6
22 -B135	3.1	3.0	2.5	2.3	1.9	1.6	1.4
19LC-B88	3.0	2.8	2.4	2.2	1.8	1.5	1.3
19LC-D88	4.0	3.8	3.2	3.0	2.4	2.0	1.8
19LC-H88	4.9	4.6	3.9	3.6	3.0	2.5	2.2
19LC-B135	2.6	2.5	2.1	1.9	1.6	1.3	1.2
19LC-H135	4.4	4.1	3.5	3.2	2.6	2.2	1.9
19LC-H175	4.1	3.9	3.2	3.1	2.5	2.0	1.8
19HC-B88	3.5	3.3	2.8	2.6	2.1	1.8	1.6
19HC-D88	4.7	4.4	3.8	3.5	2.8	2.4	2.1
19HC-H88	5.8	5.4	4.6	4.3	3.6	2.9	2.6
19HC-B135	3.1	3.0	2.5	2.3	1.9	1.6	1.4

Note 1: These return losses are based on the midsection impedance of the loaded facility at the critical frequency of that facility.

Note 2: The designation HC indicates cable pairs with a capacitance of 0.075 mf per mile or greater (Section AB42.027).

Note 3: The designation LC indicates cable pairs with a capacitance less than 0.075 mf per mile (Section AB42.027).

TABLE 3

NETWORK GAIN STEPS FOR ET REPEATERS

IN LOADED FACILITIES

ET Repeater Gain Step	Corresponding E1 or E2 Repeater Network
1.9 db	1.0 db
2.7 "	1.5 "
3.5 "	2.0 "
4.3 "	2.5 "
5.0 "	3.0 "
5.8 "	3.5 "
6.5 "	4.0 "
7.3 ")	4.5 "
8.0 ")	5.0 "
8.6 ") See Note	5.5 "
9.2 ")	6.0 "
9.8 ")	6.5 "

Note: For terminal ET repeaters on loaded facilities 6.5 db will be the highest gain for which network designs are available.

TABLE 4

## ECHO RETURN LOSS TREATMENT

AT AN INTERMEDIATE ET REPEATER

Toll Switching Center (A) — Facility 1 — ET (B) (C) — Facility 2 — (D)
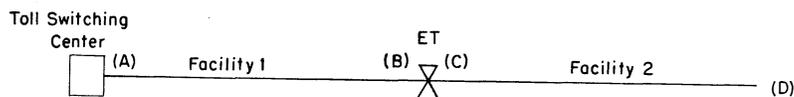
Condition for Facility 1 and Facility 2	Step	Echo Return Loss Treatment at ET Repeater
(A) Both of Same Type	(1)	Compute echo return loss at (C) looking toward (D).
	(2)	Combine with 26 db on power basis.
	(3)	Subtract (2 x G).
	(4)	Refer result to (A).
(B) Cutoff of Facility 1 Lower than Cutoff of Facility 2	(1)	Steps (1) and (2) of (A).
	(2)	Combine result with junction return loss from Table 1 on power basis.
	(3)	Steps (3) and (4) of (A).
(C) Cutoff of Facility 2 Lower than Cutoff of Facility 1	(1)	Steps (1), (2), and (3) of (A).
	(2)	Combine result with junction return loss from Table 1 on power basis.
	(3)	Step (4) of (A).

TABLE 5

TERMINAL ET REPEATER

LOADING END SECTION TREATMENT
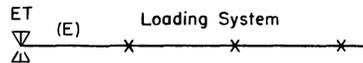
End Section (E) = $\dfrac{\text{Capacitance between Repeater and Adjacent Loading Coil}}{\text{Capacitance of Average Loading Section}}$
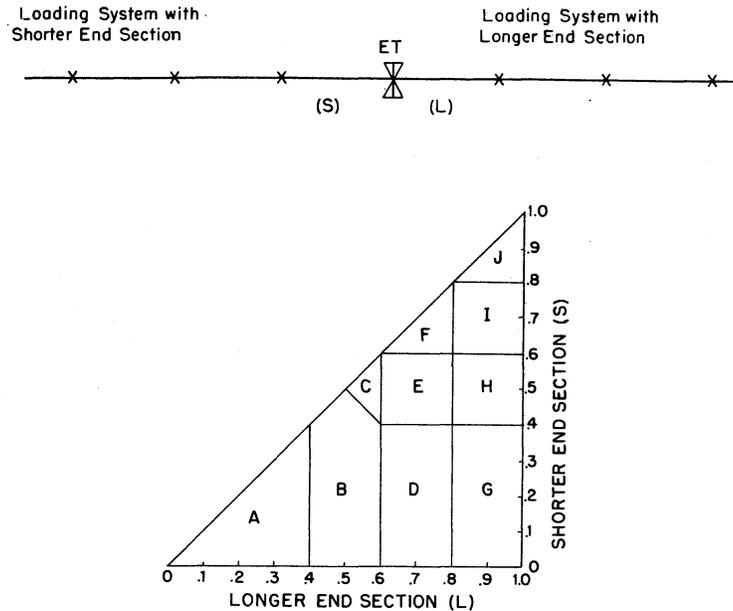
END SECTION (E)	ACTION	PENALTY (Note 1)
0 to 0.39	Build out to 0.4 to 0.6 range as closely to 0.5 as practicable with available units.	None
0.4 to 0.6	None	None
0.61 to 0.8	None	2(E - 0.6) db
0.61 to 0.8 (ALT)	Build out to 1.0 add a full coil and build out end section to 0.4 to 0.6 range as closely to 0.5 as practicable with available units.	None
0.81 to 1.2 (Note 2)	Same as 0.6 to 0.8 (ALT)	None

Note 1: The penalties apply assuming that the indicated action is taken.

Note 2: See Paragraph 5.02 for conditions which permit end sections beyond 0.8 section.

TABLE 6

INTERMEDIATE ET REPEATER
LOADING END SECTION TREATMENT

Loading System with
Shorter End Section

Loading System with
Longer End Section

ET

×   ×   ×   ×   ×   ×

(S)   (L)

[Graph: Triangular plot with LONGER END SECTION (L) on horizontal axis (0 to 1.0) and SHORTER END SECTION (S) on vertical axis (0 to 1.0). Regions labeled A, B, C, D, E, F, G, H, I, J.]

The shorter end section (S) and the longer end section (L) are expressed as decimal fractions of the average spacing on a capacitance basis for the respective loading systems.

AREA	ACTION	PENALTY (Note)
A	Build out L and S to bring both L and S into 0.4 to 0.6 range and (L + S) to at least 1.0.	None
B	Build out S to 0.4 to 0.6 range so that (L + S) is at least 1.0 and exceeds it as little as possible.	None
C	None .	None
D	Build out S to 0.4 to 0.6 range but hold excess of (L + S) over 1.0 to a minimum.	$\frac{G}{2}$ (L − 0.6) db
D (ALT)	Build out S to 0.4 to 0.6 range and also build out L to full section add a full coil and build out end section to 0.4 to 0.6 range so that the sum of the end sections is at least 1.0.	None
E	None	$\frac{G}{2}$ (L − 0.6) db
E (ALT)	Build out L to full section add a full coil and build out end section to 0.4 to 0.6 range so that the sum of the end sections is at least 1.0.	None
F	None	$\frac{G}{2}$ (L − 0.6) db
F (ALT)	Build out both L and S to full section add full coils and B.O. end sections to 0.4 to 0.6 range so that the sum of the end sections is at least 1.0.	None
G	Same as D (ALT).	None
H	Same as E (ALT).	None
I	Build out L to full section add a full coil and build out end section to the 0.4 to 0.6 range.	$\frac{G}{2}$ (S − 0.6) db
I (ALT)	Same as F (ALT).	None
J	Same as F (ALT).	None

Note: The penalties apply assuming that the indicated action is taken.