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NEGATIVE RESISTANCE AND NEGATIVE IMPEDANCE VOICE FREQUENCY REPEATERS AND VOICE FREQUENCY REPEATERED TRUNKS

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1. INTRODUCTION

1.01 This section is intended to provide REA borrowers, consulting engineers, contractors and other interested parties with technical information for use in the design and construction of REA borrowers' telephone systems. It discusses in particular the design of loaded two-wire trunks intended for negative resistance/impedance type voice frequency repeater applications. The engineering of hybrid type repeaters (V type) is not discussed in this section.

1.02 Specifically, this issue discusses the engineering considerations involved when designing loaded trunks on which E-6[1] (negative resistance) type or E-23[2] (negative impedance) type repeaters will operate and provides step-by-step engineering procedures for dealing with the following applications:

a. Uniform gauge cables.
b. Mixed gauge cables.
c. Mixed facilities.
d. Voice frequency extensions of carrier or radio systems.

1.021 In addition to the design procedures mentioned above, this section also discusses:

a. The theory of operation of negative resistance and negative impedance repeaters.

b. The type of measurements normally made on loaded repeatered trunks and the forms used for recording data.

2. GENERAL REPEATER DESIGN CONSIDERATIONS

2.01 Correct Time for Repeater Design

The correct time for carrying out the design of trunk circuits over which voice frequency repeaters will operate (repeater design) is early in the ACD stage. During this time it must be determined that applicable transmission objectives will be met. The method for determining this becomes relatively easy since one of the distinguishing characteristics of negative resistance/impedance

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[1]Hereinafter the term "negative resistance" repeater will be used to denote a voice frequency repeater having performance characteristics comparable to the Western Electric E-6 Negative Resistance Repeater.

[2]Hereinafter the term "negative impedance" repeater will be used to denote a voice frequency repeater having performance characteristics comparable to the Western Electric E-23 Negative Impedance Repeater.

repeaters is that their gain capabilities can be determined accurately well in advance. Adherence to the good practice of designing the repeaters during the ACD stage helps to eliminate many conflicts which may otherwise arise and which become difficult to resolve.

2.02 The Method Used to Compute Repeater Gains

2.021 The principle that a repeatered circuit must be designed so that singing will not take place in the idle condition even without the use of idle line circuit terminations, gain disablers, or other means constitutes the method of repeater design in this section. This method is known as the stability design method and is the safest as well as the simplest method for engineering loaded repeatered trunks. Though this method limits somewhat the available repeater gain it does provide a degree of stability in the talking condition which is usually more than sufficient to prevent echo and near-singing effects. This design method also insures that circuit stability is maintained during dialing, ringing and other conditions.

2.022 A repeatered circuit, thus designed, can be described as being passive inasmuch as it will not sing when connected to other passive lines, low loss trunks or low impedance terminations. In addition, such a repeatered circuit will remain stable (it will not sing or tend to sing) even when the following terminations are placed at each end of the repeatered trunk:

Local Office	Local or Toll Office
Open circuit	Open circuit
Open circuit	Short circuit
Short circuit	Open circuit
Short circuit	Short circuit

2.023 The "Central Office Equipment Contract," REA Form 525, revised February 1961, paragraph 1.085 states: "Idle circuit terminations shall be provided on interoffice trunks equipped for E and M signaling and...." An exception to the above is to loaded trunks on which negative resistance/impedance repeaters will operate. This is because such loaded repeatered trunks do not require idle line circuit terminations to insure circuit stability. If idle line circuit terminations are nevertheless provided for this type of trunk, they should not be used in the repeater design for the purpose of obtaining additional repeater gain over and above the gain provided by the stability design method of paragraph 2.021.

2.024 Repeater design methods which use idle line circuit terminations, gain disablers or other means for the purpose of obtaining additional repeater gain over and above the gain provided by the stability design method of paragraph 2.021 are not recommended for use in REA borrowers' plant.

2.03 The Structural Return Loss

2.031 Structural return loss is a measure of the excellence of a completed (in-place) loaded cable as regards its impedance uniformity. Since it is not practicable to manufacture cables in which all cable pairs and all cable reels have precisely the same mutual capacitance per unit length, loading coils having precisely the same inductance or spaced at precisely the same intervals, it is necessary to know the degree by which the above factors depart from their ideal values. Structural return loss takes into account the small variations in the loading coils and cables as manufactured, the accuracy of load coil spacing and the care and methods with which the cable is installed. In general, it is due wholly to the above variations which may occur in any random manner along the line. Structural return loss is expressed in db; the higher the structural return loss the better.

2.032 Structural return loss values published herein have been arrived at on the basis of maximum deviations in cable mutual capacitance load coil inductance and load coil spacing. These limits on deviations are set forth in PE-22, -23, -25, and in REA TE & CM-431, "Voice Frequency Loading for Trunk Cables," respectively. REA TE & CM-445, "How to Make Structural Return Loss Measurements," provides step-by-step procedures for measuring the actual structural return loss of loaded cables.

2.04 What Factors Determine the Available Repeater Gain

2.041 The basic factor which controls the amount of repeater gain available to a loaded cable is not the repeater itself but rather the return loss (the cable attenuation combined on a power summation basis as described in paragraph 4.02) of the cable plant over which the repeater is designed to operate, referred to the repeater location. Repeater gain cannot be introduced arbitrarily in a loaded circuit for the purpose of achieving transmission objectives without due consideration to the line section return loss. Computations will be necessary for each particular application for arriving at the answer. Once the basic concept is understood a firm foundation is established for correct repeater application.

2.042 Each type of repeater has a maximum gain associated with it. For example, the negative impedance type is rated at a maximum gain of 9.8 db while the negative resistance type is rated at 13.0 db. These values however should not be confused with available repeater gain. The maximum repeater gain is associated with maximum capability much the same way a maximum gain is associated with any amplifier. Available repeater gain refers to that amount of repeater gain for a given repeater location which can actually be applied to the loaded cable trunk in question strictly from considerations of its return loss. Stated in another way, available repeater gain is that gain which the actual return losses of the loaded cable pair in question will safely sustain, and for which the repeater should be set. For practically all applications the available repeater gain is well below maximum repeater gain capabilities; however, there may be some cases where the cable return loss allows for the repeater to be set (available gain) near or at its maximum gain settings.

2.043 In addition to the return loss considerations outlined in the above paragraphs, crosstalk is also a factor that controls the maximum gain at which a repeater can operate. This is usually in the form of a repeater gain limit and mainly it affects terminal repeaters when located at the local office where connection is made to the subscriber loops. These limits are discussed in paragraph 3.14.

2.0431 Though noise is also of concern in a loaded repeatered trunk it is not one of the design factors considered in this section. This is because in the repeater itself noise is controlled by proper design and in the cable plant it is dealt with by proper application and maintenance procedures treated in other sections of the engineering manual.

2.044 In summary then, a repeatered trunk design consists of finding:

a. What is the return loss of the loaded plant for the given application.
b. What repeater gain this return loss permits.
c. Verification that the available repeater gain as obtained in step (b) above does not exceed the crosstalk limitation.

The step-by-step procedure of how this is arrived at is discussed in paragraph 4.01.

3. APPLICATION CONSIDERATIONS

3.01 When designing loaded trunks intended for voice frequency repeater application, full consideration should be given to each of the factors outlined below as they are applicable to each individual situation, to insure proper cable facility-repeater coordination and thus assure proper repeatered circuit operation.

3.02 Cable Gauge Uniformity

3.021 The basic application function of the negative resistance/impedance repeater is to loaded cables. How successful the application becomes depends in turn on the impedance regularity of the loaded cable over which repeaters will operate. When designing trunks over which repeaters are intended to operate every effort should be made to insure this impedance uniformity for the entire trunk.

3.022 The importance of cable gauge uniformity in a loaded trunk cannot be overemphasized. From the standpoint of optimum repeater and circuit performance, providing uniform gauge facilities should be at all times the primary objective. For new applications, this objective will be more easily attainable. Mixing cable gauges in the same trunk group should be avoided to the extent possible. Where this is not practicable, the number of dissimilar gauges should be held to a minimum, possibly not exceeding two, and should be in sequence. For example, layouts having 19 gauge, followed by 22 gauge, followed by 19 gauge, followed by 22 gauge, etc., should be avoided.

3.023 Further, gauge "skipping," is not a recommended practice. If there is no alternative to providing a uniform gauge, the next best approach would be to provide two consecutive gauges such as 19 and 22 gauge or 22 and 24 gauge but not 24 and 19 gauge. The exception to this rule would be where short entrance cables have to be provided.

3.024 Step-by-step computation procedures are provided in this section for uniform as well as mixed gauge cable as shown in "Application Guides" I and II respectively.

3.03 Type of Uniformity - Mixed Facilities

3.031 Layouts involving loaded cable and open wire in various configurations intended for negative resistance/impedance repeaters should be avoided. The impedance of such a layout is at best very difficult to determine and in order to know its actual characteristics measurements may be necessary.

In addition, there is no standard strapping information available for negative resistance/impedance type repeaters designed to operate over such layouts. Therefore, knowing in advance whether transmission objectives and frequency response characteristics will not always be possible and, in addition, strapping the repeater to this type of facility is at best a cut-and-try process and will probably lead to a compromise performance.

3.032 Again every effort should be made to avoid layouts of this type. Where good reasons render this plan impossible, layouts of this type are best dealt with by means of hybrid type repeaters (since provision for various strapping arrangements can be made in their balancing networks) or by engineering these trunks for open wire or cable carrier.

3.033 In this type of layout it is possible to use the loaded cable portion of the mixed facility if it is adjacent to a repeater to provide a limited repeater gain. Should such a limited gain be adequate, step-by-step procedures are shown in "Application Guide" III. Several examples are also shown for accomplishing this.

3.034 The overwhelming majority of applications involving voice frequency repeaters will be in trunk cables which are loaded. Other layouts, however, may arise whose configuration is predominantly:

a. Loaded and non-loaded cables.

b. Open wire with incidental entrance cables where carrier systems may or may not be superimposed.

Application of repeaters on trunks composed of a combination of loaded and non-loaded cable should be avoided. The procedure should be to load the non-loaded portion of the trunk to the same type of loading system (assuming the nominal mutual capacitance of the two to be the same) as the loaded portion and then apply repeaters if required according to paragraphs 3.022 and 3.023. Similarly, where cables exist that are non-loaded in their entirety, loading should be applied before repeater application. Item (b) above normally calls for hybrid type repeater application. If, in addition, a voice channel is provided by the physical circuit associated with a carrier-derived system, it will be necessary to provide the hybrid repeater of the physical circuit with the line treatment (line filters, etc.,) of the same type as the carrier system superimposed on it.

3.035 Facility layouts which contain a mixture of loaded cable, non-loaded cable, open wire conductors, rural distribution wires, etc., render the engineering of the repeater complex since the resulting impedance is a nonstandard one. Application of repeaters to such layouts is not readily predictable and should be avoided.

3.036 Repeaters should not be used on loaded trunks consisting wholly or partially of the former type rural distribution wire. Sufficient experience on the Figure 8 type distribution wire from the repeater application standpoint has not yet been gained. Recommendations for repeater use for this newer wire will be made once its long term characteristics for transmission have been analyzed.

3.04 Considerations Involving Existing Cable Plant

3.041 Existing cable plant which, under former design criteria, met objectives by loading the cable may in the future require the application of repeaters in order to meet the improved transmission objectives. In order to insure the realization of this objective it is necessary that the impedance regularity characteristics of the existing plant also be suitable to repeater application. Existing plant which is known to contain or is measured and found to contain major irregularities should have these irregularities corrected prior to repeater application. This will insure stable long term circuit operation. On the other hand, application of repeaters on plant known to contain irregularities or designed on this basis will not help cure the basic fault and will result in compounding maladjustments. It is highly important therefore that the causes of irregularities and not just the symptoms be cured.

3.042 A required procedure for determining that existing plant is suitable for repeater application is to determine its 1000 cps attenuation and structural return loss at the critical frequency. The 1000 cps attenuation should be measured in accordance with Figure 2 or 3 or REA TE & CM-408, "Facility Requirements for Voice Frequency Repeatered Trunks", latest issue, and the structural return loss at the critical frequency with REA TE & CM-445, latest issue. If the results of the measurements indicate random variations only, facility suitability to repeater application has been assured. If major irregularities are indicated, the detection and location procedures of REA TE & CM-408 will have to be applied for correcting these irregularities prior to repeater installation.

3.05 Loading Spacing Deviations

3.051 The increasing application as well as the successful operation of voice repeaters to exchange trunk plant requires attention to the design and uniformity of load spacing. These factors are discussed in detail in REA TE & CM-431.

3.06 End Sections

3.061 The considerations pertaining to the length of end sections are discussed fully in REA TE & CM-431.

3.07 Building-Out Procedures

3.071 Capacitance building-out (referred to as CBO) as applied to loaded cables offers a means of improving the transmission irregularity resulting from loading sections which depart from standard lengths. REA TE & CM-431 discusses in detail these capacitance building-out procedures. When using building-out capacitors for plant of REA borrowers, these capacitors should be specified in accordance with PE-30, "Specification for Building-Out Capacitors", latest issue.

3.08 The D-66/H-88 Junction Impedance Compensator

3.081 Where repeaters are to operate over D-66 and H-88 loaded cables in the same circuit, an impedance compensator will be required at their junction. This impedance compensator is known as a "D-66/H88 Junction Compensator" and its function is to minimize the reflection loss at the junction produced by the two types of loading systems. The component parts of this compensator and how they are arrived at for each particular application are discussed in REA TE & CM-431. PE-31 is the applicable specification pertaining to the transmission, protection and physical characteristics of the completed assembly and should be used when ordering the compensators.

3.09 Impedance Compensators at Toll Centers

3.091 Intertoll trunks which are terminated at the toll center (Class 4 office) at VNL db on the two-wire switches require for proper transmission performance the use of impedance compensators on loaded cable toll connecting trunks (VNL + 2), with cutoff frequencies equal to or lower than H-88 (3500 cps). The theory of operation and the makeup of the impedance compensator are discussed in REA TE & CM-408 and in "Notes on Distance Dialing," AT&T Company, 1961.

Though different names are given to the impedance compensator depending on the particular application, the theory of operation is nevertheless the same in all cases.

3.092 To bring forth the role of the impedance compensator reference should be made to Figure 7 which illustrates the manner of interconnection at the toll center, the intertoll (four-wire, VNL) trunk and the direct-toll connecting (two-wire VNL + 2) trunk through a hybrid. The table below in conjunction with Figure 7 illustrates the transmission improvement gained by the use of the impedance compensator on the toll connecting trunk as reflected by the increase in the return loss of the 900 + 2 µf compromise network and the compensated two-wire loaded toll connecting trunk. A 22-H-88 loaded trunk is used as an illustration.

0.5 End Section			Impedance Compensated	
Frequency	Impedance	Return Loss	Impedance	Return Loss
300	1230	16	1212	17
500	1090	19	1072	21
1000	1050	21	1004	25
2000	1196	17	1005	23
3000	1877	9	902	25

3.093 <u>It should not be inferred that use of the impedance compensator will correct poor structural return losses of a trunk</u>. For trunks containing irregularities, the considerations of paragraph 3.04 are fully applicable.

3.10 Considerations Affecting Repeater Selection

3.101 Both the negative impedance and the negative resistance repeaters are adaptable to loaded trunk application. The negative resistance type however is inherently capable of more gain for a given return loss and will generally provide improved performance over the negative impedance for the same application. Trunks using negative resistance type repeaters can usually be operated at up to 2 db lower net losses than trunks equipped with negative impedance types, the actual amount depending on the total line return loss and repeater location. This lower net circuit loss can be obtained with equal or improved return losses at the end of the trunks. For toll connecting trunks of VNL + 2 application, this additional gain in many instances becomes a significant design factor especially in the longer lengths of trunks usually found in REA borrowers' systems. Other characteristics of the negative resistance type are:

a. Improved overall circuit performance, since the repeaters are placed into service on the basis of in-plant return loss measurements thereby optimizing the performance of each cable pair to its respective repeater.

b. Greater number of repeater gain steps are available thus increasing the possibility of operating nearer the required transmission objectives.

c. Improved method for setting repeaters at the desired gain (by eliminating strapping) contributes toward simpler placement and maintenance procedures.

3.102 The higher gains of the negative resistance type repeater are made possible through the improved matching now possible between the line-building-out (LBO) component of the repeater (known as gain-unit). Changes in gain, in the negative resistance type repeater are affected by simple adjustment of variable resistors only as contrasted to the complex impedance networks in the negative impedance type repeaters which are required for adjustment of both gain and impedance match. Stated in another way, much of the improved performance of the negative resistance type can be attributed to the range and precision of adjustment available in the LBO networks and that the impedance of the repeater converter itself is essentially constant with gain setting (900 ohms in series with approximately 2 microfarads).

3.103 For EAS applications sufficient gain will usually be realized from the application of either negative resistance or impedance repeaters to meet the transmission objectives for the same facility and repeater configuration, though the application of the negative resistance type will always result in a lower net circuit loss. In other cases a negative resistance type at one location only may be capable of meeting the transmission objective, where with negative impedance repeaters at two locations may be required to accomplish this. In addition, toll connecting trunks due to their more stringent transmission requirements invariably demand higher gains in order to meet objectives. Where this is the case the added gain of the negative resistance type should be an important consideration. A last consideration concerns circuit capability towards increased transmission performance. For example, should it become necessary to lower net circuit losses by improved transmission objectives or other special considerations and the return loss of the plant could be improved, the added gain of the negative resistance type would make this objective more readily realizable.

3.11 Use of Series Type Repeaters

3.111 Under former transmission objectives the use of the series type repeater only was limited to those applications where echo considerations were not the controlling factor and in addition where a limited amount of gain was sufficient to meet transmission objectives. For these reasons the series type repeater found use in EAS applications but not on toll connecting trunks. Due to the lower net losses which EAS trunks are presently required to operate, the use of the series unit of the negative impedance or resistance repeater is no longer recommended. For these applications both the series and the shunt unit of either the negative resistance or impedance repeater should be used.

3.12 Available Repeater Gain Exceeds Gain Required to Meet Objectives

3.121 In some instances, depending on the cable layout, the total return loss referred to repeater location will be such that it will allow the repeater or repeaters to provide an available gain greater than that required to meet transmission objectives. In such cases the following should be kept in mind.

a. For EAS trunk applications this added gain can be taken advantage of by setting the repeater(s) at these higher gains and thus resulting in a lower net circuit loss.

b. For VNL + 2 toll connecting trunks set or strap the repeater only for the gain required to meet the VNL + 2 db transmission objectives, but not lower.

3.13 Repeater Location

3.131 From the standpoint of deriving the maximum possible available repeater gain and still provide optimum circuit return loss performance the most desirable repeater location is at or near the electrical mid-point of the facility where this is possible. If the resulting gain is not sufficient an additional repeater location will be necessary; where an intermediate location is not available two terminal locations may have to be considered.

3.132 In general, since increasing the number of repeaters by two does not generally increase the total repeater gain by the same ratio and since no rigid rules can be given pertaining to all situations, it is the characteristics of the individual layout which will determine where to place the repeaters and how many repeater locations will be required. At all times the designer should determine for the particular application the optimum combination of repeater locations which use the minimum number of repeaters to meet applicable transmission objectives. In order to arrive at the repeater configuration best suited to the given application, several repeater layout configurations will have to be computed during the design stage and the optimum one selected.

3.133 Better return losses are obtained in most instances by locating the negative impedance/resistance repeaters away from the toll center (Class 4 office), preferably at the Class 5 office or at an intermediate point, if available. Where the connecting company will furnish repeaters at the toll center or other location it is important that the type of repeater, the repeater gain and the cable layout be known to the designer so that the overall repeater design can proceed on a coordinated basis.

3.134 There will be no transmission advantage in using two repeaters in the same link, in tandem, rather than a single repeater in the same location. This condition however may occur in tandem connections when two links each equipped with terminal repeaters are switched together. In such cases, the resulting total repeater gain will be the sum of the individual repeater gains in the switched connection. There is an advantage however where tandeming is involved, to locate all repeaters in the same location for ease of maintenance.

3.14 Crosstalk Limitations

3.141 From the crosstalk standpoint the most severe location of repeaters is at the end of a trunk where access is made to subscriber loops, that is, at the local office end of a toll connecting trunk or at either end of a direct EAS trunk. The gains of such terminal repeaters should not exceed the gains shown below so that a crosstalk index of good should be realized:

Type of Loading	Terminal Repeater - db	
D-66	7 objective	8 maximum
H-88	7 "	8 "
D-88	6	

For intermediate repeaters the gains shown in the above tabulation may be increased by the amount of the trunk loss between the repeater location and the trunk end connecting to the subscriber loop. In all calculations involving terminal repeaters, reference should be made to the above tabulation to see that the given gains are not exceeded.

3.15 Office Losses

The transmission losses with which the term "office loss" is associated are contributed mainly by: a) the repeating coil in the trunk circuit, b) the wiring and capacitance of the trunk circuit, and c) office wiring. A representative value for office losses is 0.5 to 0.6 db at 1000 cps for equipment supplied to REA borrowers and this value is used for repeater design. In toll center locations where extensive office wiring or older type repeating coils may still be in use, office losses may be higher. Since these losses are a part of the overall loss of a talking connection, the exact value of the office loss must be known and accounted for in the repeater design. The particular value of office loss for the office in question should be obtained from the connecting company during the time the repeater design is carried out.

3.16 Line Building-Out (LBO) Losses and Other Considerations

3.161 Paragraph 6.04 discusses the number of components which a complete line building-out network (LBO) contains for building out a natural end section to approximately a full loading section. The loss of the LBO network varies with the amount of building-out resistance (BOR) used; the greater the amount of the end section being built out with BOR the greater this loss will be. The BOR loss however although additive to the line loss does not have any significant effect on the final net circuit loss. This is because the return loss which the BOR presents to the repeater increases at a faster rate than the insertion loss it introduces, producing more repeater gain which overcomes the BOR insertion loss. For this reason, the BOR loss of the LBO need not be considered in the repeater computations.

3.1611 When placing the repeater in service, BOR must be used in order to maximize the circuit return loss. This is necessary with increasing need as the cable gauge decreases. For example, it is required for 22- and 24-gauge cables but if used for 19 gauge it will not produce marked return loss improvement.

3.162 As outlined in REA TE & CM-431, the natural end section (the end section of the physical cable plant) of each trunk portion connecting to a repeater should be 0.5 by design and within 0.4 to 0.6 (of a full loading section) when staked and built. For the purpose of calculating the d-c resistance of the trunk which must be known for signaling, each natural end section can be considered to be 0.5 with the remaining 0.5 assumed to be built-out by the BOR; therefore, the BOR will contribute approximately 100 ohms for 22 gauge and 155 ohms for 24 gauge cable pairs which must be added to the other d-c resistances making up the trunk.

3.163 Because of the presence of the LBO networks in the negative resistance repeater and the insertion loss which these networks add to the line loss, the concept of repeater gain is somewhat different from that of the negative impedance in that the LBO loss is included with the line loss. For this reason, the term gain-unit gain is applied to the insertion gain of the negative resistance repeater (shown in Gain Chart II), which is the insertion gain of the repeater gain unit itself when operating between 900 ohm and 2 mfd impedances. Stated another way, gain-unit gain is the repeater gain before recovery of the LBO loss; if the LBO loss is subtracted, the conventional definition of repeater gain is obtained.

3.17 Structural Return Loss for D-66 Loaded Cable

3.171 The structural return loss for cables furnished under applicable REA specifications and built in accordance with applicable REA practices is shown in Table IV. The 19 and 16 db values shown for 22 and 19 gauge respectively D-66 loaded cables (66 mh loading coils spaced at 4,500 foot intervals and having 2,250 foot nominal end sections) are minimum values. The structural return loss of D-66 loaded cables is inherently higher than those of H-88 loaded cables having the same gauge. However, until such time as the new values become available, the values shown in Table IV may be used with good results.

3.172 Where the connecting company furnishes the facilities for a portion of the trunk route, it is necessary that the structural return loss value for their portion be known in advance so that the overall design can be coordinated during the repeater design stage.

3.18 Effect of Temperature on Return Loss

3.181 Cable attenuation varies with temperature. When repeaters are used, singing will be most likely to occur when the cable temperature is the lowest because the attenuation is the lowest and consequently the return loss is the lowest.

For buried cables where maximum outdoor temperature variation produces but a nominal change in the cable temperature, the published values of attenuation in Table II at 68°F may be used.

For aerial cables the cable temperature follows more closely the outdoor temperature. For this reason, in areas where 0°F temperature may be expected to be the rule during winter periods, the attenuation values of Table II should be reduced by about eight percent when carrying out the repeater design.

3.19 Voice Frequency Extensions

3.191 Voice frequency extensions are that portion of an overall trunk consisting of carrier or radio-derived facilities and a voice circuit without switching occurring at the point of interconnection. (See Figure 8.) A 4-wire terminating set is provided at the location where the carrier or radio system is translated to a voice frequency basis. To the proper terminals of the 4-wire terminating set are connected the "transmit" and "receive" legs of the carrier, the "loaded cable" which serves as the voice frequency extension and the "precision balancing network" for the loading system used. (For a detailed description of the 4-wire terminating set or hybrid, refer to REA TE & CM-445, paragraph 5.) When the trunk is operated in this manner, so that no switching takes place at the location where the 4-wire terminating set is located, the carrier derived portion of the trunk is capable of operating at a net gain. That is for a given voice frequency power input (say zero dbm at 1000 cps) to the carrier input terminals at office A, more power will be obtained (possibly as much as 3.0 db at 1000 cps) on the 2-wire end of the carrier terminal at office B. This net gain is made possible as a direct result of the following:

a. No switching takes place at office B (that is, the entire trunk is a direct trunk), and

b. The precision balancing network impedance matches the loaded vf extension. The resulting net gain under this condition can be used to make up some of the transmission losses in the loaded vf extension, or it can supplement the gain of a voice frequency repeater located at an intermediate or terminal location but not adjacent to the 4-wire terminating set at office B.

3.192 The vf extension mode of transmission operation is not exclusive to one side of a carrier system; vf extensions can be operated at both ends of the carrier system. Whether vf extensions are applied to one or both sides of the carrier system the considerations of paragraph 3.191 apply. In most carrier or radio systems, connected as voice frequency extensions, the maximum two-wire drop to two-wire drop net gain which the equipment can provide is limited to approximately 3.5 db from maximum power output, distortion and other considerations. In any case, where the carrier derived portion is furnished by the connecting company it is required that they state in advance the two-wire drop to two-wire drop net 1000 cps vf gain at which they intend to operate the carrier for the application under consideration so that it can be considered when carrying out the complete repeater design as discussed in Application Guide IV. In other cases the seller of the carrier system should provide this information on the basis of the layout information of each particular application.

3.193 When engineering trunks operating as vf extensions, the entire trunk should be taken into consideration. For example, for toll connecting trunks the VNL+2 objective applies to the vf plus the carrier derived portion. Coordination between all parties involved for designing and furnishing the carrier equipment, the vf repeater equipment, the 4-wire terminating set equipment, the precision balancing network and signaling equipment is essential in order to derive proper circuit performance. The stability considerations outlined in this section are applicable in the design of trunks operating as vf extensions.

3.194 Where switching takes place at the intermediate office, operation at a net gain is no longer possible. In switched type of operation the precision balancing network must be replaced with a compromise type network (600 or 900 ohms in series with 2 microfarads).

4. STEP BY STEP REPEATER DESIGN PROCEDURES

4.01 Complete Repeater Design Procedure

The fundamental procedure for carrying out the complete repeater design for the cable layout under consideration and for a specific repeater configuration is as follows:

4.011 Prepare a sketch of the complete circuit layout of the entire trunk (all cable gauges, length of each, type of loading, end sections, capacitance building-out if performed at locations other than in the repeater itself, the D-66/H-88 junction impedance compensator, if applicable, and the structural return loss, etc. If a connecting company is involved, the same information will be required of the connecting company and the proposed repeater(s) location(s). (If a connecting company is involved, the type of repeater(s) used and the repeater(s) location(s) is required.)

4.012 Calculate the transmission objective for the type of service which the trunk group will provide, from the information given in paragraph 4.011. This is the net circuit loss at which the trunk group under consideration is to be operated.

a. For toll connecting trunks the objective is VNL+2 db. This is obtained by multiplying the VNL factor for the type of facility involved (see Table I) by the length of each type facility in miles. To this is added a fixed 2.0 db plus a 0.4 db for maintenance. Mathematically this can be expressed:

$$\text{VNL} + 2 = \text{Length of facility (miles)} \times \text{VNL db/mi} + 2.4$$

b. For intrasystem EAS trunks, the objective will be found in REA TE & CM-415, "Transmission Objectives," latest issue.

c. For other special applications use the transmission objective in db, as required.

4.013 Compute Total Non-Repeatered 1000 cps Circuit Loss

This is accomplished as follows:

Total non-repeatered circuit loss: (1000 cps) in db

= Length (KF or Mi) x attenuation (db)/KF or db/mi
  for each different type facility
+ Reflection losses (if any)
+ C.O. losses
+ LBO losses (for negative resistance repeaters)

The attenuation information is shown in Table II.
The reflection loss information is shown in Table III.
The LBO loss information is shown in Table V.

4.014 Compute the total required repeater gain as follows:

Total Non-Repeatered Circuit Loss (Par. 4.013)
Minus
The Transmission Objective (Par. 4.012)

4.015 Compute the return loss which the repeater sees at each point where a repeater is located. This is known as "referring the return loss to the repeater location" and is the primary purpose of the computation. The step-by-step procedure of how this is accomplished is shown in paragraph 4.02.

4.016 Enter the losses obtained in paragraph 4.015 in the Gain Charts I or II, as applicable, to obtain the available repeater gain. This is the maximum gain at which the repeater can be safely set.

4.017 Check the available repeater gain(s) obtained in paragraph 4.016 with those of Table VI, to see that the crosstalk limitations are not exceeded.

4.018 Check to see that the sum of all available repeater gains as obtained by the step of paragraph 4.016 meet the required transmission objective of paragraph 4.012.

4.019 In summary: the task of the repeater designer is, that for the cable layout under consideration, the designer should consider a number of repeater configurations which, when computed in accordance with paragraphs 4.014 to 4.017, yield sufficient available gain to meet the objectives of paragraph 4.012. When several repeater configurations will meet the objectives, the optimum repeater configuration should be selected. A desirable objective during this repeater design phase is for the total available repeater gain to be not less than 0.5 db from the total required.

4.02 Computation of Return Loss

4.021 One Terminal Repeater

a. The attenuation (plus LBO loss if negative resistance repeater is used) of the cable section length under consideration is computed from the attenuation information of Table II. Central office losses are not included.

b. The terminal return loss at the end of the furthermost cable from the repeater is taken as zero db.

c. The zero db terminal return loss of step (b) above is referred to the repeater location by adding to it twice the attenuation of step (a) above combined with the structural return loss of the cable section on a power summation basis, in accordance with Chart I. This gives the return loss referred to the repeater location; that is, the return loss which the repeater sees when facing the cable side.

d. The terminal return loss which the repeater sees when facing the office side is taken as zero db.

e. Entering repeater gain Chart II or III at the return loss values of steps (c) and (d) above yields the available repeater gain.

4.022 Two Terminal Repeaters (Repeaters Facing Each Other)

a. The attenuation (plus both LBO losses if negative resistance repeaters are used) of the entire cable section length under consideration is computed from the attenuation information of Table III and then increased by 20% if negative resistance repeaters are used, and by 10% if negative impedance repeaters are used. Central Office losses are not included.

b. The attenuation of step (a) above is combined with the structural return loss of the cable section on a power summation basis in accordance with Chart I which gives the return loss referred to each of the repeater locations; that is, the return loss which each repeater sees when facing the cable side.

c. The terminal return loss which each repeater sees when facing the office side is zero db.

d. Entering the repeater gain, Chart II or III, at the return loss values of steps (b) and (c) above yields the available repeater gain.

4.023 One Intermediate Repeater

a. The attenuation of the cable section length (including the LBO loss) on each side of the repeater is computed from the attenuation information of Table II. Central Office losses are not included.

b. The terminal return loss at each cable end furthermost from the repeater is taken as zero db.

c. The zero db terminal return loss of step (b) above for each cable section length is referred to the repeater location by adding to it twice the attenuation of the same section length. This is performed separately for each cable section length.

d. For each cable length, twice the attenuation found in step (c) above combined on a power summation basis with its corresponding structural return loss gives the return loss referred to the repeater location for each cable section length.

e. Entering the repeater gain, Chart II or III, at the return loss values which the repeater sees facing each cable section length as found in step (d) above yields the available repeater gain.

4.024 The repeater configuration of paragraphs 4.021 to 4.023 can be considered as basic building blocks. More complex repeater configuration such as two intermediate repeaters or repeaters at three offices can be adequately covered by the simpler layouts since they are essentially combinations of the three basic applications shown above.

4.03 Use of Application Guides for Computing Available Repeater Gain

4.031 The step-by-step procedures of paragraphs 4.01 and 4.02 have been applied to a number of more complex layouts covering a large number of different type repeater applications and a varied number of repeater configurations. It is anticipated that the number and type of applications covered will be adequate for the overwhelming majority of applications. In each case the step-by-step procedure is shown on a general basis so that it may be applied to any repeater situation similar to it. It is then supplemented with a large number of examples of actual repeater layouts solved on a step-by-step basis. This complete packet for each basically different type of application has been called an "application guide"; it should enable the repeater designer to apply it to the particular layouts under consideration. Application Guides have been prepared covering the following type of repeater applications:

Application Guide I - Computation of available repeater gain of negative resistance and negative impedance repeaters operating over uniform gauge loaded cables.

Application Guide II - Computation of available repeater gain of negative resistance and negative impedance repeaters operating over mixed gauge cables.

Application Guide III - Computation of available repeater gain of negative resistance and negative impedance repeaters operating over mixed facilities.

Application Guide IV - Computation of available repeater gain of negative resistance and negative impedance repeaters over loaded cables operating as voice frequency extensions off carrier or radio multiplex equipment.

4.04 Gain Charts II and III as They Apply to Other Types of Loading System

4.041 Repeater insertion gains as shown in Charts II and III are solely a function of return loss; for example, both the horizontal and vertical scales are marked in terms of db return loss. At any time that the return loss of a given loaded cable is known the corresponding repeater gain can be found by reference to these Gain Charts. From this standpoint they are universal in character, that is, their use is not restricted to the D-66, H-88, and D-88 loading systems discussed in this section. The Gain Charts are equally applicable to all types of loading systems whose return loss is known and for which appropriate repeater settings or strappings are available.

5. COMPARATIVE THEORY OF OPERATION OF THE NEGATIVE RESISTANCE AND NEGATIVE IMPEDANCE REPEATER

5.01 The theory of operation of the negative resistance repeater differs from that of the negative impedance. In order to point out this difference as well as the principle of operation of negative resistance repeaters, the operation of the negative impedance repeater is discussed first in paragraph 5.02 below.

5.02 Theory of Operation of the Negative Impedance Repeater

5.021 Figure 1-a shows the variation experienced by the magnitude of the mid-section impedance of a uniform 22 gauge cable H-88 loaded in the frequency range of 200 to 3700 cps. The mid-section impedance means that the office end-sections of the cable are one-half the length of the full-sections or 3,000 feet in this instance. It may be seen from inspection of Figure 1-a that the mid-section impedance of this cable is 1000 ohms and is flat (does not vary) only in a very narrow frequency band around 1000 cps. At other frequencies below and above 1000 cps, rapid impedance variations take place. A voice repeater operating over such a loaded cable is required to match its network to this complex impedance precisely at all frequencies of interest. In fact, the negative impedance repeater does just that. A considerable amount of space in the negative impedance repeater is taken up by a number of precision inductor, capacitor, and resistor components whose sole function is that of matching the complicated mid-section impedance of the loaded cable pair over which the repeater is to operate. For this reason, strapping of different component parts in the repeater network is necessary in this type of repeater and in addition, these strappings are different for each of the different repeater gain steps.

5.022 If the end-section of the loaded cable is not at mid-section (i.e., 0.5, 0.7 or other) further complications arise since the cable impedance is now different at each new end-section and the negative impedance repeater strapping must be modified accordingly. An idea of the rapid change which takes place in the impedance when the end-section of the loaded cable varies can be obtained by reference to Figure 2. The information there is shown for a 24 gauge cable, H-88 loaded, only to illustrate this point. In conclusion therefore, the basic principle of operation of the negative impedance repeater is that it must provide a good match to a wide range of impedance values for the type of loading on which it is operating. Even though the loading system remains the same, different components which are frequently dependent, need to be shaped in the repeater for different gain steps and different end sections.

5.023 Figure 3 shows the components required in the network of a series unit (shunt unit is similar) of a negative impedance repeater and the manner in which the components would appear on the repeater terminal lugs for strapping. Figure 4 is a simplified schematic of the repeater unit strapped for operation of a typical H-88 loaded cable facility.

5.03 Theory of Operation of the Negative Resistance Repeater

5.031 If the complex mid-section impedance of a loaded cable, Figure 1-a for 22-H-88, for example, is "treated" in some manner, it is possible to reduce the complexity of this impedance to a type of impedance easier to deal with. Such devices which in effect "treat" a complicated loaded cable impedance to something less complex, are known under the general term of "impedance compensators."

5.032 The impedance compensator consists basically of a variable capacitor and an inductor (loading coil). The capacitor portion of the unit is bridged across the cable pair at the end-section while the inductor is inserted afterwards in series with the cable pair at the end-section. The amount of capacitance (known as capacitance building-out or CBO) which is added to the cable end-section is that which now makes the end-section approximately 0.8 in electrical length while the loading coil required is usually one-half the value of the loading coil used to load the cable pair. (For example, for an H-88 loaded cable the value of the inductor unit in the impedance compensator would be one-half or 44 millihenries.)

5.033 The "treatment" of a loaded cable at mid-section (refer to the loaded cable pair of Figure 1-2), with an "impedance compensator" has the effect of flattening out the curve of Figure 1-2 and yields the curve shown in Figure 1-b. This curve is less complicated than the curve of Figure 1-2; is approximately 1000 ohms and does not vary with frequency. From the repeater design standpoint, the "impedance compensated" curve of Figure 1-b has desirable characteristics which the mid-section curve of Figure 1-a does not; that is, it now becomes possible to use less complicated components in the repeater network. (The facility loss measurements in REA TE & CM-408, Figure 2, are inherently based on the use of the impedance compensator for simplifying an otherwise complex cable impedance and thus makes possible attenuation type measurements. Paragraph 6 of the same section gives a complete discussion on the theory of operation of the impedance compensator and should be consulted for this purpose.)

5.034 The negative resistance repeater contains an impedance compensator device for improving the impedance characteristics of the loaded cable pair over which it will operate. For repeater design purposes it is known as a Line Building-Out Network or simply LBO, rather than an impedance compensator. For a terminal repeater only, one LBO is required to match the cable side whereas an intermediate repeater requires two, one on each side of the cable pair.

5.035 Therefore, the application of the repeater LBO units to the loaded cable pair produces the following significant effects:

a. It makes the impedance of the cable essentially independent of frequency and approximately 1000 ohms through the important voice frequency range, i.e., the cable pair impedance resembles a 1000 ohm resistor.

b. Since the cable pair appears resistive, only resistors are required in the repeater network.

c. More repeater gain is possible as a result of the improved cable pair and LBO matching to the repeater gain unit as well as repeater gain-step adjustments in finer steps.

5.036 In conclusion therefore, the fundamental difference pertaining to the operation of the two types of repeaters is that:

a. The negative impedance repeater must have its network designed to match a complicated loaded cable pair impedance.

b. In the negative resistance repeater, instead of matching the repeater to the line, the line is matched to the repeater. Since the line is now a relatively simple impedance (made so by the LBO treatment) a simpler repeater network is possible.

c. It is now possible to separate the impedance matching functions and gain functions in the negative resistance repeater, that is, impedance matching is provided by the LBO (which can be thought of as being in effect external to the repeater) while repeater gain is provided by adjusting simple resistors in the repeater amplifier. Figure 5 is a simplified schematic diagram of the negative resistance repeater. A comparison between it and the series unit of the negative impedance shown in Figure 4 will reveal the apparent simplicity of the former.

6. DESCRIPTION AND FUNCTION OF THE NEGATIVE RESISTANCE REPEATER COMPONENTS

6.01 Like the negative impedance, the negative resistance type repeater must be inserted in <u>series</u> with the cable pair on which it will operate. Thus, in this respect it belongs to the negative impedance type family as contrasted to a hybrid type repeater. Unlike the negative impedance repeater one unit houses the series and shunt repeater functions. As in the negative impedance the negative resistance repeater consists of three basic component parts, the Line or Coupling Transformer, the Converters, and the LBO(s). These are discussed in detail below. The simplified schematic of the negative impedance type repeaters shown in Figure 5 is discussed in paragraphs 7.02 to 7.09.

6.02 The Coupling Transformer

6.021 The coupling transformer is used to couple the series and shunt repeater units to the cable pair and it is common to both. It maintains tip and ring line continuity and passes ringing currents but removes direct-current supervisory voltages from the series converter. It also couples speech currents from both directions of transmission to the series and shunt converters; no signal step-up to the shunt converter is provided. The line side windings of the coupling transformer are tapped at the mid-point for connection to the shunt repeater unit through d-c blocking capacitors.

6.03 The Converter Unit

6.031 The converter unit performs the amplifying and phase shifting functions in the repeater as well as maintaining a constant image impedance for purposes of matching the cable impedance at approximately 1000 ohms. Amplification is accomplished by means of transistorized positive feedback amplifiers having variable resistance networks as loads. Separate converters are used for the series and shunt repeater units inside the repeater. The series converter presents a negative resistance to the line terminals at an approximate 180° angle while the shunt converter presents a negative impedance. The variable resistors used in the series and shunt unit are usually made of precision resistors. By coordinating the adjustment of the series and shunt variable resistors the gain can be varied in steps of 0.2 db from 1 to 13 db. Note: The converter unit in conjunction with the coupling transformer is often referred to as the "gain-unit."

6.04 The Complete LBO Unit

6.041 As pointed out in paragraph 5.036c, in the negative resistance type repeater the impedance matching and repeater gain functions have been separated. The gain function is provided by the converter unit which is non-frequency dependent as discussed in paragraph 6.03. The LBO transforms the cable impedance from an impedance which changes with frequency to one which is constant with frequency and has a value of approximately 1000 ohms, thus matching the impedance into which the converter unit of the negative resistance repeater has been designed to operate. A different type of LBO is required for each type of loading, (i.e., LBO for H-88 will be different for D-66, etc.,). The components which go into the makeup of a complete LBO unit are shown in Figure 6-A.

6.042 Building-Out Capacitance Network of LBO - BOC

The BOC is used for building out the cable capacitance to approximately a full-section. Several capacitors are provided, having a total range of approximately 0.1 uf, and shown in Figure 6-a as BOC.

6.043 Building-Out Resistance Network Unit of LBO - BOR

These are resistors for building out the resistance component of the cable to a full-section, where necessary.

Several resistors (or a potentiometer) are provided for this purpose, usually adjustable in 28 ohm steps and having a total range of 196 ohms. The BOR, if used, will be effective mostly on 24 and 22 gauge conductors from the return loss standpoint. The BOR component of the LBO is shown in Figure 6-a.

6.044 High Frequency Correction Network Unit of LBO - HFC

This network as the name implies is used to maintain good return loss characteristics at the higher frequencies of the voice band, and is shown in Figure 6-a as HF corrector.

6.045 Low Frequency Correction Network Unit of LBO - LFC

Since the impedance compensating effect of the LBO due to the BOC and HFC is effective above 1000 cps, an LFC network is used to provide correction at lower frequencies by adding shunt admittance across the cable pair. The amount of LFC to be provided depends on the cable gauge and the need for correction increases as the gauge becomes finer. Three adjustments are usually provided to accommodate 19, 22, and 24 gauge cables. Figure 6-a shows this low frequency corrector.

6.046 The "Dummy LBO"

It was pointed out in paragraph 5.034 that for a repeater operating in a terminal configuration, only one LBO is required located on the cable side. The additional LBO, such as is shown in Figure 6-b for the same terminal configuration facing the office side, is known as a "dummy LBO." It consists of two shorting jumpers needed to maintain tip and ring continuity respectively between the tip and ring repeater terminals facing the office side and the office. Dummy LBO is not required for intermediate repeater applications, since two regular type LBOs are used. Figure 6-c shows the terminal and intermediate repeater LBO configuration.

7. MAJOR CHARACTERISTICS OF NEGATIVE RESISTANCE REPEATERS

7.01 Some of the major characteristics of negative resistance repeaters designed to operate over loaded cable trunks are as follows:

Type - Negative resistance, two-wire voice frequency.

Gain Capabilities - 1 to 13 db adjustable in 0.2 db steps.

LBOs - Adjustable, 0 to 5,800 feet.

Power Consumption - 48 volt central office battery, unfiltered, 30-50 milliamperes.

Overload - +8 VU for speech or music.
+16 dbm repeater output, single frequency.

Maximum Metallic Current in Coupling Transformer Windings - 60 ma d-c.

In-Service Temperature Range - $0^{o}F$ to $140^{o}F$.

8. TRANSMISSION MEASUREMENTS

8.01 With increasing usage of electronic equipment dictated by improved transmission objectives it becomes necessary that increasing attention be paid to the characteristics of the plant over which this equipment will operate to insure that a repeatered circuit will perform initially and will continue to provide its rated performance. Correct maintenance procedures become as important as proper circuit design procedures. Therefore, the importance of measurements as a transmission maintenance tool cannot be overemphasized. This portion of this section provides step-by-step measuring procedures and suitable forms for recording the results of the measurements needed for accomplishing this and can also be used to cover the following range of functions:

a. To provide a project with a complete record of circuit performance during the initial system line-up and installation which can be used as a guide during future routine testing.

b. To establish whether the actual performance of the entire system or the performance of any of the constituent parts such as the cable plant or the repeater equipment meet design or other performance criteria.

c. Trunk trouble-clearing can be performed on a coordinated basis to locate and correct the source of trouble. Compensating maladjustments must be avoided.

8.02 The type of measurements which are made for accomplishing the above objectives are as follows:

a. Measurement of non-repeatered, or partially-repeatered circuit loss.

b. Measurement of totally-repeatered circuit loss (net circuit loss).

c. Repeater gain can thus be determined from measurements of (a) and (b) above.

d. Measurement of structural return loss.

8.03 The step-by-step procedure for calibrating the test equipment, and the measurement of the non-repeatered, partially-repeatered, or totally-repeatered trunk loss (from which the repeater gain is found) and the form for recording the results of the measurements is shown in REA Form 397a.

8.04 The step-by-step procedure for calibrating test equipment, measuring the structural return loss and the form used to record the results of the measurements is shown in REA TE & CM-445, Figures 11A, 11B and Table I respectively.

APPLICATION GUIDE I

THIS SECTION SHOWS THE GENERAL STEP-BY-STEP PROCEDURES APPLIED TO A NUMBER OF BASIC CABLE LAYOUTS AND REPEATER CONFIGURATIONS FOR COMPUTING AVAILABLE REPEATER GAIN(S) OF NEGATIVE RESISTANCE/ IMPEDANCE REPEATERS WORKING OVER UNIFORM GAUGE LOADED CABLES. THESE DESIGN PROCEDURES ARE THEN SHOWN IN REPRESENTATIVE SITUATIONS IN EXAMPLES 1 THROUGH 8.

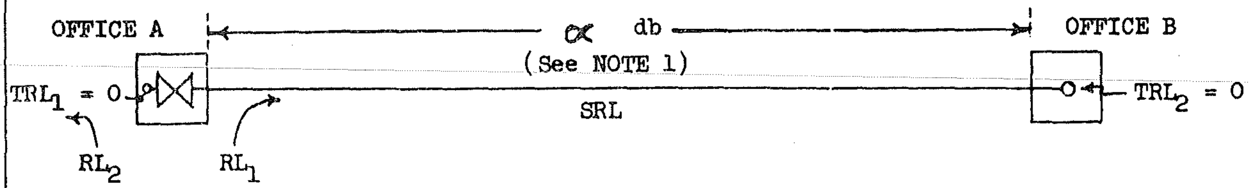
ABBREVIATIONS USED IN APPLICATION GUIDES AND EXAMPLES HEREIN

α	= Attenuation
$\perp$	= SRL combined on a power summation basis as per Chart I
SRL	= Structural return loss
SRL(T)	= SRL referred to repeater locations when combining cable gauges having different SRL's
LBOL	= LBO loss
TLBOL	= Total LBO loss when more than one LBO is used
COL	= Central office loss
TRL	= Terminal return loss
NRCL	= Non-repeatered circuit loss
RRG	= Required repeater gain
TRRG	= Total repeater gain when more than one repeater is involved
ARG	= Available repeater gain (the repeater gain which the line section return loss will allow.)
TARG	= Total available repeater gain when more than one repeater is involved
TO	= Transmission objective
CR	= Crosstalk rating
NES	= Natural end section (cable only)

APPLICATION GUIDE I

UNIVERSAL STEP-BY-STEP PROCEDURE FOR COMPUTING AVAILABLE REPEATER GAIN OF NEGATIVE RESISTANCE AND NEGATIVE IMPEDANCE REPEATERS WORKING ON UNIFORM GAUGE LOADED CABLES FOR THE CONFIGURATIONS SHOWN BELOW:

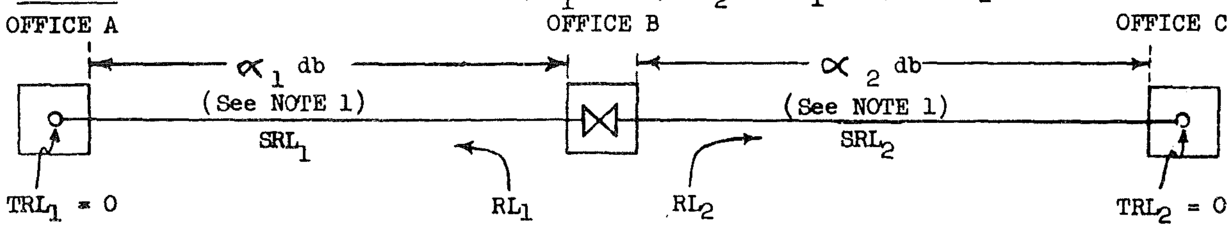
CASE I - ONE TERMINAL REPEATER



a. COMBINE $RL_1 = 2\alpha \perp SRL = N$ db
RL_2 = Zero db

b. REPEATER GAIN
(NEG. RES.) From RL_1 and RL_2. Enter Gain Chart II at N and Zero db
(NEG. IMP.) From RL_1 and RL_2. Enter Gain Chart III at N and Zero db

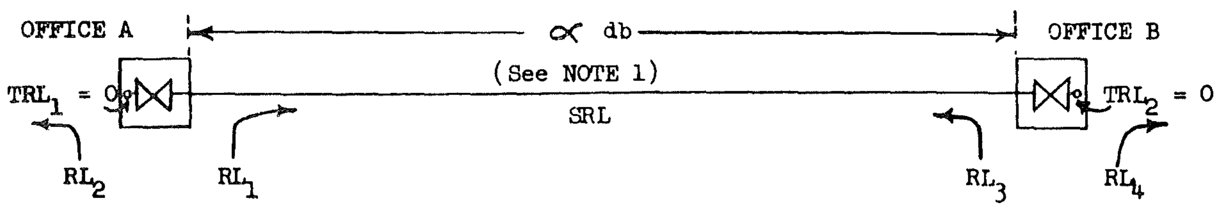
CASE II - ONE INTERMEDIATE REPEATER (α_1 = or $\neq \alpha_2$) (SRL_1 = or $\neq$ SRL_2)



a. COMBINE $RL_1 = 2\alpha_1 \perp SRL_1 = M$ db
$RL_2 = 2\alpha_2 \perp SRL_2 = N$ db

b. REPEATER GAIN
(NEG. RES.) From RL_1 and RL_2. Enter Gain Chart II at M and N db
(NEG. IMP.) From RL_1 and RL_2. Enter Gain Chart III at M and N db

CASE III - TWO TERMINAL REPEATERS



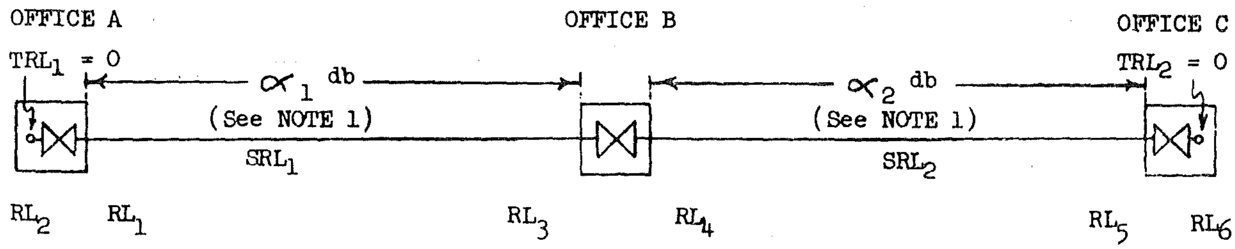
a. COMBINE (NEG. RES.) $RL_1 = RL_3 = 1.2\alpha \perp SRL = M$ db
$RL_2 = RL_4$ = Zero db
(NEG. IMP.) $RL_1 = RL_3 = 1.1\alpha \perp SRL = N$ db
$RL_2 = RL_4$ = Zero db

b. REPEATER GAIN (EACH OFFICE)
(NEG. RES.) From RL_1 and RL_2. Enter Gain Chart II at M and Zero db
(NEG. IMP.) From RL_1 and RL_2. Enter Gain Chart III at N & Zero db

NOTE 1: Include LBO loss but no office losses.

APPLICATION GUIDE I, CONT'D.

CASE IV - TERMINAL AND INTERMEDIATE REPEATERS (α_1 = or $\neq \alpha_2$) (SRL_1 = or $\neq$ SRL_2)



a. (NEG. RES.) COMBINE $RL_1 = RL_3 = 1.2\alpha_1 \perp SRL_1$ = N db
$RL_2 = RL_6$ = Zero db
$RL_4 = RL_5 = 1.2\,\alpha_2 \perp SRL_2$ = M db

REPEATER GAIN

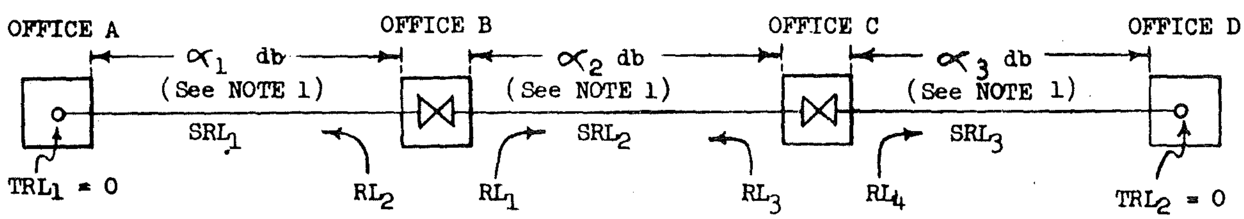
Office A From RL_1 and RL_2. Enter Gain Chart II at N and Zero db
Office B From RL_3 and RL_4. Enter Gain Chart II at N and M db
Office C From RL_5 and RL_6. Enter Gain Chart II at M and Zero db

b. (NEG. IMP.) COMBINE $RL_1 = RL_3 = 1.1\alpha_1 \perp SRL_1$ = P db
$RL_2 = RL_4$ = Zero db
$RL_4 = RL_5 = 1.1\alpha_2 \perp SRL_2$ = S db

REPEATER GAIN

Office A From RL_1 and RL_2. Enter Gain Chart III at P and Zero db
Office B From RL_3 and RL_4. Enter Gain Chart III at P and S db
Office C From RL_5 and RL_6. Enter Gain Chart III at S and Zero db

CASE V - TWO INTERMEDIATE REPEATERS ($\alpha_1, \alpha_2, \alpha_3$ = or $\neq$ each other)
(SRL_1, SRL_2, SRL_3 = or $\neq$ each other)



a. (NEG. RES.) COMBINE $RL_1 = RL_3 = 1.2\alpha_2 \perp SRL_2$ = M db
$RL_2 = 2\alpha_1 \perp SRL_1$ = N db
$RL_4 = 2\alpha_3 \perp SRL_3$ = P db

REPEATER GAIN

Office B From RL_1 and RL_2. Enter Gain Chart II at M and N db
Office C From RL_3 and RL_4. Enter Gain Chart II at M and P db

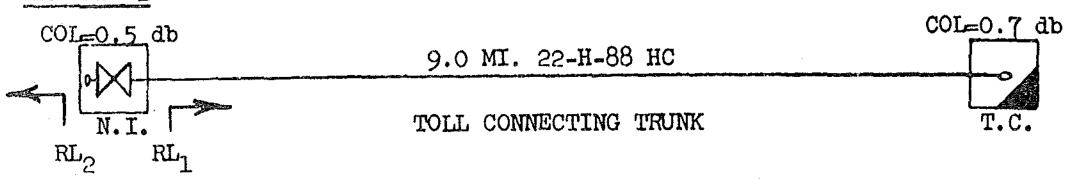
b. (NEG. IMP.) COMBINE $RL_1 = RL_3 = 1.1\alpha_2 \perp SRL_2$ = R db
$RL_2 = 2\alpha_1 \perp SRL_1$ = S db
$RL_4 = 2\alpha_3 \perp SRL_3$ = T db

REPEATER GAIN

Office B From RL_1 and RL_2. Enter Gain Chart III at R and S db
Office C From RL_3 and RL_4. Enter Gain Chart III at R and T db

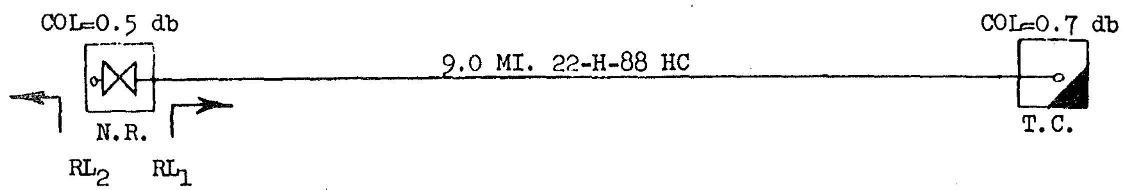
NOTE 1: Include LBO loss but no office losses.

EXAMPLE 1



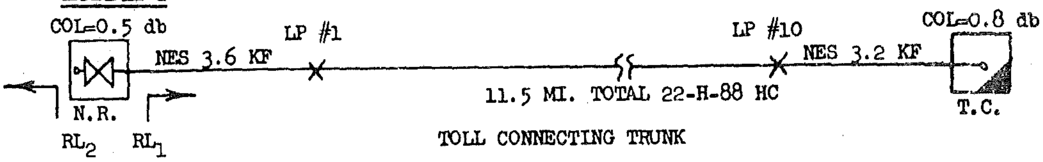
	PROCEDURE			REFERENCE
1.	TO	:	VNL + 2 = (facility length x VNL factor) + 2.0 (fixed) + 0.4 (maint.)	Table I
		:	VNL + 2 = (9.0 x 0.04) + 2.4 = 2.8 db	
2.	NRCL	:	(Attenuation) + (COL)	Table II
		:	(9.0 x 0.792) + (0.7 + 0.5) = 8.3 db	
3.	RRG	:	8.3 - 2.8 = 5.5 db	
4.	RL_1	:	2 x attenuation $\perp$ SRL	Case I
		:	2 x 7.1 $\perp$ 19 = 13.0 db	Table IV, Chart I
5.	RL_2	:	0 db	
6.	ARG	:	from 13 and 0 db = 4.6 db	Chart III
7.	NCL	:	8.3 - 4.6 = 3.7 db DOES NOT MEET VNL + 2 OBJECTIVE	

Since, for the facility length and gauge shown, one repeater at the end office does not meet objectives an additional repeater could be considered at the toll center. This would be, however, a disadvantageous alternative from the economic standpoint and return loss reasons given in paragraph 3.133. The capability of a negative resistance repeater is therefore considered next as shown below.



	PROCEDURE			REFERENCE
1.	TO	:	VNL + 2 = (facility length x VNL factor) + 2.0 (fixed) + 0.4 (maint.)	Table I
		:	VNL + 2 = (9.0 x 0.04) + 2.4 = 2.8 db	
2.	NRCL	:	(Attenuation) + (COL) + (LBO)	Tables II, V
		:	(9 x 0.792) + (0.7 + 0.5) + 0.4 = 8.7 db	
3.	RRG	:	8.7 - 2.8 = 5.9 db	
4.	RL_1	:	2 (Attenuation + LBO) $\perp$ SRL	Tables II, V
		:	2 (7.1 + 0.4) $\perp$ 19 = 13.5 db	Table IV, Chart I
5.	RL_2	:	0 db	
6.	ARG	:	from 13.5 and 0 db = 5.9 db	Chart II
7.	NCL	:	8.7 - 5.9 = 2.8 db MEETS VNL + 2 OBJECTIVE	
8.	CR	:	Good	Table VI

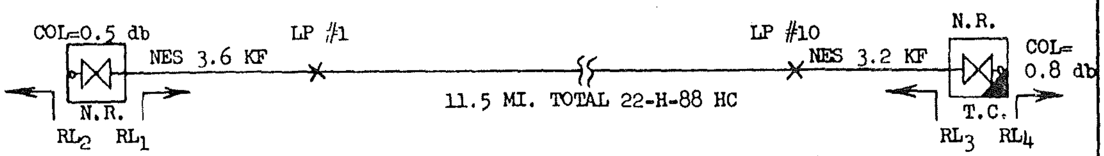
EXAMPLE 2



TOLL CONNECTING TRUNK

	PROCEDURE		REFERENCE
1.	TO	: VNL + 2 = (11.5 x 0.04) + 2.4 = 2.9 db	Table I
2.	NRCL	: (Attenuation) + (COL) + (LBO)	Tables II, V
		: (11.5 x 0.792) + (0.5 + 0.8) + 0.4 = 9.1 + 1.7 = 10.8 db	
3.	RRG	: 10.8 - 2.9 = 7.9 db	
4.	RL_1	: 2 (Attenuation + LBO) ⊥ SRL	Case I
		: 2 (9.1 + 0.4) ⊥ 19 = 16 db	Table IV, Chart I
5.	RL_2	: 0 db	
6.	ARG	: from 16 and 0 db = 6.8 db	Chart II
		DOES NOT MEET VNL + 2 OBJECTIVES	

Two repeaters are therefore required as shown below.



	PROCEDURE		REFERENCE
1.	TO	: VNL + 2 = (11.5 x 0.04) + 2.4 = 2.9 db	Table I
2.	NRCL	: (Attenuation) + (COL) + (LBO)	Tables II, V
		: 10.8 + 0.4 = 11.2 db	
3.	RRG	: 11.2 - 2.9 = 8.3 db	
4.	$RL_1 = RL_3$	: 1.2 (Attenuation + LBO) ⊥ SRL	Case II
		: 1.2 (9.1 + 2 x 0.4) ⊥ 19 = 11.1 db	Table IV, Chart I
5.	$RL_2 = RL_4$	: 0 db	
6.	ARG	: from 11.1 and 0 db = 4.9 db	Chart II
7.	TARG	: 2 x 4.9 = 9.8 db	
8.	NCL	: 11.2 - 9.8 = 1.4 db MEETS VNL + 2 OBJECTIVE	
9.	CR	: Good	Table VI

This example is next computed by using the BOR component of the LBO. It is intended to show that when the BOR is used, in computations to build out the natural end section (NES) to 5800', it does not necessarily increase the overall net circuit loss. This is shown below.

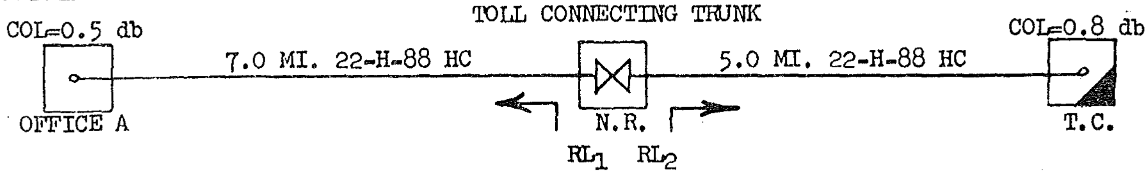
	PROCEDURE		REFERENCE
1.	TO	: VNL + 2 = (11.5 x 0.04) + 2.4 = 2.9 db	Table I
2.	NRCL	: (Attenuation) + (COL) + (LBO) + (BOR)	Tables II, V
		: 11.2 + (5.8 - 3.6) x 0.152 + (5.8 - 3.2) x 0.152	
		: 11.2 + 0.33 + 0.4 = 11.9 db	
3.	RRG	: 11.9 - 2.9 = 9.0 db	
4.	$RL_1 = RL_3$	: 1.2 (Attenuation + LBO + BOR) ⊥ SRL	Case II
		1.2 (9.1 + 2 x 0.4 + 0.33 + 0.4) ⊥ 19 = 11.9 db	Table IV, Chart I
5.	$RL_2 = RL_4$	: 0 db	
6.	ARG	: from 11.9 and 0 db = 5.2 db	Chart II
7.	TARG	: 2 x 5.2 = 10.4 db	
8.	NCL	: 11.9 - 10.4 = 1.5 db MEETS VNL + 2 OBJECTIVE	

Thus, by comparing steps (2) and (7) of the computations with and without the BOR component it can be seen that the increase in loss (in NRCL) has been overcome by additional repeater gain (in TARG) so that the net circuit loss has remained essentially the same.

Note: In this example the return losses allow a total available repeater gain which is more than required to meet the transmission objective of 2.9 db. Nevertheless, the repeaters should be set to produce a net circuit loss of 2.9 db but not lower. This is regardless of whether the BOR adjustment is used or not.

EXAMPLE 3

TOLL CONNECTING TRUNK

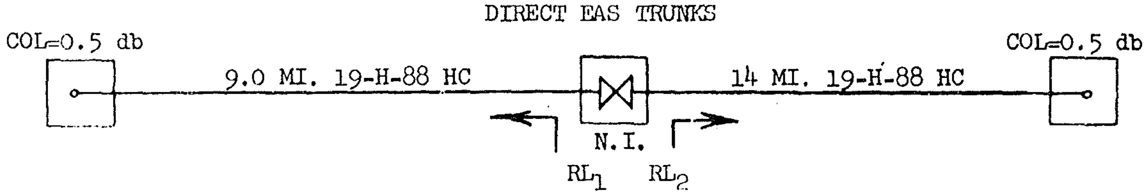


	PROCEDURE			REFERENCE
1.	TO	:	VNL + 2 = (12 x 0.04) + 2.4 = 2.9 db	Table I
2.	NRCL	:	(Attenuation) + (COL) + (LBO)	Tables II, V
		:	(7 x 0.792 + 5 x 0.792) + (0.5 + 0.8) + (2 x 0.4)	
			(5.54 + 3.96) + 2.1 = 11.6 db	
3.	RRG	:	11.6 - 2.9 = 8.7 db	
4.	RL_1	:	2 (Attenuation + LBO) $\perp$ SRL_1	Case III
		:	2 (5.54 + 0.4) $\perp$ 19 = 11.1 db	Table IV, Chart I
5.	RL_2	:	2 (Attenuation + LBO) $\perp$ SRL_1	Case III
		:	2 (3.96 + 0.4) $\perp$ 19 = 8.3	Table IV, Chart I
6.	ARG	:	From 11.1 and 8.3 db = 9.0 db	Chart II
7.	NCL	:	11.6 - 9.0 = 2.6 db MEETS VNL + 2 OBJECTIVE	
8.	CR	:	Good	Table VI

Note: In this example, use of negative impedance type repeaters would have necessitated repeaters at office A in addition to the office shown.

EXAMPLE 4

DIRECT EAS TRUNKS



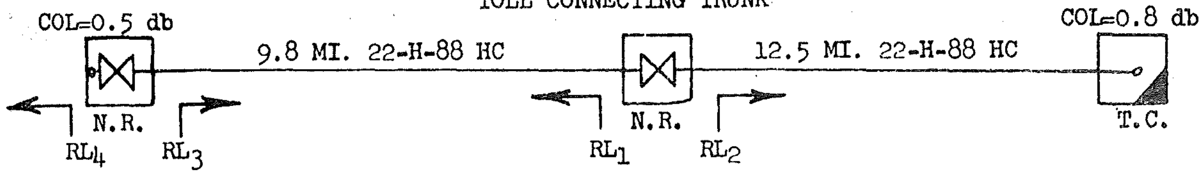
	PROCEDURE			REFERENCE
1.	TO	:	6 db, maximum	
2.	NRCL	:	(Attenuation) + (COL)	Table II
		:	(9.0 x 0.428 + 14 x 0.428) + (2 x 0.5)	
			= (3.85 + 5.99) + 1.0 = 10.8 db	
3.	RRG	:	10.8 - 6.0 = 4.8 db	
4.	RL_1	:	2 (Attenuation) $\perp$ SRL_1	Case III
		:	2 x 3.85 $\perp$ 16 = 7.1 db	Table IV, Chart I
5.	RL_2	:	2 (Attenuation) $\perp$ SRL_2	Case III
		:	2 x 5.99 $\perp$ 16 = 10.6 db	Table IV, Chart I
6.	ARG	:	From 7.1 and 10.6 db = 6.9 db	Chart III
7.	NCL	:	10.8 - 6.9 = 3.9 db MEETS OBJECTIVE	

In this example the negative impedance or the negative resistance repeater can meet circuit objectives. (Had a negative resistance type been used the circuit would have been capable of being operated at a 2.6 db net loss.

Note: When placing the repeater in service this trunk can be set to operate at a 3.9 db net loss (instead of the 6 db of the objective). See paragraph 3.121a.

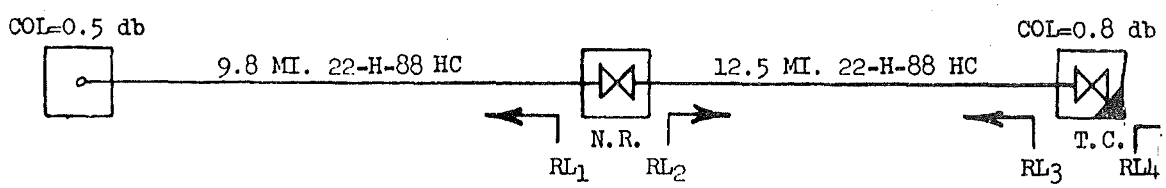
EXAMPLE 5

TOLL CONNECTING TRUNK



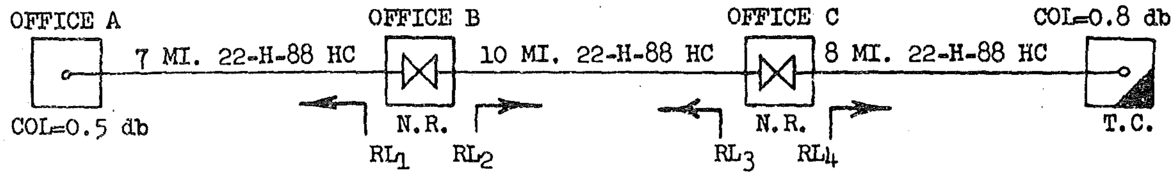
PROCEDURE			REFERENCE
1.	TO	: VNL + 2 = (22.3 x 0.04) + 2.4 = 3.3 db	Table I
2.	NRCL	: (Attenuation) + (COL) + (LBO)	Tables II, V
		: (9.8 x 0.792 + 12.5 x 0.792) + (0.5 + 0.8) + (3 x 0.4) = (7.75 + 9.9) + 2.5 = 20.2 db	
3.	TRRG	: 20.2 - 3.3 = 16.9 db	
4.	RL_1	: 1.2 (7.75 + 2 x 0.4) ⊥ 19 = 9.6 db	Case II, Table
5.	RL_2 = RL_3	: 2 (9.9 + 0.4) ⊥ 19 = 16.7 db	Case I, Table I
6.	RL_4	: 0 db	
7.	ARG	: office A: from 9.6 and 0 db = 4.2 db	Chart II
		office B: from 9.6 and 16.7 db = 11.8 db	ChartII
8.	TARG	: 4.2 + 11.8 = 16 db DOES NOT MEET VNL + 2 OBJECTIVE	

In order to bring the trunk to within objectives an additional repeater may be considered at the toll center. However, before this is done, the repeater at office A is relocated at the toll center. This latter approach is shown below:



PROCEDURE			REFERENCE
1.	TO	: VNL + 2 = (22.3 x 0.04) + 2.4 = 3.3 db	Table I
2.	NRCL	: (Attenuation) + (COL) + (LBO)	Tables II, V
		: (9.8 x 0.792 + 12.5 x 0.792) + (0.5 + 0.8) + (3 x 0.4) = (7.75 + 9.9) + 2.5 = 20.2 db	
3.	TRRG	: 20.2 - 3.3 = 16.9 db	
4.	RL_1	: 2 (7.75 + 0.4) ⊥ 19 = 14.4 db	Case I, Table
5.	RL_2 = RL_3	: 1.2 (9.9 + 2 x 0.4) ⊥ 19 = 11.8 db	Case II, Table
6.	RL_4	: 0 db	
7.	ARG	: Office B . from 11.8 and 14.4 db = 12 db	
		Toll Center: from 11.8 and 0 db = 5.1 db	
8.	TARG	: 12 + 5.1 = 17.1 db	
9.	NCL	: 20.2 - 17.1 = 3.1 MEETS VNL + 2 OBJECTIVE	
10.	CR	: Good	Table VI

EXAMPLE 6

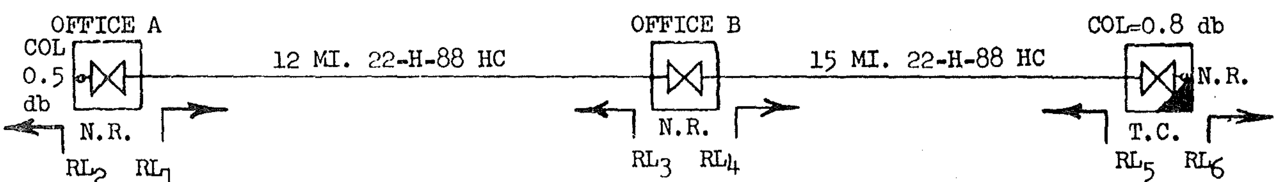


TOLL CONNECTING TRUNK

	PROCEDURE		REFERENCE
1.	TO	: VNL + 2 = (25 x 0.04) + 2.4 = 3.4 db	Table I
2.	NRCL	: (Attenuation) + (COL) + (LBO)	Tables II, V
		: (7 x 0.792 + 10 x 0.792 + 8 x 0.792) + (0.5 + 0.8) + (4 x 0.4) = (5.54 + 7.92 + 6.34) + 2.9 = 22.7 db	
3.	RRG	: 22.7 - 3.4 = 19.3 db	
4.	RL_1	: 2 (5.5 + 0.4) ⊥ 19 = 11.1 db	Case I, Table IV, Chart I
5.	RL_2 = RL_3	: 1.2 (7.9 + 2 x 0.4) ⊥ 19 = 9.9 db	Case II, Table I, Chart I
6.	RL_4	: 2 (6.3 + 0.4) ⊥ 19 = 12.3 db	Case I, Table IV, Chart I
7.	ARG	: Office B: From 11.1 and 9.9 db = 9.7 db	Chart II
		Office C: From 9.9 and 12.3 db = 10.2 db	Chart II
8.	TARG	: 9.7 + 10.2 = 19.9 db	
9.	NCL	: 22.7 - 19.9 = 2.8 db MEETS VNL + 2 OBJECTIVE	

Note: Operate circuit at VNL + 2 (3.4 db) only; <u>not</u> at a lower loss.

EXAMPLE 7

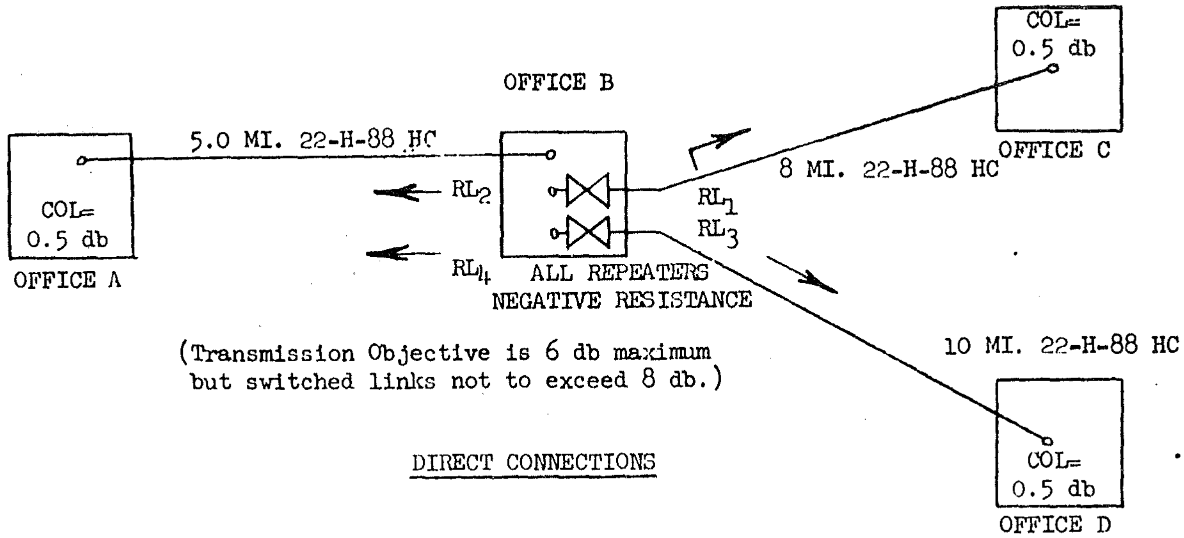


TOLL CONNECTING TRUNK

	PROCEDURE		REFERENCE
1.	TO	: VNL + 2 = (27 x 0.04) + 2.4 = 3.5 db	Table I
2.	NRCL	: (Attenuation) + (COL) + (LBO)	
		: (12 x 0.792 + 15 x 0.792) + (0.5 + 0.8) + (4 x 0.4) = (9.5 + 11.9) + 2.9 = 24.3	
3.	TRRG	: 24.3 - 3.5 = 20.8 db	
4.	RL_1 = RL_3	: 1.2 (9.5 + 2 x 0.4) ⊥ 19 = 11.5 db	
5.	RL_4 = RL_5	: 1.2 (11.9 + 2 x 0.4) ⊥ 19 = 13.7 db	
6.	RL_2 = RL_6	: 0 db	
7.	ARG	: Office A: from 11.5 and 0 db = 5.0 db	Chart II
		Office B: from 11.5 and 13.7 db = 11.6 db	Chart II
		T.C. : from 13.7 and 0 db = 5.9 db	Chart II
8.	TARG	: 5.0 + 11.6 + 5.9 = 22.5 db	
9.	NCL	: 24.3 - 22.5 = 1.8 db MEETS VNL + 2 OBJECTIVE	

Note: Operate circuit at VNL + 2 (3.5 db) only; <u>not</u> at a lower loss.

EXAMPLE 8 Tandeming Intrasystem EAS Trunks. (In this example EAS exists between all offices. Switching is performed at Office B.)



(Transmission Objective is 6 db maximum but switched links not to exceed 8 db.)

DIRECT CONNECTIONS

A TO B
1. NRCL: (5 x 0.792) + (2 x 0.5) = 5.0 db

B TO C
1. NRCL: (Attenuation + (COL) + (LBO)
: (8 x 0.792) + (2 x 0.5) + (0.4) = 7.7 db
2. RL_1 : 2 (6.3 + 0.4) $\perp$ 19 = 12.4 db RL_2 = 0 db
3. ARG : from 7.7 and 0 db = 5.3 db
4. NCL : 7.7 - 5.3 = 2.4 db

B TO D
1. NRCL: (Attenuation) + (COL) + (LBO)
: (10 x 0.792) + (2 x 0.5) + (0.4) = 9.3 db
2. RL_3 : 2 (7.9 + 0.4) $\perp$ 19 = 14.6 db RL_4 = 0 db
3. ARG : from 14.6 and 0 db = 6.3 db
4. NCL : 9.3 - 6.3 = 3.0 db

SWITCHED CONNECTIONS

A TO C
1. NCL: NCL (A to B) + NCL (B to C) = 5.0 + 2.4 = 7.4 db

A TO D
1. NCL: NCL (A to B) + NCL (B to D) = 5.0 + 3.0 = 8.0

C TO D
1. NCL: NCL (B to C) + NCL (B to D) = 2.4 + 3.0 = 5.4 db

All direct and switched connections meet the objectives.

NOTE: It should be evident from the above example that had the terminal repeaters, all of which are shown located at Office B, been placed at the other terminal offices (locations C and D) the same repeater gains and therefore the same net circuit losses would have been realized. Whenever possible, all repeaters should be located at the same office for ease of maintenance.

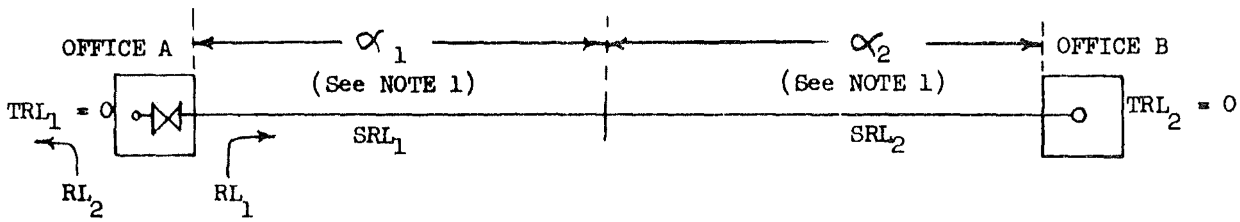
APPLICATION GUIDE II

THIS SECTION SHOWS THE GENERAL STEP-BY-STEP PROCEDURES APPLIED TO A NUMBER OF BASIC CABLE LAYOUTS AND REPEATER CONFIGURATIONS FOR COMPUTING AVAILABLE REPEATER GAIN(S) OF NEGATIVE RESISTANCE/IMPEDANCE REPEATERS WORKING OVER MIXED GAUGE LOADED CABLES. THESE DESIGN PROCEDURES ARE THEN SHOWN IN REPRESENTATIVE SITUATIONS IN EXAMPLES 1 THROUGH 4.

APPLICATION GUIDE II

UNIVERSAL STEP-BY-STEP PROCEDURE FOR COMPUTING AVAILABLE REPEATER GAIN OF NEGATIVE RESISTANCE/IMPEDANCE REPEATERS WORKING ON MIXED GAUGE LOADED CABLES FOR THE CONFIGURATIONS SHOWN ABOVE

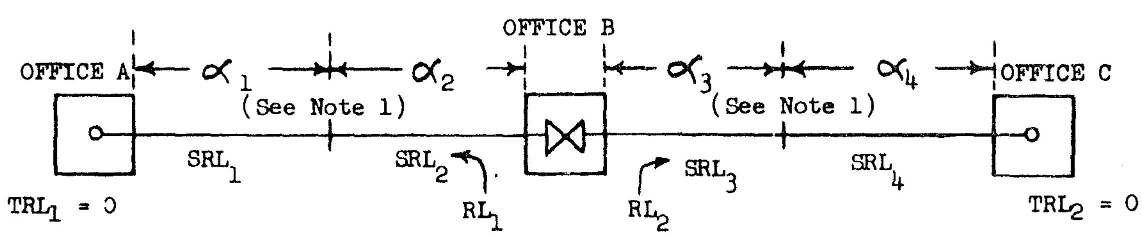
CASE I - ONE TERMINAL REPEATER (α_1 = or $\neq \alpha_2$)



a. FIND : $SRL\ (T) = (2\alpha_1 + SRL_2) \perp SRL_1$
b. COMBINE: $RL_1 = 2(\alpha_1 + \alpha_2) \perp SRL\ (T)$ = N db
RL_2 = Zero db
c. REPEATER GAIN

(NEG. RES.) From RL_1 and RL_2. Enter Gain Chart II ant N and Zero db
(NEG. IMP.) From RL_1 and RL_2. Enter Gain Chart III at N and Zero db

CASE II - ONE INTERMEDIATE REPEATER ($\alpha_1, \alpha_2, \alpha_3, \alpha_4$, = or $\neq$ each other)



a. FIND : $SRL\ (T_1) = (2\alpha_2 + SRL\ ) \perp SRL_2$
b. COMBINE: $RL_1 = 2(\alpha_1 + \alpha_2) \perp SRL\ (T_1)$ = N db

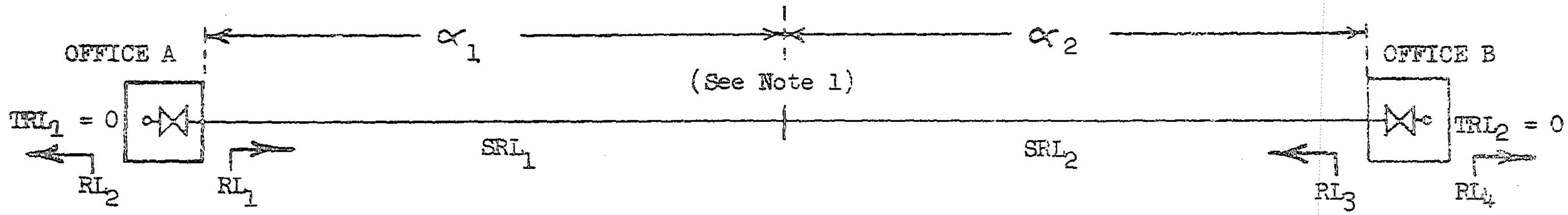
c. FIND : $SRL\ (T_2) = (2\alpha_3 + SRL_4) \perp SRL_3$
d. COMBINE: $RL_2 = 2(\alpha_3 + \alpha_4) \perp SRL\ (T_2)$ = M db

e. REPEATER GAIN:
(NEG. RES.) From RL_1 and RL_2. Enter Gain Chart II at M and N db
(NEG. IMP.) From RL_1 and RL_2. Enter Gain Chart III at M and N db

NOTE 1: Includes LBO loss but no offices losses

APPLICATION GUIDE II, CONT'D.

CASE III - TWO TERMINAL REPEATERS (α_1 = or $\neq \alpha_2$)



(NEG. RES.) a. COMBINE $RL_1 = 1.2\ (\alpha_1 + \alpha_2) \perp SRL_1$ = M db
RL_2 = 0 db

b. COMBINE $RL_3 = 1.2\ (\alpha_1 + \alpha_2) \perp SRL_2$ = N db
RL_4 = 0 db

c. REPEATER GAIN
Office A: from RL_1 and RL_2. Enter Gain Chart II at M and Zero db
Office B: from RL_3 and RL_4. Enter Gain Chart II at N and Zero db

(NEG. IMP.) a. COMBINE $RL_1 = 1.1\ (\alpha_1 + \alpha_2) \perp SRL_1$ = P db
RL_2 = 0 db

b. COMBINE $RL_3 = 1.1\ (\alpha_1 + \alpha_2) \perp SRL_1$ = S db
RL_4 = 0 db

c. REPEATER GAIN
Office A: from RL_1 and RL_2. Enter Gain Chart III at P and Zero db
Office B: from RL_3 and RL_4. Enter Gain Chart III at S and Zero db

CASE IV, V - FOR REPEATER CONFIGURATIONS AS SHOWN IN CASE IV AND V OF APPLICATION GUIDE I, BUT INVOLVING MIXED GAUGES, THE BASIC COMPUTATION PROCEDURES WILL BE THOSE OF APPLICATION GUIDE I AS MODIFIED APPLICATION GUIDE II.

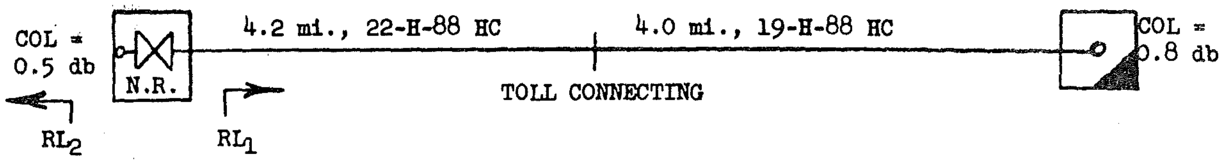
CASE VI - MIXED GAUGES OF GREATER COMPLEXITY

FOR MIXED CABLE GAUGES OF GREATER COMPLEXITY THAN THOSE COVERED BY CASES I, II AND III ABOVE, COMPUTE LINE SECTION RETURN LOSS AS FOLLOWS:

a. AT EACH REPEATER LOCATION WHERE THE RETURN LOSS IS BEING DESIRED, USE THE STRUCTURAL RETURN LOSS OF THE CABLE GAUGE ADJACENT TO THE REPEATER WHOSE 1000 CPS ATTENUATION IS GREATER THAN 2 DB.

b. USING THE SRL AS DETERMINED IN STEP a) ABOVE, PERFORM THE COMPUTATIONS FOR FINDING THE RETURN LOSS AS PER CASES I, II, III, IV AND V, AS APPLICABLE, OF "APPLICATION GUIDE I."

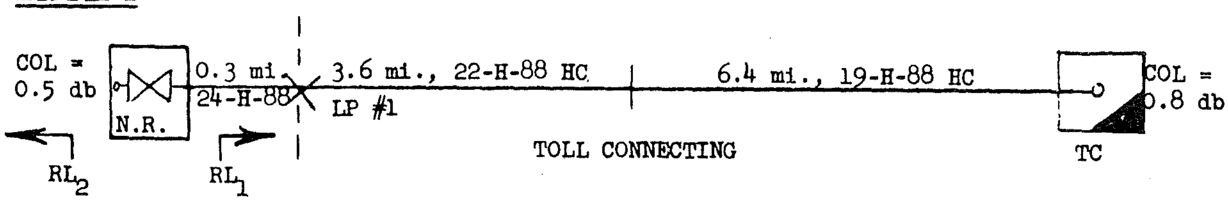
EXAMPLE 1



PROCEDURE			REFERENCE
1. TO	:	VNL + 2 = (8.2 x 0.4) + 2.4 = 2.73	Table I
2. NRCL	:	(attenuation) + (refl. loss) + (COL) + LBO 4.2 x 0.792 + 4.0 x 0.428) + (0) + (0.5 x 0.8) + 0.4 (3.33 + 1.71) + 1.7 = 6.74 db	Tables II, III
3. RRG	:	6.7 - 2.7 = 4.0 db.	
4. $SRL(T_2)$	:	(2 x 3.3 + 16) $\perp$ 19 = 17.4	Case I
5. RL_1	:	2 (attenuation + LBO) $\perp$ SRL 2 (3.33 + 1.71 + 0.4) $\perp$ 17.4 = 10 db	Chart I
6. RL_2	:	Zero db	
7. ARG	:	From 10.0 and zero db = 4.4 db	Chart II
8. NCL	:	6.7 - 4.4 = 2.3 Meets VNL + 2	
9. CR	:	Good	Table VI

Note: When placing the repeater into service, set the repeater only for gain required to meet VNL + 2 objectives, but not lower. (See par. 3.12b.)

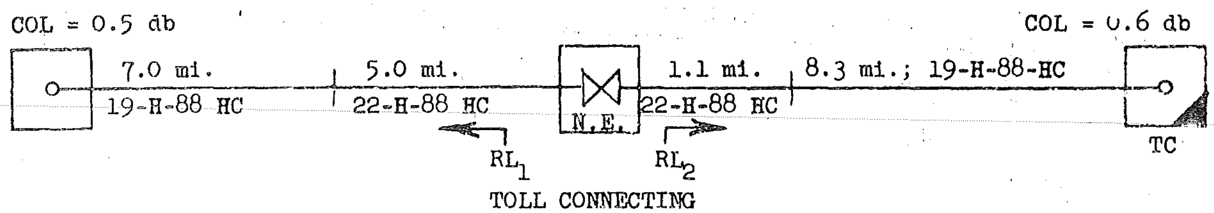
EXAMPLE 2



PROCEDURE			REFERENCE
1. TO	:	VNL + 2 = (10.3 x 0.04) + 2.4 = 2.8 db	Table I
2. NRCL	:	(attenuation) + (refl. losses) + (COL) + (LBO) + (BOR[1]) (0.3 x 1.21 + 3.6 x 0.792 + 6.4 x 0.428) + (0) + (0.5 + 8) + (0.5) + (5.8 - 3.4) 0.235 = (0.36 + 2.85 + 2.74) + 2.36 = 8.3 db	Tables II, III
3. RRG	:	8.3 - 2.8 = 5.5 db	
4. RL_2	:	2 (attenuation + LBO + BOR) $\perp$ SRL 2 (0.36 + 2.85 + 2.74 + 0.5 + 0.56) $\perp$ 19[2] = 12.8 db	Chart I
5. RL_2	:	Zero db	
6. ARG	:	From 12.8 and zero db = 5.5 db	Chart II
7. NCL	:	8.3 - 5.5 = 2.8 db Meets VNL + 2	
8. CR	:	Good	Table VI

Notes:
1. BOR is used for illustrative purposes.
2. SRL of 22 gauge is used since loss of 24 gauge is less than 2 db loss and since loss of 22 gauge is greater than 2 db. (See Application Guide II, Case VI, par. 2.)

EXAMPLE 3

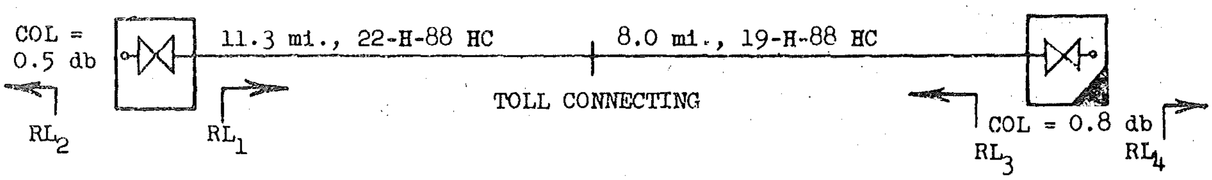


PROCEDURE | REFERENCE

1. TO : VNL + 2 = (21.4 x 0.04) + 2.4 = 3.3 db — Table I
2. NRCL : (attenuation) + (refl. losses) + (COL) + LBO's — Tables II, III, V
3. : (7.0 x 0.428 + 5 x 0.792 + 1.1 x 0.792 + 8.3 x 0.428) + (0.5 + 0.6) + (2 x 0.4) = (3.0 + 3.96 + 0.87 + 3.55) + 1.9 = 13.3 db
3. RRG : 13.3 - 3.3 = 10 db
4. $SRL(T_2)$: (2 x atten. of 22-H-88 + SRL of 19-H-88) $\perp$ SRL of 22-H-88 — Case I
(2 x 3.96 + 16) $\perp$ 19 = 17.8 db — Chart I
5. RL_1 : 2 (3.0 + 3.96 + 0.4) $\perp$ 17.8 = 16.1 — Chart I
6. $SRL(T_2)$: 19 db (Note 1) — Table IV
7. RL_2 : 2 (attenuation + LBO) $\perp$ SRL_2
2 (0.87 + 3.55 + 0.4) $\perp$ 19 = 9.1 db — Chart I
8. ARG : from 16.1 and 9.1 db = 11.4 db Meets VNL + 2 — Chart II
9. CR : Good — Table VI

Note 1: When placing repeater into service, set the repeater only for gain required to meet VNL + 2 (3.3 db) but not lower. (See paragraph 3.12b.)

EXAMPLE 4



PROCEDURE | REFERENCE

1. TO : VNL + 2 = (19.3 x 0.04) + 2.4 = 3.2 db — Table I
2. NRCL : (attenuation) + (refl. loss) + (COL) + (LBO's) — Tables II, III, V
(11.3 x 0.792 + 8.0 x 0.428) + (0) + (0.5 + 0.8) + 2 x 0.4)
= (8.95 + 3.42) + 2.1 = 14.5 db
3. TRRG : 14.5 - 3.2 = 11.3 db
4. RL_1 : 1.2 (8.95 + 3.42 + 2 x 0.4) $\perp$ 19 = 14.1 db — Case III, Chart I
5. RL_2 : 1.2 (8.95 + 3.42 + 2 x 0.4) $\perp$ 16 = 12.9 db — Case III, Chart I
6. ARG :
Office A: from 14.1 and zero db = 6.2 db — Chart II
Office B: from 12.9 and zero db = 5.6 db — Chart II
7. TARG : 6.2 + 5.6 = 11.8 db
8. NCL : 14.5 - 11.8 = 2.7 db Meets VNL + 2
9. CR : Good — Chart VI

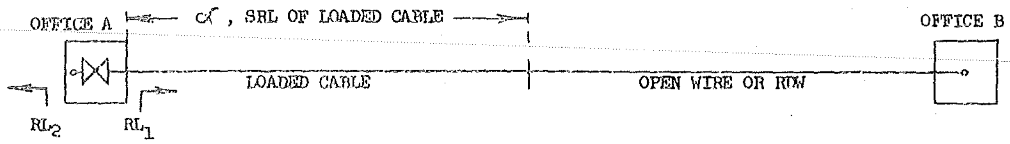
APPLICATION GUIDE III

THIS SECTION SHOWS THE GENERAL STEP-BY-STEP PROCEDURES APPLIED TO A NUMBER OF BASIC CABLE LAYOUTS AND REPEATER CONFIGURATIONS FOR COMPUTING AVAILABLE REPEATER GAIN(S) OF NEGATIVE RESISTANCE/IMPEDANCE REPEATERS WORKING OVER MIXED TYPE FACILITIES. THESE DESIGN PROCEDURES ARE THEN SHOWN IN REPRESENTATIVE SITUATIONS IN EXAMPLES 1 THROUGH 5.

APPLICATION GUIDE III

UNIVERSAL STEP-BY-STEP PROCEDURE FOR COMPUTING AVAILABLE REPEATER GAIN FOR NEGATIVE RESISTANCE/IMPEDANCE REPEATERS OPERATING ON MIXED TYPE FACILITIES FOR THE CONFIGURATIONS SHOWN BELOW

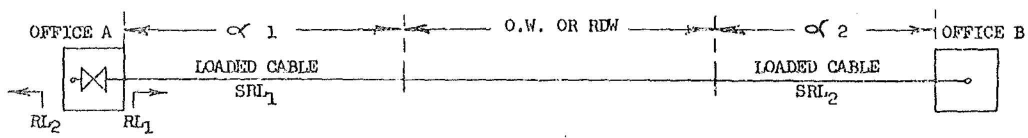
CASE I-A ONE TERMINAL REPEATER



PROCEDURE

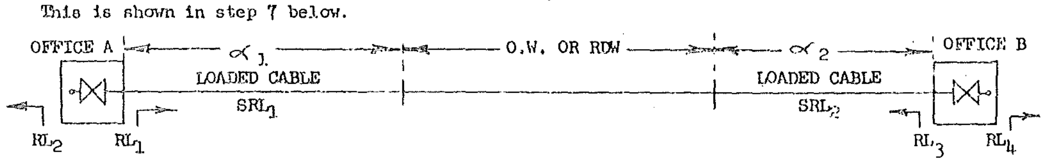
1. Locate repeater in office adjacent to loaded cable. (Do not locate repeater in office adjacent to open wire.)
2. For repeater calculations, assume the circuit begins at the repeater and ends at the loaded cable-open wire junction.
3. Now, calculate the section return loss for the loaded cable portion only as per Application Guides I or II. This is shown below.
4. $RL_1 = 2\alpha \perp SRL = N$ db
   $RL_2 = 0$ db
5. Repeater gain is found from entering N and zero db in Charts II and III for the Negative Resistance and Negative Impedance repeater types respectively.

CASE I-B ($\alpha_1 > \alpha_2$)



PROCEDURE

1. Place one repeater only in office whose adjacent loaded cable has the most loss. Do not place repeaters in both offices.
2. For repeater calculation purposes the circuit begins from the repeater in office A to the loaded cable-open wire junction. This is shown below.
3. Now, calculate the section return loss for the loaded cable portion only as per Application Guides I or II. This is shown below.
4. $RL_1 = 2\alpha_1 \perp SRL = N$ db
   $RL_2 = 0$ db
5. Repeater gain is found from entering N and zero db in Charts II and III for the Negative Resistance and Negative Impedance type repeaters respectively.
6. If repeater gain obtained from steps 1 through 5 above is not sufficient to meet objectives consider the use of additional repeater at office B and repeat calculation procedure of steps 2 through 5. This is shown in step 7 below.



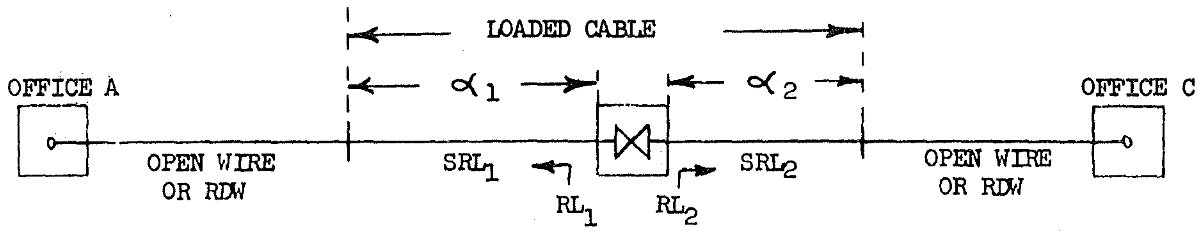
7. For repeater calculation (repeater at office B) purposes the circuit begins from the repeater in office B to the loaded cable-open wire (or RDW) junction.

   a. $RL_3 = 2\alpha_2 \perp SRL_2 = M$ db
   b. $RL_4 = 0$ db
   c. Repeater gain is found from entering M and zero db in Charts II or III for the Negative Resistance and Negative Impedance respectively.

8. Repeaters at offices A and B will generally provide sufficient gain to meet EAS objectives. If, however, more gain is required consideration should be given to the alternatives listed below:

   a. Use of carrier (and carrier repeaters, depending on carrier frequency loss) for the entire trunk.
   b. Overbuilding the O.W. or RDW portion with cable plant (and loaded to the same loading system) and using repeaters at offices A and/or B as required.
   c. Use of a hybrid type v.f. repeater.

CASE II ONE INTERMEDIATE REPEATER

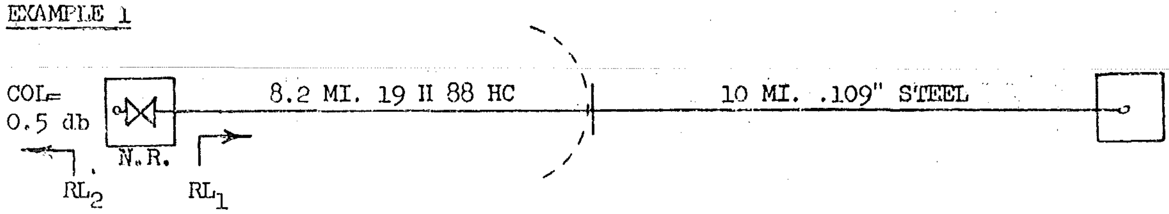


PROCEDURE

1. Locate repeater between the loaded cable. (Repeater should not be in office adjacent to open wire.)
2. For repeater calculations assume the circuit begins at and ends at each of the loaded cable-open wire junctions.
3. Now, calculate the section return loss for the loaded portion only as per Application Guides I or II. This is shown below.
4. $RL_1 = 2\alpha_1 \perp SRL_1 = M$ db
   $RL_2 = 2\alpha_2 \perp SRL_2 = N$ db
5. Repeater gain is found from entering M and N db in Charts II and III for Negative Resistance and Negative Impedance repeaters respectively.

EXAMPLES: The examples shown below are existing, nonrepeatered EAS trunks proposed for operation to 6 db net loss. Determine if the repeater will be able to provide enough gain to meet the objective.

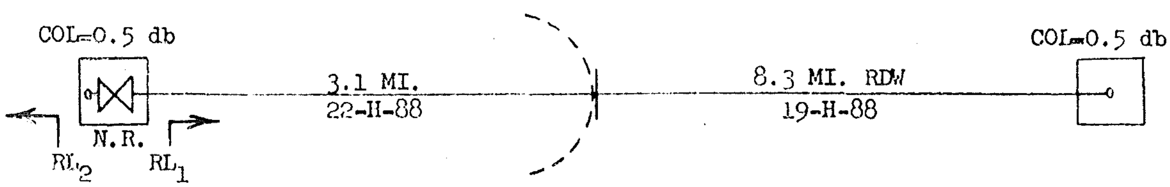
EXAMPLE 1



PROCEDURE			REFERENCE
1.	TO :	6 db	
2.	NRCL:	(Attenuation) + (Refl. Loss) + (COL) + (LBO)	Tables II, III, V
	:	(8.2 x .428 + 10 x .31) + (0) + (2 x 0.5) + (0.4)	
		= 3.52 + 3.1 + 1.4 = 8.02	
3.	RRG :	8.0 - 6 = 2.0 db	
4.	RL_1 :	2 x (3.52 + 0.4) ⊥ 16 = 7.5 db	Chart I
5.	RL_2 :	0 db	
6.	ARG :	From 7.5 and zero db = 3.3 db	Chart II
7.	NCL :	8.02 - 3.3 = 4.7 db	

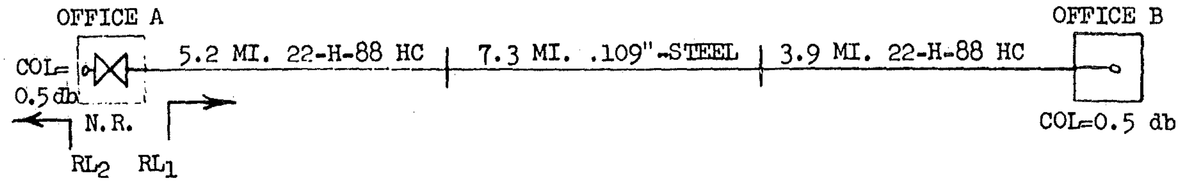
Sufficient repeater gain can therefore be obtained from this repeater in this particular layout to meet the objective. Actually the circuit can operate at the 4.7 db net loss shown.

EXAMPLE 2



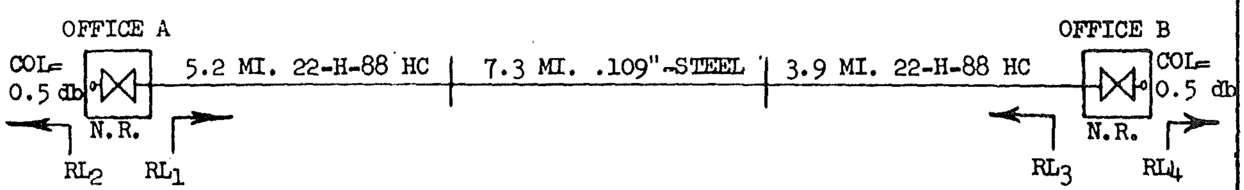
PROCEDURE			REFERENCE
1.	TO :	6 db	
2.	NRCL:	(Attenuation) + (Refl. Loss) + (COL) + (LBO)	Tables II, III, V
	:	(4.1 x 0.792 + 8.3 x 0.514) + (0) + (2 x 0.5) + (0.4)	
		= (3.25 + 4.27) + 1.4 = 8.92 db	
3.	RRG :	8.9 - 6.0 = 2.9 db	
4.	RL_1 :	2 (3.25 + .4) ⊥ 19 = 7.0 db	Chart I
5.	RL_2 :	0 db	
6.	ARG :	From 7.0 and zero db = 3.0 db	Chart II
7.	NCL :	8.9 - 3.0 = 5.9 db MEETS OBJECTIVE	

EXAMPLE 3



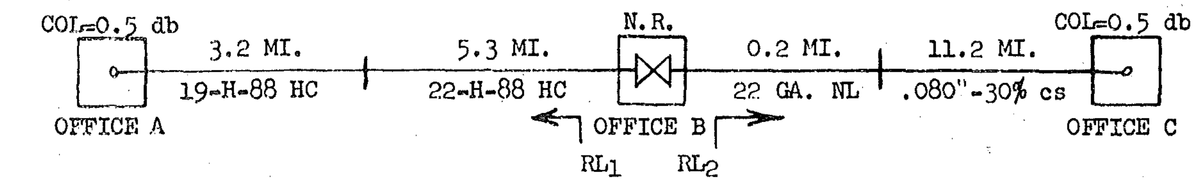
	PROCEDURE			REFERENCE
1.	TO	:	6 db	
2.	NRCL	:	(Attenuation) + (Refl. Losses) + (COL) + (LBO)	Tables II, III, V
		:	(5.2 x 0.792 + 7.3 x 0.31 + 3.9 x 0.792) + (0) + (2 x 0.5) + (0.4) = (4.12 + 3.09 + 2.26) + 1.4 = 10.9 db	
3.	RRG	:	10.9 - 6.0 = 4.9 db	
4.	RL_1	:	2 (4.12 + 0.4) ⊥ 19 = 8.6 db	Chart I
5.	RL_2	:	0 db	
6.	ARG	:	From 8.6 and 0 db = 3.8 db	Chart II
7.	NCL	:	10.9 - 3.8 = 7.1 DOES NOT MEET OBJECTIVE	

Since objectives are not met with one repeater an additional repeater is placed at office B. The computations are shown below.



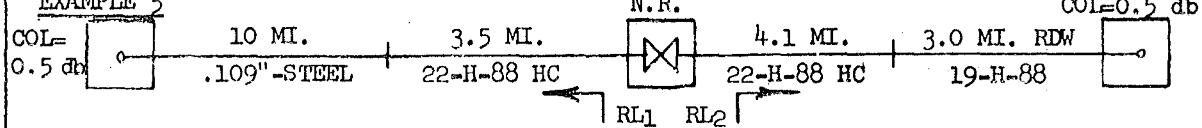
	PROCEDURE			REFERENCE
1.	TO	:	6 db	
2.	NRCL	:	(Attenuation) + (Refl. Losses) + (COL) + (LBO)	Tables II, III, V
			(5.2 x 0.792 + 7.3 x 0.31 + 3.9 x 0.792) + (0) + (2 x 0.5) + (0.4) = (4.12 + 3.09 + 2.26) + 1.4 + 0.4 = 10.9 + 0.4 = 11.3 db	
3.	RRG	:	11.3 - 6.0 = 5.3 db	
4.	RL_3	:	2 (3.09 + 0.4) ⊥ 19 = 6.7 db	
5.	RL_4	:	0 db	
6.	ARG	:	From 6.7 and 0 db = 2.8 db	Chart II
7.	TRG	:	2.8 + 3.8 = 6.6 db	
8.	NCL	:	11.3 - 6.6 = 4.7 db ANS. MEETS OBJECTIVE	

EXAMPLE 4



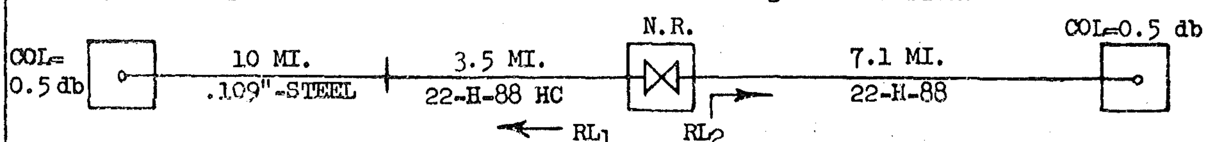
	PROCEDURE			REFERENCE
1.	TO	:	6 db	
2.	NRCL	:	(Attenuation) + (Refl. Losses) + (COL) + (LBO)	Tables I, V
		:	(3.2 x 0.428 + 5.3 x 0.792 + 0.2 x 1.8 + 11.2 x 0.28) + (0) + (2 x 0.5) + (0.4) = (1.37 + 4.20 + 0.36 + 3.14) + 1.4 = 10.47 db ≅ 10.5 db	
3.	RRG	:	10.5 - 6.0 = 4.5 db	
4.	SRL (T)	:	(2 x 4.2 + 16) ⊥ 19 = 17.9 db	Case I
5.	RL_1	:	2 (1.37 + 4.20 + 0.4) ⊥ 17.9 = 10.9 db	Chart I
	RL_2	:	0 db	
6.	ARG	:	From 10.9 and 0 db = 4.8 db	Chart II
7.	NCL	:	10.5 - 4.8 = 5.7 db MEETS OBJECTIVE	

EXAMPLE 5



	PROCEDURE			REFERENCE
1.	TO	:	6 db	
2.	NRCL	:	(Attenuation) + (Refl. Losses) + (COL) + (LBO)	Tables II, III, V
		:	(10 x 0.31 + 3.5 x 0.792 + 4.1 x 0.792 + 3.0 x 0.514) + (-0.2) + (2 x 0.5) + (2 x 0.4) = (3.1 + 2.77 + 3.25 + 1.54) + 1.6 = 12.3 db	
3.	RRG	:	12.3 - 6.0 = 6.3 db	
4.	RL_1	:	2 (2.77 + 0.4) ⊥ 19 = 6.2 db	Chart I
	RL_2	:	2 (3.25 + 0.4) ⊥ 19 = 7.0 db	Chart I
5.	ARG	:	From 6.2 and 7.0 db = 6.2 db	Chart II
6.	NCL	:	12.3 - 6.2 = 6.1 MEETS OBJECTIVE	

Assuming that it has been decided to overbuild the 3.0 miles of 19 RDW with 22-H-88 cable, the computations shown below show the resulting transmission.



	PROCEDURE			REFERENCE
1.	TO	:	6 db	
2.	NRCL	:	(10 x 0.31 + 3.5 x 0.792 + 7.1 x 0.792) + (-0.2) + 1.6 = (3.1 + 2.77 + 5.62) + 1.6 = 13.1 db	Tables II, III, V
3.	RRG	:	13.1 - 6.0 = 7.1 db	
4.	RL_1	:	2 (2.24 + 0.4) ⊥ 19 = 5.1 db	Chart I
5.	RL_2	:	2 (5.62 + 0.4) ⊥ 19 = 11.2 db	Chart I
6.	ARG	:	From 5.1 and 11.2 db = 7.4 db	Chart II
7.	NCL	:	13.1 - 7.4 = 5.7 db ANS. MEETS OBJECTIVE	

APPLICATION GUIDE IV

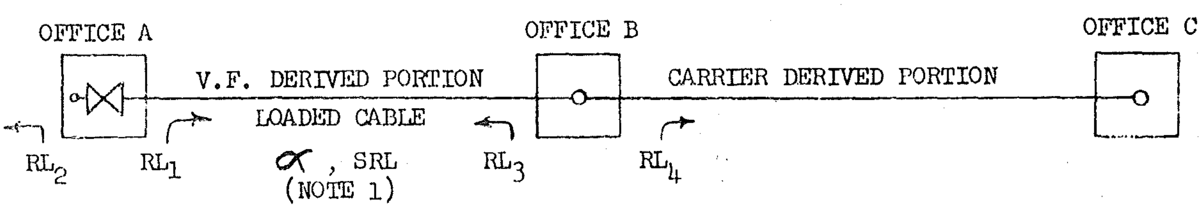
THIS SECTION SHOWS THE GENERAL STEP-BY-STEP PROCEDURES APPLIED TO A NUMBER OF BASIC CABLE LAYOUTS AND REPEATER CONFIGURATIONS FOR COMPUTING AVAILABLE REPEATER GAIN(S) OF NEGATIVE RESISTANCE/IMPEDANCE REPEATERS OPERATING AS VOICE FREQUENCY EXTENSIONS OFF CARRIER OR MICROWAVE RADIO EQUIPMENT.

THESE DESIGN PROCEDURES ARE THEN SHOWN IN REPRESENTATIVE SITUATIONS AND ARE SHOWN IN EXAMPLES 1 THROUGH 7.

APPLICATION GUIDE IV
UNIVERSAL STEP-BY-STEP PROCEDURE FOR COMPUTING AVAILABLE REPEATER GAIN(S) FOR NEGATIVE RESISTANCE/IMPEDANCE REPEATERS OPERATING ON V.F. EXTENSIONS OFF CARRIER OR MICROWAVE RADIO EQUIPMENT

CASE I

(SEE FIGURE 8 FOR DETAIL)



1. CONSIDER THE CARRIER V.F. TERMINAL AT LOCATION B TO BE ACTING AS A TERMINAL NEGATIVE REPEATER AND CAPABLE OF PROVIDING A GAIN OF UP TO 3.5[2] DB MAXIMUM, WHEN THE RETURN LOSS ASSOCIATED WITH THE LOADED CABLE PLANT ALLOWS. (CALL THE CARRIER V.F. TERMINAL AN "APPARENT" REPEATER.)

2. THIS NOW REDUCES TO THE CASE OF TWO TERMINAL REPEATERS. THE PROCEDURE FOR FIND AVAILABLE REPEATER GAINS IS AS FOLLOWS:

FOR NEG. RES. REPEATERS	FOR NEG. IMP. REPEATERS
$RL_1 = RL_3 = 1.2\alpha \perp SRL = M$ db	$1.1\alpha \perp SRL = N$ db
$RL_2 = RL_4 = 0$ db	0 db

REPEATER GAINS

V.F. REPEATER AT A:	FROM RL_1 AND RL_2 IN APPLICABLE[3] GAIN CHART
"APPARENT" REPEATER AT B:	FROM RL_3 AND RL_4 IN APPLICABLE[3] GAIN CHART

3. NOTE: THOUGH THE LINE SECTION RETURN LOSS FACING THE APPARENT REPEATER MAY ALLOW AN AVAILABLE REPEATER GAIN MORE THAN 3.5[2] DB; THIS ADDITIONAL GAIN (OVER AND ABOVE 3.5[2] DB) CANNOT BE PROVIDED BY THE "APPARENT" REPEATER. (SEE PARAGRAPH 3.192 WHICH DISCUSSES THIS.)

CASE I-A SAME AS CASE I ABOVE BUT MIXED GAUGE CABLES ARE EMPLOYED

PROCEDURE: USE STEP 1 OF CASE I ABOVE AND THEN TREAT AS PER CASE III OF APPLICATION GUIDE III, WHICH SHOWS TWO TERMINAL REPEATERS OPERATING ON MIXED GAUGE CABLES.

NOTES

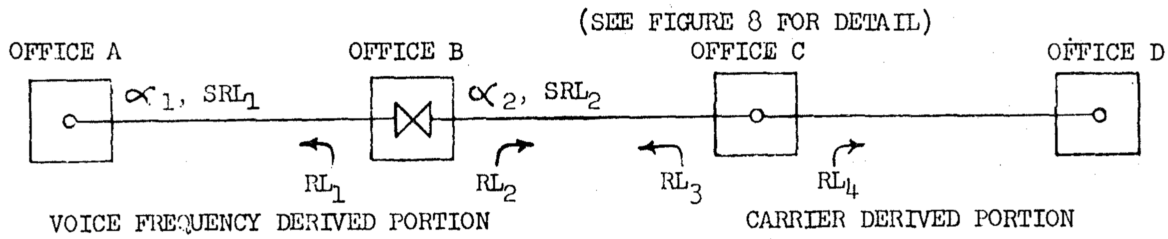
1. Includes LBO losses but no office losses.

2. The actual maximum will be as recommended by the connecting company or carrier manufacturer.

3. Chart II for Negative Resistance. Chart III for Negative Impedance.

APPLICATION GUIDE IV - Cont'd

CASE II



1. CONSIDER THE CARRIER VOICE FREQUENCY TERMINAL AT LOCATION C TO BE ACTING AS A TERMINAL NEGATIVE REPEATER AND CAPABLE OF PROVIDING A GAIN OF UP TO 3.5[2] DB MAXIMUM, WHEN THE RETURN LOSS ASSOCIATED WITH THE LOADED CABLE PLANT ALLOWS. (CALL THE CARRIER VOICE FREQUENCY TERMINAL AN "APPARENT" REPEATER.)

2. REPEATER AND "APPARENT" REPEATER GAINS AS FOLLOWS:

	FOR NEG. RES. REPEATERS	FOR NEG IMP. REPEATERS
A.	$RL_1 = 2\alpha_1 \perp SRL_1 = M$ DB	$2\alpha_1 \perp SRL_1 = M$ DB
B.	$RL_2 = RL_3 = 1.2\alpha_2 \perp SRL_2 = N$ DB	$1.1\alpha_2 \perp SRL_2 = P$ DB
C.	$RL_4 = 0$ DB	

REPEATER GAINS

V.F. REPEATER AT B: FROM RL_1 AND RL_2 IN APPLICABLE[3] GAIN CHART.
"APPARENT" REPEATER AT C: FROM RL_3 AND ZERO DB, IN APPLICABLE[3] GAIN CHART.

3. NOTE: THOUGH THE LINE SECTION RETURN LOSS FACING THE "APPARENT" REPEATER MAY ALLOW AN AVAILABLE GAIN MORE THAN 3.5[2] DB, THIS ADDITIONAL GAIN (OVER AND ABOVE 3.5 DB) CANNOT BE PROVIDED BY THE "APPARENT" REPEATER. (SEE PARAGRAPH 3.192 WHICH DISCUSSES THIS.)

CASE II-A SAME AS CASE II ABOVE BUT MIXED CABLE GAUGES ARE INVOLVED.

PROCEDURE: USE STEP 1 OF CASE II ABOVE AND THEN TREAT AS PER EXAMPLES 3 AND 4 IN APPLICATION GUIDE II.

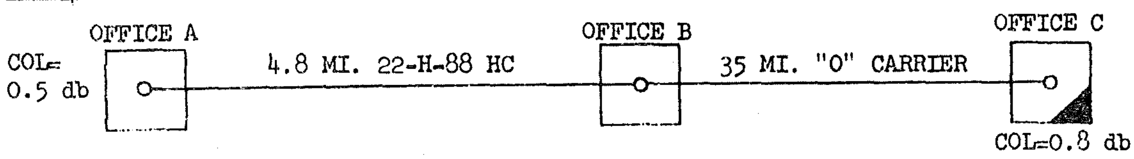
NOTES:

1. Includes LBO losses but no office losses

2. The actual maximum will be as recommended by the connecting company or the carrier manufacturer.

3. Chart II for Negative Resistance. Chart III for Negative Impedance.

EXAMPLE 1



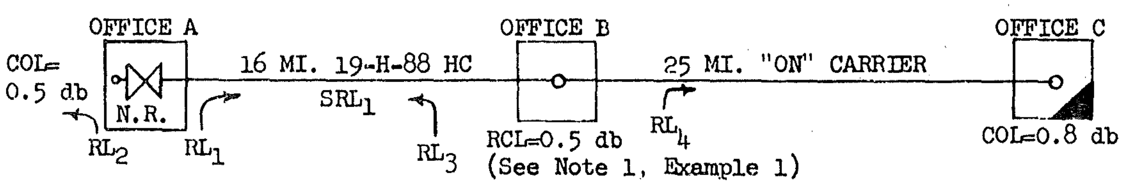
TOLL CONNECTING

PROCEDURE			REFERENCE
1.	TO	: VNL + 2 = (4.8 x 0.04 + 35 x 0.0017) + (2.4) = 2.7 db	Table I
2.	NRCL	: (attenuation) + (COL) + (RCL of Note 1)	Table II
		: (4.8 x 0.792) + (0.5 + 0.8) + (0.5) = 3.8 + 1.8 = 5.6 db	
3.	RRG	: 5.6 - 2.7 = 2.9 db	

The required gain to meet the above objectives is 2.9 db and can therefore be provided by the carrier equipment. For this reason no voice frequency repeater is required. It is also assumed in this example that the connecting company which furnishes the carrier equipment has also indicated that a carrier net gain of 2.9 db is possible for this type of equipment and are also agreeable in furnishing this gain.

Note 1: Repeating coil loss used at office B for signaling purposes only, if required. If not required, the above NRCL is reduced by 0.5 db. In the remaining examples shown herein this loss is assumed to apply.

EXAMPLE 2

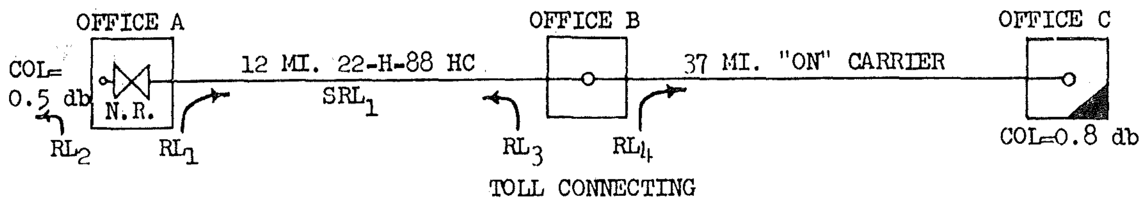


TOLL CONNECTING

PROCEDURE			REFERENCE
1.	TO	: VNL + 2 = (16 x 0.04 + 25 x 0.0019) + (2.4) = 3.1 db	Table I
2.	NRCL	: (attenuation) + (COL) + (RCL) + (LBO)	Tables II, V
		: (16 x 0.482) + (0.5 + 0.8) + (0.5) + (0.3) = 9.0 db	
3.	TRRG	: 9.0 - 3.1 = 5.9 db	
4.	$RL_1 = RL_3$	: 1.2 (attenuation + LBO) ⊥ SRL	Chart I
		: 1.2 (5.9 + 0.3) ⊥ 16 = 8.0 db	
5.	$RL_2 = RL_4$	: 0 db	
6.	ARG	: v.f. repeater, office A: from 8.0 and 0 db = 3.4 db	Chart II
		carrier, office B : from 8.0 and 0 db = 3.4 db	Chart II
7.	TARG	: 2 x 3.4 = 6.8 db MEETS VNL + 2	

For this particular example the total available repeater gain is more than that required for meeting objectives. The v.f. repeater therefore and "carrier" should be set to provide the gain required only. For example, for the gain required the v.f. repeater can be set at the 3.4 db while the carrier at 2.5 db net gain for a total of 5.9 db.

EXAMPLE 3



PROCEDURE			REFERENCE
1.	TO	: VNL + 2 = (12 x 0.04 + 37 x 0.0019) + (2.4) = 3.0 db	Table I
2.	NRCL	: (attenuation) + (COL) + (RCL) + (LBO)	Tables II, V
		: (12 x 0.792) + (0.5 + 0.8) + (0.5) + (0.4) = 11.7 db	
3.	TRRG	: 11.7 - 3.0 = 8.7 db	
4.	$RL_1 = RL_3$	: 1.2 (attenuation + LBO) ⊥ SRL_1	Chart I
		: 1.2 (9.5 + 0.4) ⊥ 19 = 11.1 db	
5.	$RL_2 = RL_4$	: 0 db	
6.	ARG	: v.f. repeater, office A: from 0 and 11.1 db = 4.8 db	Chart II
		carrier, office B : from 0 and 11.1 db = 4.8 db	Chart II

7. It would appear from step (6) above that more than sufficient gain will be realized for meeting the objectives. However, as stated in paragraph 3.192, the carrier or "apparent" repeater cannot provide a gain higher than 3.5 db <u>even when the return loss allows</u>, as in this case. Therefore, the carrier is set at 3.5 db net gain (assuming concurrence of the v.f. repeater). This is shown below.

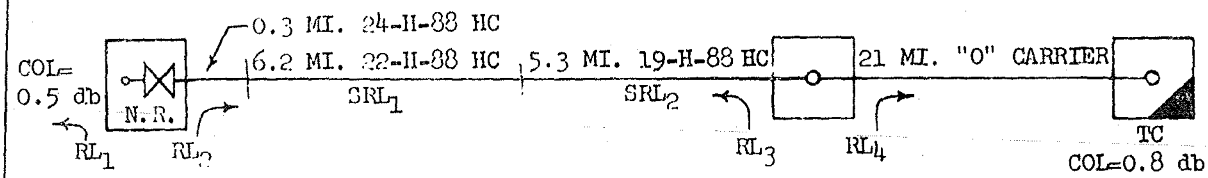
Carrier :	3.5 db		3.0 db		2.5 db		2.0 db
V.F. Repeater:	5.2 db	or	5.7 db	or	6.2 db	or	6.7 db
Total	8.7 db		8.7 db		8.7 db		8.7 db

NOTE: <u>WHEN THE V.F. REPEATER IN ADDITION TO FURNISHING ITS OWN SHARE OF GAIN, IS USED TO MAKE-UP FOR SOME OF THE CARRIER GAIN THE FOLLOWING CONDITIONS MUST AT ALL TIMES BE MET:</u>

1. THE TOTAL GAIN FOR WHICH THE V.F. REPEATER AND CARRIER WILL BE SET MUST NOT BE GREATER THAN THE SUM OF THE <u>AVAILABLE</u> GAINS AS ALLOWED BY THE COMPUTATIONS OF STEP (6) ABOVE. (In this case, for example, step (6) allows a <u>total</u> gain of 9.6 db in the circuit. In step (7), however, only 8.7 db total gain is used to meet the objectives. Therefore, the transfer of gains is proper.)

2. THE TOTAL V.F. REPEATER GAIN MUST NOT EXCEED THE CROSSTALK LIMIT OF TABLE VI. (In this example the 5.2 db v.f. <u>terminal</u> repeater gain is well within the 7 db objective for H-88 facilities.)

EXAMPLE 4



TOLL CONNECTING

	PROCEDURE			REFERENCE
1.	TO	:	VNL + 2	Table I
		:	(0.3 x 0.04 + 6.2 x 0.04 + 5.3 x 0.04 + 21 x 0.0017) + (2.4) = 2.9 db	
2.	NRCL	:	(Attenuation) + (Reflection) + (COL) + (RCL) + (LBO)	Tables II, V
		:	(0.3 x 1.21 + 6.2 x 0.792 + 5.3 x 0.428) + (0) + (0.5 + 0.8) + (0.5) + (0.4) = 7.5 + 2.2 = 9.7 db	
3.	TRRG	:	9.7 - 2.9 = 6.8 db	
4.	RL_2	:	1.2 (Attenuation + LBO) ⊥ SRL_1	Chart I
		:	1.2 (7.5 + 0.4) ⊥ 19 = 9.0 db	
5.	RL_3	:	1.2 (Attenuation + LBO) ⊥ SRL_2	Chart I
		:	1.2 (7.5 + 0.4) ⊥ 16 = 8.6 db	
6.	RL_1 = RL_4	:	0 db	
7.	ARG	:	v.f. repeater at office A: from 9.0 and 0 db = 3.9 db	Chart II
			carrier and location B : from 8.6 and 0 db = 3.7 db	Chart II

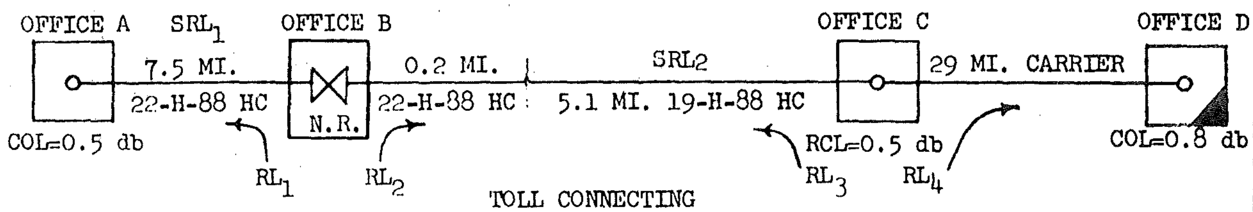
Since step (7) above yields more available gain than that required in step (3) proceed as follows:

a. Set the v.f. repeater at:	3.9	db gain
b. Set the carrier at :	2.9	db gain
Total	6.8	db

8. NCL : 9.7 - 6.8 = 2.9 db MEETS VNL + 2

Therefore, the objectives have been met and in addition the v.f. repeater and carrier are set at proper gains

EXAMPLE 5

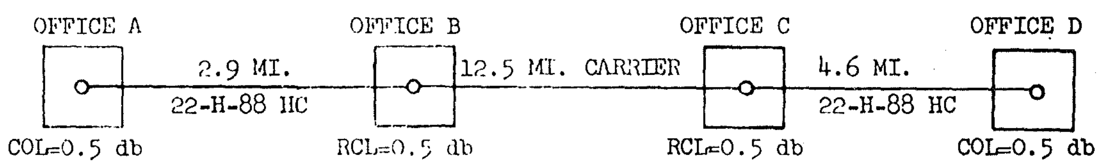


TOLL CONNECTING

PROCEDURE			REFERENCE
1.	TO	: VNL + 2 : (7.5 x 0.04 + 0.2 x 0.04 + 5.1 x 0.04 + 29 x 0.0017) + (2.4) = 3.0 db	Table I
2.	NRCL	: (Attenuation) + (Reflection) + (COL) + (RCL) + (LBO) : (7.5 x 0.792 + 0.2 x 0.792 + 5.1 x 0.428) + (0) + (0.5 + 0.8) + (0.5) + (2 x 0.4) = 10.9 db	Tables II, V
3.	TRRG	: 10.9 - 3.0 = 7.9 db	
4.	RL_1	: 2 (Attenuation + LBO) ⊥ SRL_1 : 2 (5.9 + 0.4) ⊥ 19 = 11.7 db	Chart I
5.	RL_2 = RL_3	: 1.2 (Attenuation + LBO) ⊥ SRL_2 : 1.2 (2.3 + 0.4) ⊥ 16 = 3.0 db	Chart I
6.	RL_4	: 0 db	
7.	ARG	: v.f. repeater, office B: from 11.7 and 3.0 db = 6.6 db carrier, office C : from 0 and 3.0 db = 1.2 db	Chart II Chart II
8.	TARG	: 6.6 + 1.2 = 7.8 db	
9.	NCL	: 10.9 - 7.8 = 3.1 db	

Therefore, the VNL + 2 objectives have been exceeded by 0.1 db.

EXAMPLE 6



INTRASYSTEM EAS

PROCEDURE			REFERENCE
1.	TO	: 6 db max.	
2.	NRCL	: (Attenuation) + (COL) + (RCL) : (2.9 x 0.792 + 4.6 x 0.792) + (0.5 + 0.5) + (0.5 + 0.5) = 7.9 db	Table II
3.	RRG	: 7.9 - 6 = 1.9 db	

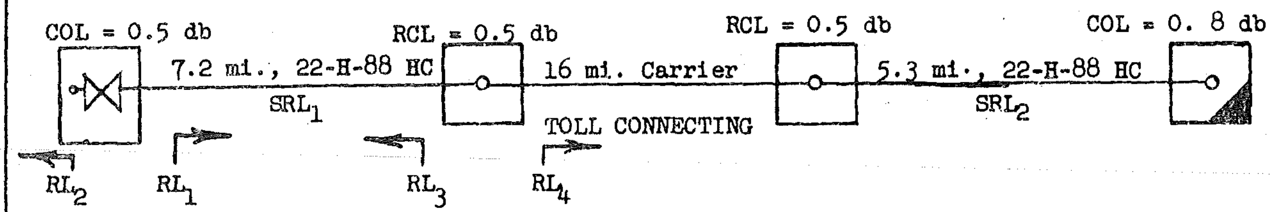
In this layout, therefore, if the carrier can operate at a net gain of 1.9 db (depending on manufacturer's actual recommendations), no v.f. repeaters will be required at either office A or D.

4. NCL : 7.9 - 1.9 db = 6.0 db ANS.

In this layout, it is also possible to operate the carrier at a net gain of 3.0 db. The net circuit loss then becomes:

5. NCL : 7.9 - 3.0 = 4.4 db ANS.

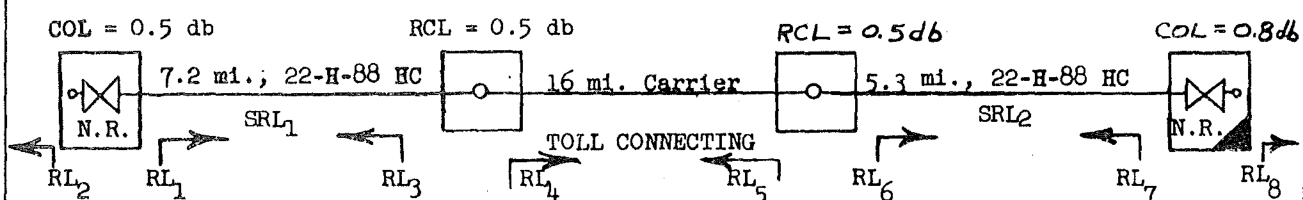
EXAMPLE 7



PROCEDURE | REFERENCE

1. TO	:	VNL + 2 = (7.2 x 0.04 + 5.3 x 0.04) + (2.4) = 2.9 db	TABLE I
2. NRCL	:	(attenuation) + (COL) + (RCL) + (LBO) 7.2 x 0.792 + 5.3 x 0.792) + (0.5 + 0.8) + (0.5 + 0.5) + (0.4) = (5.7 + 4.2) + 2.7 = 12.6 db	TABLES II, V
3. TRRG	:	12.6 - 2.9 = 9.7 db	
4. $RL_1 = RL_3$	:	1.2 (attenuation + LBO) SRL_1 1.2 (5.7 + 0.4) 19 = 7.0 db	CHART I
5. $RL_2 = RL_4$	:	0 db	
6. ARG	:	N.R. Repeater at Office A: from 0 and 7.0 = 3.0 db Carrier at location B: from 0 and 7.0 = 3.0 db	CHART II CHART II

Since objectives are not met with the use of one repeater, an additional repeater is considered at the toll center. The computations are shown below.



PROCEDURE | REFERENCE

1. TO	:	Same as above = 2.9 db	
2. NRCL	:	Same as above + 0.4 (LBO) = 13 db	
3. RRG	:	13 - 2.9 = 10.1 db	
4. $RL_6 = RL_7$	:	1.2 (attenuation + LBO) $\perp$ SRL_2 1.2 (4.2 + 0.4) $\perp$ 19 = 5.3 db	CHART I
5. $RL_5 = RL_8$	:	Zero db	CHART I
6. ARG	:	From 5.3 and 0 db = 2.3 db	
7. TARG	:	N.R. Repeater (T.C.) = 2.3 db Carrier neg gain = 2.3 db	
8. TARG	:	N.R. Repeaters: 3.0 + 2.3 = 5.3 db Carrier : 3.0 + 2.3 = 5.3 db	

The total gain of 10.6 db, if available, is sufficient to meet objectives. However, the carrier can only provide a net gain of up to 3.5 db only. (See para. 3.192.) Since the return loss is adequate, the N.R. repeaters can make up the difference. The gain transfer is shown below:

Carrier Net Gain:	2.5	3.0	3.5
N.R. Repeater (Office A):	4.5	3.0	3.5
N.R. Repeater (T.C.):	4.1	3.1	3.1
	10.1 db	10.1 db	10.1 db

NOTE: THE ABOVE TRANSFER OF GAINS HAS BEEN MADE POSSIBLE ONLY BECAUSE CONDITIONS 1 AND 2 (DISCUSSED IN BOTTOM OF EXAMPLE 3, "APPLICATION GUIDE IV") HAVE BEEN MET IN THIS EXAMPLE.

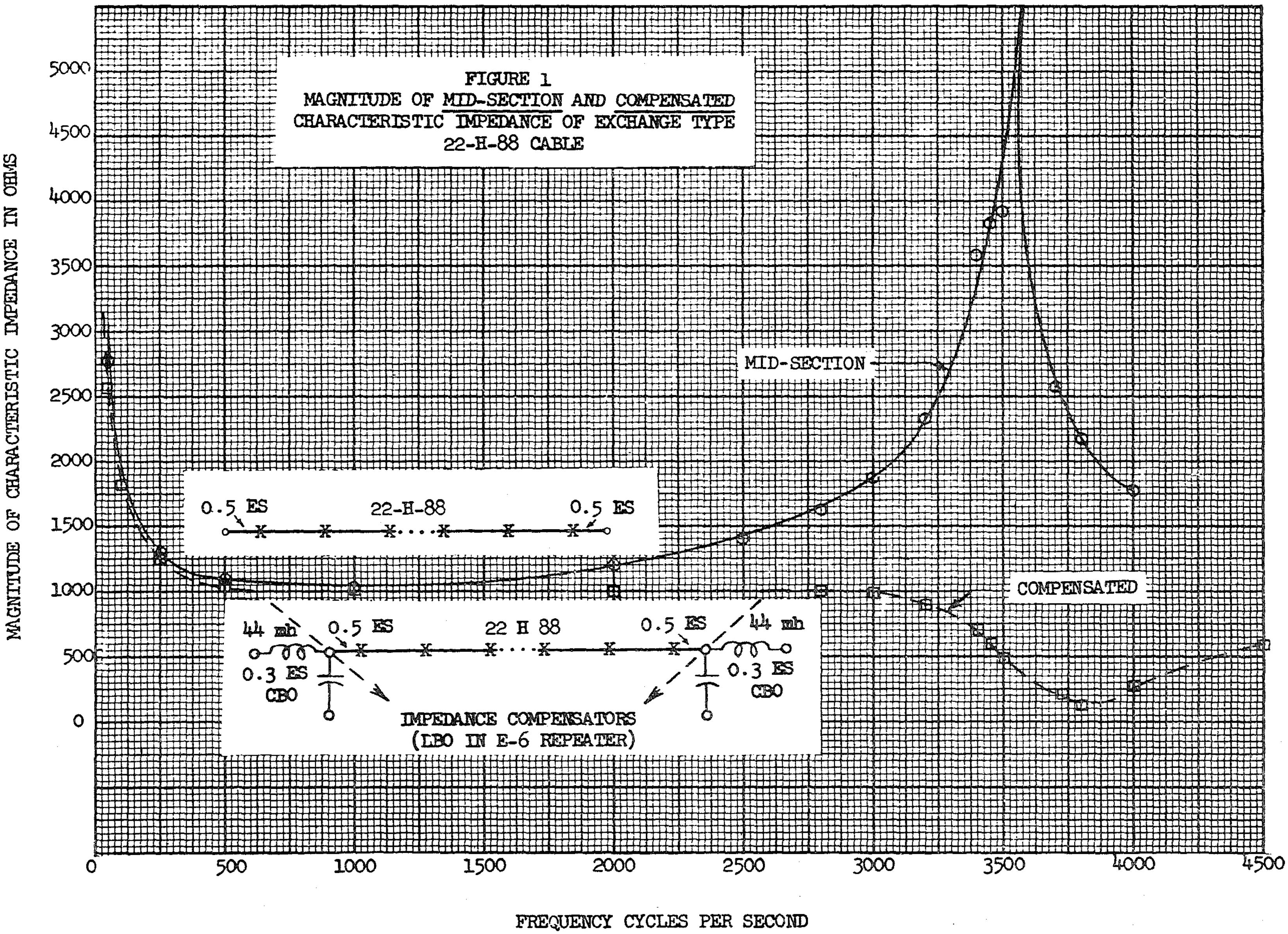
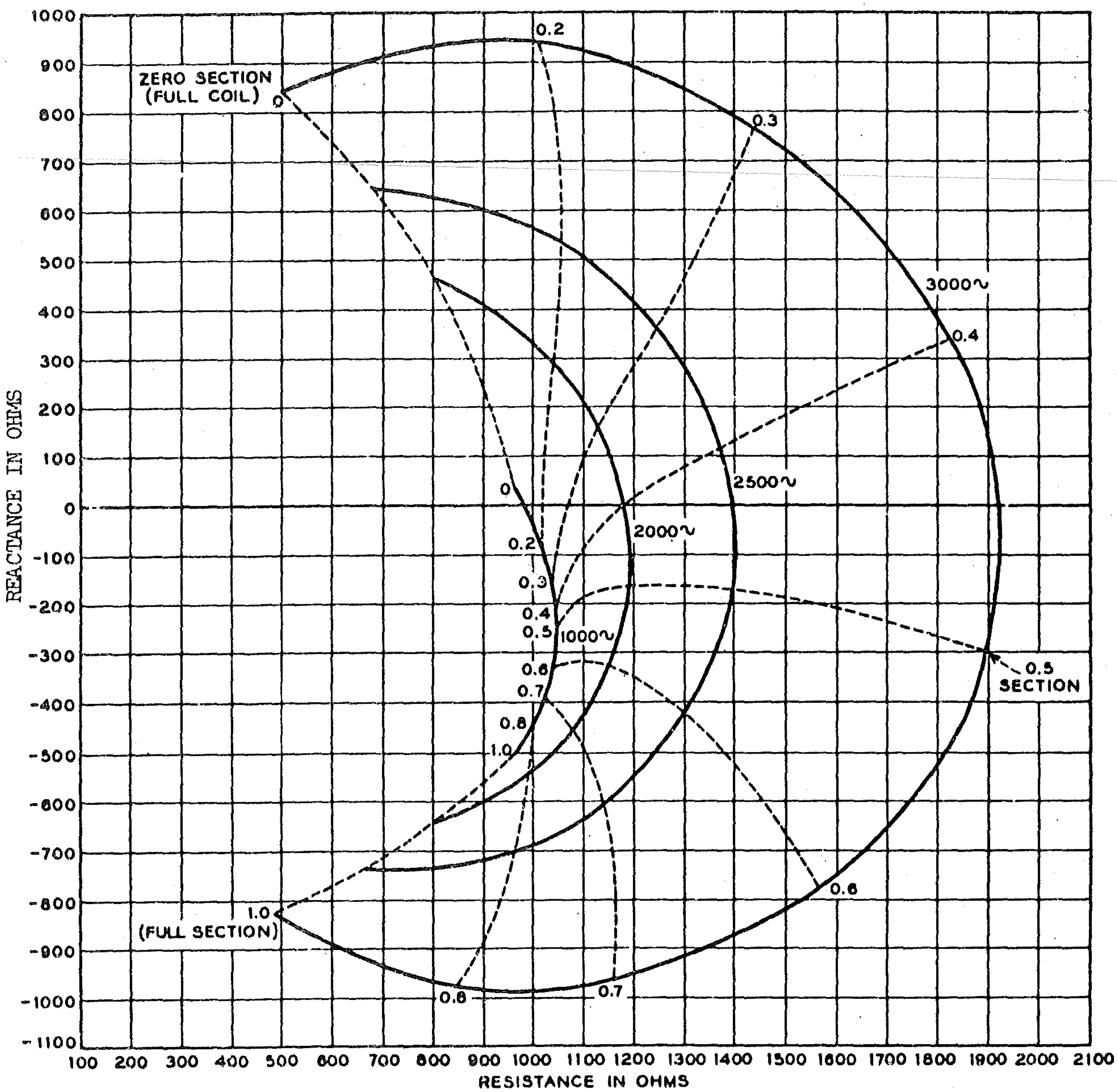


FIGURE 1
MAGNITUDE OF MID-SECTION AND COMPENSATED CHARACTERISTIC IMPEDANCE OF EXCHANGE TYPE 22-H-88 CABLE

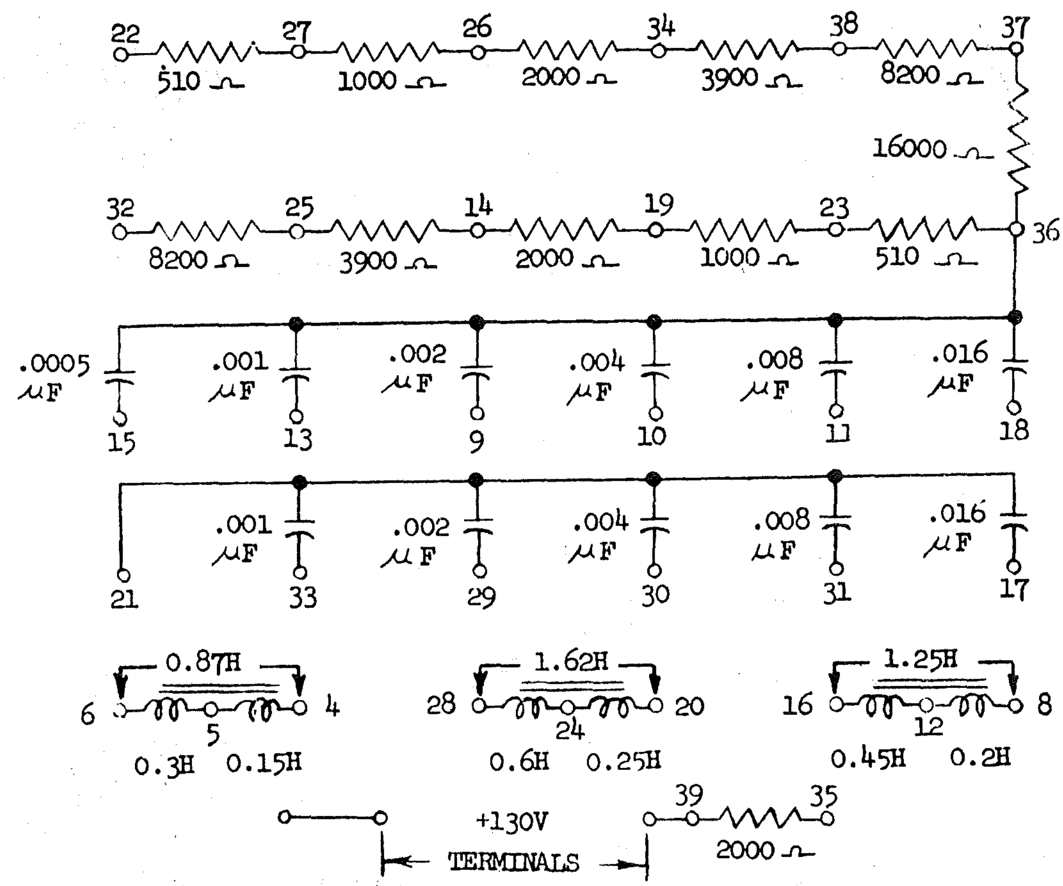


VARIATION OF CHARACTERISTIC IMPEDANCE OF
24H88 LOADED CABLE WITH FREQUENCY AND
FOR VARIOUS END-SECTIONS

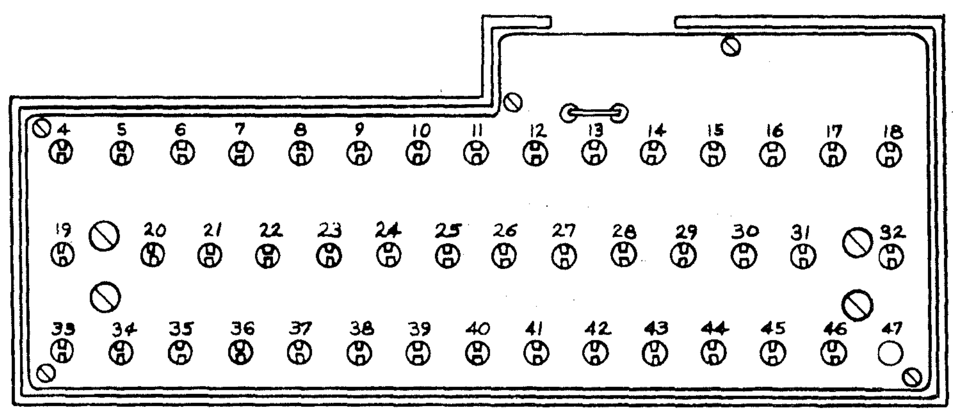
Reprinted from AIEE Conference Paper, February 1-5. 1960. by L. Hochgraf
Paper No. CP 60-350

FIGURE 2

E-2 GAIN ADJUSTING NETWORK

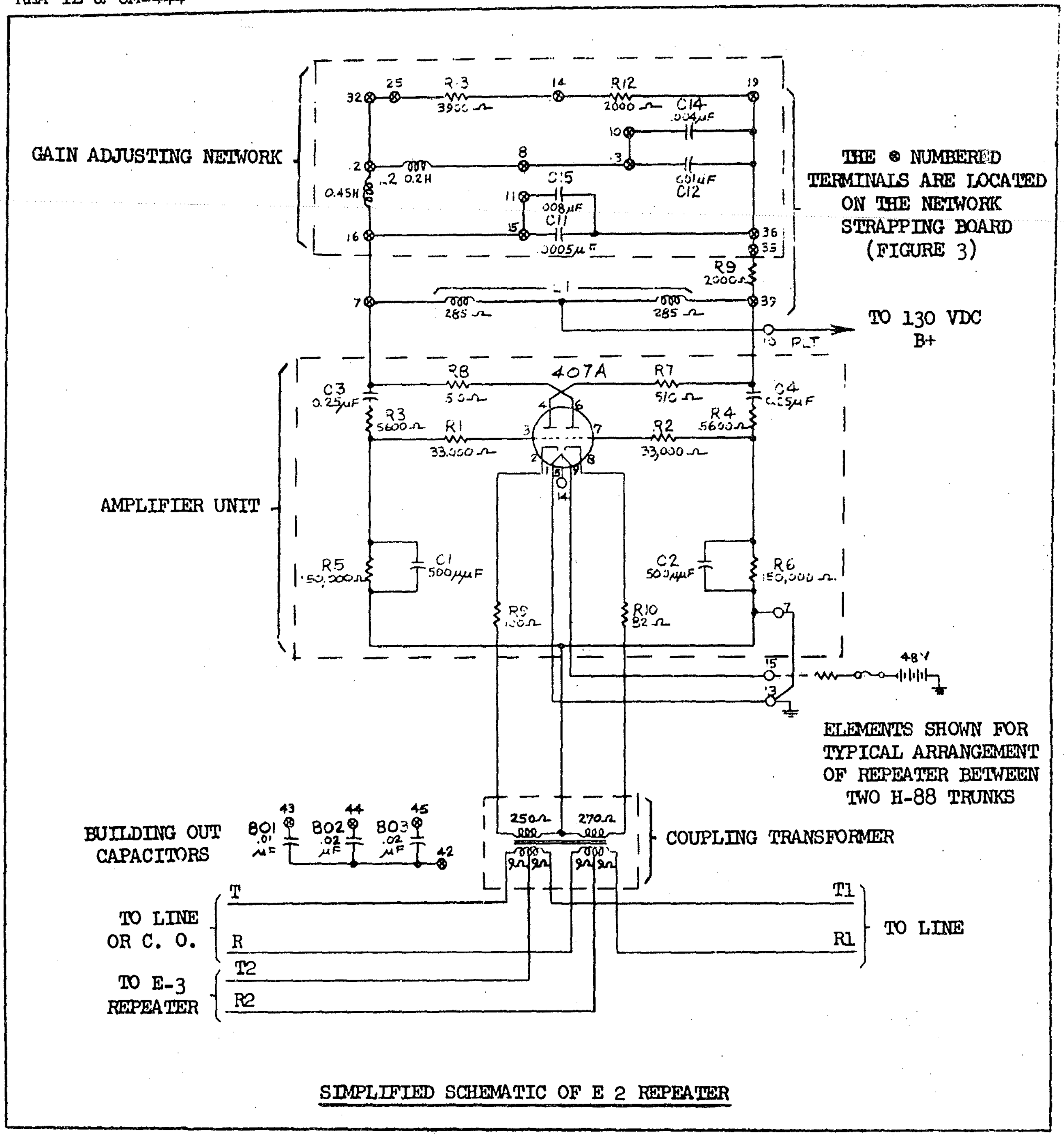


E-2 REPEATER TERMINAL ARRANGEMENT (E-3 SIMILAR)



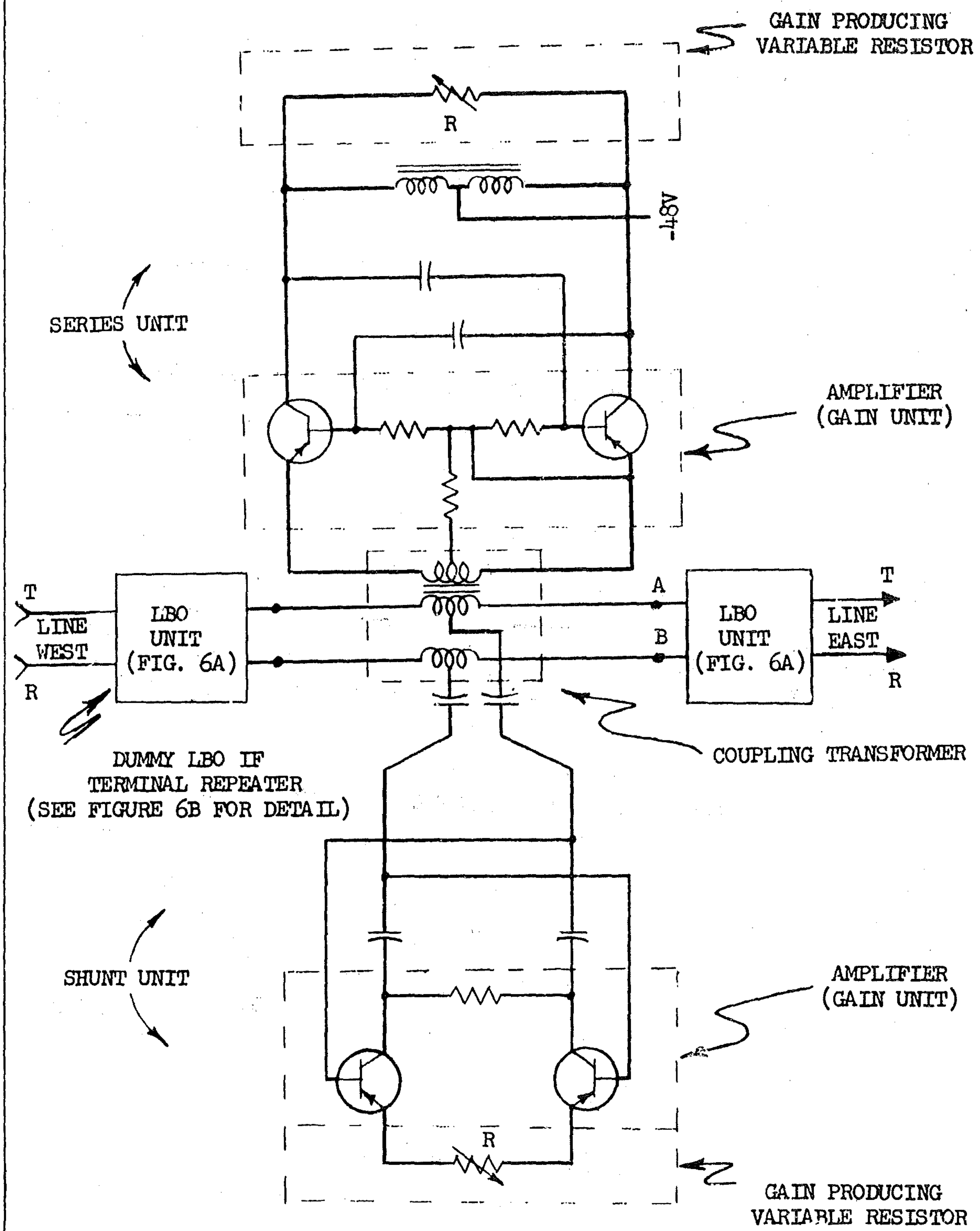
COMPONENT CONFIGURATION AND TERMINAL LUG ARRANGEMENT FOR AN E-2 REPEATER

FIGURE 3



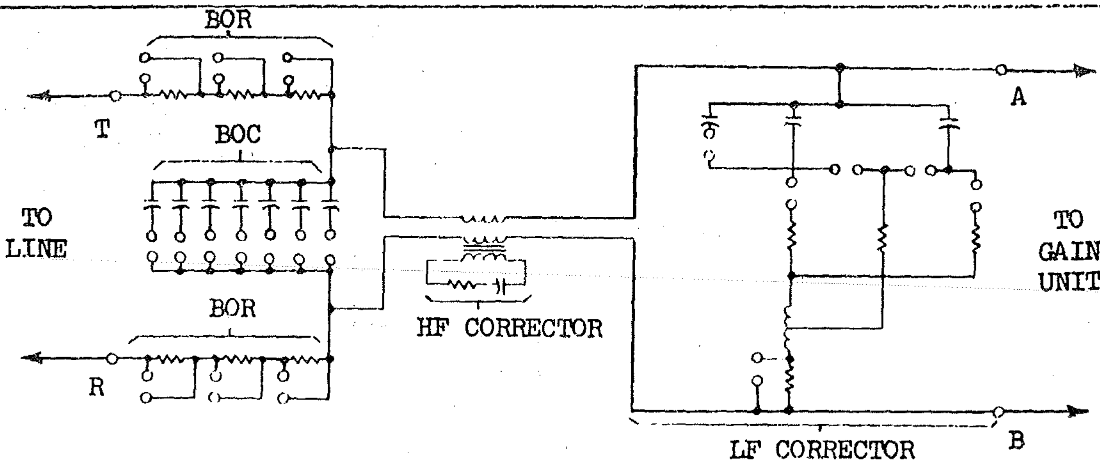
SIMPLIFIED SCHEMATIC OF E 2 REPEATER

FIGURE 4

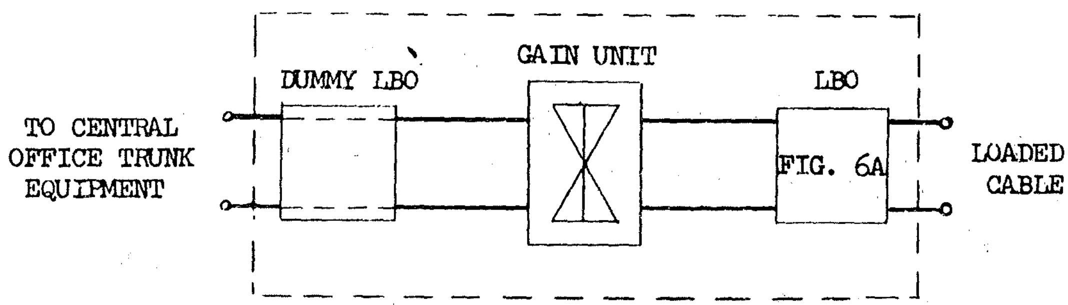


SIMPLIFIED SCHEMATIC OF E-6 REPEATER

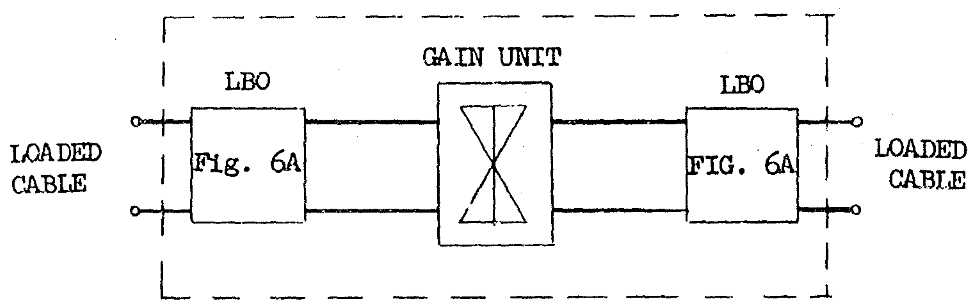
FIGURE 5



A. CONFIGURATION OF "LINE BUILDING OUT" NETWORK - LBO

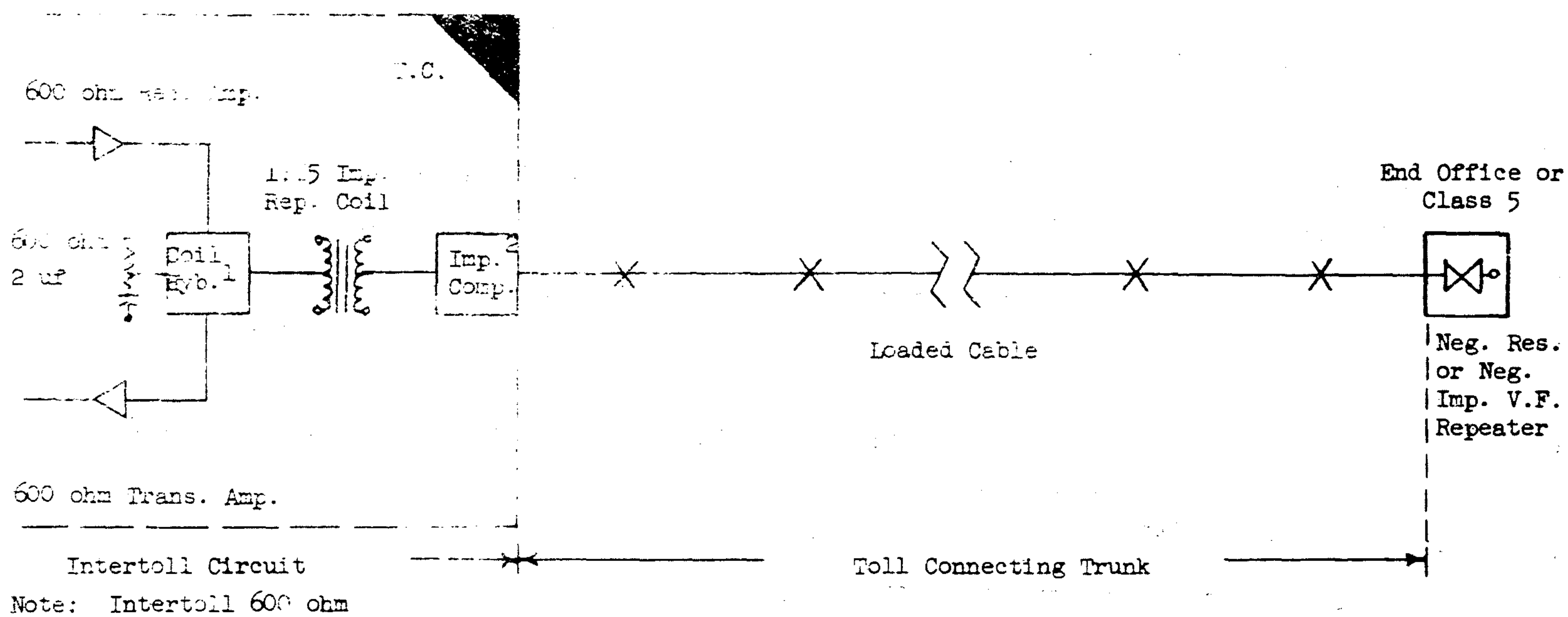


B. LBO ARRANGEMENT FOR TERMINAL E-6 TYPE REPEATER



C. LBO ARRANGEMENT FOR INTERMEDIATE E-6 TYPE REPEATER

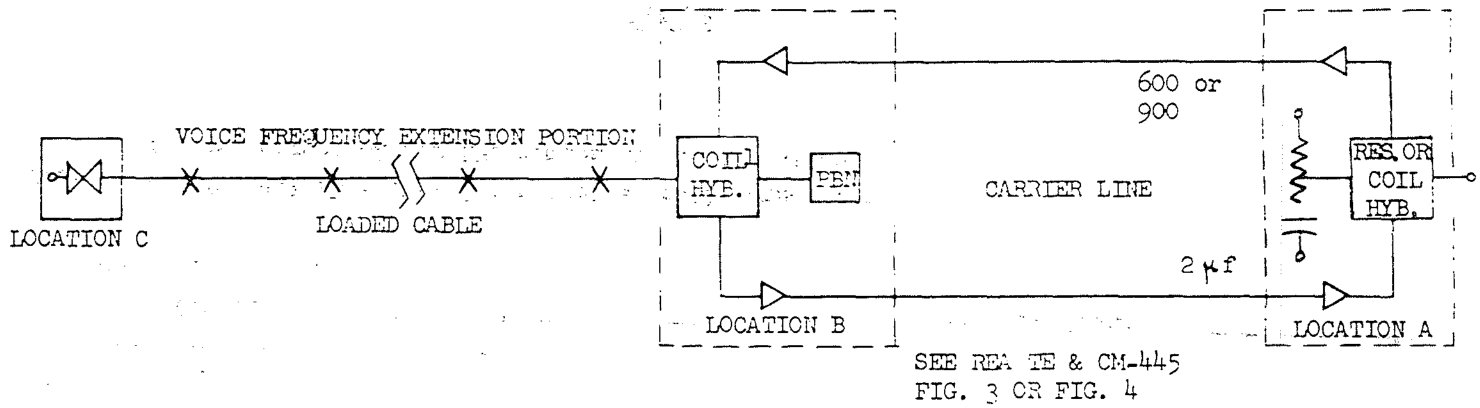
FIGURE 6. LBO CONFIGURATIONS



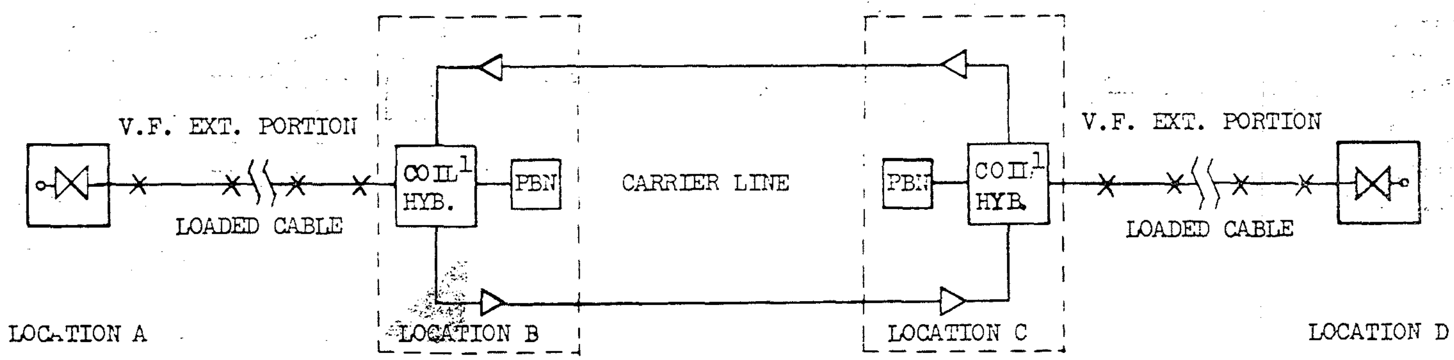
<u>Notes</u>: 1. See REA TE & CM-445 for typical coil connections.
2. See Figure 6A for LBO component configuration.

FIGURE 7

USE OF IMPEDANCE COMPENSATOR AT TOLL CENTER



A. EXAMPLE OF VOICE FREQUENCY EXTENSION AT ONE END OF CARRIER



B. EXAMPLE OF VOICE FREQUENCY EXTENSION AT EACH END OF CARRIER

FIGURE 8
BLOCK DIAGRAM OF TRUNK OPERATING AS A VOICE FREQUENCY EXTENSION

1. It includes additional repeating coil if required for signaling.
2. PBN refers to Precision Balancing Network matching the loaded cable portion.

TABLE I

VIA NET LOSS FACTORS FOR TYPICAL TELEPHONE FACILITIES

Type of Facility	Two-Wire Factor	Four-Wire Factor
H-88 HC Loaded (any gauge)	0.04	--
H-88 LC Loaded	0.03	--
Open Wire - v.f.	0.01	--
Open Wire - Carrier (all types)	--	0.0017
Type K or N Carrier	--	0.0019
Carrier Circuits on Radio	--	0.0014

TABLE II

ATTENUATION OF TYPICAL FACILITIES
@ 1000 cps and 68°F

1. Loaded Trunk Cable

Type of Facility	Attenuation db/Mi.	Attenuation db/KF
24-D-66 HC	1.21	0.23
22-D-66 HC	0.792	0.15
19-D-66 HC	0.428	0.081
26-H-88 HC	1.79	0.34
24-H-88 HC	1.21	0.23
22-H-88 HC	0.792	0.15
19-H-88 HC	0.428	0.081
19-H-88 LC (quadded)	0.375	0.071
19-D-88 HC	0.375	0.071

Note: For buried cables use information shown.
For aerial cable, use information shown, modified where necessary, by paragraph 3.18.

2. Open Wire Conductor - Bare, Wet

.104"-CU[1]	0.078	0.0145
.104"-40% c-s[1]	0.16	0.0303
.080"-30% c-s[1]	0.28	0.0530
.109"-Steel[2]	0.31	0.0587

Notes:
1. 8" spacing and number and type of insulators shown in REA TE & CM-406, Table III.
2. 12" spacing and number and type insulators shown in REA TE & CM-406, Table IV.

For other open conductors and configurations, use applicable loss in REA TE & CM-406.

TABLE III

REFLECTION LOSS OF TYPICAL FACILITIES @ 1000 cps

Facility Combination	Reflection Loss-db
22-H-88 HC and .104" - CU	+0.2
19-H-88 HC and .104" - CU	+0.1
22-H-88 HC and .104"-40% c-s	0
19-H-88 HC and .104"-40% c-s	0
22-H-88 HC and .080"-30% c-s	-0.2
19-H-88 HC and .080"-30% c-s	-0.3
22-H-88 HC and .109" Steel	0
19-H-88 HC and .109" Steel	0
22-H-88 HC and 24-H-88 HC	0
22-H-88 HC and 19-H-88 HC	0
22-D-66 HC and 24-D-66 HC	0
22-D-66 HC and 19-D-66 HC	0

TABLE IV

STRUCTURAL RETURN LOSS

Type of Facility	Structural Return Loss-db
24-D-66[1] HC	22
22-D-66[1] HC	19
19-D-66[1] HC	16
24-H-88 HC	22
22-H-88 HC	19
19-H-88 HC	16
19-H-88 LC	15
19-D-88 HC	14

Note 1. Tentative values. Refer to paragraph 3.171.

TABLE V

LBO LOSS INFORMATION -
NEGATIVE RESISTANCE REPEATERS ONLY

Type of Facility	LBO Loss-db/LBO	BOR Loss-db/KF
24-D-66 HC	0.5	0.235
22-D-66 HC	0.4	0.152
19-D-66 HC	0.3	0.06
24-H-88 HC	0.5	0.235
22-H-88 HC	0.4	0.152
19-H-88 HC	0.3	0.06
19-H-88 LC	0.3	0.06
19-D-88 HC	0.3	0.06

TABLE VI

CROSSTALK LIMITATIONS FOR TERMINAL REPEATERS
(ALL TYPES)

Type of Facility	Terminal Repeater Gain[1]-db	
D-66 (all gauges)	7 objective	8 maximum
H-88 (all gauges)	7 objective	8 maximum
D-88 (all gauges)	6 maximum	

Note 1. For intermediate repeaters see paragraph 3.14.

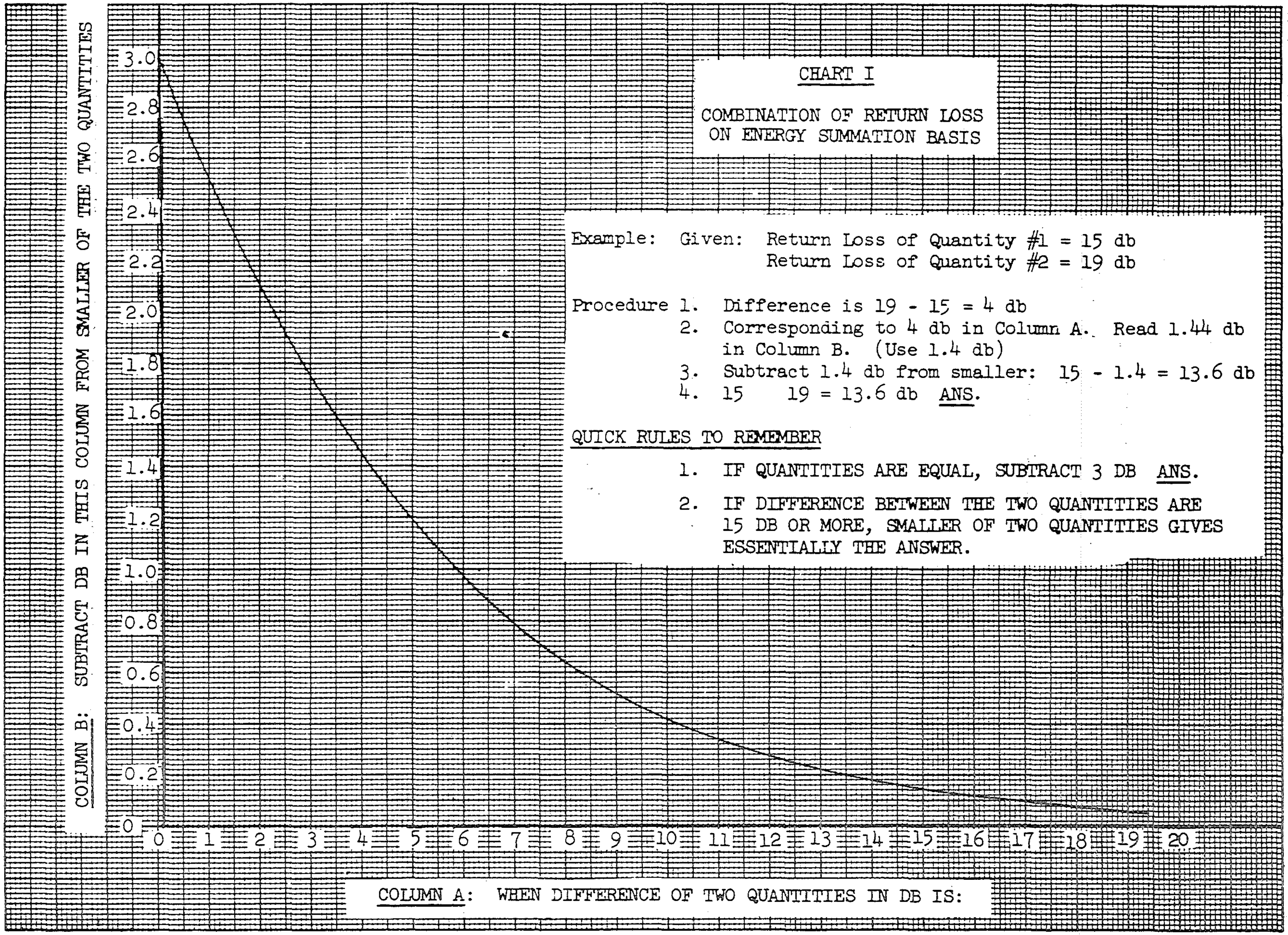


CHART I

COMBINATION OF RETURN LOSS ON ENERGY SUMMATION BASIS

Example: Given: Return Loss of Quantity #1 = 15 db
Return Loss of Quantity #2 = 19 db

Procedure 1. Difference is 19 - 15 = 4 db
2. Corresponding to 4 db in Column A. Read 1.44 db in Column B. (Use 1.4 db)
3. Subtract 1.4 db from smaller: 15 - 1.4 = 13.6 db
4. 15 19 = 13.6 db ANS.

QUICK RULES TO REMEMBER

1. IF QUANTITIES ARE EQUAL, SUBTRACT 3 DB ANS.
2. IF DIFFERENCE BETWEEN THE TWO QUANTITIES ARE 15 DB OR MORE, SMALLER OF TWO QUANTITIES GIVES ESSENTIALLY THE ANSWER.

TABLE V

LBO LOSS INFORMATION - NEGATIVE RESISTANCE REPEATERS ONLY

Type of Facility	LBO Loss-db/LBO	BOR Loss-db/KF
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22-D-66 HC	0.4	0.152
19-D-66 HC	0.3	0.06
24-H-88 HC	0.5	0.235
22-H-88 HC	0.4	0.152
19-H-88 HC	0.3	0.06
19-H-88 LC	0.3	0.06
19-D-88 HC	0.3	0.06

TABLE VI

CROSSTALK LIMITATIONS FOR TERMINAL REPEATERS (ALL TYPES)

Type of Facility	Terminal Repeater Gain[1]-db
D-66 (all gauges)	7 objective 8 maximum
H-88 (all gauges)	7 objective 8 maximum
D-88 (all gauges)	6 maximum

Note 1. For intermediate repeaters see paragraph 3.14.

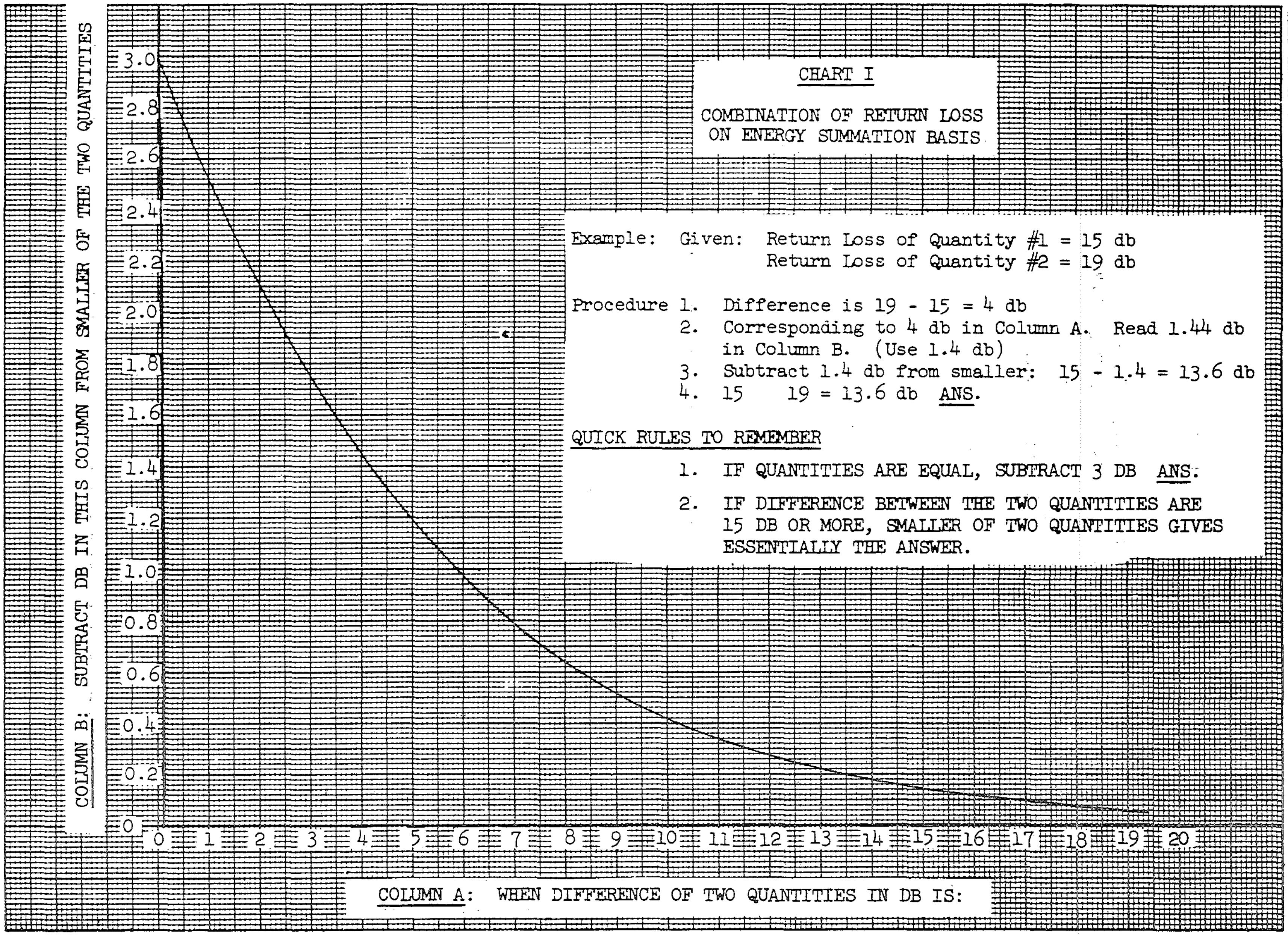

CHART I

COMBINATION OF RETURN LOSS ON ENERGY SUMMATION BASIS

Example: Given: Return Loss of Quantity #1 = 15 db
Return Loss of Quantity #2 = 19 db

Procedure
1. Difference is 19 - 15 = 4 db
2. Corresponding to 4 db in Column A. Read 1.44 db in Column B. (Use 1.4 db)
3. Subtract 1.4 db from smaller: 15 - 1.4 = 13.6 db
4. 15   19 = 13.6 db ANS.

QUICK RULES TO REMEMBER

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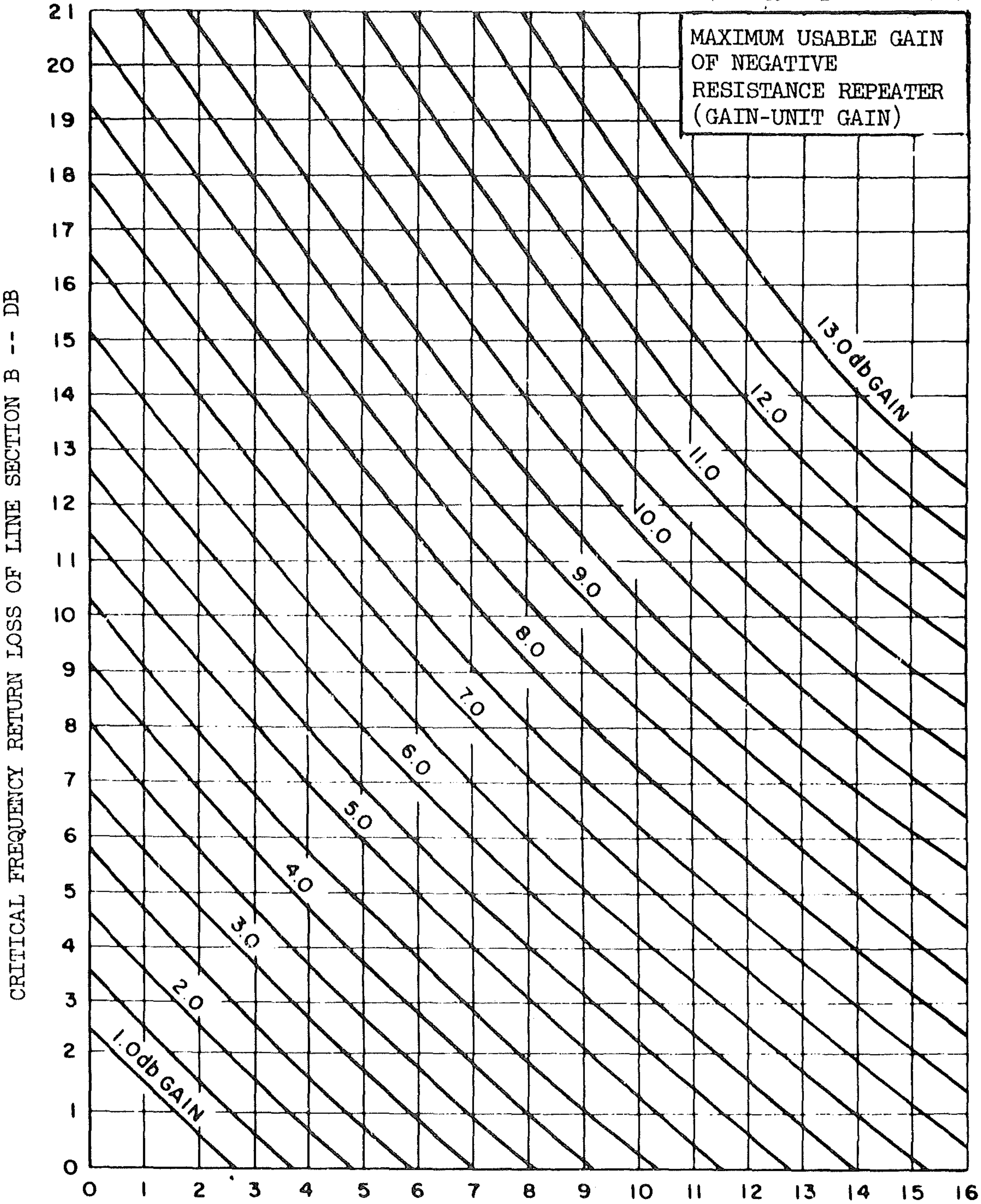

CRITICAL FREQUENCY RETURN LOSS OF LINE SECTION A -- DB

CHART II

Reprinted from AIEE Conference Paper, February 1960
by E. T. Doyle and T. J. Talley
Paper No. CP 60-314

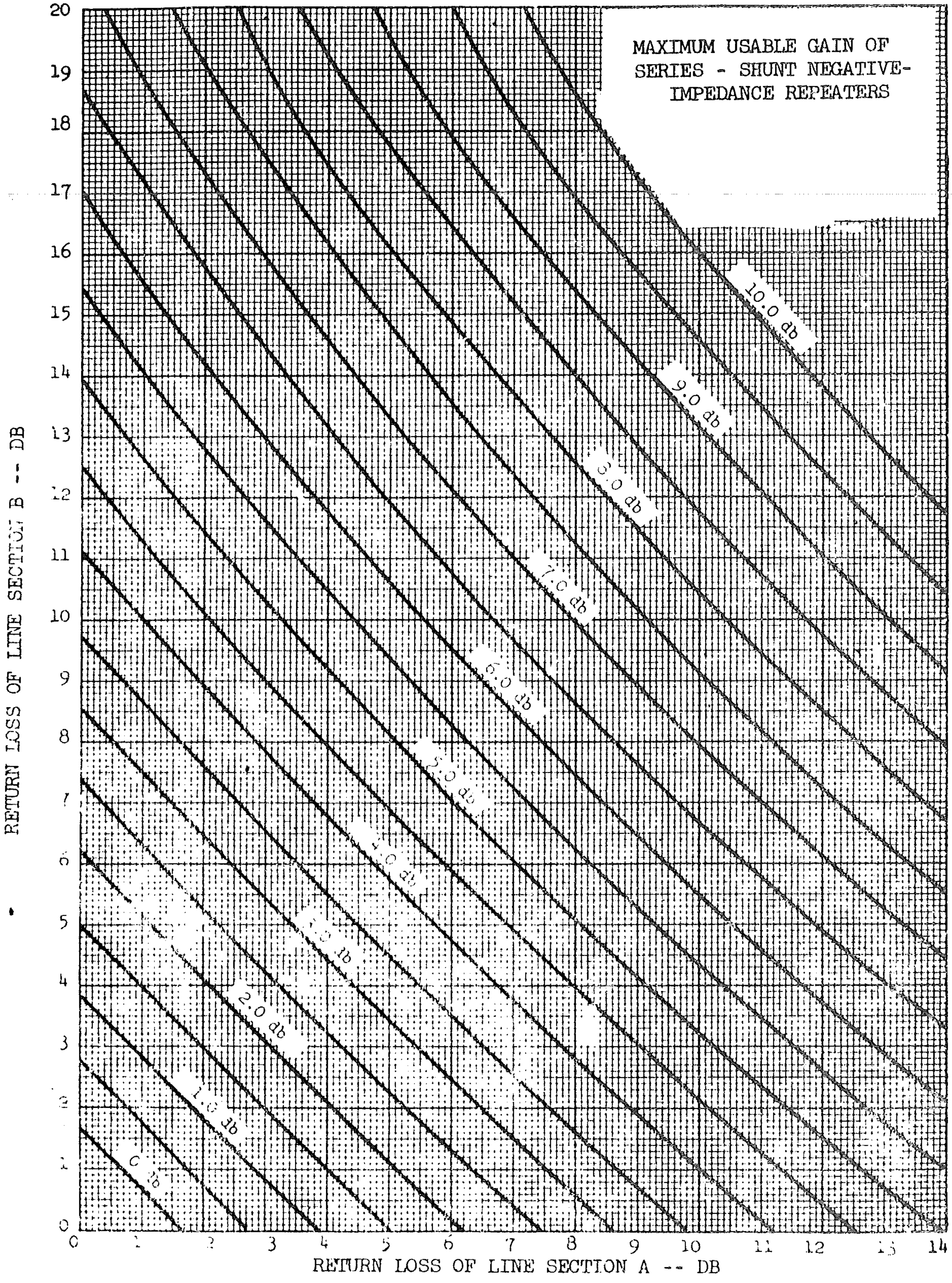

CHART III - CHART FOR DETERMINING MAXIMUM USABLE GAIN OF SERIES-SHUNT NEGATIVE IMPEDANCE REPEATERS FROM LINE RETURN LOSSES