Section 427
Issue No. 3
March 1982

APPLICATION OF VOICE FREQUENCY REPEATERS FOR SUBSCRIBER LOOPS & TWO-WIRE TRUNK CIRCUITS

CONTENTS

TABLES

FIGURES

1. GENERAL

1.1 This section contains information on 2-wire voice frequency repeaters and their application in two-wire trunk circuits and subscriber loops. The application techniques presented in this practice are based on the stability design method which eliminates the need for idle-line terminations, gain disablers, and other devices used to keep the circuit from singing while idle.

1.2 This section has been revised to reflect the current state of the art in repeater design. With the recent advances in repeater technology the application of repeaters has been simplified. As a result, the following TE&CMs have been condensed into this revised Section 427:

1.2.1 TE&CM 427, "Application and Use of Voice Frequency Repeaters for Subscriber Loops", Issue No. 2, November 1965.

1.2.2 TE&CM 444, "Negative Resistance and Negative Impedance Voice Frequency Repeaters and Voice Frequency Repeatered Trunks", Issue No. 2, November 1961. (Cancelled)

1.2.3 TE&CM 446, "Design of Two-Wire D66 Loaded Negative Resistance Repeatered Trunk Plant", Issue No. 1, April 1964. (Cancelled)

1.3 Repeaters meeting the requirements of REA PE-29, "Specification for Two-Wire Voice Frequency Repeater Equipment" will give excellent performance when applied to circuits designed in accordance with the following:

1.3.1 TE&CM 424, "Design of Two-Wire Subscriber Loop and PABX Trunk Plant".

1.3.2 TE&CM 431, "Voice Frequency Loading for Trunks".

1.4 Special applications of repeaters are included in TE&CM 470, "Switched Special Services and Private Branch Exchange Services".

2. DESCRIPTION OF 2-WIRE VOICE FREQUENCY REPEATERS

2.1 General

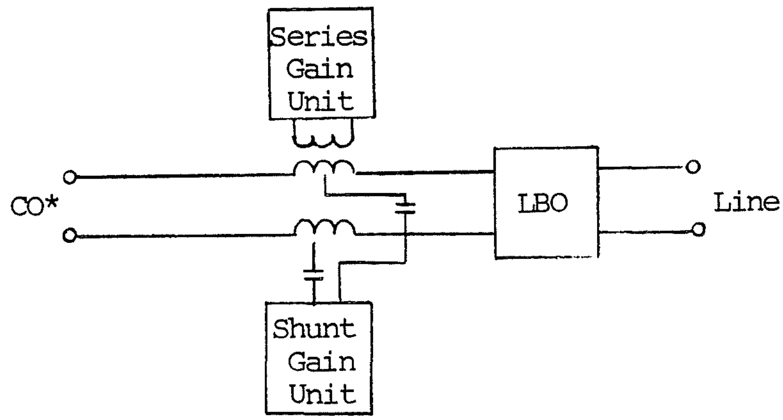
2.1.1 Two-wire voice frequency repeaters for "plain old telephone service" (POTS) type application are divided into two categories, negative impedance type and hybrid type. The negative impedance type applies bi-directional gain in series with the transmission line. The hybrid type repeater separates the line into two transmission paths and applies gain in each direction of transmission. The gain may be fixed, manually adjusted, or self adjusting (see TE&CM 429 for information on repeaters with automatic gain control (AGC)).

2.1.2 Generally repeaters for use on subscriber loops require little or no user adjustments, while repeaters for use on trunk circuits require precision adjustments.

2.1.3 <u>Switched gain repeaters</u> provide bidirectional gain. However, the gain is applied in the direction of the stronger signal and an equal amount of loss is applied in the direction of the weaker signal.

Therefore, this type repeater provides unconditional stability without the need for special line matching networks. It is recommended for use in special service applications only and should not be used for POTS type circuits.

2.2 Negative impedance repeaters are normally composed of a series gain unit, a shunt gain unit and a line matching unit commonly referred to as a line buildout (LBO) network, as illustrated in Figure 1. The definition of repeater insertion (or net) gain varies among equipment manufacturers. When specifying overall repeater gain some include the LBO loss (normally about 0.5 dB) and others do not.



* If used as an intermediate repeater (transmission line on both sides) an LBO is required at the CO side also.

Figure 1. Negative Impedance Repeater

2.2.1 The series and shunt gain units are connected to the line through a transformer as shown in Figure 1. They amplify the line current and voltage in such a way as to produce series negative and shunt negative impedances across the transformer. These impedances combine to provide the gain unit image impedance of 900 Ω in series with 2μF. The series component is open circuit stable and the shunt component is short circuit stable. The transformer provides a low resistance dc path for ringing and supervisory signals.

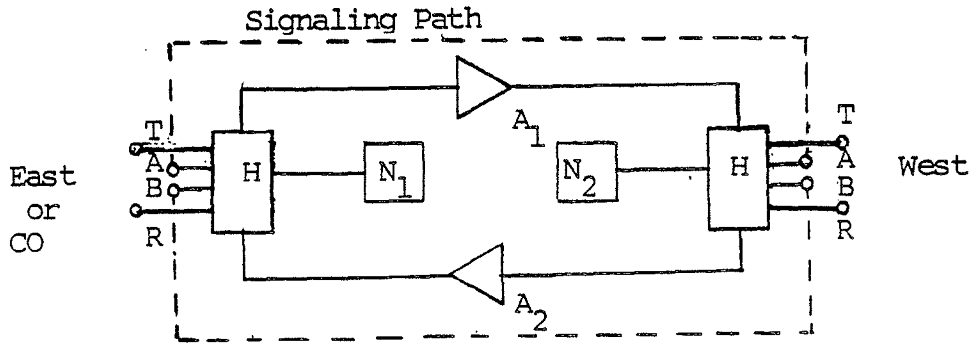
2.2.2 The line build out network provides the means for matching the line impedance to the gain units image impedance. Separate LBO networks are usually provided for D66 loaded, H88 loaded, and nonloaded cable. Each type LBO network usually consists of buildout resistors (BOR), line buildout capacitors (BOC), and a high frequency and low frequency corrector network.

2.2.2.1 Compromise LBO networks provide the best fit match for more than one cable gauge without user adjustments.

2.2.2.2 Repeaters for use on subscriber loops may have LBO networks which have very simple or no user adjustments.

2.2.2.3 Repeaters for use on toll-trunk circuits require precise LBO adjustments to meet the required return loss performance.

2.3 Two-wire hybrid repeaters are composed of two hybrid networks, two unidirectional line amplifiers, and two balance networks as shown in Figure 2.



N_1 = East Balance Network
N_2 = West Balance Network
H = Hybrid Network
A_1 = East to West amplifier
A_2 = West to East Amplifier

Figure 2. Hybrid Repeater

2.3.1 The hybrid network separates the two wire path into two distinct transmission paths. One path transmits from east to west through amplifier A_1 and the other transmits from west to east through amplifier A_2. The degree of isolation between the two transmission paths depends on the impedance matching between the balance networks and the circuits connected to the east and west terminals. Therefore, a high degree of balance is required to prevent regenerative feedback between the two transmit paths of the hybrid. For terminal repeaters the east port faces the central office and a compromise balance network of 900 ohms in series with 2 µF is used to match the central office impedance. The west network facing the line side matches the cable impedance. The balance network which faces a cable pair consists of balance network resistance (NR), network build-out capacitance (BOC), and network gauge compensation.

2.3.2 Repeaters used on toll trunk circuits require adjustable precision balance networks. Terminal repeaters used on subscriber loops with a central office end section equal to approximately 50 percent of a full section need not have any user adjustments available on the balance network.

2.3.3 As illustrated in Figure 2, A and B leads are provided for signaling continuity. The A lead is associated with the tip side and the B lead is associated with the ring side of the line.

3. REPEATER PERFORMANCE CHARACTERISTICS

3.1 Minimum operating requirements for repeaters are contained in REA specification PE-29, "Two-Wire Voice Frequency Repeater Equipment". Repeaters manufactured in accordance with the REA specification and used on loops designed in accordance with REA recommended practices will provide the desired transmission performance of REA TE&CM 415, "Transmission Objectives".

3.2 A brief outline of some of the performance characteristics as required by PE-29 is as follows:

3.2.1 The amplitude-frequency response of the repeater determines the maximum usable bandwidth of the repeatered voice frequency circuit. The bandwidth is normally limited to those frequencies between the points where their amplitude is diminished by 3 dB with reference to the 1000 Hz level. The amplitude of the frequencies between the 3 dB points should be relatively flat (± 1 dB) with respect to the 1000 Hz level.

3.2.1.1 Repeaters for use with D66 loaded cables have a minimum bandwidth of 300 to 3400 Hz.

3.2.1.2 Repeaters for use with H88 loaded cables have a minimum bandwidth of 300 to 2800 Hz.

3.2.2 Stability: The repeater is unconditionally stable when its central office terminals are opened, or shorted and the subscriber end of the loop is either open or shorted.

3.2.3 The echo return loss and singing return loss performance is based on the repeater application. Terminal repeaters, for use on subscriber loops, may have a minimum of 16 dB echo return loss and 11 dB singing return loss when their line matching network (compromise) has no user adjustments and may be used on more than one gauge of cable. All other repeaters provide a minimum of 18 dB echo return loss and 12 dB singing return loss.

3.2.4 Crosstalk separation between adjacent units is nominally 90 dB.

4. APPLICATION OF REPEATERS TO SUBSCRIBER LOOPS

4.1 General

4.1.1 Repeaters should be applied according to the general rules of TE&CM 424, "Design of Two-Wire Subscriber Loop and PABX Trunk Plant".

4.1.2 The application of self regulating repeaters to common mode operation is discussed in TE&CM 429, "Automatic Gain Control Repeaters and their Application to Common Mode Operation".

4.1.3 When the system has more than one gauge of loaded cable pairs which require gain, repeaters with a compromise LBO network may be used. To assure reasonable return loss performance the central office end section length should be 50% of a full section length. The benefit in using the compromise LBO is that the same fixed LBO network can treat more than one cable gauge thereby reducing engineering, administration, and record keeping expenses. Repeaters with compromise LBO networks have poorer return loss than those with more precise LBO networks.

4.2 Loading

4.2.1 To maximize repeater performance loaded subscriber loops should be designed according to the office end section length and load spacing requirements of TE&CM 424.

4.2.2 When existing loaded loops are being extended they should meet the desired results of the acceptance tests of PC-4, "REA Standard for Acceptance Tests and Measurements of Telephone Plant" before applying repeaters. Loops which do not meet REA standards should be upgraded to assure stability when using repeaters.

4.3 Circuit Net Loss

4.3.1 The 1000 Hz circuit net loss (CNL), calculated in accordance with TE&CM 426, "Subscriber Loop Computation (Design by Loss Method)", should range between 3 and 8 dB for all repeatered loops. A CNL less than 3 dB may degrade the repeater return loss performance and result in stability problems. Generally repeaters may be set for an insertion gain as high as 9 dB and still provide satisfactory crosstalk performance.

4.3.2 When the objective 8 dB CNL is exceeded the loop may be extended by using a carrier derived circuit or an intermediate or field mounted repeater. Intermediate repeaters require remote power and weather proof housings. Physical loops become increasingly susceptible to noise as they extend beyond the point where an intermediate repeater is required. Considering the possible transmission degradation, installation costs, and on-going maintenance costs, carrier derived circuits are preferred to the use of intermediate repeaters.

4.4 Subscriber End Sections

4.4.1 As defined in TE&CM 424 the subscriber end section is the "total length of exchange cable (0.083 microfarads per mile average mutual capacitance) extending beyond the last loading coil on the subscriber end of the facility". For best performance, the ideal end section of a loaded loop should equal 50% of the full section. The ideal end section length for D spacing is 0.686 kilometers (2.25 kilofeet) and for H spacing is 0.914 kilometers (3 kilofeet). As the end section increases beyond its ideal length it degrades the performance of the loop. The 1000 Hz insertion loss increases and the bandwidth decreases. Figure 3 shows the average insertion loss for end sections in excess of their ideal length. As can be seen from Figure 3 the end section length rapidly replaces the repeater as the controlling factor for circuit bandwidth. Also, as the end section length increases the line impedance seen by the repeater changes. Loops with less than 9 load coils are affected the most by excess end section lengths. These loops may deteriorate the repeater return loss somewhat.

4.4.2 Loops designed for <u>single-party</u> service should have end sections close to their ideal length. However, those single-party loops with the maximum recommended end section lengths should provide satisfactory performance. A D66 loop with an ideal end section reaches about 193 kilometers (120 miles) before it exhausts its usable bandwidth. The maximum end section recommended for D66 loaded loops, 2 kilometers (6.5 kilofeet), increases the 1000 Hz loss by about 1.3 dB and 3000 Hz loss by about 2.9 dB for a net reduction of 1.6 dB in the usable bandwidth. This reduces the maximum length of the D66 loop to 113 kilometers (70 miles), certainly not a significant impact on single party design.

4.4.3 Loops designed for multi-party service which require end sections in excess of about 2.6 kilometers (8.5 kilofeet) may have a serious impact on the circuit bandwidth, as illustrated in Figure 3. At about this length the end section exhausts all the useable bandwidth. As the end section increases beyond this length the circuit bandwidth diminishes. These circuits provide adequate transmission performance but do not meet REA bandwidth objectives.

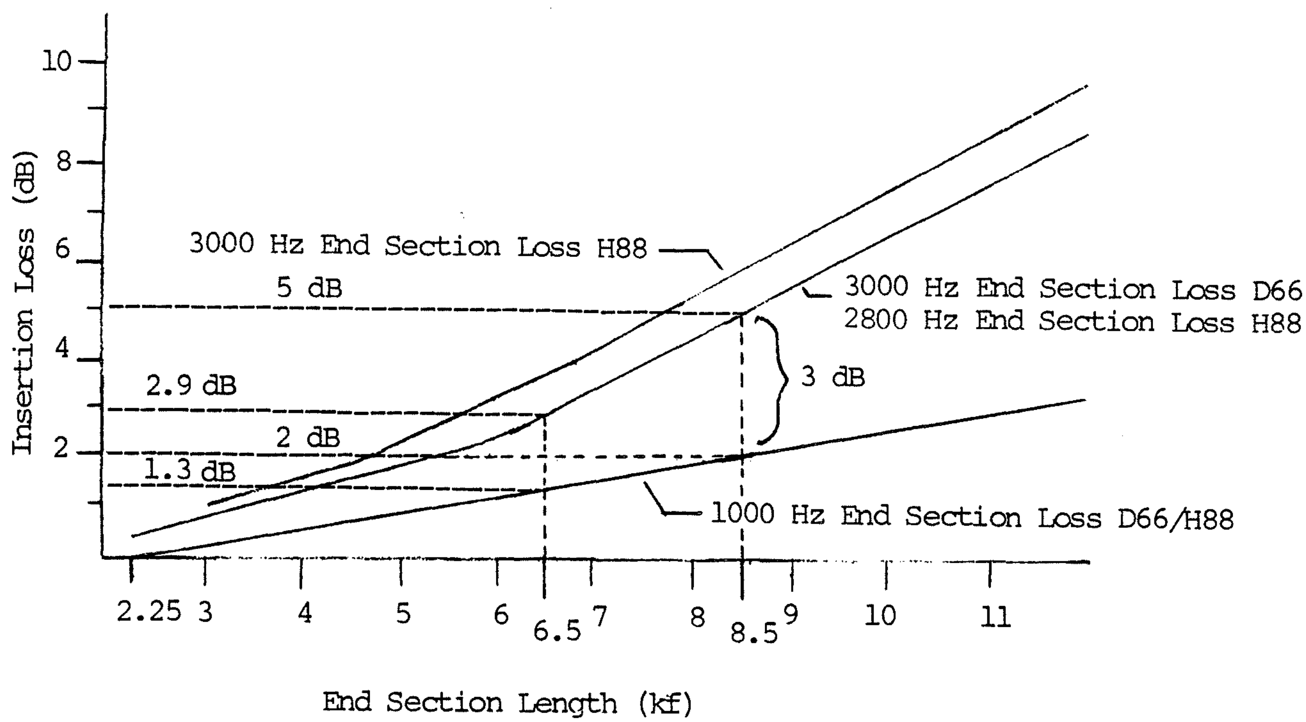


Figure 3. Average End Section Insertion Loss Between 900 Ohm Impedances for Different Lengths of D66 and H88 Loaded 24 Gauge Facilities

4.5 Bridged Tap Isolators

4.5.1 Repeaters may be used on loaded loops requiring bridged tap isolators (BTI) located at either the subscriber end or central office end of the loop. When the BTI is located at the central office end of the loop, repeaters meeting REA requirements for stability should be placed between the BTI and the line. This arrangement requires a repeater for each branch. As an alternative arrangement a single repeater with an idle circuit disable feature should be placed on the central office side of the BTI. Either of these methods will ensure stability in the idle circuit state.

4.5.2 Consideration should be given to using a repeater with automatic gain control as a means to provide uniform gain to each party on the line.

4.5.3 As indicated in TE&CM 428, "Application and Use of Bridged Tap Isolators (BTI) for Subscriber Loops" great care should be used when designing circuits requiring the use of BTIs as they are a potential source of trouble.

5. APPLICATION OF REPEATERS TO TRUNK CIRCUITS

5.1 General: To maximize repeater performance, loaded trunk circuits should be designed in accordance with TE&CM 431, "Voice Frequency Loading for Trunk Cables". Insertion loss and structural return loss measurements should be made in accordance with PC-4, "REA Standard for Acceptance Tests and Measurements of Telephone Plant". The structural return loss should comply with PC-4 Paragraph 9.4, "Applicable Results".

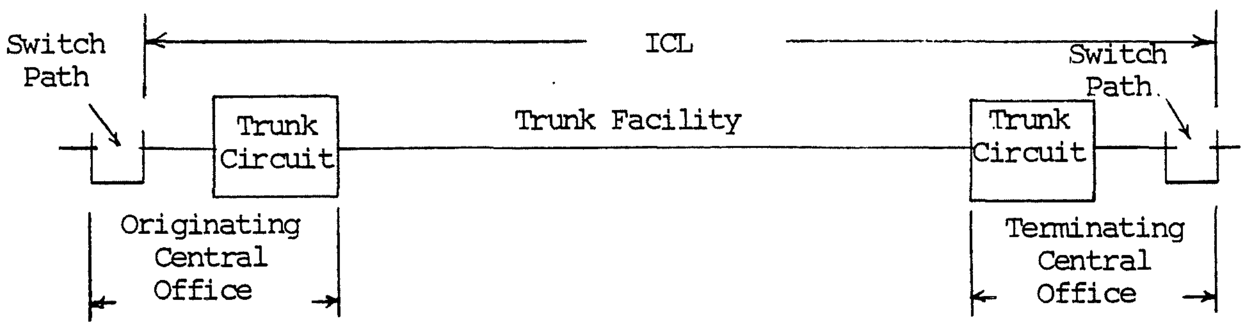
5.2 Inserted Connection Loss (ICL) as defined by the 1980 AT&T "Notes on the Network" is the net circuit loss which "reflects all of the gains or losses from the originating out going switch appearance through the trunk to the out going appearance of the terminating switch with the switch terminated in the nominal office impedance". Table 1 lists the ICL objectives for trunks with gain from the 1980 "Notes on the Network". Figure 4 illustrates the components that are included in the ICL for trunk circuits.

Table 1. Inserted Connection Loss Design Objectives

Type Trunk	Length in Miles	ICL Objectives	ICL Maximum
Toll Connecting	<200	3 dB	4 dB
Class 5 to Class 5	<200	3 dB	–
Class 5 to Higher Class	<200	3 dB	–
Interend Office[1]	200 Max	3 dB	5 dB
Tandem Connecting[2]	200 Max	3 dB	4 dB

Notes: 1. An interend office trunk connects any two end offices but does not connect to another trunk. Interend office trunks carry only local traffic.

2. A tandem connecting trunk connects an end office with a tandem switching system and may connect to another trunk.



ICL = Originating Office Losses + Trunk Facility Loss + Terminating Office Losses

Figure 4. Components of Trunk Circuit ICL

5.3 Amplitude - frequency response (bandwidth) objectives as defined in TE&CM 415, Table A are based on the minimum design objectives of a repeatered D66 loaded trunk circuit. A repeatered H88 loaded trunk circuit can not meet the TE&CM 415 objective. It should be noted, however, that in their publication "Notes on the Network" AT&T does not specifically define bandwidth limits for trunk circuits in general. They do, however, define the overall amplitude-frequency response ("slope") for data transmission as a maximum loss of 8 dB at 2804 Hz relative to 1004 Hz for all trunks and switching equipment between two class 5 offices. Repeatered H88 loaded trunk circuits and all other trunk facilities designed in accordance with REA suggested practices exceed the suggested response of AT&T's "Notes on the Network".

5.4 Echo return loss objectives as stated in Table B of TE&CM 415 should exceed 18 dB and singing return loss should exceed 10 dB.

5.5 Repeater Location

5.5.1 Non toll trunk circuits should have repeaters located in the electrical mid-third portion of the trunk facility to allow for maximum repeater gain and the best return loss performance. Where the repeater can not readily be placed in the middle portion of the facility, terminal repeaters may be used at either or both ends of the facility.

5.5.2 Toll connecting trunk circuits should have the repeater located in the electrical mid-third portion of the trunk facility or at the class 5 office. The minimum return loss objective of 18 dB is difficult to meet during terminal balance procedures if the repeater is located at the class 4 office. If a repeater must be placed at the toll center the gain should be set no higher than 3 dB. Each dB of repeater gain degrades the echo return loss by 2 dB.

5.5.3 Repeaters may be used at the junction of D66 and H88 loaded cables to eliminate the need for junction impedance compensators.

5.6 Calculation of Repeater Gain

5.6.1 The objective ICL for trunks less than 322 Km (200 miles) in length is 3.0 dB as indicated in Table 1. The repeater gain required to produce the desired ICL is determined by subtracting the ICL value (usually 3.0 dB) from the total losses in the trunk circuit. Typical losses for equipment and facilities used in trunk circuit design are listed in Table 2.

Table 2. Typical Equipment and Facility Losses

Item	Insertion Loss (dB)
Class 5 Central Office	0.5 (Note 1)
Class 4 Central Office	0.7
22 D66 or H88 Cable	0.52 dB/Km (0.16 dB/kf)
24 D66 or H88 Cable	0.75 dB/Km (0.23 dB/kf)
Negative Impedance Repeater	
22 gauge cable LBO	0.4
24 gauge cable LBO	0.5
Junction Impedance Compensator (JIC)	0.3
Reflection Loss	(Note 2)

Notes: 1. The 0.5 dB loss for class 5 analog central offices is generally attributed to the repeating coil. Class 5 digital central office loss is set between 0 and 0.5 dB. Losses for office cabling less than 500 feet can be neglected. A good compromise value for office cabling longer than 152 meters (500 feet) is (0.4 dB/kilofoot).

2. Reflection loss is encountered at the junction of facilities with dissimilar impedances. Table II in TE&CM 431 lists reflection losses for various combinations of cable facilities.

5.6.1.1 With the transmission level at the originating central office assigned the level of 0 dB, the transmission level at any point in the trunk circuit should not exceed an objective of +6 dB. The minimum repeater input level should be no lower than -9 dB relative to the originating office. The controlling factor for the maximum level is crosstalk performance.

5.6.1.2 If cables and equipment are manufactured in accordance with current REA specifications the repeater gain may be set as high as 9 dB and provide good crosstalk performance. In such circumstances the upper limit of the Paragraph 5.6.1.1 transmission level is 9 dB and the minimum input level is -12 dB relative to the originating office.

5.7 Examples of Repeater Applications

5.7.1 The first step in engineering the repeater application is to calculate the required gain in accordance with Paragraph 5.6. After calculating the required gain the repeater location is selected in accordance with Paragraph 5.5. Preference should be given to maintaining the transmission level below the +6 dB objective of Paragraph 5.6.2.1. However, if the +6 dB objective level can not be maintained and the crosstalk conditions of Paragraph 5.6.2.2 are met the repeater gain may be set to provide a transmission level not exceeding +9 dB.

5.7.2 Figure 5 illustrates a direct trunk facility between class 5 offices and its transmission level diagram. All components of the circuit meet REA standards. For the sake of establishing the initial design criteria assume a single terminal repeater will meet the 3 dB ICL requirements. From Table 2 the circuit losses are as follows:

CO loss (.5 + .5) dB	= 1 dB
LBO loss (24D66)	= 0.5 dB
24 D66 Facility loss (38 kf x .23 dB)	= 8.7 dB
Total loss	= 10.2 dB

The required repeater gain is 10.2 dB - 3 dB = 7.2 dB. From the transmission level diagram we see that inserting 7.2 dB of gain exceeds the objective limit of +6 dB. Rather than use two repeaters to meet the objective a single repeater set for 7.2 dB may be used at either central office since we determined the conditions of Paragraph 5.6.2.2 are met.

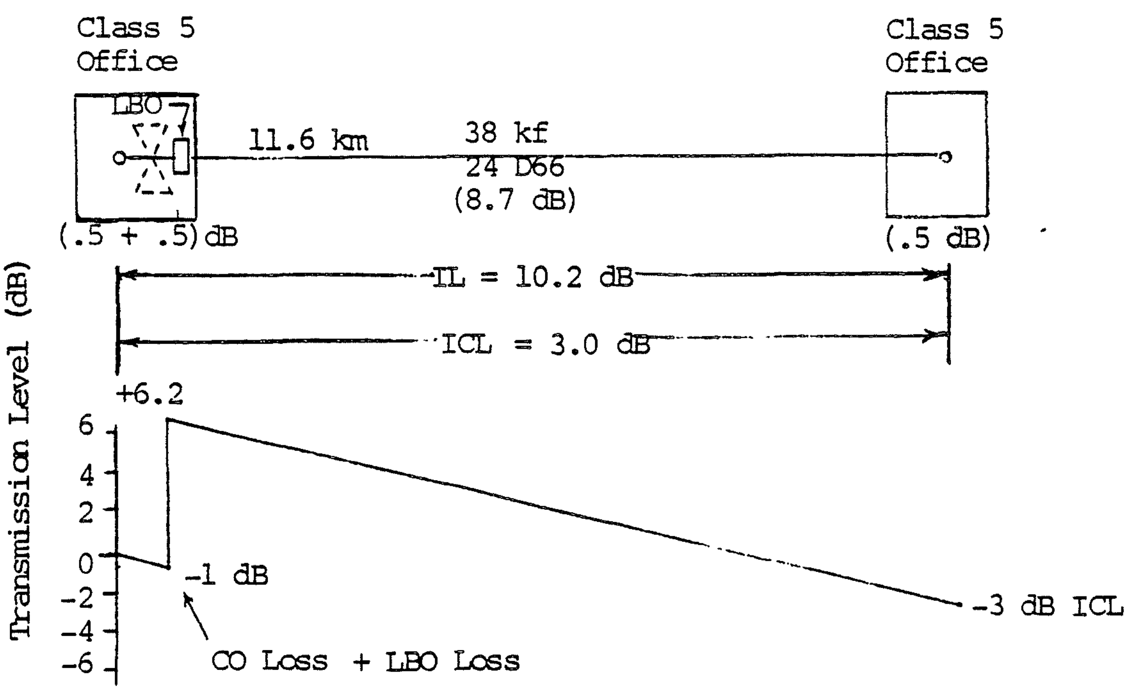


Figure 5. Local Trunk Circuit and Level Diagram

5.7.3 Figure 6 illustrates a toll connecting trunk facility through an intermediate office and its transmission level diagram. All components within the exchange area meet REA standards. The repeater location of first choice is the intermediate office. From Table 2 the circuit losses are as follow:

CO Loss (.5 + .7) dB =	1.2 dB
LBO Loss (.4 + .5) dB =	.9 dB
Facility Loss	
22 H88 (.16 dB/kf x 29 kf) =	4.6 dB
22 D66 (.16 dB/kf x 20 kf) =	3.2 dB
24 D66 (.23 dB/kf x 25 kf) =	5.8 dB
Junction Impedance Compensator (JIC) =	0.3
Total Loss =	16 dB

Therefore the repeater gain required to produce the objective 3 dB ICL is (16-3) dB = 13 dB.

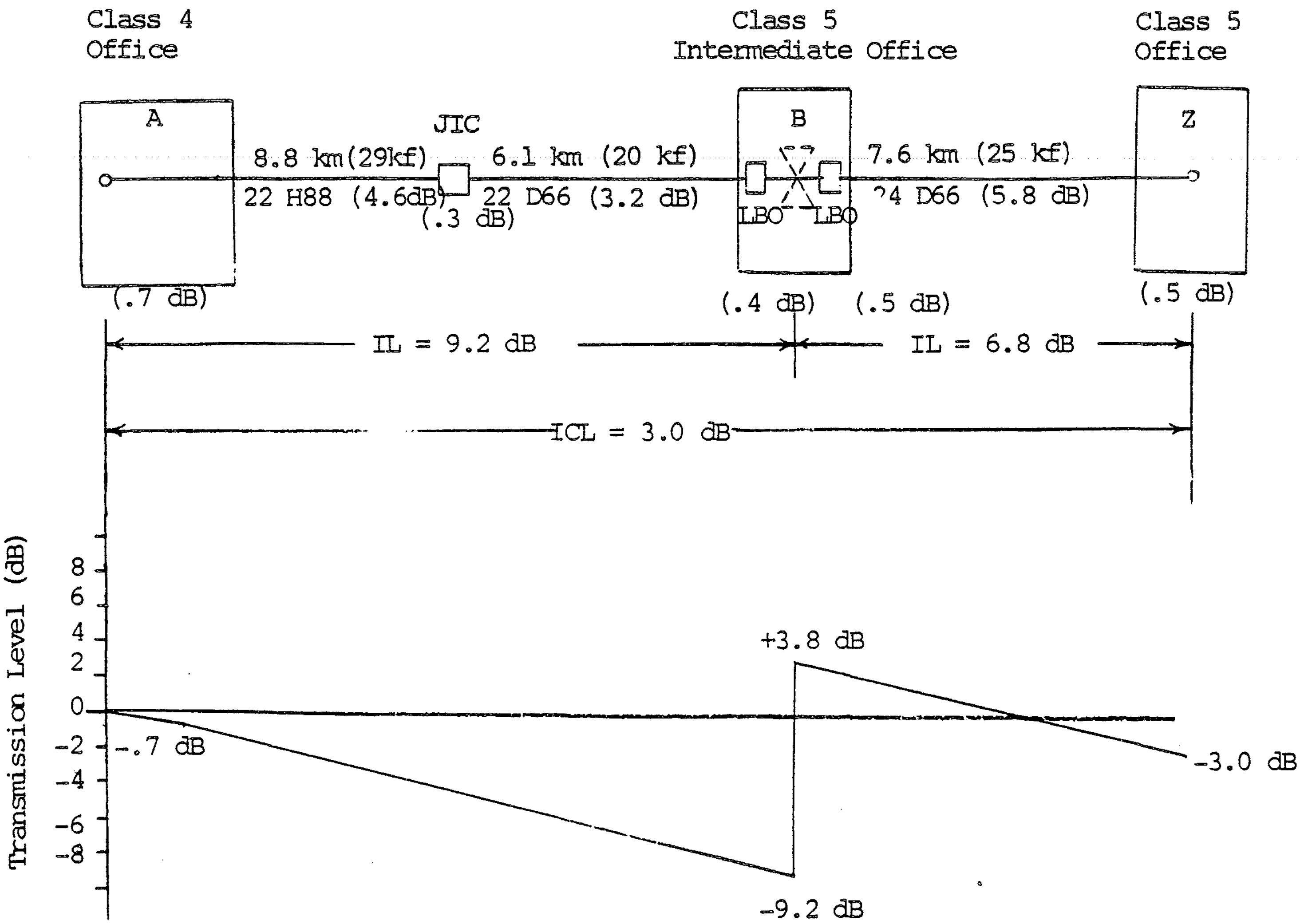


Figure 6. Toll Connecting Trunk and Level Diagram

6. REFERENCES

6.1 AT&T Network Planning Division Fundamental Network Planning Section, American Telephone and Telegraph Co., 1980.

6.2 "Transmission Objectives", REA TE&CM Section 415, Issue No. 4, Addendum No. 1, November 1978.

6.3 "Design of Two-Wire Subscriber Loop and PABX Trunk Plant", REA TE&CM Section 424, Issue No. 3, May 1973.

6.4 "Subscriber Loop Computations - Design by Loss Method" REA TE&CM Section 426, Issue No. 2, December 1977.

6.5 "Application and Use of Bridged Tap Isolators for Subscriber Loops", REA TE&CM Section 428, Issue No. 1, October 1965.

6.6 "Automatic Gain Control Repeaters and Their Application to Common Mode Operation", REA TE&CM Section 429, Issue No. 2, January 1979.

6.7 "Voice Frequency Loading for Trunk Cables", REA TE&CM Section 431, Issue No. 2, October 1962.

6.8 "REA Standard for Acceptance Tests and Measurements of Telephone Plant", REA Bulletin 345-63, PC-4, May 1976.

6.9 "REA Specification for Two-Wire Voice Frequency Repeater Equipment", REA Bulletin 345-69, PE-29, January 1978.

☆U.S. GOVERNMENT PRINTING OFFICE: 1982-360-931:REA-567