Section 470
Issue No. 1
June 1980

Switched Special Services and Private Branch Exchange Services

CONTENTS

Tables

Figures

1. GENERAL

1.1 This section discusses the general design concepts and procedures for the design of switched special service circuits.

1.2 Special services are all those services which fall outside the realm of "plain old telephone service" (POTS). POTS generally includes residence, coin, and non-private branch exchange (PBX) business telephone service. Unlike POTS, special services require engineering on an individual basis. Usually transmission, signaling and maintenance require special treatment. Although special services normally use existing facilities designed for POTS, they will most likely require less loss and different signaling techniques than a similar circuit used for POTS. However, the design objectives for special services are chosen to be compatible with comparable message network service. When designing special services, it is important that they have no noticeable contrast with POTS type services for a given customer. The overall loss objectives are required to be less than or equal to an ordinary subscriber loop as outlined in TE&CM 415.

1.3 Switched special services are used mostly for business purposes to connect the business with geographically dispersed areas. These services are characterized by circuits (lines or trunks) which may be switched either over the message network or private networks. Private networks are composed of private branch exchanges (PBX's) and their associated lines and trunks and generally have access to the message network. Switched special services can, therefore, be divided into two broad categories (1) non-PBX related, and (2) PBX related.

1.3.1 Non-PBX related switched special services are similar to subscriber loop circuits. These special service circuits consist mainly of the following:

1) Foreign Exchange (FX) Lines
2) Wide Area Telecommunications Services (WATS) Lines
3) Off-Premises Extension (OP) Lines
4) Secretarial Lines (SL)

1.3.2 PBX related special services have access to the message network through subscriber trunk facilities. These special service circuits consist mainly of the following:

1) PBX-CO Trunks
2) Tie Trunks
3) FX Trunks
4) WATS Trunks
5) Off-Premises Extension Lines
6) Long Distance Trunks (LD)
7) Centrex Lines & Trunks
8) Automatic Call Distribution (ACD) Trunks

2. DESCRIPTION OF NON-PBX RELATED SWITCHED SPECIAL SERVICES

2.1 Non-PBX related switched special service circuits can generally be thought of as extensions of POTS loops. They usually provide the subscriber with a circuit beyond his normal exchange area. These circuits usually require both a loop facility and a dedicated interoffice facility which, when combined, provide the same function as an ordinary subscriber loop.

2.2 Foreign exchange (FX) circuits, as illustrated in Figure 1, provide a direct connection between a subscriber in one exchange area, through the local central office (serving CO), to a central office (FX CO) located in some other exchange area. The central office located in the foreign exchange area provides the only connection to the message network. The FX circuit, therefore, requires two links (1) subscriber to CO (loop facility), and (2) CO to CO (interoffice facility). The interoffice facility will normally be routed over existing toll facilities on a dedicated basis. Dial tone, ringing signals and loop current originate at the FX CO.

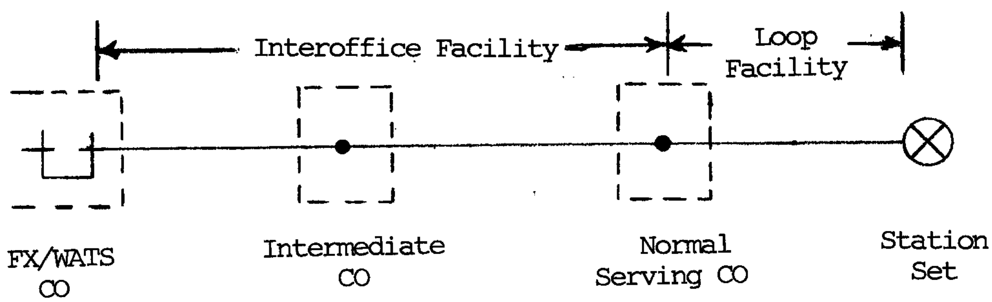


FIGURE 1 FX/WATS LINES

2.3 Wide area telecommunications service (WATS), see Figure 1, provides the customer direct access to selected wide interstate and intra-state geographical areas (bands) for a fixed monthly charge. As of this writing, separate access lines for intrastate and interstate service are required to the most conveniently located central office equipped for WATS. Where the local central office is equipped for WATS service, the one link WATS lines are identical in design to PBX-CO trunks. Where the local central office does not provide WATS, remote WATS lines, similar to FX circuits, connect the subscriber through the serving CO to the WATS CO. WATS lines are exclusively one-way outgoing or one-way incoming circuits connecting to the direct distant dialing network.

2.4 Off-premises extension (OP) lines, as illustrated in Figure 2, provide a bridged connection between a remotely located extension station and the main station. The extension line is usually bridged at the CO but may be bridged at the main station. Bridged tap isolators (bridge lifters) may be required to meet the loss requirements.

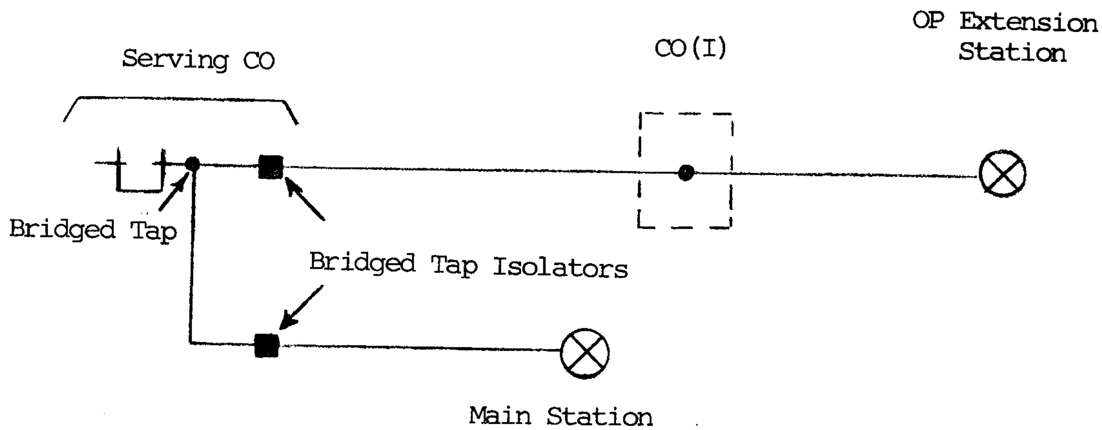


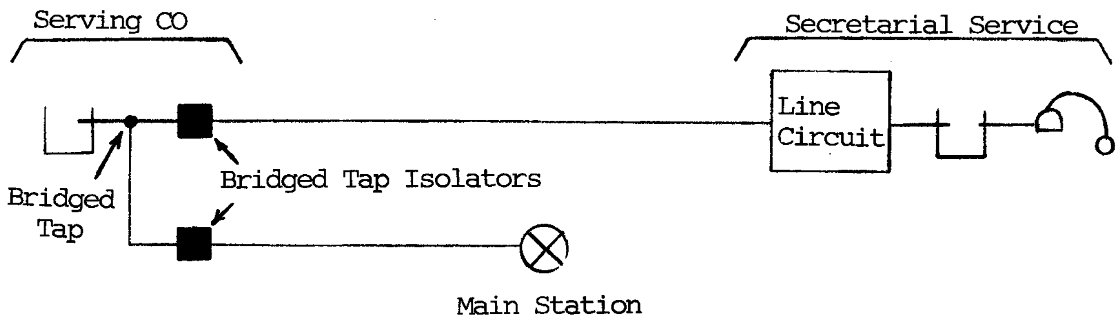
FIGURE 2 Off-Premises Extension (OP) Station

2.5 Secretarial service lines (SL), as illustrated in Figure 3, are similar to off-premises extension lines. The subscriber main station loop is bridged to the secretarial service line at the serving CO. The secretarial lines are usually one-way inward (receive only). As with off-premises lines, bridged tap isolators (bridge lifters) may be required.

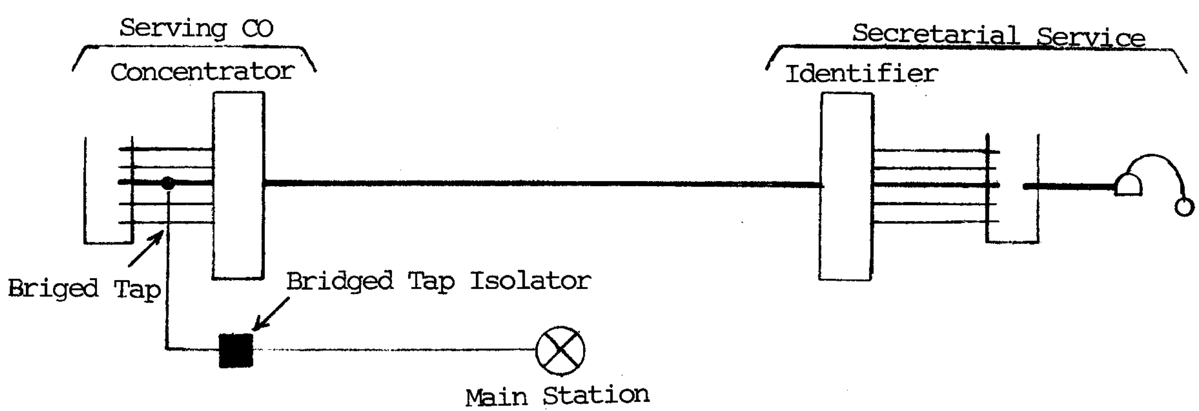
3. DESCRIPTION OF PBX RELATED SERVICES

3.1 A PBX is a manual or dial (automatic) switching machine located on the subscriber premises. Most new PBXs are automatic switching machines (PABX) controlled by microprocessors. However, at this time, some PBXs are still available which require manual connection of all incoming and all outgoing calls. The primary function of the PBX is to interconnect PBX stations and to connect PBX stations to the message network or other PBXs. Several PBXs may be interconnected in a tie trunk network. PBXs in a tie trunk network are classified according to their function in the network.

3.1.1 Main PBXs have a directory number and an attendant. They connect PBX stations via station conductor loops to the local central office trunk for both incoming and outgoing calls. The PBX may also use



(a) Direct Loop Secretarial Service



(b) Concentrator - Identifier Secretarial Service

FIGURE 3 Secretarial Service

FX trunks, WATS trunks, long distance trunks, tie trunks, and off-premises lines for services other than PBX to local central office. Figure 4 illustrates the interconnection of two main PBXs.

3.1.2 A tandem PBX performs the same functions as a main PBX and is also used as an intermediate switching point for main PBXs and other tandem PBXs as shown in Figure 5.

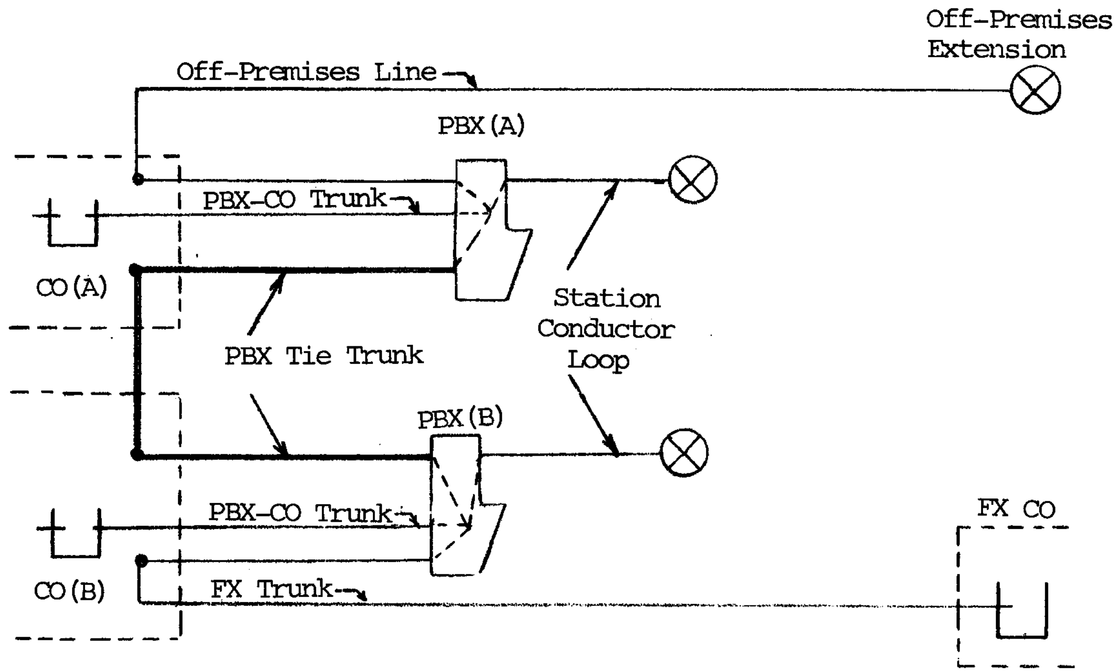


FIGURE 4 Main PBXs Interconnected via Non-tandem Tie Trunk

3.1.3 Satellite PBXs have no directory number and are unattended. They are connected to their main PBX, usually located in the same exchange area, via two-way satellite tie trunks. Since they have no direct incoming connection from the message network, all incoming calls are through the main PBX. They may, however, have one-way outgoing trunk connections to the central office. Figure 5 illustrates a satellite PBX.

3.2 PBXs are connected to the local central office or to other PBXs via trunk facilities. Connection to the central office is via the PBX CO trunk and connection to other PBXs is via a tie trunk. Tie trunks are classified according to their function in the tie trunk network.

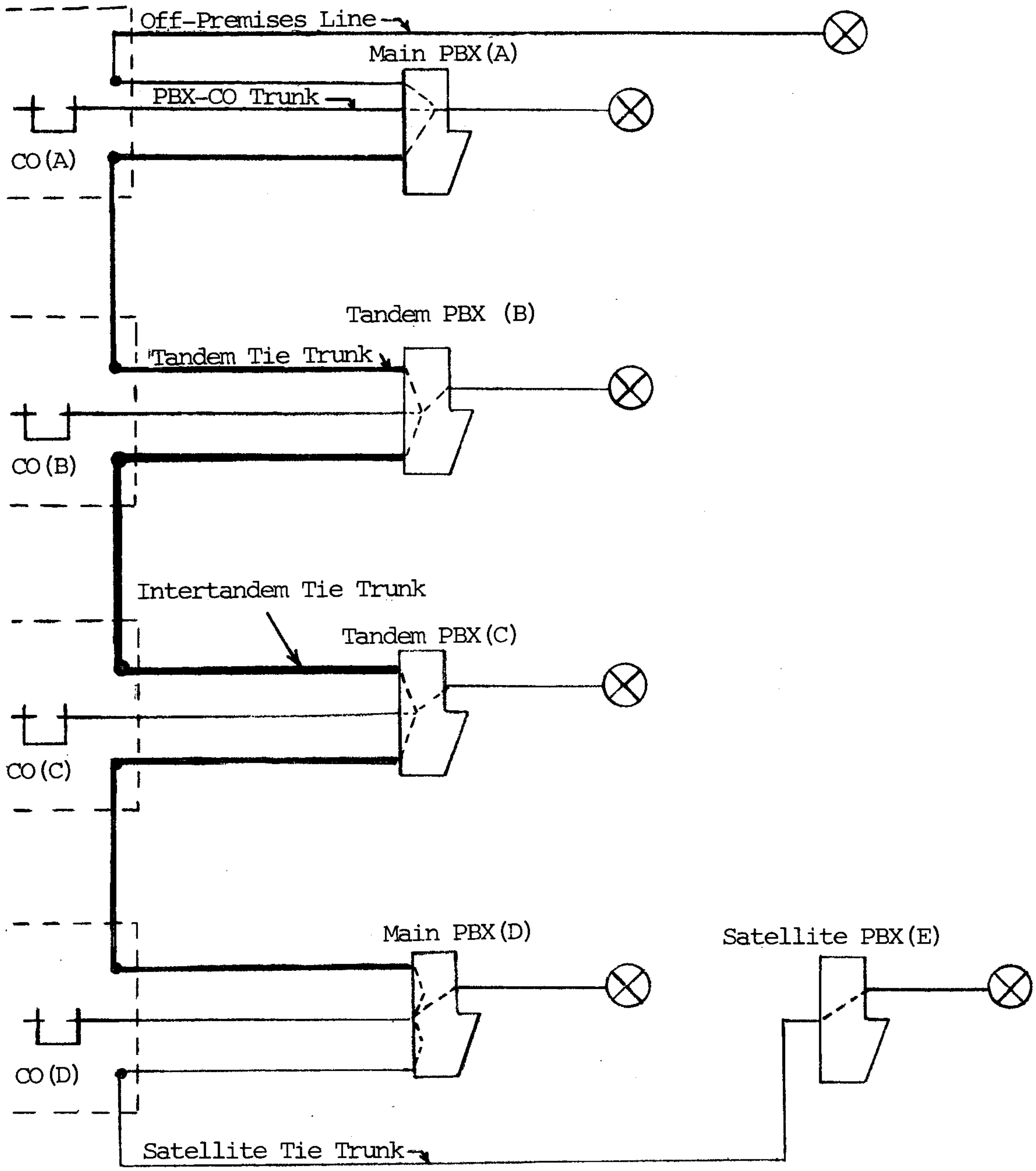


FIGURE 5 Tandem Tie Trunk Network

3.2.1 PBX-CO Trunks connect the PBX to the local central office. These trunks normally appear as station lines at the central office and may be arranged for one-way incoming, one-way outgoing, or two-way (incoming and outgoing) signaling. Carrier facilities may be used for PBX-CO trunks which require a large number of circuits to the serving central office.

3.2.2 Non-tandem tie trunks connect main PBXs, as illustrated in Figure 4, for the purpose of interconnecting stations at the two PBX locations. The non-tandem tie trunk may be connected to a PBX-CO trunk, FX trunk, or WATS trunk at either end of the circuit. Non-tandem tie trunks are not connected together or to other tie trunks.

3.2.3 Tandem tie trunks interconnect main PBXs and tandem PBXs. Tandem tie trunks have access to other tie trunks at the tandem PBX only. Tandem tie trunks are analogous to toll connecting trunks in the message network. Tandem tie trunks are illustrated in Figure 5.

3.2.4 Intertandem tie trunks interconnect tandem PBXs. Intertandem tie trunks have access to other tie trunks at both ends. They are, therefore, analogous to intertoll trunks in the message network. Intertandem tie trunks are illustrated in Figure 5.

3.2.5 Satellite tie trunks interconnect the main PBX with a satellite PBX. They are designed as non-tandem, tandem, or intertandem tie trunks depending on their function. Figure 5 illustrates a satellite tie trunk.

3.2.6 Long distance trunks connect a PBX directly to a class 4 or higher toll switching point. These trunks are normally used in motel/hotel telecommunications networks. Long distance trunk circuits are illustrated in Figure 6.

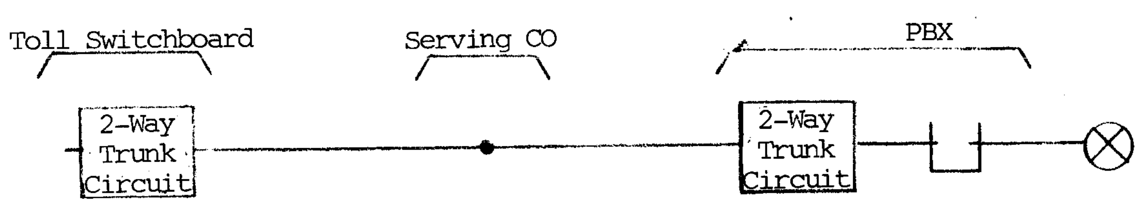


FIGURE 6 Long Distance Trunk Circuit

3.3 An automatic call distributor (ACD) is a switching machine which distributes large numbers of incoming calls equitably between stations and in order of arrival. Unlike most other PBX type switching systems, the ACD system usually has more incoming trunks than station lines.

3.3.1 ACD trunks are treated as PBX-CO trunks.

3.3.2 In addition to ACD-CO trunks, there may also be ACD-FX trunks, ACD-WATS trunks, and ACD-overflow trunks. ACD-overflow trunks are one-way trunks connected between two ACD's to reroute traffic when the capacity of one ACD is exceeded.

3.4 Centrex is a PBX type service with direct inward dialing to a centrex station from the message network. Centrex switching equipment is normally located at the central office. With centrex service, the centrex station sets are connected to the centrex switch via subscriber lines.

3.4.1 Basic centrex features are as follows:

3.4.1.1 Direct outward dialing (DOD) offers direct access to the message network without attendant assistance.

3.4.1.2 Station to station calling permits dial access between PBX stations without attendant assistance.

3.4.1.3 Station hunting directs calls to alternate stations when the called station is busy.

3.4.1.4 Station restriction denies specific stations the ability to place outgoing calls.

3.4.1.5 Call transfer allows the called station, while connected to the incoming line, to signal the attendant and have the call transferred to another station within the PBX system.

3.4.1.6 Direct inward dialing (DID) permits calls from the message network to have direct access to a PBX station without attendant assistance.

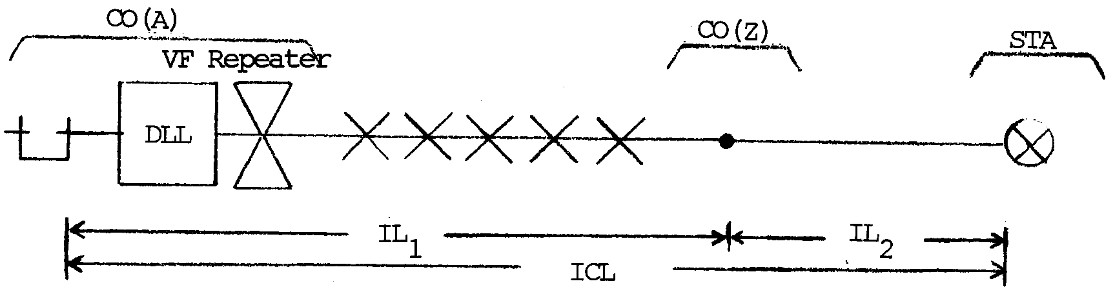
3.4.1.7 Automatic identified outward dialing (AIOD) identifies the calling station on outgoing toll calls for billing purposes.

3.4.2 Any stored program control PBX available today can provide any of the above features.

4. TRANSMISSION CONSIDERATIONS

4.1 Insertion Loss (IL) is the loss which results when a network is inserted into a transmission system. The network may be any circuit item (such as the loop treatment equipment or the loaded cable inserted between CO(A) and CO(Z) in Figure 7). The insertion loss is a measure of the power loss resulting from the network being inserted into the system. In Figure 7 the insertion loss between CO(A) and CO(Z) is the sum of the losses of the DLL and the loaded interoffice facility.

For loaded cable, insertion loss and the cable attenuation loss as calculated from Table 1 are equivalent. However, for nonloaded cable the insertion loss is somewhat less than the cable attenuation loss calculated from Table 1. The cable attenuation constant is calculated with the cable terminated in its characteristic impedance. Since non-loaded cable terminated in either 600 or 900 ohms does not look like non-loaded cable terminated in its characteristic impedance the attenuation constant does not give a good indication of the cables insertion loss. The 1004 Hz insertion loss for non-loaded cable terminated with 900 ohms should, therefore, be determined from Figure 8.



IL_1 = DLL Loss + CO (A) to CO (Z) 1004 Hz Cable Attenuation Loss from Table 1

IL_2 = CO (Z) to STA 1004 Hz Cable Insertion Loss for 900Ω Terminations from Figure 8.

$ICL = IL_1 + IL_2 - GA$

GA = CO (A) Repeater Gain

FIGURE 7 Inserted Connected Loss (ICL) and Insertion Loss Calculations

4.2 Inserted connected loss (ICL) is the 1004 Hz loss to which the circuit is designed. It is, therefore, the circuit net loss with all the loop/trunk treatment equipment in place. ICL includes the circuit net loss between the originating and terminating outgoing switch appearances for a trunk and between the line-side switch appearance and customer station for a line.

4.3 As shown in Figure 7, ICL is calculated from the circuit insertion loss (IL) and any circuit gain. Cable attenuation values used to calculate the cable attenuation loss are listed in Table 1. Values for non-loaded cable insertion loss are in Figure 8. Office wiring and all equipment losses should be included in the calculations where significant. Table III in REA TE&CM 426, "Subscriber Loop Computation Design-by-Loss Method" contains nominal 1000 Hz loss values which may be found in a typical subscriber loop facility. In designing special services circuits the ICL should be chosen to give minimum contrast between the special services circuit and the POTS type circuit to the same customer. Normally up to a 2 dB contrast between circuits will not be detected by the customer. At all times transmission objectives (return loss, frequency response) must be maintained.

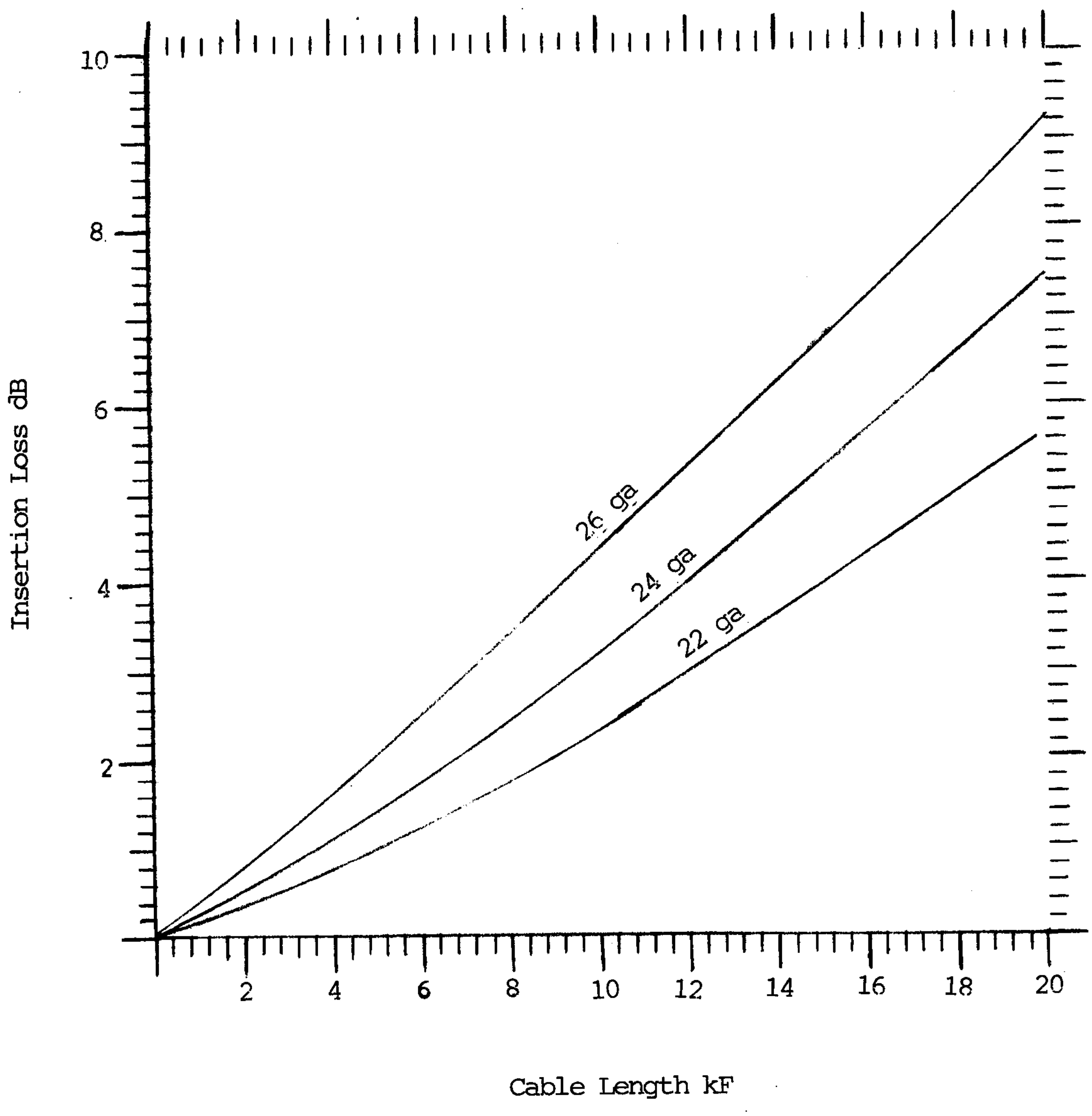


FIGURE 8 1kHz Loss of Non-Loaded Cable with 900Ω Terminal & Source Impedance

4.4 Attenuation loss is temperature dependent for aerial cable but virtually independent of temperature for buried cable. Attenuation loss for aerial cable varies by about ± 1% for each ± 2.6°C change in temperature. The reference temperature is that temperature at which the initial loss measurements were made. For example, if the initial loss measurement were made at an ambient temperature of 20°C and the temperature at some future date were to go to 40°C then the loss would increase by approximately 8%.

4.5 Many of the existing facilities which may be used for special services circuits may have bridged taps. Preference should be given to facilities without bridged taps. Although, bridged taps generally will not be a problem and may be left intact. If problems arise the bridged taps should be suspect. The 1004 Hz loss introduced by the bridged taps, about 0.25 dB per kilofoot (0.3km) should be accounted for in the circuit design. However, the bridged tap loss varies with frequency and may impair the frequency response of the special service circuit. It should be noted that where the special services circuit may carry data the bridged taps could cause problems. Refer to TE&CM 428, "Application and Use of Bridged Tap Isolators (BTI) for Subscriber Loops" for more information on bridged taps.

4.6 For interoffice links a minimum of two load points is permissible provided that transmission objectives for frequency response, and return loss are met (see TE&CM 431).

4.7 To insure circuit stability, normally no more than two 2-wire repeaters should be used in any special service circuit.

4.8 Repeater gain requirements are determined by calculating the overall loss of the system minus the desired ICL (see Figure 7). Repeatered circuits should be designed by the stability design method of TE&CM 444.

4.9 Four wire voice frequency circuits may use 2-wire/4-wire voice frequency repeaters or term sets, line amplifiers, and equalizers.

4.9.1 As illustrated in Figure 9, the transmit direction of 2-wire/4-wire voice frequency repeaters is towards the 4-wire side. Conversely the receive direction is towards the 2-wire side.

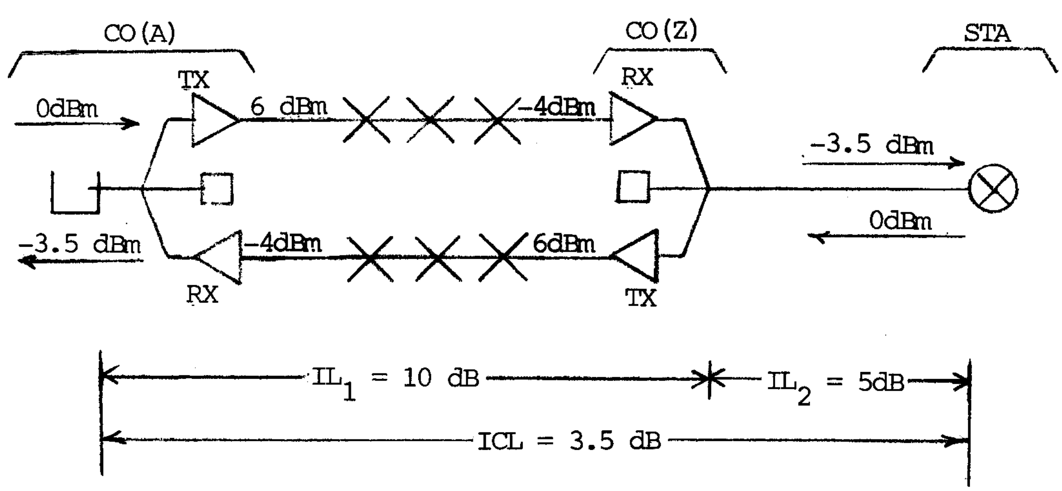
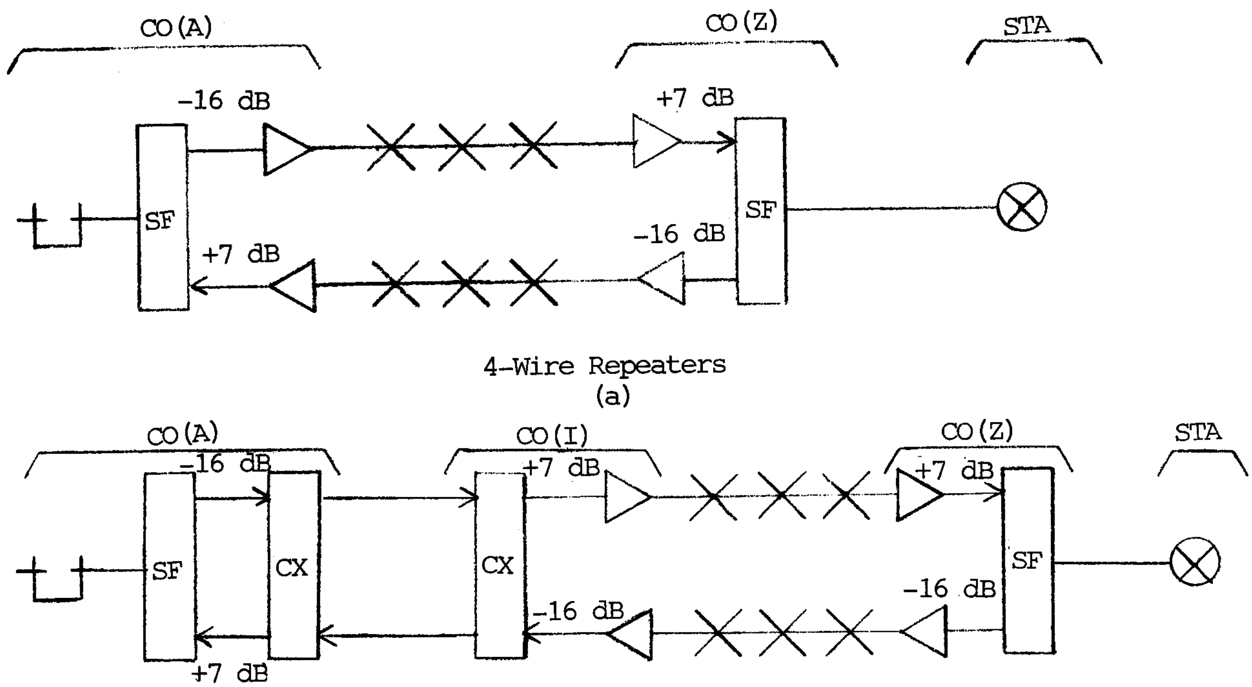


FIGURE 9 2-Wire/4-Wire Voice Frequency Repeater Circuit Design

4.9.2 The gain in the transmit direction should not exceed an output power level of +6 dBm permitted for good cross talk performance.

4.10 When carrier or single frequency (SF) signaling equipment is used, a transmit and receive level separation of 23 dB should be maintained. That is the SF equipment normally transmits at -16 dB and receives at +7 dB as shown in Figure 10.



4-Wire Repeaters & Carrier

FIGURE 10 4-Wire Repeater Levels Relative to CO Transmit Level

4.11 Since the computed losses are estimates, minor gain adjustments will be required during line up to obtain the desired ICL. However, manufacturer's suggested operating parameters must be observed.

4.12 The loss you expect to measure with the actual test set up is the expected measured loss (EML) and may be about 0.5 dB greater than the ICL. The difference can arise because the point where ICL loss calculations begin in the CO may not be accessible for measurement purposes. It is, therefore, necessary to be aware of any additional loss which may be attributable to the test set up.

5. FX AND WATS LINES DESIGN OBJECTIVES FOR SWITCHED NON-PBX RELATED SPECIAL SERVICES

5.1 General

5.1.1 The following transmission and signaling concepts are based on universal design criteria. The benefit lies in commonality and ease in administration and record keeping. The necessity arises because the bulk of these services will be originating and terminating in areas served by different telephone companies. These services require the use of both normal loop plant and interoffice facilities for a single subscriber to CO switching machine connection. Because of the multi-facility use for a single connection, transmission and signaling requirements will fall between normal trunk and subscriber loop requirements.

5.1.2 In an effort to produce universality, some of the requirements may seem a bit stringent. However, for the sake of economics, some deviation from the loop requirements for the serving CO to subscriber are permissable to the extent that requirements for normal loop plant are not violated for the overall connection. In the design of these circuits it is important to keep in mind that there should be minimal contrast between the customer's special service circuits and his POTS circuits.

5.1.3 For the sake of clarity in this practice, the FX CO and remote WATS CO shall be defined as CO(A), and the serving CO as CO(Z). Any intermediate CO shall be defined as CO(I). CO(A) to CO(Z) constitutes one link and CO(Z) to STA (subscriber station) constitutes the second link. Figure 11 illustrates a typical FX or WATS line layout for 2-wire circuits.

5.1.4 The CO(Z)-STA link consists of a 2-wire, non-loaded or loaded subscriber loop, or 4-wire subscriber carrier facility. The CO(A) to CO(Z) link may be a 2- or 4-wire loaded voice frequency facility, carrier facility, or some combination of 2-wire, 4-wire, voice frequency, or carrier facilities. The application of station carrier is discussed in TE&CM 911.

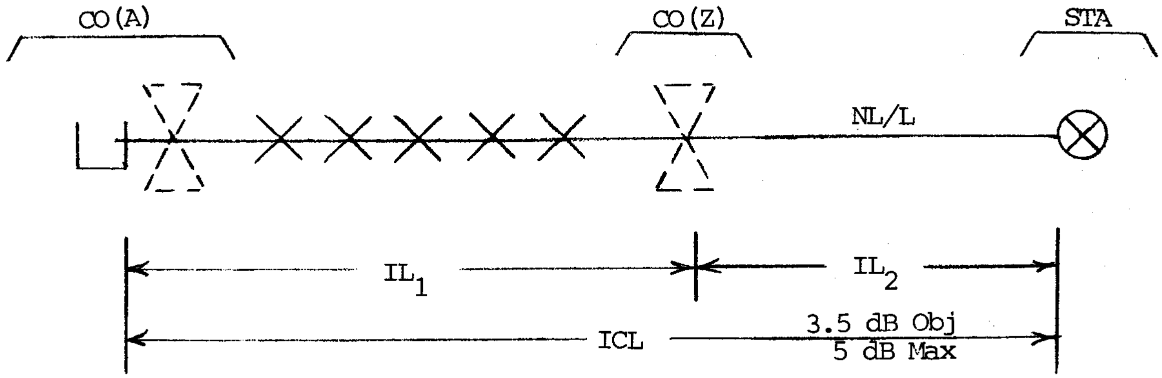
5.1.5 Except as noted herein circuits should conform to requirements of TE&CM 424, "Design of Two-Wire Subscriber Loop and PABX Trunk Plant". Loaded interoffice facilities should conform to requirements of TE&CM 431, "Voice Frequency Loading for Trunk Cables".

5.1.6 Loaded 2-wire interoffice facilities may interface with non-loaded subscriber loops. When the length of the non-loaded subscriber loop plus the loaded interoffice facility end section exceeds 12 kf (3.6km) special services type repeater which can interface with loaded cable at one port and non-loaded cable at the other port should be inserted at the non-loaded circuit interface to provide proper equalization for both links.

5.2 Transmission Objectives

5.2.1 FX and WATS circuits should be designed for an objective ICL of 3.5 dB. The ICL is allowed to go to 5 dB before a repeater or additional repeater is required.

5.2.2 Figures 11 through 13 contain design guidelines for 2-wire voice frequency circuits, 4-wire voice frequency circuits, and trunk carrier circuits for FX and WATS lines. The following is an example of the application of the guidelines in Figure 11 to a 2-wire voice frequency FX



Cable Insertion Loss

CO(A) to CO(Z) Max IL_1	CO(Z) to STA Max IL_2	CO(A) to STA Max IL	Repeater Requirements
4 dB	4 dB (NL)* 5 dB (L)	5 dB	No repeater required
6 dB	4 dB (NL)* 7 dB	12 dB	Terminal Repeater at CO(A)
9 dB	11 dB	15 dB	Intermediate Repeater at CO(Z)
15 dB	15 dB	23 dB	Terminal repeater at CO(A) Intermediate repeater at CO(Z)

Notes: * See Paragraph 5.1.6

NL = Non-Loaded Cable

L = Loaded CO(Z) to STA Loop

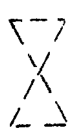
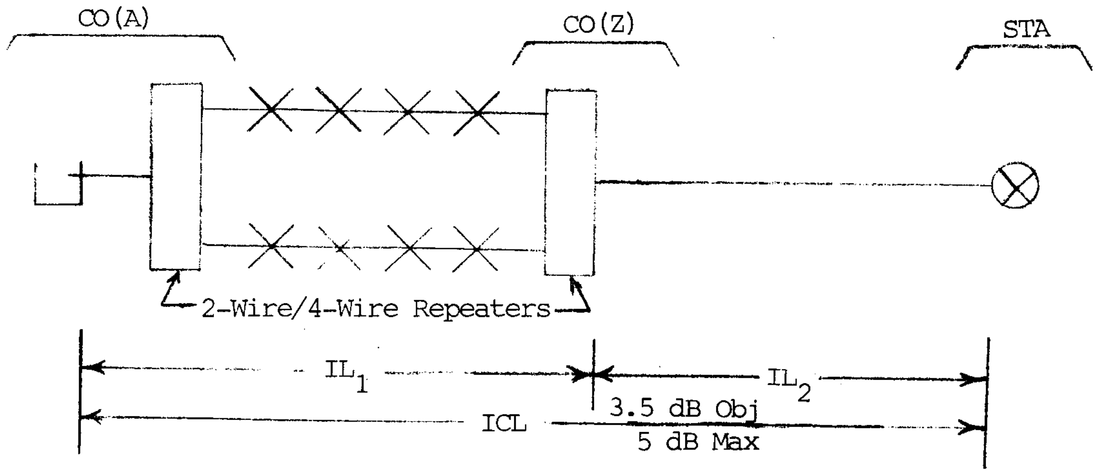
 = 2-Wire Repeater When Required

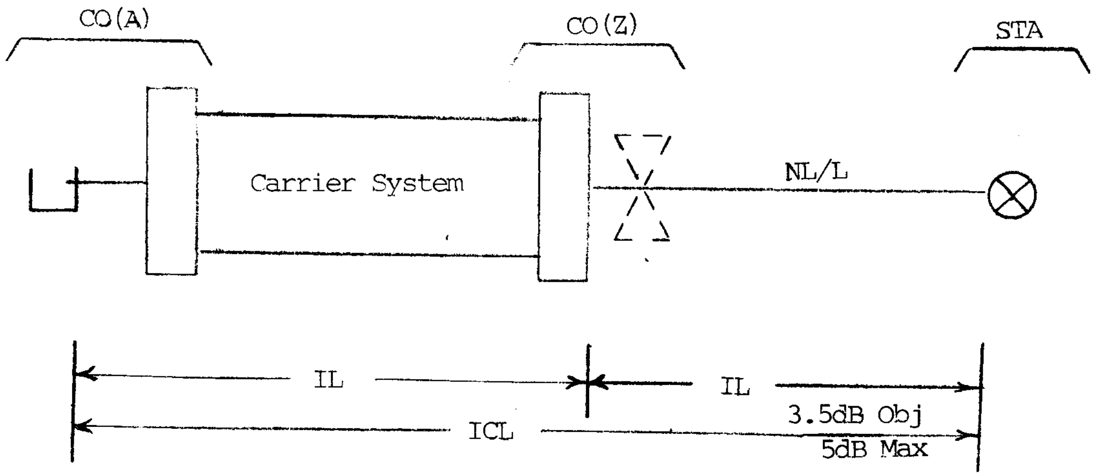
FIGURE 11 Guidelines for 2-Wire Voice Frequency Design of FX or WATS Lines



Cable Insertion Loss

CO(A) to CO(Z) MAX IL1	CO(Z) to STA MAX IL_2	CO(A) to STA MAX IL
15 dB	15 dB	23 dB

Figure 12 Guidelines for 4-Wire Design of FX or WATS Lines



Cable Insertion Loss

CO(A) to CO(Z)	CO(Z) to STA Max IL	2-Wire Repeater Requirements
Carrier	5 dB	No repeater required
Carrier	11 dB	Repeater required at CO(Z)

Notes: NL = Non-loaded Cable CO(Z) to STA Loop

L = Loaded Cable CO(Z) to STA Loop

= 2-Wire Repeater When Required

Figure 13 Guidelines for Trunk Carrier Design of FX or WATS Lines design problem. This example is typical, and a similar approach would be used for other design applications.

5.2.2.1 Consider the following facilities available for this FX design

1) CO(A) to CO(Z): 50 Kf (15.2 Km) of 24D66
2) CO(Z) to STA: 15 Kf (4.6 Km) of 24NL

5.2.2.2 Calculate the CO(A) to CO(Z) attenuation loss using Table 1 values:

50 Kf x 0.23 dB/Kf = 11.5 dB

5.2.2.3 Determine the CO(Z) to STA attenuation loss using Figure 8 values:

15 Kf of 24 NL = 5.2 dB

5.2.2.4 Calculate the CO(A) to STA attenuation loss using above results

11.5 dB + 5.2 dB = 16.7 dB

5.2.2.5 From Figure 11 we see that the CO(A) to CO(Z) attenuation loss may range up to 15 dB for 2-wire voice frequency circuits. Also we see that for a total insertion loss greater than 15 dB we should use a terminal repeater at CO(A) and intermediate repeater at CO(Z). The repeaters should be adjusted to yield an ICL of 3.5 dB. The following rule may be used as a guide to determine repeater gain.

$$G(A) = (L_1 + L_2 + L_0 - ICL)/3$$

$$G(Z) = 2\ (L_1 + L_2 + L_0 - ICL)/3$$

Where G(A) = repeater gain at CO(A)
G(Z) = repeater gain at CO(Z)
L_1 = CO(A) - CO(Z) insertion loss
L_2 = CO(Z) - STA insertion loss
L_0 = CO insertion loss

Therefore the CO(A) repeater is adjusted for a 4.5 dB gain and the repeater at CO(Z) is adjusted for a 9 dB gain. The gain values determined are only design guides. The actual gain is determined by the stability design method of TE&CM 444.

5.3 Signaling Considerations

5.3.1 Signaling functions (dial tone, ringing, and loop current) originate from the FX central office. Signaling requirements are generally the same as normal subscriber loop operation. Methods of providing signaling incorporate both trunk and subscriber loop signaling techniques. Basic to all signaling schemes is the minimum loop current required for the supervisory, alerting, addressing, and ring-trip functions. Generally, a minimum loop current of 23 ma is required at the station set.

5.3.2 Different types of central offices may have different signaling limits. Those COs with a 51.6 volt float battery meeting REA central office equipment specifications have a 1700 ohm outside plant loop dc resistance limit (see Table 1 for dc resistance values). When the FX CO limits are exceeded, the following methods of extending signaling can be used:

5.3.2.1 Loop Extenders (LE) are terminal equipment located at the CO that provide boost battery to extend CO signaling limits to about 4300 ohms of outside plant dc resistance for COs with 51.6 volt float battery. The loop extender is discussed in TE&CM 332, "Guide for Utilization of Central Office Loop Extenders".

5.3.2.2 Loop Signaling Repeaters (LSR) normally repeat supervision, addressing, and ring-trip functions. Options for dial pulse correction, repeated ringing, reverse battery supervision, loop start only (LSO), and loop start/ground start (LS/GS) are generally available.

5.3.2.2.1 Since the LSR pulsing relay opens the transmission path during the idle condition, the repeater disable option may be required to maintain stability if an E type repeater is used at the same location. Most repeaters available today are open circuit stable at the CO port. If a hybrid type repeater is used, A & B leads are available for signaling. A & B leads are signaling leads where the A lead is associated with the tip lead and the B lead is associated with the ring lead of a transmission circuit. Hybrid type repeaters normally have A & B leads for the purpose of removing the signaling equipment from the transmission path thereby eliminating the loss of the hybrid coil from the signaling path. This allows maximum repeater efficiency.

5.3.2.2.2 A single LSR may be used to extend the CO(A) signaling limit up to 6000 ohms when used with 96 vdc. The voltage source may be either CO talk battery or an external boost battery. For other than 48 vdc operation an external boost battery is required. The equipment may be located at CO(A) or any intermediate point. No more than two units should be used in tandem unless the dial pulse correction option is used.

5.3.2.2.3 LSR units may be used with 2-wire/4-wire repeaters when the repeaters are equipped for simplex operation.

5.3.2.3 Dial Long Line (DLL) signaling equipment converts the signal format of 2-wire/4-wire circuits from A & B leads to interface with carrier equipment single frequency (SF) signaling equipment or duplex (DX) equipment. DLL equipment is similar to the loop signaling repeater discussed above.

5.3.2.4 Single Frequency (SF) signaling units provide signaling in the voice frequency band over 4-wire circuits. They can be used over a number of 4-wire facilities in tandem without signaling degradation. SF signaling may be used with 4-wire voice frequency repeaters, analog carrier, or digital carrier equipment. The drop limit for FX SF units is normally about 1800 ohms. Station carrier, or DLL units and VF repeaters may be used to extend the subscriber loop. Integrated SF equipment is available which provides both the signaling and transmission interface for 2-wire/4-wire circuits.

5.3.2.4.1 The central office end unit, commonly designated FXO, converts signaling tones from the station end to local loop supervisory and address signals. It also converts the central office ringing and supervisory signals to SF tones for transmission to the station end.

5.3.2.4.2 The station end unit, commonly designated FXS, converts incoming tones to local loop ringing and supervisory signals. It also converts station supervisory and address signals to SF tones for transmission to the central office.

5.3.3 TE&CM 319, "Interoffice Trunking and Signaling", discusses interoffice signaling methods which may apply to some special service circuits.

5.3.4 For loop resistance computations, assume 200 ohms for telephone sets with dial pulse signaling and 320 ohms for telephone sets with DTMF signaling. These are nominal values; actual terminal dc resistance will most likely be different than the stated values.

6. OFF-PREMISES EXTENSION LINES FOR SWITCHED NON-PBX RELATED SPECIAL SERVICES

6.1 General

6.1.1 Non-loaded off-premises (OP) extension lines and main station lines may be bridged to the main station line at either the main station location or the central office location. Preference should be given to bridging at the central office.

6.1.2 Non-loaded OP and main station lines up to 1.8 Km (6 kilofeet) in length may be treated as an ordinary bridged tap.

6.1.3 When the OP line is bridged at the CO and either line exceeds 1.8 Km (6 kilofeet) in length a bridged tap isolator (bridge lifter) should be installed in that line(s).

6.1.4 When the OP line is bridged at the CO and either the OP line or station line is loaded, bridged tap isolators (bridge lifters) are required on both lines.

6.1.5 The bridged tap isolator (bridge lifter) is a saturable inductor which has an idle circuit (no dc loop current) impedance of about 100,000 ohms. The bridge tap isolator will pass 20 Hz ringing current with minimal loss and has a dc resistance of about 20 ohms. When the telephone set goes off-hook a dc loop current of 20 mA or greater will reduce the impedance to about 50 ohms. A 2 mA leakage current in the unused branch will result in an impedance of about 15,000 ohms. The impedance decreases logarithmically with increasing current until about the 20 mA point

6.1.6 When using bridged tap isolators (bridge lifters), therefore, it is necessary that the plant be well maintained. Also, excessive power induction is likely to have a more detrimental effect than in normal plant. Furthermore, when bridged tap isolators are used with divided ringing, without ringer isolators, serious noise problems can be expected. For more information on bridged tap isolators refer to REA TE&CM 428, "Application and Use of Bridged Tap Isolators for Subscriber Loops".

6.2 Transmission and Signaling Design

6.2.1 OP lines should be designed for an objective ICL of 3.5 dB with a maximum loss of 8 dB.

6.2.2 OP lines in the same exchange as the main station are treated as normal loop plant except for the use of bridged tap isolators.

6.2.3 OP lines extending into a different exchange than the main station are treated as FX lines except for the bridged tap isolators.

7. PBX RELATED SERVICES DESIGN OBJECTIVES

7.1 General

7.1.1 The design of PBX systems can be divided into two categories: (1) PBX systems which may include satellite and non-tandem tie trunks, and (2) PBX systems which may include tandem and intertandem tie trunks. The primary difference between the two categories is that those systems which include tandem and intertandem tie trunks require terminal balance and through balance at the tandem PBX. Terminal balance and through balance are measurements of echo return loss (ERL) at the various switching points in a switched network. These measurements are necessary to insure system stability.

7.1.2 The PBX subscriber loop is composed of the PBX trunk and station loops. The trunk loop consists of the connection between the originating outgoing switch appearance of the calling CO or PBX and the terminating outgoing switch appearance of the called PBX or CO (refer to Figure 14). And the PBX station loop consists of the connection between the station set and the line side of the PBX switch appearance.

7.1.3 A PBX may be of the cut-through or the non-cut-through type. The cut-through type PBX uses CO talk battery for station set functions. The non-cut-through type PBX uses local battery for station set functions. Unlike the cut-through PBX, non-cut-through PBX station loop signaling is independent of trunk signaling except for emergency transfer circuits. Generally, PBXs available today are of the non-cut-through type.

7.1.4 PBXs may reduce the normal supervisory range of the CO. The PBX manufacturer should be consulted for the PBXs trunk and station loop ranges.

7.1.5 The PBX trunk circuit may be either 900 ohms or 600 ohms impedance.

7.2 PBX-CO Trunks

7.2.1 Transmission Design for most PBX-CO trunks is similar to normal loop design. The main difference is the trunk loss objective. The objective ICL, as illustrated in Figure 14, is 3.5 dB. The ICL is allowed to go to 4 dB before adding gain. The facilities may be either metallic or carrier. Except as noted herein, circuits should conform to requirements of TE&CM Section 424, "Design of Two-Wire Subscriber Loop and PABX Trunk Plant", and TE&CM Section 911, "Station Carrier Application".

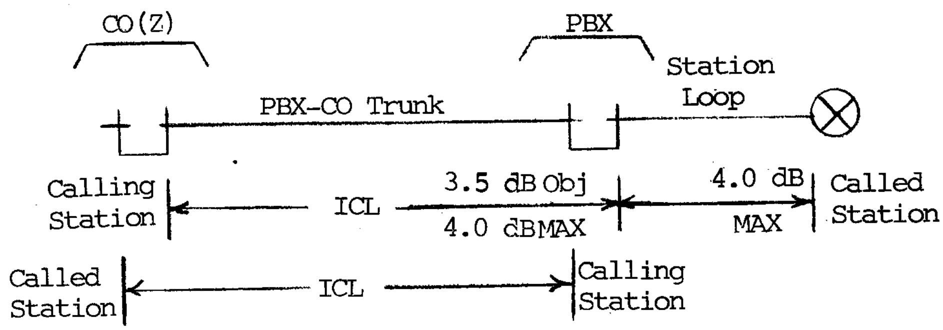


FIGURE 14 PBX-CO Trunk and Station Loop ICL's

7.2.2 Signaling Design depends to a great extent on the type of PBX (manual or automatic). The vast majority of PBX equipment available today is of the automatic variety (direct-outward-dialing) with a dial attendant or unattended console. However, some manual PBXs and some cord switchboards are still available.

7.2.3 Manual PBXs require loop start signaling. Loop start signaling is the type used on a normal loop between the central office and subscriber station set.

7.2.4 Automatic PBXs using two-way trunks will generally employ ground start signaling. Ground start signaling was developed to prevent simultaneous seizures (glare) from both ends of the trunk. Ground start signaling requires that the line circuit be modified by removing ground from the tip conductor when the PBX-CO trunk is idle.

7.2.4.1 When the CO switch seizes the trunk for a call towards the PBX, it simultaneously places a ground on the tip conductor and negative battery on the ring conductor. The trunk circuit at the PBX recognizes the tip ground as a seizure and makes itself busy to outgoing calls on that trunk.

7.2.4.2 When the PBX seizes a trunk, it places a ground on the ring conductor toward the CO and supplies battery and local ground to the PBX station set. The CO recognizes the ring ground as a request for service from the PBX and prepares itself to receive the address signal. When ready to receive the address signal, the CO places ground on the tip conductor toward the PBX. The PBX then connects the station to the CO.

7.2.4.3 Care should be taken to ensure that the grounds at the PBX and CO are at the same potential for ground start systems.

7.2.5 PBXs using DTMF signaling require precision dial tone from the central office.

7.2.6 Most signaling equipment available today can work with either loop start or ground start operation.

7.3 Station Loops

7.3.1 The maximum ICL for on-premises station loops, as shown in Figure 14, is 4.0 dB. However, it should be kept in mind that the station set may be connected to the message network via a tie trunk and distant PBX-CO trunk. Therefore, station loops should be designed for minimum loss.

7.3.2 The objective ICL for off-premises station lines, as shown in Figure 15, is 4.0 dB and the maximum ICL is 4.5 dB. Off-premises station lines function the same as on-premises station lines. They have access to other PBX stations, to the message network, to tie trunks, to FX trunks, or to WATS trunks. Loop treatment equipment may be located at the PBX or CO.

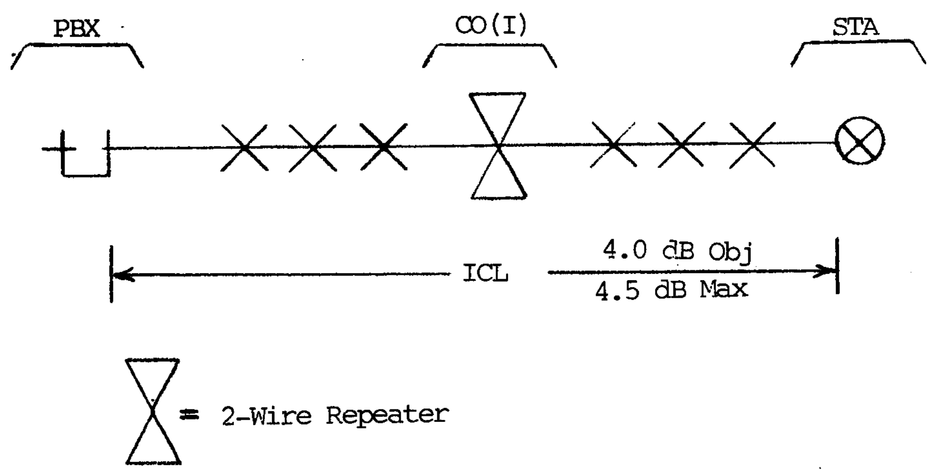


FIGURE 15 Off-Premises Station Loop ICL

7.4 Tie Trunks General Information

7.4.1 A PBX tie trunk, as illustrated in Figure 4, is a direct circuit, between two PBXs, through the central office. When both PBXs are served by the same central office only two links are needed, one from each PBX. Where the PBXs are not served by the same central office, a CO-CO link is also required. The links may be either voice frequency or carrier derived. The tie trunk should be designed as a tandem tie trunk if the possibility exists that the PBX system may be expanded before the investment is recovered.

7.4.2 Since there are many different PBXs in use with different switching methods, timing compatibility between PBXs should be considered in the overall design.

7.4.3 Tie trunks are normally classified according to their usage, selection, and completion of incoming calls. A two-way tie trunk can be selected from either of the two connecting PBXs. A one-way tie trunk can be selected at only one of the two connecting PBXs. Tie trunks may be manual or dial selected. The method of call completion may be ringdown, automatic, or dial repeating.

7.4.3.1 Two-way dial repeating tie trunk circuits can be dial selected at either end. Dial address digits are repeated by the trunk circuit. Calls may be completed without attendant assistance.

7.4.3.2 Two-way automatic tie trunk circuits signal the distant PBX directly upon seizure. Answer and disconnect signals are provided upon seizure. Answer and disconnect signals are provided to the originating and terminating PBX attendant. Access to the trunk may be either manual or dial and at the distant end the called station is connected by the PBX attendant.

7.4.3.3 Two-way ringdown tie trunk circuits send a 20 Hz ringing signal to alert the distant PBX attendant. Generally, ringdown tie trunks supply no answer or disconnect signals. Therefore, the called station is selected by the PBX attendant. Dial selected and some manually selected ringdown tie trunks send a single 5-second burst of 20-Hertz ringing voltage upon seizure.

7.4.4 Tie Trunk Signaling consists mainly of E & M, ringdown, and loop type signaling. E & M type signaling is fast becoming the standard signaling interface.

7.4.4.1 E & M signaling is the most commonly used signaling system. It generally uses duplex (DX) circuits to derive the signaling path. With DX signaling both signaling and transmission use the same path. One wire of the trunk pair is used for signaling while the other is used for ground potential compensation. DX circuits can signal over dc loop resistances of up to 5000 ohms. Some PBXs have DX circuits built in. Duplex signaling is discussed in TE&CM 319, "Interoffice Trunking & Signaling".

7.4.4.2 Ringdown signaling applies a 16-67 Hz ringing voltage to the selected tie trunk. This voltage may be applied manually by an attendant or automatically on a dial repeating trunk. A signaling converter is required for carrier facilities.

7.4.4.3 Loop signaling applies loop current to a relay or other sensing device to indicate a change in loop status. There are three types of loop signaling - high low signaling, reverse battery signaling, and battery and ground signaling.

7.4.4.3.1 High-low signaling circuits apply a voltage to the tie trunk when the local PBX originates a call. The trunk circuit resistance at the distant PBX is decreased by about two orders of magnitude when the called station is answered.

7.4.4.3.2 Reverse - battery signaling circuits are open circuit at the local PBX during the idle state. Upon seizure the loop is closed. The tie trunk circuit at the distant PBX reverses tip and ring to indicate answer.

7.4.4.3.3 Battery and ground signaling circuits are open circuit at the local end during idle state. Upon seizure the local tie trunk circuit applies a series aiding voltage to the loop. The tie trunk circuit at the distant end reverses tip and ring to indicate answer. The local PBX holds the circuit by removing the series aiding battery source.

7.5 Non-tandem Tie Trunk Transmission Objectives

7.5.1 Non-tandem tie trunks should be designed for an objective ICL of 4 dB, as shown in Figure 16. The ICL is allowed to go to 4.5 dB before a repeater or additional repeater is required.

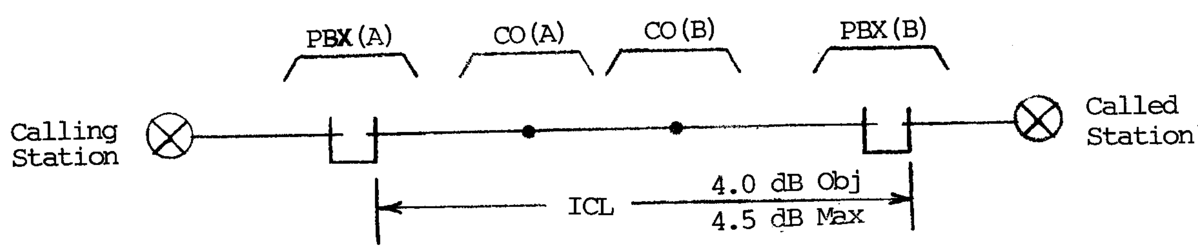


FIGURE 16 Typical Non-Tandem Tie Trunk

7.5.2 Idle circuit terminations may be required to prevent repeater singing when used with some tie trunk circuits.

7.5.3 Loading must conform to requirements of TE&CM Section 431, "Voice Frequency Loading for Trunk Cables".

7.5.4 Trunk treatment equipment may be installed at the PBX and/or at the CO.

7.5.5 Carrier equipment may be used in any or all of the possible three links or between PBX's as the situation warrants.

7.6 Foreign Exchange and Remote WATS Trunks Design Objectives

7.6.1 The PBX FX trunks are similar to PBX CO trunks in design. PBX WATS trunks are similar to remote WATS lines in design.

7.6.2 The FX CO and remote class 5 WATS CO are defined as CO(A). The serving CO is defined as CO(Z). Any intermediate CO is defined as CO(I). CO(A) to CO(Z) constitutes the interoffice link and CO(Z) to PBX is the PBX-CO link.

7.6.3 The CO(Z) to PBX link consists of a 2-wire, non-loaded or loaded circuit; 4-wire, nonloaded or loaded circuit; or 4-wire carrier derived circuit. The CO(A) to CO(Z) link may be a 2- or 4-wire loaded voice frequency facility, carrier facility, or some combination of voice frequency or carrier facility. Normally the CO to CO link is a carrier facility.

7.6.4 FX and WATS trunks should be designed for an objective ICL of 3.5 dB as shown in Figure 17. The maximum ICL should not exceed 4 dB. Figures 18 and 19 contain design guidelines for 2-wire and 4-wire voice frequency circuits for FX and WATS trunks.

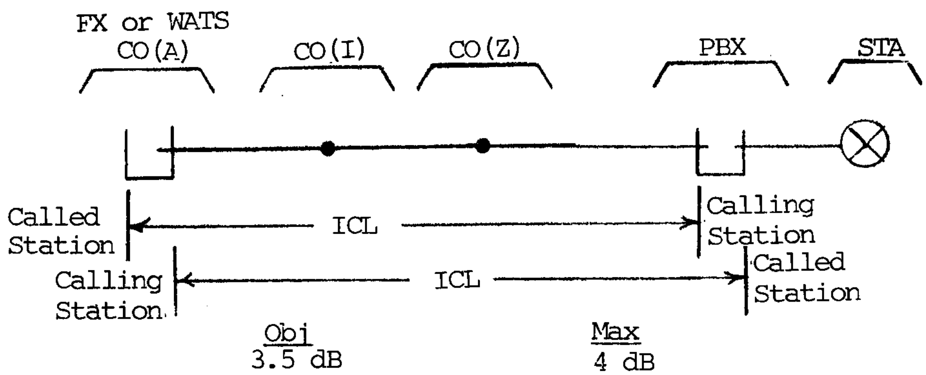


FIGURE 17 FX or WATS Trunk

7.6.5 When two 2-wire repeaters are required, the gain of the CO(A) repeater is:

$$G(A) = (L1 + L2 + L0 - ICL)/3$$

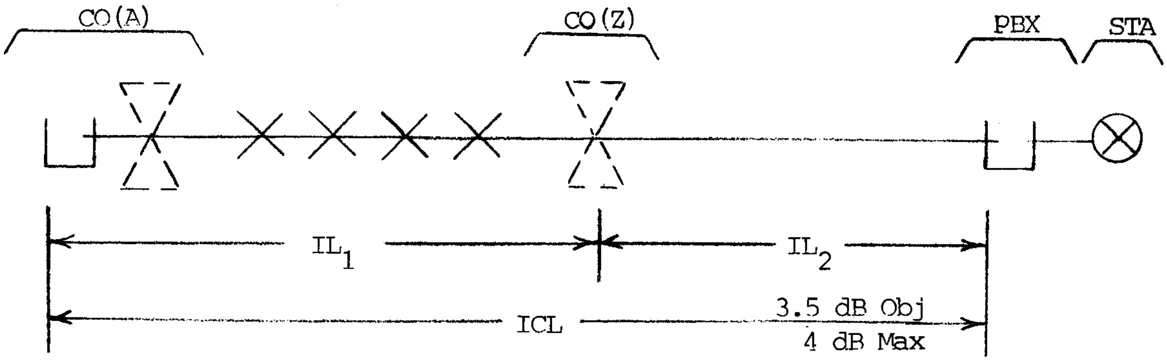
and the gain of CO(Z) repeater is

$$G(Z) = 2(L1 + L2 + L0 - ICL)/3$$

Where L1 is the CO(A) - CO(Z) insertion loss, L2 is the CO(Z)-PBX insertion loss and L0 is office loss.

7.7 Tandem and Intertandem Tie Trunk Design Objectives

7.7.1 Tandem and intertandem tie trunks are designed on a via net loss (VNL) basis. A tandem tie trunk is analogous to a toll connecting trunk; and, an intertandem tie trunk is analogous to an inter toll trunk in the message network.



Cable Insertion Loss

CO(A) to CO(Z) Max IL_1	CO(Z) to PBX Max IL_2	CO(A) to PBX Max IL	Repeater Requirements
3.5 dB	3 dB	4 dB	No repeater
6 dB	4 dB (NL)* 7 dB (L)	11 dB	Repeater at CO(A)
9 dB	11 dB	14 dB	Repeater at CO(Z)
15 dB	15 dB	22 dB	Repeaters at CO(A) and CO(Z)

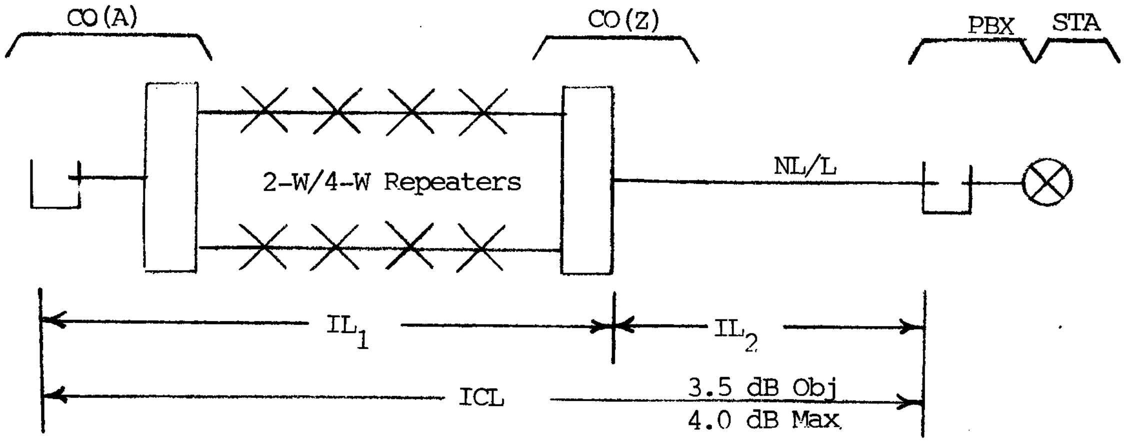
Notes: *See Paragraph 5.16

NL = Non-loaded Cable

L = Loaded Cable

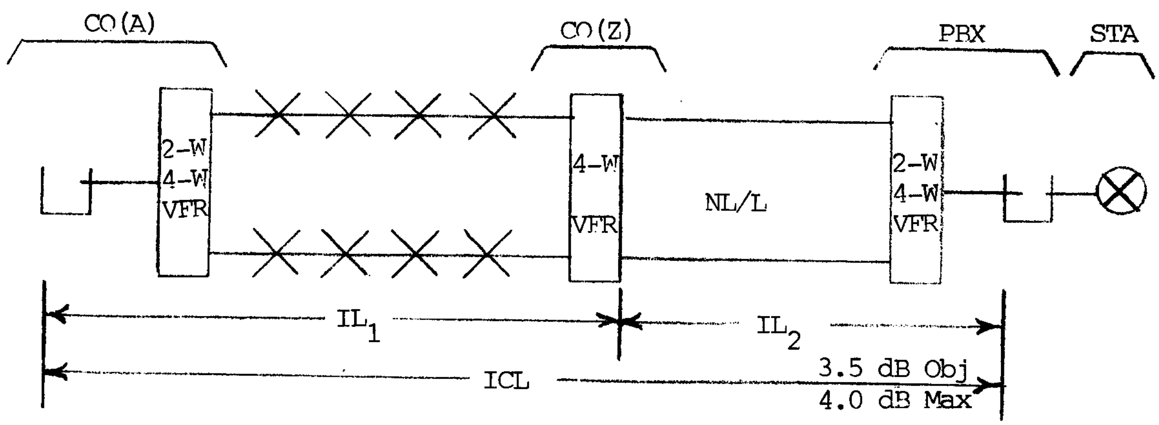
 = 2-Wire Repeater When Required

FIGURE 18 Guidelines for 2-Wire Voice Frequency Design of FX and WATS Trunks



Cable Insertion Loss

CO(A) to CO(Z) Max IL_1	CO(Z) to PBX MAX IL_2	CO(A) to PBX MAX IL
15 dB	15	22 dB



Cable Insertion Loss

CO(A) to CO(Z) Max IL.	CO(Z) to PBX MAX IL_2	CO(A) to PBX MAX IL
15 dB	15 dB	30 dB

Notes: NL = Non-loaded Cable
L = Loaded Cable

Figure 19 Guidelines for Design of 4-Wire FX or WATS Trunks

7.7.2 VNL is discussed in the AT&T publication, "Notes on Distance Dialing". The main points of VNL are as follows:

7.7.2.1 VNL is "the loss value in dB assigned to a trunk to compensate for its added propagation delay, terminal delay, and loss variability."[1] In equation form

$$VNL = \{\Sigma(VNLF \times Length) + .4\} \text{ dB}$$

Where VNLF is the via net loss factor. VNLF for a one-way distance in miles has the following values:

(a) 2-wire exchange cable (loaded or non-loaded): VNLF = 0.4dB/mile

(b) 4-wire vf circuits: VNLF = .017 dB/mile

(c) carrier circuits: VNLF = .0015 dB/mile

The 0.4 dB loss factor accounts for trunk connection loss variations.

7.7.2.3 The VNL value is the minimum net loss allowable for a given trunk.

7.7.3 Tandem and intertandem tie trunks should be designed for an objective ICL of (VNL + 2) dB for through connections and (VNL +4) dB for terminal connections.

7.7.4 Tie trunk circuits for tandem PBX's should be equipped with a switchable 2 dB pad. The pad should be switched out on through connections and switched in on terminal connections.

7.7.5 Minimum values for echo return loss (ERL) and singing return loss (SRL) are given in Tables 2 and 3.

7.7.5.1 Through balance is required when 4-wire trunks are switched at a 2-wire PBX. It is measured with hybrids at both ports and with the 2 dB pad switched out.

7.7.5.2 Terminal balance is required when a tandem tie trunk is switched to a non-tie trunk or to PBX station lines.

7.7.5.3 Terminal balance is measured with 900 ohms and 2.16 μf at the central office for non-tie trunk connections. When terminating at the PBX the termination should be 600 ohms and 2.16 μf.

7.7.6 End sections should be half (0.5) a full section length. End sections for trunk circuits are discussed in TE&CM 431.

7.7.7 Idle circuit terminations may be required with repeaters located at the PBX.

7.7.8 The tie trunk at one PBX must be compatible with the tie trunk at the distant PBX.

8. GLOSSARY

Address Signals - convey call destination information such as station numbers.

Alerting Signal - indicates an incoming call.

Attenuation Loss - the loss resulting when a two-port network is terminated in its characteristic or image impedance.

Centrex - a PBX type service with direct inward dialing where the switching equipment is generally located at the central office.

Channel - transmission path between two points.

Circuit - a communication path between two or more points.

Expected Measured Loss (EML) - the calculated loss quantity which specifies the 1004 Hz loss that one would expect to measure on a terminated test connection between readily accessible test points.

Foreign Exchange (FX) - connects a subscriber in one exchange area to a central office located in some other exchange area.

Inserted Connected Loss (ICL) - the 1004 Hz loss between the originating and terminating outgoing switch appearances for a trunk and between the line-side switch appearance and customer station for a line.

Ground Start - a supervisory signal used for PBX's given by connecting one side of the line to ground.

Insertion Loss (IL) - the loss which occurs when a network is inserted into a transmission medium. That is, the ratio of power delivered to that part of the system following the network, before the network is inserted, to that same part of the system after the network is inserted.

Loop - a channel between a customer's terminal and a central office.

Message Network - the public switched telecommunications network.

Off-Premises Extenstion (OP) Lines - connect a remotely located extension station to the main station.

POTS - plain old telephone service.

Private Branch Exchange (PBX) - a switching machine located on the customer's premises for the purpose of interconnecting customer station sets and connecting customer station sets to other PBXs or the message network.

PBX, Main - has a directory number and access to the message network.

PBX, Satellite - has no directory number and no attendant. The main PBX provides attendant services for the satellite PBX.

PBX, Tandem - provides same function as main PBX plus acts as an intermediate switch point for two or more PBXs

PBX-CO Trunk - connects PBX to the local central office and normally appears as a station line at the CO.

Ringtrip Signal - removes the ringing signal at the central office when the called telephone is answered.

Secretarial Service Line - Connects the customer station set to a telephone answering service.

Tie Trunk, Intertandem - interconnects tandem PBXs

Tie Trunk, Non-tandem - interconnects main PBXs

Tie Trunk, Satellite - interconnects main PBX and satellite PBX

Tie Trunk, Tandem - interconnects main PBX and Tandem PBX

Wide Area Telecommunications Service (WATS) - provides direct access to selected wide interstate and intrastate geographical areas (bands) for a fixed monthly charge.

WATS Line, Inward - used exclusively for incoming calls from a designated geographical area to a customer.

WATS Line, Outward - used exclusively for outgoing bulk rate calls from the customer to a designated geographical area.

9. REFERENCES

1. AT&T Engineering and Network Services Department Systems Planning Section, "Notes on Distance Dialing" American Telephone and Telegraph Company, 1975.

2. Technical Personnel AT&T, Bell Telephone Companies, and Bell Laboratories, "Telecommunications Transmission Engineering"; Volume I, Second Edition 1977; Volume II, First Edition, 1977; Volume III, Second Edition, 1977; Western Electric Company, Inc., Technical Publications; Winston - Salem, North Carolina.

3. "Interoffice Trunking and Signaling" REA TE&CM, Section 319, Issue 4, October 1978.

4. "Guide for Utilization of Central Office Loop Extenders", REA TE&CM, Section 332, Issue 1, August 1969.

5. "Transmission Objectives", REA TE&CM, Section 415, Issue 4, May 1973.

6. "Design of Two-Wire Subscriber Loop and PABX Trunk Plant", REA TE&CM, Section 424, Issue 3, May 1973.

7. "Subscriber Loop Computations - Design by Loss Method", REA TE&CM, Section 426, Issue 2, December 1977.

8. "Application and Use of Bridged Tap Isolators for Subscriber Loops", REA TE&CM, Section 428, Issue 1, October 1965.

9. "Voice Frequency Loading for Trunk Cables", REA TE&CM, Section 431, Issue 2, October 1962.

10. "Negative Resistance and Negative Impedance Voice Frequency Repeaters and Voice Frequency Repeatered Trunks", TE&CM, Section 444, Issue 2, November 1961.

11. "Station Carrier Application", REA TE&CM, Section 911, Issue 2, September 1971.

TABLE 1

CABLE RESISTANCE AND ATTENUATION LOSS PER KF (KM)

Cable Type	Loading	Resistance Ohms/kf (km)	dB/kf (km)
22	NL	32.8 (108)	.34 (1.12)
24	NL	51.9 (170)	.43 (1.41)
26	NL	83.3 (273)	.55 (1.80)
22	H88/D66	Note (1)	.16 (.52)
24	H88/D66	Note (1)	.23 (.75)
26	H88/D66	Note (1)	.35 (1.15)
Office & PBX	NL	40 (131) Note (2)	.4 (1.31)

NOTES: (1) 66 MH Coils = 6 ohms/coil

88 MH Coils = 8.5 ohms/coil

(2) Compromise resistance value for several types of cabling.

TABLE 2

Tandem PBX Through Balance (Pad Out)

VNL Tie Trunk to VNL Tie Trunk	ERL 23 dB min SRL 16 dB min

TABLE 3

Tandem PBX Terminal Balance

VNL Tie Trunk to Non-VNL Tie Trunk	ERL 16 dB min SRL 11 dB min
Tie Trunk to Non-Tie Trunk	ERL 13 dB min SRL 10 dB min
Tie Trunk to Test Termination (600Ω & 2.16 μf)	ERL 20 dB min SRL 14 dB min

*U.S. GOVERNMENT PRINTING OFFICE : 1980 0-310-944/REA-75