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PRIVATE LINE TELEPHONE SERVICES

CONTENTS

1. GENERAL

1.1 This section discusses general design concepts and procedures for private line telephone services not switched into the public message network.

1.2 Private line telephone circuits interconnect two or more station sets over local loops and, as required, dedicated interoffice facilities. There is no connection to central office or PBX switching equipment. Station sets may be located in geographically dispersed areas. With such private line systems, the rural telephone company typically provides only a portion of the overall circuit.

1.3 Point-to-point telephone circuits provide a direct connection between two station sets. Generally these circuits are designed using "plain old telephone service" (POTS) techniques. Figure 1 illustrates a point-to-point connection.

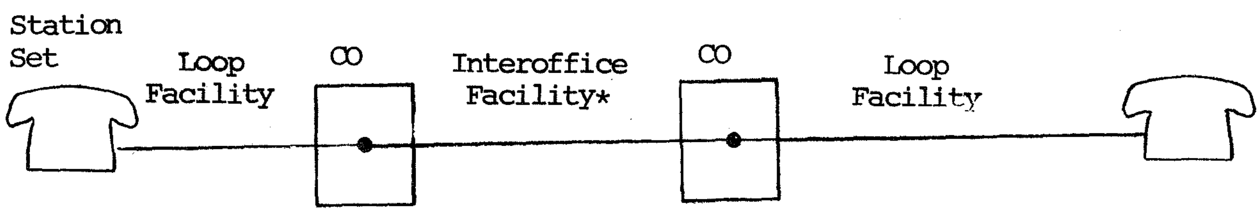


Figure 1 Point-to-Point Circuit

* An interoffice facility may or may not be required.

1.4 Multipoint telephone circuits interconnect three or more station sets. Because of the complexity of these circuits special engineering considerations are required. Figure 2 illustrates a typical multipoint circuit.

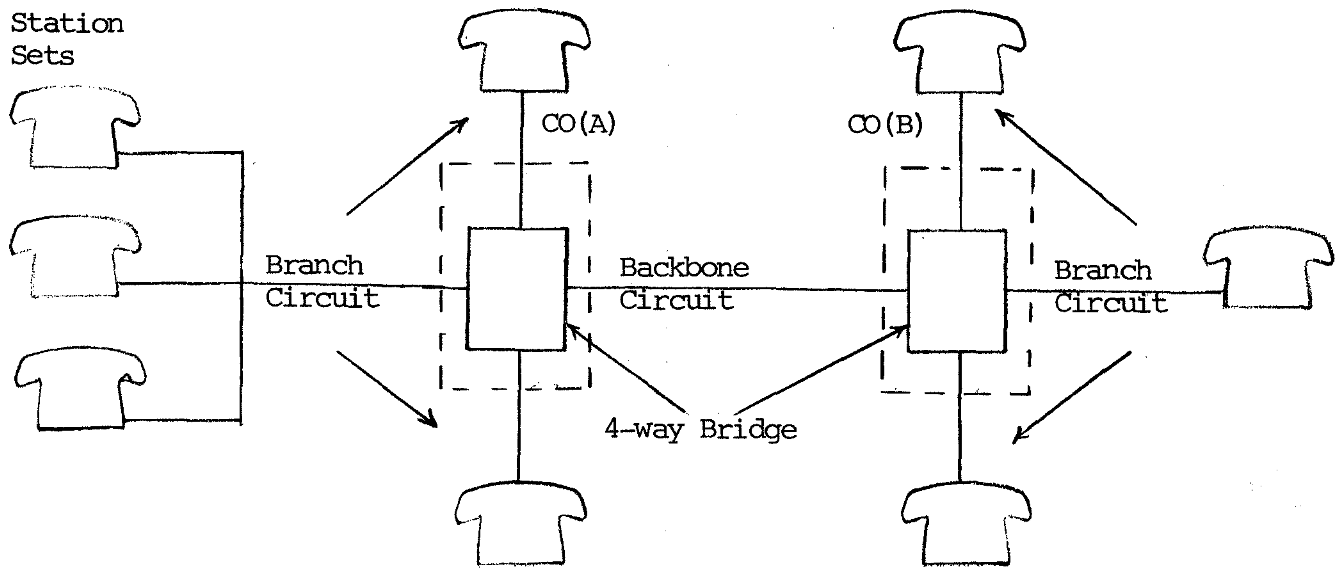


Figure 2 Multipoint Circuit

1.5 Special applications of private line circuits are discussed in other TE&CM sections as indicated in Table 1.

TABLE 1

SPECIAL APPLICATIONS OF PRIVATE LINE CIRCUITS

Service	Publication
Fire Alarm Conference Service	TE&CM 141
Mobile Radio	TE&CM 940
Voiceband Data	TE&CM 472 (Proposed)
Broadcast Audio Circuits	TE&CM 473 (Proposed)

2. DESCRIPTION OF MULTIPOINT PRIVATE LINE TELEPHONE SERVICE

2.1 Normally in a multipoint circuit each station can signal and communicate with all other stations either individually or collectively for conference calls. However, should the user not require the conference calling feature, the circuit may be designed as a point-to-point circuit using POTS type design techniques. For this application it is assumed that only two telephone sets will be off-hook simultaneously. The customer should be informed that the circuit will not perform satisfactorily should it be used for conference calling. The advantage here is economics, both in material costs and design time.

2.2 The first step in the design process for a multipoint circuit is the preparation of a geographical layout. Existing cable routes between the desired locations should be followed and existing facilities should be used as much as possible.

2.3 Multipoint circuits which may be used for conference calling generally require 4-wire facilities. The number of stations served, distance between furthermost stations, and type of service required (that is half or full duplex or some combination of half and full duplex operation) determine the extent to which 4-wire facilities are used. Multiple singing and echo paths produced by several 2-wire branches is a limiting factor for systems whose maximum circuit length exceeds about 250 miles where full duplex transmission is required. Such systems require a detailed return loss analysis to insure stability. However, some 2-wire branches may be used where the circuit is primarily a 4-wire facility.

2.4 Four-wire multipoint circuits may require the use of 4-wire station sets. Two-wire station sets should be kept to a minimum. The use of many 2-wire/4-wire terminating sets in a multipoint system can cause echo or singing. Four-wire station sets eliminate the need for hybrid type terminating sets and their potential as sources of instability and echo.

3. BRIDGING ARRANGEMENTS

3.1 Multipoint private line circuits, see Figure 2, interconnect stations at common bridging points. Lines connecting station locations to a bridge are commonly called branch circuits. Extension station sets may be bridged at the terminal location of the branch circuit. More than one bridging point may be required for a multipoint system. The connection between bridges is commonly referred to as the primary or backbone route. Connections to the bridging point, both branch and backbone lines, are defined as legs. Of primary importance is that the impedances of each leg be as close as possible. Repeat coils or equivalent matching devices should be used for proper impedance matching where different facilities are bridged at the same point. For the most part rural telephone companies will only be involved with providing service for branch circuits

3.2 Two-wire bridges are relatively simple to implement. They find their greatest application in alarm monitoring and half duplex circuits. The three basic types are the straight bridge, resistance bridge and pad bridge.

3.2.1 <u>The straight bridge</u>, the simplest of the bridge types, consists of two or more lines connected in parallel at a common point as illustrated in Figure 3. It provides a bridge connection with minimum insertion loss. However, this arrangement intensifies any irregularities that may exist in a given leg and affects the performance of all other legs connected to the bridging point. A large impedance irregularity in any leg has a direct effect on the balance of all legs and, therefore, the backbone circuit as well. All legs must have similar impedances. The impedance at the bridging point varies with the number of station sets off-hook at any given time.

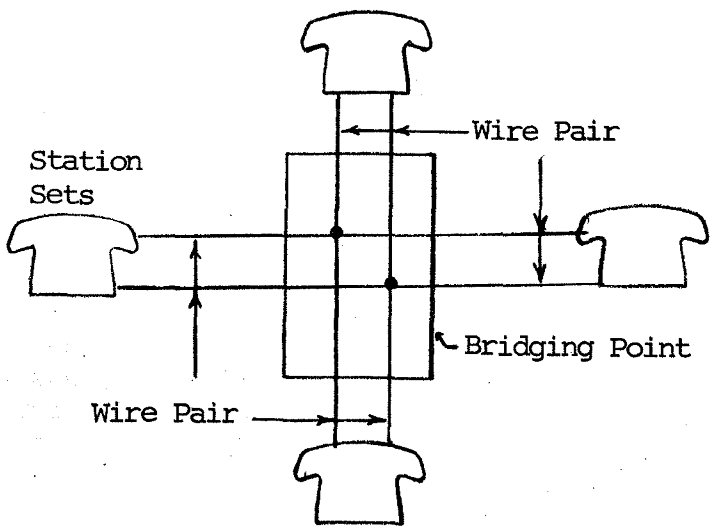


Figure 3 Straight Bridge

3.2.1.1 When one leg requires a repeater adjacent to the bridging point, and the other legs are not repeatered a 600 ohm pad of at least 5 dB should be placed in each non-repeatered leg adjacent to the bridge. The pads provide uniform impedance and thereby insure repeater stability. If the circuit loss is too high as a result of the addition of the pads, then another bridging scheme should be used.

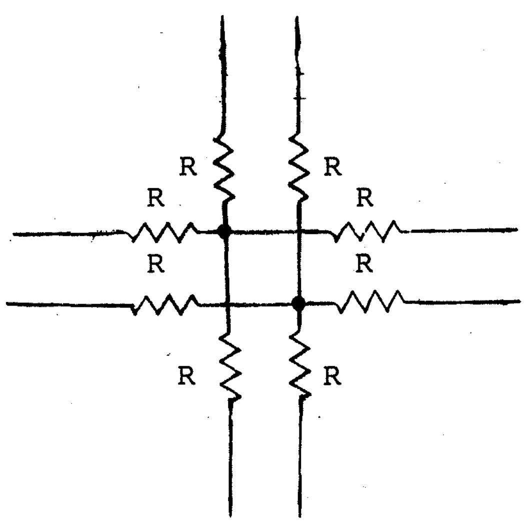
3.2.1.2 The insertion loss of the straight bridge is 20 log n/2 dB where n is the total number of legs. The calculated loss is valid when all legs are terminated in the same impedance, usually 600 ohms. Insertion losses for 3 to 6 legs are listed in Table 2.

TABLE 2

INSERTION LOSS FOR STRAIGHT BRIDGES

Number of Legs (n)	Insertion Loss (dB)
3	3.5
4	6.0
5	8.0
6	9.5

3.2.2 The resistance bridge has resistors inserted in each leg as shown in Figure 4. The resistors are chosen to present a uniform impedance, usually 600 ohms, at the bridge point. Impedance irregularities in any leg connected to the resistance bridge are less likely to affect other legs or the singing margin of the overall circuit than with the straight bridge. When the bridge insertion loss is not a limiting factor, this bridge is preferred to the straight bridge. Resistance bridges are available commercially.



R = 150 ohms for a
4 leg bridge

Figure 4 Resistive Bridge

3.2.2.1 Repeaters are generally used in each leg of the resistance bridge.

3.2.2.2 The insertion loss of the resistance bridge, with all legs terminated in their nominal impedance (usually 600 ohms) is 20 log (n-1) dB where n is the number of legs. Table 3 lists the insertion loss for 3 to 8 legs. Units are available with greater bridging capability than listed in Table 3.

TABLE 3

INSERTION LOSS FOR RESISTANCE BRIDGES

Number of Legs (n)	Insertion Loss (dB)
3	6.0
4	9.5
5	12.0
6	14.0
7	15.6
8	16.9

3.2.2.3 The value of the series resistor (R) shown in Figure 4 is calculated from

$$R = \frac{R_B\ (n - 2)}{2n}$$

Where R_B is the nominal bridge impedance (normally 600 ohms) and n is the number of legs. A bridge with 4 legs and a nominal impedance of 600 ohms should have a series resistance, R, of 150 ohms.

3.2.3 The <u>pad bridge</u> has 600 ohm, 5 dB pads in each leg as shown in Figure 5. The pads provide uniform impedance between bridge legs. Therefore, use of the pad bridge tends to improve singing margins and minimizes the effect that an impairment in one leg may have on the other legs.

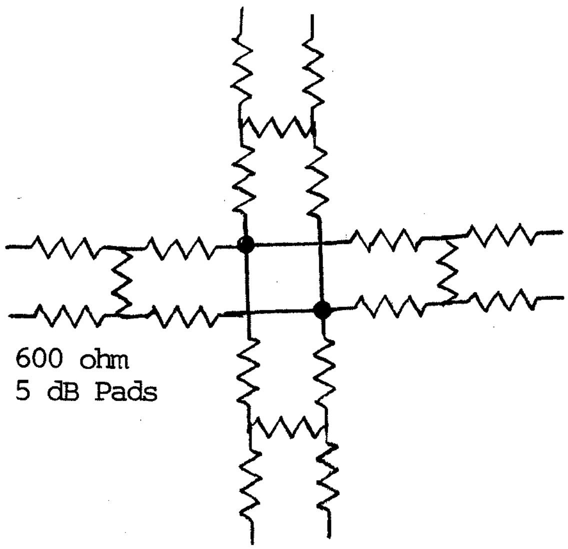


Figure 5 Pad Bridge

3.2.3.1 Each leg normally requires a repeater to offset the insertion loss of the 5 dB pads.

3.2.3.2 The insertion loss of the pad bridge is the same as that of the straight bridge plus the loss of the pads; 10 dB + 20 log n/2 dB where n is the number of legs. The insertion loss for 3 to 6 legs is listed in Table 4.

Table 4

INSERTION LOSS FOR PAD BRIDGES

Number of Legs (n)	Insertion Loss (dB)
3	13.5
4	16.0
5	18.0
6	19.5

3.3 Four-wire bridges, see Figure 6, are available in the form of active (electronic) or passive (resistive) networks, normally designed for 600 ohm impedances at each 4-wire port. Each port has an input and an output. The input of each port provides a transmission path to the output of all other ports.

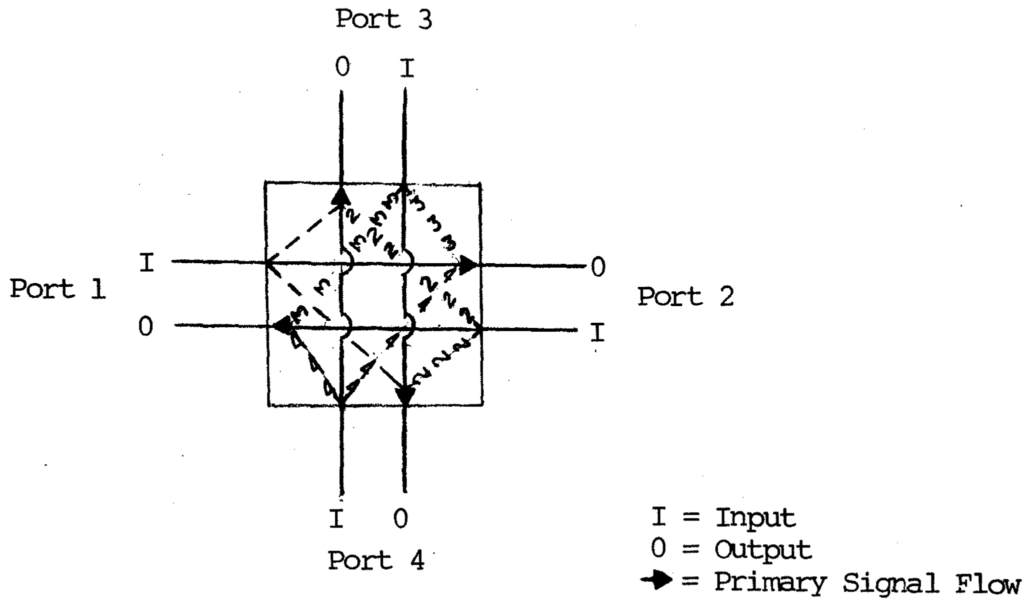


Figure 6 Four-Way, 4-Wire Bridge

3.3.1 Active bridges use integrated circuit technology to provide the bridging function. Generally the bridge insertion loss is selectable; and electronic circuits provide undirectional paths between inputs and outputs thereby isolating each input from all other inputs and the input and output of the same port.

3.3.2 Passive bridges are composed of a complex resistive network. In the 4-way resistive bridge there is a direct transmission path (link) between the input of each port and the output of all other ports (Refer to Figure 6). This requires twelve resistive links between inputs and outputs. These links also provide indirect paths between the input of each port and the input of all other ports and the input and output of the same port. Of interest are the input and output of the same port. By providing tip and ring reversals within the bridge the return currents can be made to cancel. However, it is only possible to have three such reversals. Therefore, one port, normally port No. 4, has a poorer return loss than the others, in the order of 10 dB. Insertion loss is as indicated in Table 5.

Table 5

4-WIRE RESISTIVE BRIDGE INSERTION LOSS

Number of Ports	Insertion Loss (dB)
4	15
6	20
8	23

4. TALK-BACK CIRCUIT

4.1 As mentioned previously multipoint private line circuits are generally designed for conference services using 4-wire facilities. These systems may require 4-wire stations. The standard 4-wire telephone sets do not provide any connection between the transmitting and receiving side of the circuit. Thus, no sidetone. Subjective tests indicate that some sidetone is desirable. Further, it is not possible to communicate between stations bridged at the same station terminating equipment. Therefore, four-wire telephone sets require an external circuit called a talk-back path which provides a transmission path between the transmitter and receiver. Any talk back path should be a unidirectional circuit with a reverse loss of at least 40 dB. The talk-back circuit is provided at the bridging point or as part of the four wire station terminating equipment.

4.2 One method to provide a talk-back path is to bridge a line amplifier across the transmit and receive pair of the branch as shown in Figure 7. In general the amplifier should be set so that the transmission level from the station talker to his own receiver is equivalent to that of a distant talker. Some 4-wire bridges and station terminating equipment have a talk-back (sidetone) option.

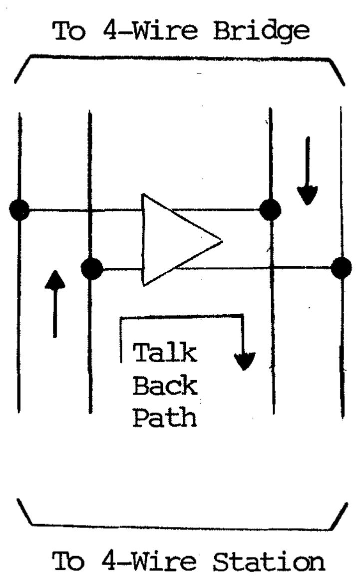


Figure 7 Talk Back Amplifier

5. STATION TERMINATING EQUIPMENT

5.1 Private line telephone circuits may terminate in a station set, key system, or PBX. Interface equipment is normally required between the private line circuit and the station sets, Key system, or PBX. Packages containing the equipment necessary to provide all the interface functions are generally available from manufacturers who provide special services products. Circuits for use with 2-wire or 4-wire facilities are available with such options as local or common battery, idle circuit or loudspeaker termination, extension station capability, station level control, talkback, loop back testing, and various signaling arrangements. This equipment is generally divided into two broad categories:

5.1.1 Equipment associated with the line is generally referred to as common equipment.

5.1.2 Equipment associated with the station set is generally referred to as station equipment.

5.2 <u>Common equipment</u> usually provides impedance matching between the line and station set and is common to all station sets at one location. The basic common equipment is the line termination unit which provides impedance matching, and options such as amplifiers or pads, talkback (sidetone) amplifier, or loop back capability. To accommodate more than one 4-wire station set the line termination unit typically presents a relatively low impedance source to the station sets. With this arrangement the reflection loss due to the impedance mismatch decreases and bridging loss increases as the number of extension stations increases; thus, a uniform loss can be maintained for various numbers of extension stations. Figure 8 illustrates one type of common equipment for terminating a 4-wire circuit.

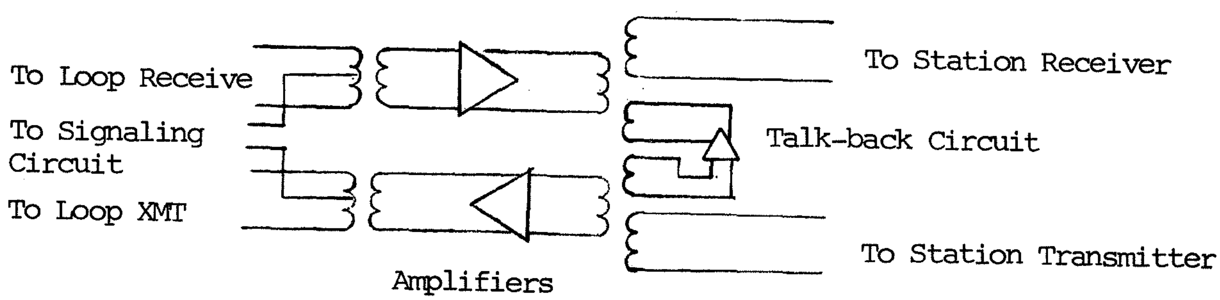


Figure 8 Typical Common Equipment

5.3 Station equipment generally provides for the application of talk battery, ringing signals, and any other functions necessary for the operation of the station set. Transmit, receive, and signaling leads are commonly controlled by a pick-up relay which in turn is controlled by the hook switch contacts.

6. TRANSMISSION CONSIDERATIONS

6.1 For multipoint private line circuits the standard transmission plan calls for a 0 dB (lossless) backbone circuit between bridging locations with the allowable net loss assigned to the branch circuits. The maximum net loss for multipoint circuits is 10 dB between 2-wire stations and 16 dB between 4-wire stations. The transmission plan is typically based on a 0 dB transmission level at the station set and +7 dB at the receiving port of a bridge. Figure 9 illustrates a typical transmission layout for a multipoint circuit.

6.2 For point-to-point circuits the maximum net loss is 16 dB between 2-wire station sets and 22 dB between 4-wire station sets.

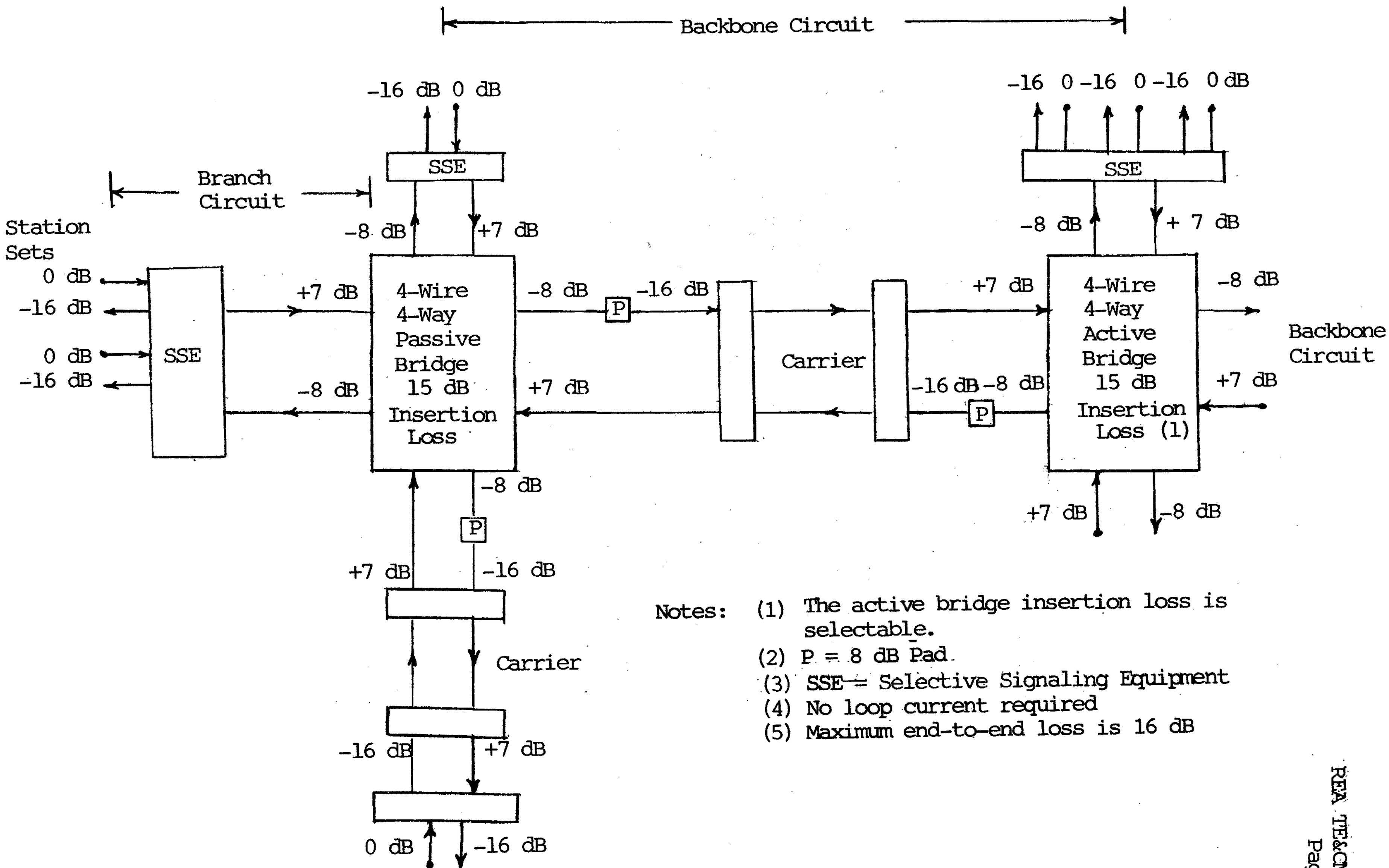
6.3 Circuits should conform to design practices of TE&CM 424 "Design of Two-Wire Subscriber Loop and PBX Trunk Plant" and TE&CM 431 "Voice Frequency Loading for Trunk Cables." TE&CM 470 "Switched Special Services and Private Branch Exchange Services", Paragraph 4 should be referred to for further transmission considerations.

6.4 At passive 4-wire bridges all the input levels for a given bridge should be the same. Pads and amplifiers may be required to adjust levels at some input ports. Levels may vary from bridge to bridge. However for convenience in transmission maintenance, it is desirable as far as feasible, to provide common input levels for all bridges in a given system.

7. SIGNALING

7.1 There are several types of signaling used for private line circuits. Usually all status signals and battery feed functions are implemented by the signaling equipment. Circuits should be designed to maintain the 23 ma minimum loop requirement for proper station set performance. Only the more commonly used equipment, automatic ringdown and selective signaling equipment, is covered.

7.2 Automatic ringdown (ARD) equipment is generally used for non-dial point-to-point circuits. It signals either end of the circuit when the opposite end goes off-hook. Various options may be available such as selectable battery feed voltage, 600 ohm or 900 ohm impedance matching, interrupted ringing, and one-way and two-way ringing. The battery feed voltage option determines the maximum loop limit. Transmission facilities may be either 2-wire, 4-wire, or carrier derived.



Notes: (1) The active bridge insertion loss is selectable.
(2) P = 8 dB Pad.
(3) SSE = Selective Signaling Equipment
(4) No loop current required
(5) Maximum end-to-end loss is 16 dB

FIGURE 9 Transmission Layout for Multipoint System

7.3 Selective signaling systems are available for both rotary dial signaling, common designation SS-1 (relay logic) or SS-4 (transistorized version), and dual tone multifrequency (DTMF) signaling, common designation SS-3. Equipment packages are available containing common equipment and station equipment. One such package is required at each subscriber location. The common equipment is capable of handling various numbers of 4-wire station sets depending on the equipment type. The system uses tone signaling with no loop current between equipment locations. Each station in the system is assigned one or more codes. Normally a broadcast code is available to signal all stations in the systems simultaneously. Transmission facilities are 4-wire. Since all stations are interconnected via a single channel, a privacy option is usually available. This option locks out all other stations, either manually or automatically, when a station set goes off-hook while the system is idle.

7.3.1 The SS-1 system is capable of selectively signaling up to 81 individual stations. The system uses a 2-digit code generated by dial pulses (options are available for DTMF signaling). The dial pulses are converted to frequency-shifted tones for transmission over 4-wire facilities. Equipment at the various station locations decodes the 2-digit code and signals only the called station or stations.

7.3.2 The SS-3 selective signaling system uses 3-digit DTMF signal codes. Up to 729 codes are generally available. Equipment at each station location decodes the 3-digit codes and signals only the called station or stations. In addition to signaling station sets, dedicated codes may be arranged to control auxiliary equipment such as lights, loudspeakers, motors, etc.

8. TYPICAL PRIVATE LINE CIRCUITS

8.1 <u>Point-to-Point circuits</u> normally use 2-wire voice frequency facilities and automatic ringdown (ARD) signaling equipment. The ARD equipment may be located at any point along the circuit within its signaling range limit. Negative resistance (E-6) or hybrid type repeaters may be used to extend voice frequency signals and loop extenders or dial long line (DLL) equipment may be used to extend the loop limit. Normal POTS type design techniques may be used.

8.1.1 The simplest application of the ARD equipment (see Figure 10) is when the Station A to CO facility is similar to the Station B to CO facility, and both facilities are within the loop limits of the central office battery. The battery feed resistance is normally 400 ohms. When the ARD is powered by a 51.6 volt CO battery, the loop limit for each side is about 1700 ohms of outside plant, assuming that the telephone set dc resistance does not exceed 200 ohms.

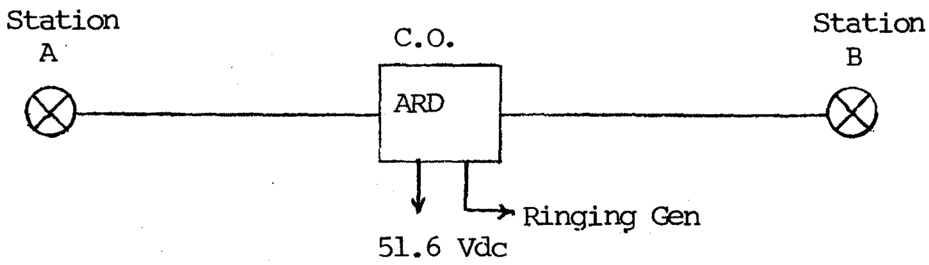
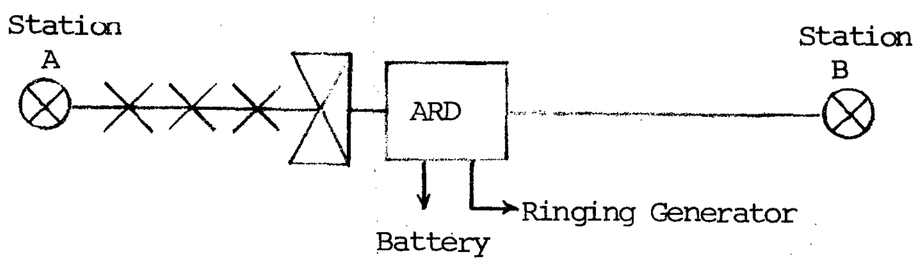


Figure 10 Typical Ringdown Circuit

8.1.2 When either facility A or B is loaded, then ARD equipment with an impedance matching option should be used. The ARD equipment should be set for 600 ohms facing the nonloaded cable and 900 ohms facing the loaded cable.

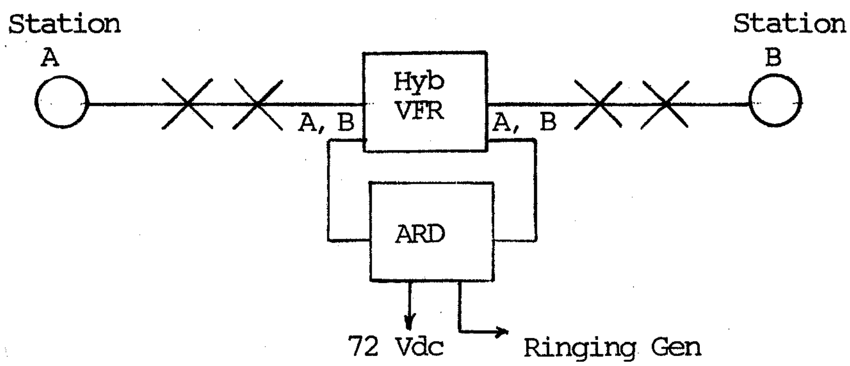
8.1.3 When range extension is required on one side only, a repeater and loop extender or DLL may be used as shown in Figure 11. The repeater may be used as the interface between dissimilar facilities.



1. X = Load Points
2.  = Repeater and loop extender or DLL
3. The maximum circuit net loss should not exceed 16 dB end-to-end.
4. The circuit net loss should be within ± 2 dB of a similar POTS type circuit.

Figure 11 Ringdown Circuit When One Side Requires Range Extension

8.1.4 When the facility between Station A and Station B is loaded, a booster battery and repeater may be used to extend the circuit limits. Figure 12 illustrates the use of an intermediate hybrid repeater and battery boost. Repeaters without A & B leads, must be used as terminal repeaters.



Notes: 1. X = Loading Point
2. A, B = A and B leads of hybrid repeater
3. The maximum circuit net less should not exceed 16 dB
4. The circuit net loss should be within ± 2 dB of a similar POTS type circuit.

Figure 12 Ringdown Circuit When Both Sides Require Range Extension

8.1.5 Circuits which extend beyond the exchange area may require 4-wire voice frequency or carrier derived facilities. Ringdown to E&M and ringdown to SF converters are available for 4-wire voice frequency or carrier facilities. Circuits originating from a connecting company, such as the Bell System, will normally be engineered by the connecting company. The local company need only supply the facilities and terminating equipment required. All equipment is normally adjusted to meet the connecting companies' specifications. Should an interexchange circuit be composed of two-wire facilities with different loading schemes, the ARD equipment and precision balancing equipment may be placed at the interface to improve the return loss of the circuit.

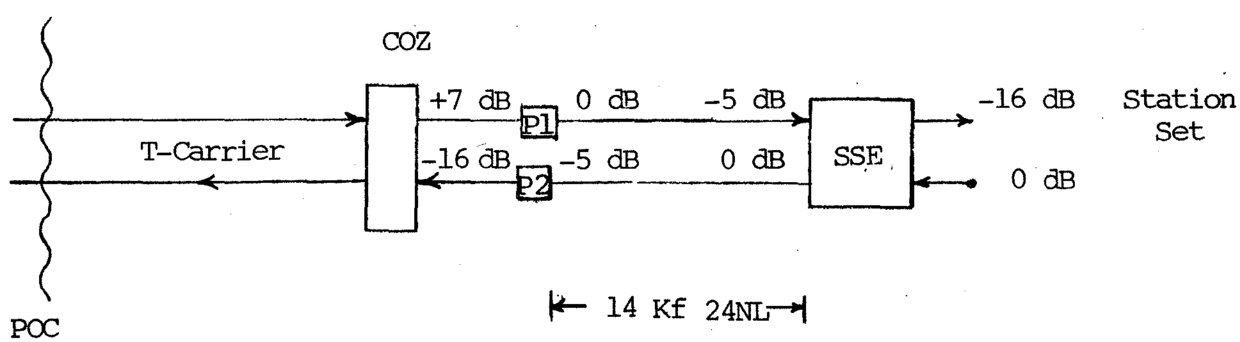
8.2 <u>Multipoint circuits</u> generally cover a wide geographical area with only one branch circuit extending into a rural exchange. These circuits generally use 4-wire facilities and selective signaling systems with 4-wire station sets. The common equipment line interface unit provides for transmission level adjustment. The station equipment provides the local talk battery connections.

8.2.1 Refer to Figure 13 for the following example of a multipoint branch circuit.

8.2.1.1 A T-carrier circuit is required between the local central office and the connecting company's interface point. The 4-wire channel derived from the carrier system has the standard interface levels of +7 dB and -16 dB. The +7 dB receive level is attenuated to 0 dB by pad P_1 and the -5 dB transmit level is attenuated to -16 dB by pad P_2. A 4-wire facility extends the circuit to SS-1 compatable selective signaling equipment at the customer premises. The selective signaling equipment terminates in a 5 line key system with DTMF signaling. The key system requires modification to provide 4-wire service for one line. A DTMF to dial conversion unit is required for the SS-1 system.

8.2.1.2 The local telephone company must provide the 4-wire channel to the connecting company, the local loop, and the customer premises equipment. A kit is available to modify the key system for use with one 4-wire line.

8.2.1.3 The local circuit chosen is 4.3 Km (14 Kf) of 24 gauge cable. This information is given to the connecting company to complete the design of the branch circuit. The local circuit is terminated at both ends in 600 ohm impedances. The insertion loss of the cable can be determined with 0.5 dB by using TE&CM 470, Figure 8, "1 KHz Loss of Non-Loaded Cable with 900 Ohms Terminal and Source Impedance." The insertion loss of the local cable is about 5 dB.



Notes: 1. PI = 7 dB pad
2. P2 = 11 dB pad
3. COZ = serving central office
4. BT = Bridge Tap
5. SSE = Selective signaling equipment
6. POC = point of connection

Figure 13 Multipoint Branch Circuit

9. GLOSSARY

DTMF - Dual tone multifrequency signal used to provide address signaling.

Echo - A reflection of the primary signal, caused by one or more impedance irregularities, with sufficient magnitude and delay to be perceptible to the ear as distinct from the primary signal.

Full-Duplex Transmission - A method of operating a communications circuit such that each end can simultaneously transmit and receive.

Half-Duplex Transmission - A method of operating a communications circuit such that each end can transmit and receive, but not simultaneously. Normal operation is alternate one-way-at-a-time transmission.

Network

a. The facilities network is the aggregate of transmission systems, switching systems, and station equipment.

b. An electrical/electronic circuit, usually packaged as a single piece of apparatus or on a printed circuit pack.

Private Line - A circuit leased by a customer for his exclusive use, connecting two or more terminal locations to each other and working independently of any central office switched interconnections.

Reflection Loss - The difference in dB between the power that is actually transferred from one circuit to the next and the power that would be transferred if the second circuit were identical to the first.

Sidetone - The portion of the signal from a telephone transmitter which is fed back to the receiver.

Singing - A continuous whistle or howl caused by oscillations in a telephone circuit. It occurs when the sum of the gains in the circuit exceeds the sum of all circuit losses.

Talkback Circuit - A circuit to provide a sidetone path for 4-wire telephone sets.

Transhybrid Loss - The transmission loss between opposite ports of a hybrid network; i.e., between the four wire input and output ports on the same side of the hybrid network.

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