DESIGN GUIDELINES FOR TELECOMMUNICATIONS SUBSCRIBER LOOP PLANT

CONTENTS

1. GENERAL

1.1 This section provides REA borrowers, consulting engineers, contractors and other interested parties with guidelines and technical information for use in the design and construction of REA borrowers telecommunications subscriber loop plant. The guidelines and information are advisory.

1.2 This revision replaces REA TE&CM Section 424, Issue No. 3, dated May 1973. Much of the information and recommendations in the earlier issue remain valid. However, the deregulation of the telephone industry that began in 1983 requires modification of some earlier recommendations. Telecommunications rules, facilities and services are now in a state of rapid change because of deregulation. Specifically, customer owned telephone sets and other terminal equipment can have a direct effect on the design of subscriber loop plant. Cooperation with subscribers (customers) in resolving issues is recommended. On the other hand, financial caution is also recommended so that subscriber loop facilities are not replaced or significantly altered unless necessary.

1.3 The Federal Communications Commission (FCC) deregulated customer premise equipment (CPE) on January 1, 1983, and provided for registration of terminal equipment under Part 68 of the FCC Rules and Regulations. The purpose of registration is for the protection of the telephone network from harm by the connection of terminal equipment. Part 68 registration and rules have widely been interpreted as limited to network harm, and not to address terminal equipment quality, reliability, or even if the terminal equipment will function in the network environment. The information and recommendations in this section are based on that interpretation, but tempered by the realization that present and future rules by states, courts, and the FCC may provide more specific interface requirements between the telephone company and the subscriber.

1.4 Before deregulation, various parts of the telephone system could be characterized in broad general terms. There were few interface criteria defined in specific quantities to ensure subscriber loop plant and equipment compatibility. Compatibility existed because of a general knowledge of plant and equipment characteristics, a conservative design that provided for some margin of error, and undivided responsibility (telephone company) to correct incompatibilities that did occasionally occur.

1.5 Design of loop facilities and equipment was sometimes adjusted from the "standard" characteristics for a more cost effective overall design. For instance, it has been standard practice to use frequency selective ringers on long subscriber loops for both single party and multiparty subscribers. Frequency selective ringers are more sensitive and selective than the straight line ringers generally used for single party service. This provides for ringing over a longer distance with less false ringing. While the telephone company may control the use of ringers (or own the ringers) for multiparty service, the subscriber has control or ownership of ringers for single party service. Customer owned equipment will almost always be equipped with a straight line ringer or its equivalent.

1.6 The recommendations in this section are based on the following telephone system nominal characteristics. This is not presented as a specification; it is presented for illustration purposes only.

Central Office Equipment
Battery supply voltage = 44 to 56 volts.
Battery feed resistance = 400 ohms, balanced.

Outside Plant
Balanced telecommunications cables.
Resistance = 0 to 1500 ohms.

Terminal Equipment
Off hook resistance = 100 to 400 ohms.
Inside Wiring = 0 to 30 ohms.
Loop current = 20 to 70 mA.
Ringers = Straight Line.

2. IMPLEMENTATION RECOMMENDATIONS

2.1 It is recommended that these revised guidelines for subscriber loop design be implemented for essentially new outside plant and for major additions to or major redesign of existing outside plant. The major parts of the earlier 1973 subscriber loop design guidelines are summarized in Appendix 1. These 1973 guidelines may continue to be referenced and used where appropriate.

2.2 The guidelines and recommendations in this section are essentially based on telecommunications systems that are constructed with standard telephone cables. These cables contain balanced, twisted pairs with a mutual capacitance of 0.083 microfarads per mile. Cable gauges include 19, 22, 24 and 26, with 24 gauge recommended for general use. The twisted pairs are well balanced to minimize circuit noise; circuit balance is typically 60 to 80 dB. Additional cable characteristics are shown in Exhibit 1.

2.3 The new guidelines are based on a maximum 1000 hertz loss to the subscriber of 8 dB, which is the same as the 1973 guidelines. The maximum outside plant loop resistance without loop treatment has been reduced from 1700 ohms (1973) to 1500 ohms. Even with loop treatment, the outside plant loop limit for a voice frequency physical loop has been significantly reduced from 4300 ohms maximum (1973) to 2600 ohms maximum. The loop limit is dictated by the ringing limit of straight line ringers. Thus, while the transmission loss objective remains at 8 dB maximum, the recommended method of achieving long loop design has shifted from long physical loops to shorter end loops from carrier derived circuits or digital remote switching terminals (RST's).

2.4 The recommendations in this section are based on "Plain Old Telephone Service" or "POTS." Subscriber loop design for POTS is essentially intended for voice or speech, but may also be used for low speed data. The recommendations do not address optical fibers in loop plant, high speed data or other special services, or integrated voice and data service. The recommendations in this section may be applied with optical fibers in the feeder plant (using carrier or RST's), but is not intended to apply to fiber to the home in distribution plant.

2.5 Various types of radio systems are available for feeder and distribution applications. Point-to-point digital radio is useful in feeder applications to serve clusters of subscribers. A radio service called Basic Exchange Telecommunications Radio Service (BETRS) is also available for service to subscribers scattered over a wide area.

2.6 The integrated services digital network (ISDN) represents the network of the future. ISDN is now evolving in terms of standards and equipment. The degree that ISDN and other high bit rate digital services will penetrate rural areas over the next decade is uncertain. Thus, our recommendation is to provide for the present and plan for the future. While future rural services such as ISDN should not be ignored in planning, financial caution is suggested. Planning for future digital services should be approached on a more general basis until the rural need (or telco specific need) for these services is more clearly defined.

3. TRANSMISSION GUIDELINES

3.1 REA subscriber loop design objectives have evolved in terms of primary facilities, target transmission criteria, and methods of calculating transmission criteria. Present transmission objectives are based on a maximum loss to the subscriber of 8 dB at 1000 hertz. The objective for subscriber circuit noise is 20 dBrnc maximum under normal circumstances, but permitting up to 26 dBrnc on long rural loops.

3.2 The 1986 REA Loop Survey provided a "loop inventory" through the random sampling of 1000 REA borrower loops. The average 1000 hertz loop loss was 3.9 dB with 5.6 percent exceeding 8 dB and 0.9 percent exceeding 10 dB. The average circuit noise was 11 dBrnc with 6.5 percent exceeding 20 dBrnc and 2.2 percent exceeding 26 dBrnc. No loop exceeded both 10 dB loss and 26 dBrnc noise.

3.3 Based on the 1986 REA Loop Survey, most rural subscribers receive excellent transmission. Only a small percentage of subscribers could register complaints of poor transmission that could be supported by the loop survey data. Many loops (30 percent) contained minor technical design violations which were not service affecting. About 4.5 percent of the loops were deficient to the point of being service affecting. The loop survey data implied that these loops were generally designed to REA objectives, and that deviations probably occur gradually over a period of time (line extensions, subscriber reassignments, etc.). Time pressures encourage telephone company personnel to take short-cuts in activities such as reassignments; and these short-cuts can lead to transmission degradation.

3.4 Examples of subscriber loop transmission characteristics are illustrated in Appendix 2. These illustrations serve to demonstrate the effects of following or not following subscriber loop design guidelines. The six illustrations were taken from the 1000 loops measured during the 1986 REA Loop Survey. A detailed summary of loop transmission characteristics and deficiencies found during the survey was presented in the 1987 REA Telecommunications Engineering and Management Seminars. Material was illustrated in a manner suitable as training references in craft level workshops.

3.5 It is highly recommended that subscriber loop design guidelines be followed during the engineering and construction phase. It is also recommended that telephone company personnel maintain the plant as designed and correct deficiencies that have occurred over time. Telephone company management should develop policies and procedures that provide for accurate plant records and for proper use of those records during subscriber reassignments. Management should also develop procedures to gradually find and improve transmission deficient loops over time at minimal cost, and to avoid the recurrence of these loop deficiencies. In part, this can be accomplished through the use of periodic loop measurements on a sampling basis. The most cost effective testing is done when a craftsman has a scheduled visit to a subscriber location. Low cost loop checkers and dial-up 1000 hertz and multi-frequency generators can pay dividends in subscriber satisfaction. It is also recommended that automatic line testing (such as automatic line insulation test) be employed on a regular scheduled basis at each central office.

3.6 The following is a summary of some of the more common transmission deficiencies found during the 1986 REA Loop Survey.

a. Subscribers between loading points
b. Line faults (such as loading point missing)
c. Nonloaded; should be loaded
d. Loss exceeds 8 dB or loss slope high
e. Noise exceeds 20 dBrnc

Except for the high noise loops, most deficiencies could be minimized by following transmission design guidelines. Excess bridge tap beyond the served subscriber was a common cause of high loss or nonuniform loss within the voice passband. The most severe example is connecting subscribers between loading points. These problems can easily be avoided by simply cutting dead any cable beyond the served subscriber. For multiparty subscribers, cut the cable dead beyond the last subscriber and make sure no coils exist after the first subscriber (between subscribers).

4. LOOP DESIGN GUIDELINES

4.1 The following is a summary of subscriber loop design guidelines.

a. Maximum loss of 8 dB at 1000 hertz.
b. Nonloaded loops: 18 kf maximum (15 kf for 26 gauge)
c. Load all loops over 18 kf. (The 18 kf includes all bridge tap.)
d. Add loop extenders and voice frequency repeaters at 1500 ohms of outside plant resistance.
e. Use carrier, concentrators or remote switching terminals to avoid physical wire loops over 2600 ohms of outside plant resistance.

4.1.1 Subscriber end sections of loaded loops need further discussion. The end section is the cable beyond the last loading coil including all bridge tap.

a. Maximum end section: 12 kf for D66 loading.
9 kf for H88 loading.
b. The end section includes all bridge tap.
c. <u>ALWAYS</u> connect subscribers <u>AFTER</u> the last loading coil in the cable. <u>DO NOT</u> connect subscribers <u>BETWEEN</u> loading coils.

4.1.2 Trunks to private automatic branch exchanges (PABX) and other special service trunks and loops should be engineered on a special case basis. These trunks and loops should be low loss circuits to accommodate the services and the end loops beyond the PABX. The use of digital carrier circuits are recommended for trunks to more distant PABX's where practicable. Also, digital interfaces are recommended for circuits between digital end offices and digital PABX's where practicable.

4.2 <u>Nonloaded Loops</u>: Subscriber loops of 24 gauge or coarser cable which are 18 kf or less in length, including all bridge tap, need not be loaded. The only general justification for bridge tap is for party line service.

Subscriber loops of 26 gauge cable should not exceed 15 kf including all bridge tap.

4.2.1 Nonloaded loops should contain no more than 6 kf of total bridge tap. This may be one bridge tap or the sum of several taps. In general, it is recommended that all unused bridge tap be removed (cut dead).

4.3 Loaded Loops: Subscriber loops should be loaded where the total length including all bridge tap exceeds 18 kf. Subscriber loops composed primarily or entirely of 26 gauge cable should not be loaded.

4.3.1 Loaded loops may be extended to 1500 ohms before applying loop treatment in the form of loop extenders and voice frequency repeaters. Loaded loops with loop treatment can be extended to 2600 ohms maximum.

4.3.2 The subscriber loop return loss (impedance) and frequency response of nonloaded loops less than 18 kf in length can be improved by adding one or two loading points. In general, loading of short loops is not recommended because of the added administrative records and possible future use for carrier or high speed data which would require removal of loading coils.

4.4 Loaded Cable End Section: The length of a loaded cable "section" is the length of cable between two loading coils. A loaded cable section is usually described as one-half a cable section followed by a loading coil followed by another one-half cable section. For D66 loading, a section length is 4.5 kf and a half section is 2.25 kf. For H88 loading, a section length is 6 kf and a half section is 3 kf. The length of cable before the first loading coil and nearest to the COE (or COE substitute such as RST or carrier equipment) is the office end section. The length of cable extending beyond the last loading coil at the subscriber end of the facility is the subscriber end section. The end section length refers to the total length of cable in that section, including any bridge tap. End section refers to subscriber end section unless stated otherwise.

4.4.1 The office end section should always be one-half end section and kept within a range of 0.4 to 0.6 end section. This equates to a range of 1.8 to 2.7 kf for D66 loading and a range of 2.4 to 3.6 kf for H88 loading.

4.4.2 The subscriber end section should be near one-half end section when practicable. Subscriber end sections should be between 2 and 12 kf for D66 loading and between 2 and 9 kf for H88 loading.

5. LOOP DESIGN ECONOMICS

5.1 Economic decisions should be made on the basis of annual costs and not on the basis of first cost. TE&CM Section 218, "Plant Annual Cost Data for System Design Purposes" provides guidelines to aid in the economic selection of cable and electronic equipment for subscriber loop design. Standard tools available for subscriber loop design include telephone cable, loop extenders, voice frequency repeaters, carrier, concentrators and remote switching terminals. On a more selective basis, optical fibers and radio equipment may be economical in subscriber loop design.

5.1.1 As a general rule, physical wire plant should be designed to a maximum of 1500 ohms with no loop treatment and to a maximum of 2600 ohms with loop extenders and voice frequency repeaters. All loops beyond 2600 ohms should be served by carrier derived circuits (subscriber carrier, concentrators or RST's). Carrier circuits may also be cost effective at much shorter distances.

5.2 Cable Gauge Selection: Economic considerations must be weighed in determining the proper cable gauge. Fine gauge cables are subject to more lightning damage and are more fragile to handle than coarse gauge cables. Fine gauge cables exhibit higher attenuation than coarse gauge cables which will generally result in higher electronic equipment costs. However, fine gauge cables are much less costly than coarse gauge cables. The engineer should weigh all known factors and choose the combination of cable size, gauge and type that provides a cost effective and long life telephone system.

5.2.1 Based on the 1986 REA Loop Survey, 24 gauge filled core, direct buried cable is the facility in dominant use by REA borrowers. It is the first choice recommended facility for subscriber loop design. Filled buried cables have been reliable and 24 gauge has been an excellent compromise choice for REA borrowers.

5.2.2 General use of 26 gauge cable is not recommended because of the higher attenuation and the higher concern for lightning and handling damage. Large pair size (200 pairs or greater) 26 gauge cables may be used for short distances near the central office for all loops. The use of all 26 gauge cables may be considered where the longest circuit length of the route does not exceed 2.8 miles (15 kf) from the central office. All 26 gauge loops should be nonloaded.

5.2.3 The general use of 24 gauge cable is recommended for loop lengths up to 10 miles. At loop lengths beyond 10 miles, the economics of 24 and 22 gauge combinations should be explored. The use of 19 gauge cable is generally not economical except for very long rural loops or special circumstances.

5.3 Outside Plant Resistance: In general, it is recommended that outside plant be designed to a resistance limit of 1500 ohms without the aid of loop electronics. Central office equipment is generally designed to provide signaling and supervision over a total of 1900 ohms, including the telephone set. Allowing 400 ohms for the telephone set, the outside plant loop limit becomes 1500 ohms. The 30 ohms inside wiring resistance is noted, but not specifically separated in these calculations.

5.4 Loop Extenders and Frequency Voice Repeaters: The application of loop extenders and voice frequency repeaters is recommended for loops between 1500 ohms and 2600 ohms. Voice frequency repeaters are not needed for loops up to 1700 ohms with short end sections (up to 6 kf). However, it may be economical to use loop extender/repeater combination units at 1500 ohms rather than to separately administer repeaters for short and long end section loops.

5.4.1 Voice frequency repeaters should be set at a gain that provides a net circuit loss range between 2 and 8 dB. Repeaters are available in set fixed gain units, manual adjustment units and automatic adjustment units. Automatic adjustment repeaters eliminate the need to calculate and set the gain. However, these repeaters are more costly. Loops in the 1500 to 2600 ohm range can exhibit a loss of 7.5 to 14.7 dB. These loops should be set at a gain of 3 to 7 dB, depending on the cable gauges and actual loss.

6. CARRIER CIRCUITS

6.1 The use of carrier derived circuits is recommended for all subscriber loops that exceed 2600 ohms of outside plant. The term "carrier circuit" is intended to include subscriber carrier, concentrators and RST's applied to wire pairs, radio or optical fiber feeder facilities. The use of carrier circuits provides for a remote equipment terminal to serve as a COE line substitute. This remote "line interface" is placed closer to the subscriber, reducing the wire loop length to the subscriber. The application of carrier circuits is covered in other REA TE&CM sections.

6.1.1 An economic cost comparison is needed to determine the most cost effective equipment and facility for each application. The following is a generalized current assessment of digital carrier circuits.

a. Digital subscriber carrier has merit in the range of 48 to 96 lines per location.
b. Digital concentrators have merit in the range of 100 to 200 or more lines per location.
c. RST's have merit beginning at about 250 to 400 or more lines per location.

6.2 Subscriber Carrier: A variety of digital and analog subscriber carrier equipment is available. The use of digital carrier is recommended where the facilities, application and economics support this choice. Digital carrier is generally 24 channels per system transported over T1 type span lines. Subscriber terminals may accommodate one to four 24 channel systems in the same housing. Some systems also provide for the termination of one or several channels of a systems at multiple locations (drop and insert). Automatic backup protection such as span line automatic protection switching is available for these digital subscribers carrier systems. However, these systems are generally reliable and protection switching is generally not recommended where a failure affects only 24 or 48 subscribers.

6.2.1 Analog subscriber carrier presently available is generally called "station carrier." Two types of analog carrier is in general use. The first is a one-channel add-on type; the carrier channel is added to a physical subscriber circuit to double the circuit capacity. The application limit is 18 kf to coincide with the nonloaded physical circuit limit. The second is a multichannel type of six to 13 channels applied to a wire pair. Repeaters and terminals are powered from the central office, eliminating the need for ac power and batteries along the route.

6.2.2 There is a definite trend toward an all digital network. However, there are many "skinny" routes in rural telephone systems where analog carrier is the only feasible method of service.

6.3 Digital Concentrators: Digital concentrators are available in systems ranging from about 100 to 600 lines operating over two to eight T1 type span lines. Because of the circuit quantities involved, backup failure protection is generally recommended. No less than two span lines should be provided with automatic protection switching or automatic load sharing within the concentrator.

6.3.1 Digital concentrators are available as self contained systems that are independent of the COE equipment. These systems contain a concentrator switching matrix at both the central office and remote system ends. Digital concentrators are also available as integrated, single ended systems (subscriber end). The span line interfaces directly into the digital COE, eliminating the concentrator switching matrix and COE line circuits at that end. At this time, integrated concentrators must generally be furnished by the COE manufacturer. (There are exceptions.)

6.4 Remote Switching Terminal: An RST is a group of digital COE lines located at some distance from the host switch. The RST is the ultimate in COE line substitution at a remote location. Most COE functions are extended to this remote location. Subscriber carrier and concentrators transfer some COE functions to the remote location.

6.5 Lightwave Systems: In some applications, the use of optical fibers as feeder circuits may be economical. Lightwave systems may be used in conjunction with digital carrier, concentrators or RST's.

6.6 Radio Systems: In some applications, the use of digital radio as feeder circuits may be economical. Digital radio systems may be used in conjunction with digital carrier, concentrators or RST's.

6.6.1 For service to subscribers that are scattered over an area, Basic Exchange Telecommunications Radio Service (BETRS) may be economical as a substitute for feeder and distribution loop plant. In a point-to-multipoint application, a base station may serve several subscribers or several hundred subscribers.

7. NOISE AND RINGING CONSIDERATIONS

7.1 The following are design guidelines and suggestions to minimize noise on subscriber loops. Use fully shielded cables with shield continuity maintained throughout the cable length and adequate cable shield grounding. Unshielded wire facilities are not recommended except for short aerial drop wire to subscribers.

7.2 When routes are established, maintain a separation from the electric power lines of 500 feet or greater when possible. Avoid placing buried telephone cable under electric power lines where possible. Where jointly buried electric and telephone facilities are provided, restrict the length to one-half mile.

7.3 Use only bridged ringers unless there is a compelling reason to provide divided ringers to ground. Standard modular jacks provide only for bridged ringing.

7.4 For two party automatic number identification (ANI) within the telephone set, divided ringing to ground may be required. Two party service by REA borrowers is presently less than one percent of all loops. For two party service over long physical loops, noise mitigation procedures may be required.

7.5 Limit multiparty service to four parties with bridged frequency selective ringing and avoid ringing frequencies of 60 or 66 hertz. ANI is generally not available beyond two party service; this eliminates the need for divided ringing for four party service.

7.6 Three different types of multifrequency ringing systems now exist. They are decimonic, harmonic and synchromonic. It is recommended that 20 hertz be chosen as the standard single party ringing frequency. When practicable, it is recommended that 20, 30, 40, and 50 hertz be chosen as the standard multiparty ringing frequencies.

8. MISCELLANEOUS CONSIDERATIONS

8.1 Miscellaneous hardware is sometimes placed in the subscriber loop for a variety of reasons. Examples are bridge tap isolators, noise reduction coils, low pass filters, etc. They may be located at the COE or along the cable route. These devices must be applied properly and considered in the overall loop design. The series resistance of devices inserted into the series wire path must be included in the loop resistance calculation. The devices must not impair the signaling and transmission path, and must not introduce noise into the circuit. For instance, bridge tap isolators used in combination with divided ringing will likely cause excessive circuit noise.

8.2 Multiparty subscribers should be carefully assigned to meet loaded end section and nonloaded bridge tap guidelines.

8.3 Portions of cable pairs extending beyond the point of the last subscriber's connection should be cut dead. For cable protection considerations (cable dielectric, damage considerations), the unused portion of the cable pairs should be left floating at both ends, and not grounded.

9. STAKING AND LOAD SPACING CONSIDERATIONS

9.1 Staking and Construction: Staking of plant for each major lead should start from the central office and proceed in the direction of the subscribers, never in the opposite direction. Staking of plant extensions should start from the office end and proceed toward the subscribers. Load spacing for plant extensions should be based on spacing along the major lead to the point of departure as a continuation of that design. The main objective during staking and construction periods is to meet the office end-section and load spacing requirements.

9.1.1 Staking of each section as close to the nominal 4500 feet (D spacing) and 6000 feet (H spacing) is desirable and will permit full benefits to be derived from the application of voice frequency repeaters. An important consideration is that within the average spacing, each loading section be staked to look as much like the other loading sections as possible. This is especially true for the four or five sections adjacent to the COE or other terminal equipment where voice frequency repeaters are to be used.

9.2 Office End Section Length: The office end section should be one-half (0.5) the length of the normal full section. Where it is not possible or practical to meet this objective, an end section length within 0.4 to 0.6 of the normal full section can be considered. Choice of the 0.4 length is preferable to the 0.6 end section because of the through circuits.

9.3 Load Spacing Requirements (D66): As built plant, including the main cable length, lateral cable distance to and from pedestals, pedestal height, pedestal loop-around and all other incidental lengths should meet the following spacing requirements.

9.3.1 Deviation of the average spacing from the standard spacing should be within ±3 percent.

9.3.2 Root Mean Square (RMS) value of all deviations of individual spacing lengths from the average spacing should not be more than two percent computed in accordance with TE&CM 431.

9.3.3 Where the application of the RMS method for determining spacing deviation requirements is not practical due to staking and/or construction or other local factors, the method discussed below is considered acceptable.

9.3.4 Average of the difference (with signs disregarded) between the individual spacings and average spacings should be within two percent.

9.3.5 Deviation of the length of longest individual sections from the average spacing should be within ±3 percent.

9.3.6 Where terrain or other local factors make it impossible for an individual loading section to meet the ±3 percent requirements with actual cable, individual loading sections may vary as much as -15 percent but only +3 percent from the average spacing. Where this becomes necessary, the short section should be electrically built-out to the correct average spacing by means of a building-out capacitor. A step-by-step procedure for computing building-out capacitance is shown in REA TE&CM Section 431. It is to be emphasized that this method is to provide staking personnel a tool for dealing successfully with abnormal situations only, and is not recommended as a general practice.

9.4 Load Spacing Requirements (H88): As built plant, including the main cable length, lateral cable distance to and from pedestals, pedestal height, pedestal loop-around and all other incidental lengths should meet the following spacing requirements:

9.4.1 Deviation of the average spacing from the standard spacing should be within ±2 percent.

9.4.2 Average of the differences (with signs disregarded) between the individual spacings and average spacings should be within one-half of one percent.

9.4.3 Deviation of the length of longest individual sections from the average spacing should be within ±2 percent.

9.4.4 Where terrain or other local factors make it impossible for an individual loading section to meet the ±2 percent requirements with actual cable, and individual loading section may vary as much as -15 percent but only +2 percent from the average spacing. Where this becomes necessary, the short section should be electrically built-out to the correct average spacing by means of a building-out capacitor. It is to be emphasized that this method is to provide staking personnel a tool for dealing successfully with abnormal situations only, and is not recommended as a general practice.

EXHIBIT 1
TELECOMMUNICATIONS CABLE CHARACTERISTICS

The following is a summary of nominal buried telecommunications cable characteristics at 55°F or 68°F used in this section. Refer to REA TE&CM Section 406 for more complete cable characteristics.

1 kHz Loss (dB/kF)

	19 Ga	22 Ga	24 Ga	26 Ga
Nonloaded	0.24	0.34	0.43	0.55
Loaded	0.08	0.15	0.23	0.34

Loaded Cable: Calculated dB/100 Ohms

19 Ga	22 Ga	24 Ga	26 Ga	22 and 24 Ga Estimate
0.497	0.463	0.443	0.404	0.45 dB/100 ohms

DC Resistance (Ohms/kF)

	19 Ga	22 Ga	24 Ga	26 Ga
Nonloaded	16.10	32.39	51.89	83.33
Loaded	17.10	33.39	52.89	84.33

Loaded Cable: 1500 Ohm Limit in kF

	19 Ga	22 Ga	24 Ga
Buried	87.7	44.9	28.4
Aerial	77.2	39.5	25.0

Loaded Cable: 2600 Ohm Limit in kF

	19 Ga	22 Ga	24 Ga
Buried	152.0	77.9	49.2
Aerial	133.8	68.6	43.3

Notes:

1. The 3 kHz loss of nonloaded cable is estimated to be 1.7 times the 1 kHz loss.
2. Loaded cables exhibit a relatively flat loss in the middle of the passband and transistion to a higher loss at higher frequencies.
3. Loaded cable resistance includes one ohm per kilofoot for H88 or D66 loading coil resistance.
4. Aerial cable length limits are 12 percent shorter than buried cable in consideration of higher temperatures.

APPENDIX 1
SUMMARY OF 1973 SUBSCRIBER LOOP DESIGN GUIDELINES

a. Maximum loss of 8 dB at 1000 hertz.
b. Nonloaded Loops: 18 kf maximum (15 kf for 26 gauge).
c. Load all VF loops over 18 kf. (The 18 kf includes all bridge taps.)
d. Add loop extenders and voice frequency repeaters for VF loops between 1700 and 3000 ohms of outside plant resistance.
e. Loop extenders will be needed at 1500 ohms for aerial plant. Voice repeaters may be needed between 1300 and 1700 ohms in some cases.
f. Add field mounted voice repeaters for loops between 3000 and 4300 ohms. (See Note 2.)

Loaded Loops - Subscriber End Sections

a. Maximum End Section: 12 kf for D66 loading.
9 kf for H88 loading.
b. Add voice repeaters at 1700 ohms for short end sections of 2 to 6.5 kf.
c. Add voice repeaters at 1300 ohms (or greater) for long end sections over 6.5 kf.
d. The end section includes all bridged taps.
e. For loops over 1300 ohms and over 6.5 kf end sections, design on an individual basis (TE&CM 424).
f. ALWAYS connect subscribers AFTER the last loading coil in the cable. Do Not connect subscribers Between loading coils.

Notes

1. Much of the discussion in the present subscriber loop design guidelines also applies to the 1973 guidelines.

2. The use of carrier, concentrators and remote switching terminals is recommended to avoid loops over 3000 ohms. Presently, carrier circuits are generally more economical for long loops; and transmission may be degraded on long physical loops.

APPENDIX 2
EXAMPLES OF SUBSCRIBER LOOP TRANSMISSION CHARACTERISTICS

Examples of subscriber loop transmission characteristics are illustrated in this appendix. These illustrations serve to demonstrate the effects of following <u>or not following</u> subscriber loop design guidelines. The presented information includes measured valves of loop resistance (R), loop current (I), circuit noise (Noise) and power influence (PI). The six illustrations were taken from the 1000 loops measured during the 1986 REA Loop Survey. A detailed summary of loop transmission characteristics and deficiencies found during the survey was presented in the 1987 REA Telecommunications Engineering and Management Seminars.

The following subscriber loops are illustrated.

A. A normal nonloaded cable loop.
B. A normal loaded cable loop.
C. A loaded loop with a long end section.
D. A loaded loop with the subscriber between loading points.
E. A loaded loop with excess bridge tap beyond the subscriber.
F. A loaded loop with a bridge tap between loading points.

Nonloaded cable loops exhibit a straight line loss slope that is very predictable. The loss at 1 kHz can be estimated from Exhibit 1. The 3 kHz loss should be approximately 70 percent higher than the 1 kHz loss. The loss slope within the voice passband should be approximately a straight line with no abrupt changes. (Note: Allow for measurement error when evaluating loop measurement results.)

Loaded cable loops exhibit the characteristics of a low pass filter. The loading coil inductance and the cable capacitance in a loading section determine the "cutoff frequency." Loaded cables exhibit a relatively flat loss in the middle of the voice passband and transition to higher loss at higher frequencies. A wider passband is exhibited for D66 loading than for H88 loading because D66 has a higher cutoff frequency.

<u>Loop A</u>: This loop is 16.4 kilofeet of 24 and 22 gauge nonloaded cable. The measured loss at 1000 hertz is near the estimated loss and the loss slope is typical of nonloaded cable. All measured values appear normal.

<u>Loop B</u>: This loop is 33.0 kilofeet of 24 gauge H88 loaded cable with five loading points and a six kilofeet subscriber end section. The measured loss at 1000 hertz is near the estimated loss and the loss slope is typical of loaded cable. All measured values appear normal.

<u>Loop C</u>: This loop is 29.3 kilofeet of 22 gauge H88 loaded cable with three loading points. As found, the subscriber end section is 14.3 kilofeet; this is far beyond the 9 kilofeet objective for H88 loading. By adding loading points four and five, the voice frequency passband was significantly improved.

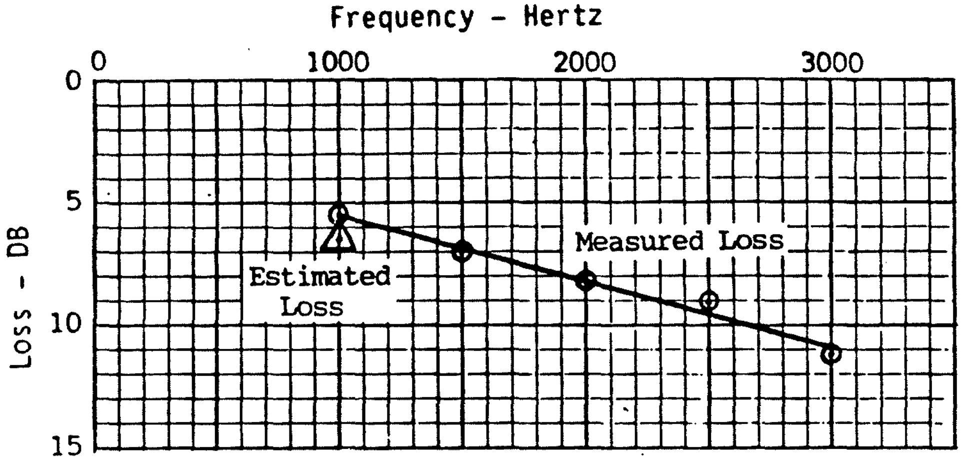
Loop D: This loop is 18.0 kilofeet of 24 gauge D66 loaded cable. There are four loading points before the subscriber and one loading point after the subscriber. The measured loss at 1000 and 3000 hertz is only slightly higher than the estimated loss, but the middle of the passband has a severe notch. This problem would go unnoticed with only 1000 hertz or 1000 and 3000 hertz loss measurements. Additional measurements at other frequencies across the passband are often needed to detect this type of problem. Sometimes this problem is found as a result of a complaint from a customer using a tone dial telephone because of the transmission impairment to tone dial frequencies.

This loop is a textbook example of connecting subscribers between loading points. The worst place to connect a subscriber is just before the last loading coil with cable beyond that last coil. The loading coil and cable capacitance beyond the loading coil form a series tuned circuit across the subscriber line. The length of the cable beyond the loading coil can be estimated by the resonant frequency (the frequency of highest loss). In this case, 4.6 kf of cable tap was estimated which is about one "D" loading section beyond the last coil.

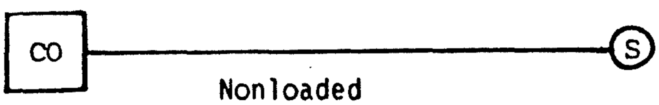
Loop E: This loop is 33.4 kilofeet of 24 and 22 gauge H88 loaded cable with five loading points. The total subscriber end section is 20.3 kilofeet of which 13.9 kilofeet is excess bridge tap beyond the subscriber. Simply cutting off the tap beyond the subscriber would significantly improve the passband of this loop.

Loop F: This loop is 23.0 kilofeet of 22 gauge D66 loaded cable with four loading points and four party line subscribers. The total end section is only 9.4 kilofeet. A long bridge tap (length unknown) was connected between loading points one and two. This has a similar effect to a missing loading point. After the bridge tap was cut off, the 1000 hertz loss measured 4.5 dB (estimated at 4.3 dB). Multifrequency measurements were not made after correction, but the voice frequency passband is expected to show dramatic improvement.

Loop A: 16.4 KF, 24 and 22 Gauge, Nonloaded

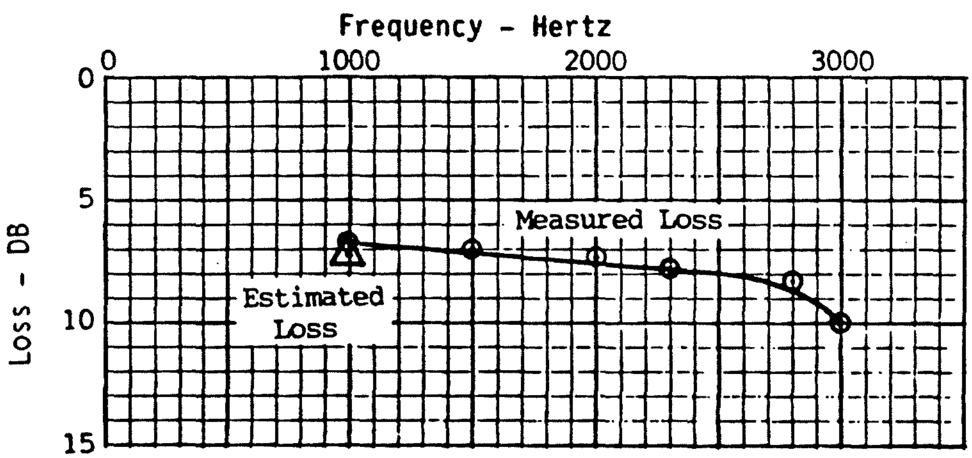


Loop Measurements
R = 720 ohms
I = 45 mA
Noise = 10 dBrnc
PI = 75 dBrnc

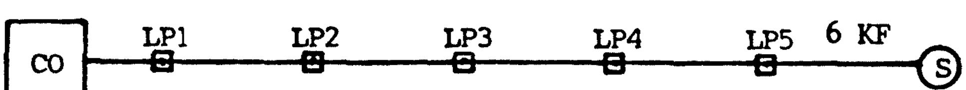


Nonloaded
Normal Nonloaded Loop

Loop B: 33.0 KF, 24 Gauge, H88 Loaded

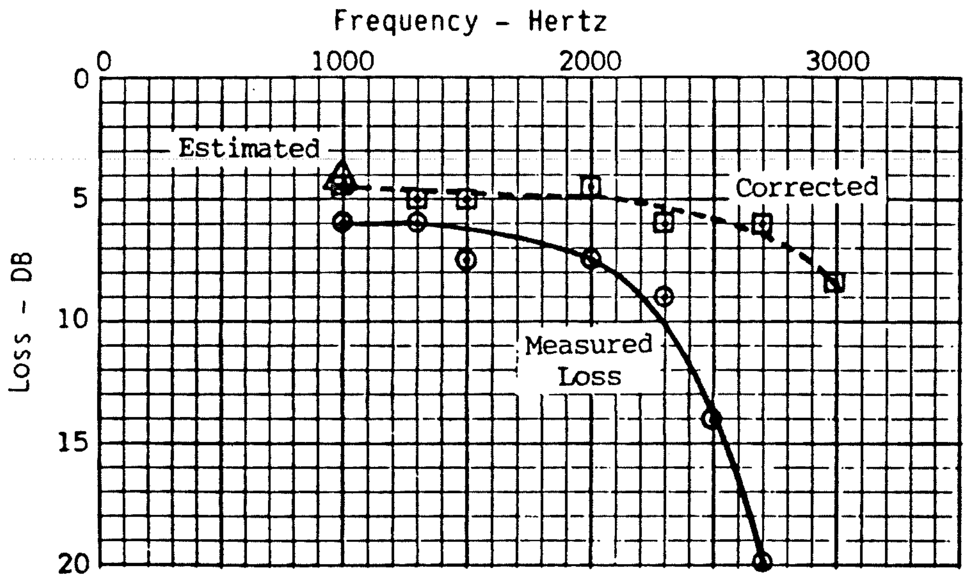


Loop Measurements
R = 1580 ohms
I = 26 mA
Noise = 8 dBrnc
PI = 76 dBrnc

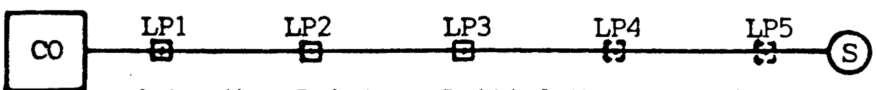


5 Loading Points, 6 KF End Section
Normal Loaded Loop

Loop C: 29.3 KF, 22 Gauge, H88 Loaded

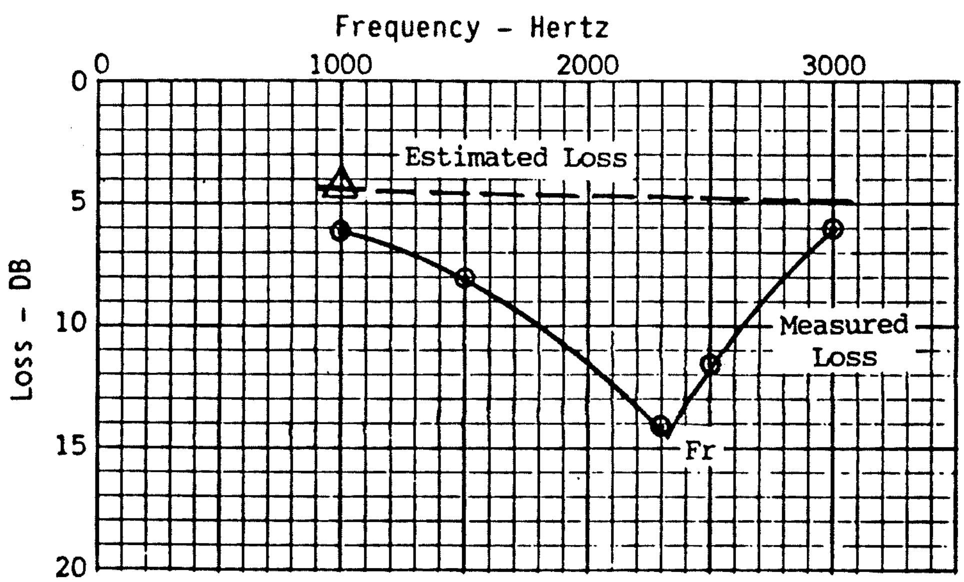


Loop Measurements
R = 952 ohms
I = 31 mA
Noise = 12 dBrnc
PI = 72 dBrnc



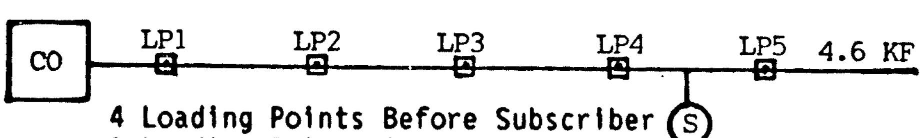
3 Loading Points - Initial Measurements
5 Loading Points - After Correction

Loop D: 18.0 KF, 24 Gauge, D66 Loaded



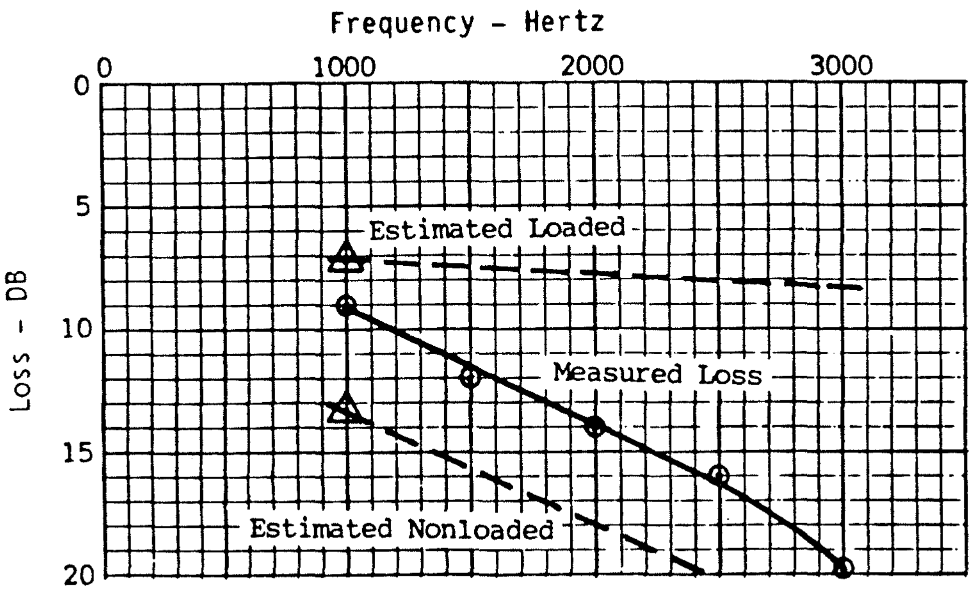
Loop Measurements
R = 962 ohms
I = 28 mA
Noise = 11 dBrnc
PI = 57 dBrnc

Fr = 2.3 kHz
Tap = 4.6 KF Beyond Coil

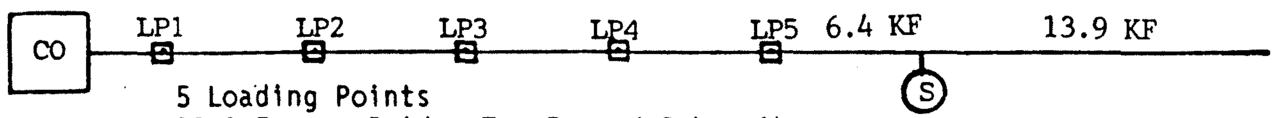


4 Loading Points Before Subscriber
1 Loading Point After Subscriber

Loop E: 33.4 KF, 24 Gauge, H88 Loaded

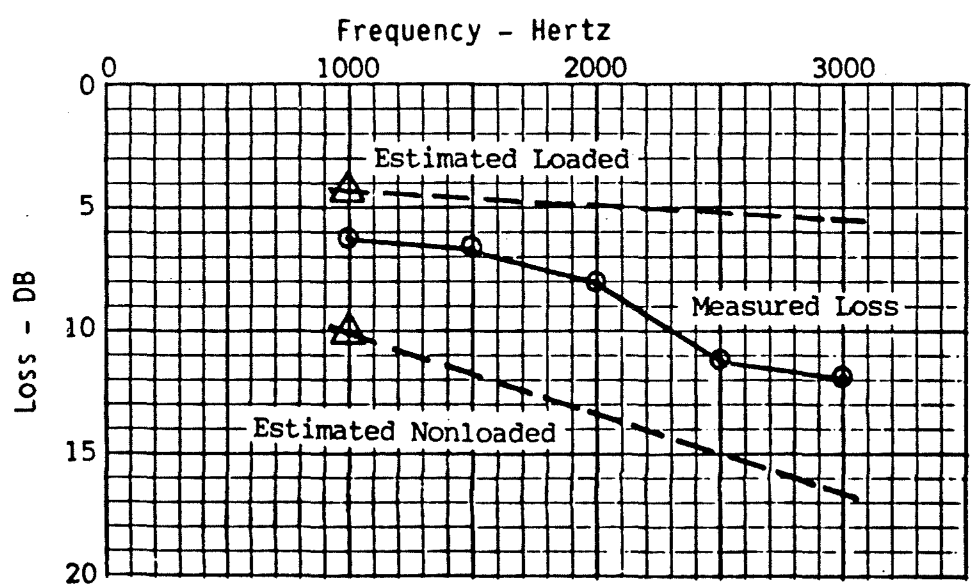


Loop Measurements
R = 1603 ohms
I = 26 mA
Noise = 10 dBrnc
PI = 76 dBrnc

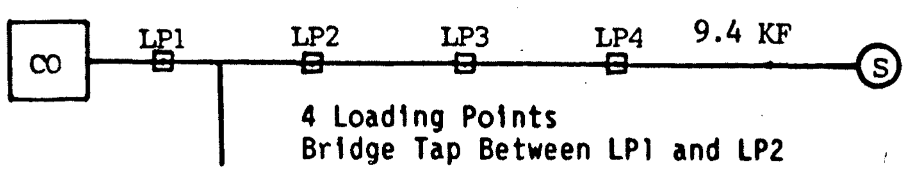


5 Loading Points
13.9 Excess Bridge Tap Beyond Subscriber

Loop F: 23.0 KF, 22 Gauge, D66 Loaded



Loop Measurements
R = 964 ohms
I = 28 mA
Noise = 13 dBrnc
PI = 83 dBrnc



4 Loading Points
Bridge Tap Between LP1 and LP2