UNITED STATES DEPARTMENT OF AGRICULTURE
Rural Electrification Administration

BULLETIN 1751H-501

SUBJECT: **Fundamentals of ISDN**

TO: Telephone Borrowers
REA Telephone Staff

EFFECTIVE DATE: Date of Approval

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OFFICE OF PRIMARY INTEREST: Transmission Branch, Telecommunications Staff Division

PREVIOUS INSTRUCTIONS: None - this bulletin is new information.

FILING INSTRUCTIONS: Place this document in Section 1751H, Transmission Design Bulletins.

PURPOSE: To provide basic information on the Integrated Services Digital Network, or ISDN. This includes theory, fundamentals, equipment, applications and deployment. The document assumes some familiarity with digital telecommunications systems but no prior exposure to ISDN.

Administrator

4/12/91
Date

FUNDAMENTALS OF ISDN

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ABBREVIATIONS & DEFINITIONS

The principal ISDN abbreviations and terms used in this document are defined below. Other abbreviations and definitions related more to general digital transmission are included in "Digital Transmission Terminology," located in Bulletin 1751H-403, *Digital Transmission Fundamentals*.

2B1Q (2 binary 1 quaternary): Digital line code having four information states used to obtain up to a 160 kb/s bandwidth over non-loaded, paired-wire facilities.

2B+D: ISDN 144 kb/s basic rate access of two 64 kb/s channels and one 16 kb/s channel.

23B+D: ISDN 1.544 Mb/s primary rate access of 23-64 kb/s channels for voice or data use, and one 64 kb/s signaling channel.

ANSI (American National Standards Institute): Principal U.S. standards setting organization.

B-channel: Designation for the 64 kb/s information-carrying channel in both the BRI and the PRI forms of the ISDN.

BRI (basic rate interface): The 2B+D form of ISDN that provides two 64 kb/s B-channels and one 16 kb/s D-channel to a subscriber over a single loop facility.

CCITT (International Telegraph and Telephone Consultative Committee): International telecommunications standards setting body.

D-channel: Designation for both the 16 kb/s and the 64 kb/s signaling channels used in the BRI and PRI forms, respectively, of ISDN.

DLC (digital loop carrier): Device that digitally encodes and multiplexes subscriber loop channels for more efficient transmission and greater range from the central office.

DSL (digital subscriber line): A metallic subscriber loop over which full-duplex voice and/or data is transmitted in digital format.

ET (exchange termination): Termination point located within the central office where a DSL is connected to the switching network.

ISDN: Abbreviation for the Integrated Services Digital Network.

LT (line termination): Physical termination point of a DSL located at the line frame of a central office switch, DLC or RT.

NT (network termination): General term used to refer to equipment that terminates a subscriber line at the customer's premises.

NT1 (network termination type 1): Type of subscriber termination that provides for the basic electrical/mechanical interface (OSI Layer 1) between customer equipment and the DSL.

NT2 (network termination type 2): Type of subscriber termination that provides for both the basic electrical/mechanical interface (OSI Layer 1) and higher level OSI protocols between customer equipment and the DSL.

OSI (open systems interconnection): Structured architecture designed for information exchange between different communication or data systems.

PRI (primary rate interface): The 23B+D form of ISDN access giving the user 23-64 kb/s B-channels and one 64 kb/s D-channel for a total bandwidth of 1.544 Mb/s.

R-interface: ISDN subscriber reference point located between the TE2 and a TA.

RT (remote terminal): Remotely-located terminal of a subscriber carrier or concentrator system that is connected to the central office.

S-interface: ISDN reference point located at a subscriber's premises between an NT2 and a TA; or, between an NT2 and a TE1.

TA (terminal adapter) Equipment that converts standard computer or voice electrical interfaces to the ISDN S-interface or the T-interface.

TE1 (terminal equipment type 1): Voice or data terminal equipment with the internal capability to directly connect without conversion to the ISDN S-interface or the T-interface.

TE2 (terminal equipment type 2): Voice or data terminal equipment that requires the use of a terminal adapter (TA) to connect to the ISDN S-interface or the T-interface.

T-interface: ISDN subscriber reference point located between an NT1 and a NT2; or between an NT1 and a TE1.

U-interface: ISDN subscriber reference point located between the network DSL and the NT.

V-interface: ISDN network reference point located at the CO between the LT and the ET.

1. INTRODUCTION

1.1 This bulletin provides REA borrowers, consulting engineers and other interested parties with technical information on the fundamentals of the Integrated Services Digital Network, generally referred to as ISDN. Much of the information contained in this document is of a descriptive nature which is intended to provide the reader with a basic overview of the subject. The emphasis is on the Basic Rate Interface (BRI) form of ISDN, known also as 2B+D. Some information is presented on the Primary Rate Interface (PRI), referred to as 23B+D, for comparative purposes. However, BRI is given considerably more treatment than PRI because of its higher likelihood for loop applications, particularly in rural environments. The key concepts of BRI ISDN are covered from both a network and customer equipment perspective. Although customer equipment is an item generally no longer directly provided by telephone companies, the complexity of an ISDN network requires some understanding of what lies beyond the subscriber side of the telephone company/customer interface.

1.2 The provisioning of BRI in the loop plant presents some important challenges to local exchange carriers (LECs), such as reducing loop length and eliminating loaded plant. In particular, proper consideration must be given to existing and future analog station carrier systems because of the potential for interference caused by the ISDN BRI signal. Means of deploying ISDN through various loop architectures are presented with a brief discussion of central office equipment (COE) considerations. Some possible applications of ISDN for different customer services are addressed. Recommendations for future loop planning are offered in the final section.

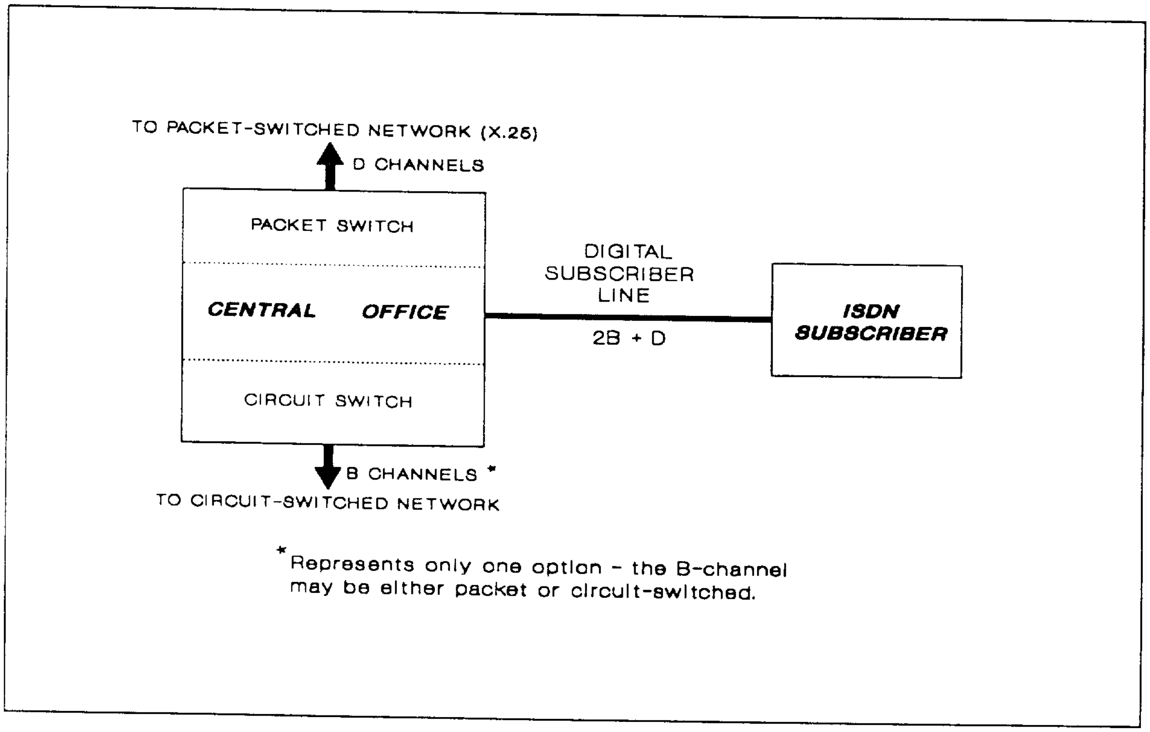
2. GENERAL OVERVIEW OF ISDN

2.1 ISDN is a recently developed method for communicating both data and voice information over the public-switched telephone network. Using ISDN, both data and voice information can be integrated and transmitted end-to-end in digital, not analog, format. Unnecessary analog to digital conversions are avoided. An intelligent overlay network provides out-of-band signaling, performance monitoring and maintenance capabilities. Moreover, ISDN provides for a set of common interfaces between the network and the end user.

2.2 In its most basic format, the digitized voice and data signals are multiplexed into a single bitstream and then transmitted over a single pair of wires to the telephone central office (CO) switch at a rate of 160 kb/s. The facility over which this information is transmitted is termed a digital subscriber line, or DSL. The 160 kb/s bandwidth results from two 64 kb/s B-channels, one 16 kb/s D-channel and 16 kb/s of network overhead. At the CO, the two B-channels and the D-channel are then separated and switched to their intended destinations. Any of the two B-channels can be either circuit-switched or packet-switched, depending upon customer requirements and network capabilities; the D-channel can be only packet-switched. Figure 1 illustrates these concepts.

2.3 ISDN at the 160 kb/s BRI rate could typically be used in a home or small business to connect a single line with three customer devices - a computer terminal, a FAX machine and a telephone, for example. ISDN in this configuration provides multiple benefits: 1) a universal interface that provides the capability for simultaneous operation of all three devices over a single telephone line; 2) a corresponding subscriber rate savings compared to purchase of three, separate lines; 3) the higher quality of digital transmission as compared to analog; and 4) a significant enhancement in bandwidth over what is available on an analog loop. ISDN in this application is serving, in effect, as simply a digital multiplexer.

FIGURE 1
ISDN 2B+D BASIC CONFIGURATION



*Represents only one option - the B-channel may be either packet or circuit-switched.

2.4 The higher bandwidth form of ISDN, the PRI, operates at an overall rate of 1.544 Mb/s. It contains 23 B-channels for information, one D-channel for signaling and 8 kb/s of overhead for framing and maintenance. Both the B and D-channels are 64 kb/s each. The PRI transmission rate has greater capacity and would typically be used to connect with PBXs or digital multiplexers which have the capability to process both voice and data traffic from many lines.

2.5 As with the lower rate BRI, the PRI would also offer the benefits of integrated voice and data digital transmission. ISDN applications in the PRI format by business customers extend into several additional areas. These include provisioning of ANI (automatic number identification) on signaling channels separate from those carrying incoming calls so that the identity of the caller is immediately known at the terminating end. This feature could be used to speed inquiries and orders in, for example, a catalog order firm. Other uses would include access to LANs and PC-to-PC communications, using both packet and circuit-switched networks.

3. ISDN IN DETAIL

3.1 Purpose

3.1.1 The purpose of the section is to provide further descriptive detail on the various aspects of ISDN, beyond the overview presented in Section 2. This section is organized around ten separate topics that cover bit rates, channel structure, line codes, functional groups, etc. ISDN provisioning and applications are addressed in later sections.

3.2 Bit Rates & Channel Structure

3.2.1 ISDN operates at two different bit rates depending upon whether one is referring to BRI or PRI ISDN. The BRI operates at the lower digital transmission rate of 160 kb/s. This is a significantly higher bit rate than what is typically used for digital transmission of a single voice channel at the standard rate of 64 kb/s, or digital signal level zero (DSO). The transmission rate of 160 kb/s coupled with use of the 2B1Q line code results in a symbol or signaling rate of 80 kilobaud. (Line codes are discussed in further detail in Section 3.4.)

3.2.2 Although 160 kb/s is the rate at which the BRI is furnished over the local loop facilities, only 144 kb/s is available for the customer "payload." The remaining 16 kb/s of overhead is used for telephone company network operating purposes, such as performance monitoring, framing, provisioning and timing. This 16 kb/s channel is sometimes referred to as the maintenance or M-channel. BRI ISDN can accommodate two full duplex 64 kb/s channels (referred to in ISDN parlance as Bearer or B-channels) and one 16 kb/s Delta, or D-channel, used for customer signaling and data.

3.2.3 The PRI ISDN operates at an overall bit rate of 1.544 Mb/s. It contains 23 B-channels and one D-channel. The B-channels can either be circuit switched voice or data. The D-channel is limited to signaling purposes and packet-switched data. Of the 1.544 Mb/s transmission rate, only 1.536 Mb/s is available for customer use or payload. The remaining 8 kb/s is used for network overhead, such as framing and maintenance. The characteristics of both the BRI and PRI ISDNs are summarized in Table 1.

TABLE 1
ISDN CHANNEL & BIT RATES

CHARACTERISTIC	BRI (2B+D)	PRI (23B+D)
Transmission Rate	160 kb/s	1.544 Mb/s
Customer Bandwidth	144 kb/s	1.536 Mb/s
B-channels	64 kb/s	64 kb/s
D-channel	16 kb/s	64 kb/s
Network Overhead	16 kb/s	8 kb/s

3.3 Clear Channel Capability

3.3.1 Both the BRI and the PRI forms of ISDN are designed for an important capability for data communications. This is clear channel capability. Clear channel capability refers to the ability to use the full 64 kb/s bandwidth of a DSO channel entirely for customer payload without any restrictions on the ones or zeros content of data. Traditionally, DSO channels provided less than 64 kb/s bandwidth to the user because of the need to maintain a minimum density of ones for timing and synchronization purposes. Furthermore, the least significant bit in every sixth frame was also robbed and used for signaling purposes. The DSO channel capacity was effectively narrowed from a data perspective by 8 kb/s to 56 kb/s because of these two requirements. While this limitation is not a problem for digitally-encoded voice signals, it presents undesirable restrictions with digital data transmission.

3.3.2 The BRI ISDN concept consists of clear capability for all three of the 2B+D channels. To satisfy signaling requirements, it includes a separate signaling channel (the D-channel). This eliminates the need to perform bit robbing for in-band signaling purposes. The minimum ones density requirements can be addressed by using a digital zero substitution code on interoffice transmission equipment. With a code such as Binary 8 Zero Substitution (B8ZS) or the lesser-used Zero Byte Time Slot Interchange (ZBTSI), timing can be properly maintained by coding and subsequently decoding successive strings of zeroes. This manipulation of the bitstream is transparent to the user and does not restrict any use of the full 64 kb/s channel. Continuous strings of zeros can, therefore, be reliably transmitted. Although clear channel capability from an exchange perspective will be available when BRI ISDN is deployed on a loop basis, the initial implementation of ISDN on certain *interoffice* networks may not result in 64 kb/s capability until SS7 is furnished and older terminal equipment has been replaced or modified.

3.4 2B1Q Transmission Line Code

3.4.1 A line code is the numeric scheme whereby digital information is converted into pulses for transmission. A variety of line codes have been developed for this purpose. The most common is the Alternate Mark Inversion (AMI), which is used in digital T-1 carrier transmission. AMI simply alternates the pulse polarity from positive to negative for every digital one; zeroes are represented by a zero voltage level. Line codes are designed to optimize the transmission of digital information over a particular type of facility. Some considerations involved in selecting a line code are spectral energy, near end crosstalk (NEXT), echo noise, impulse noise, intersymbol interference and quantizing noise.

3.4.2 The line code that has been selected for transmission of the BRI ISDN signal in the U.S. is known as 2B1Q, or 2 Binary 1 Quaternary. 2B1Q means that two bits of digital information are represented by a four-level, or quaternary, line signal. Digital information *is not* represented on a single bit basis, as with AMI, but in blocks of two bits. Because the block code has four possible logical states, the two bit blocks are known as quats. The 2B1Q code was standardized in the U.S. by the American

National Standards Institute (ANSI) standard for telecommunications.[1] This quaternary line code is compared graphically to the AMI code for a given 10-bit bitstream in Figure 2. Table 2 shows the 2B1Q code in terms of bits, blocks and pulse voltages.

FIGURE 2
COMPARISON OF AMI & 2B1Q LINE CODES

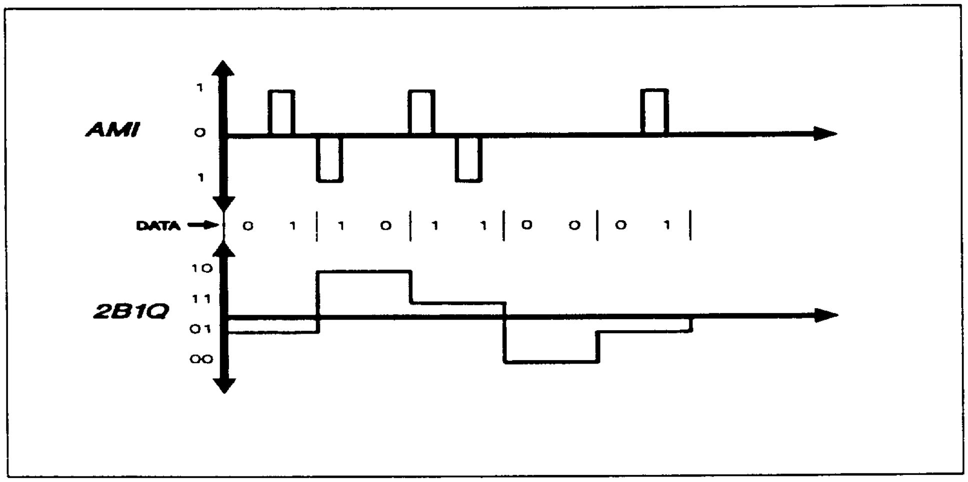


TABLE 2
2B1Q SYMBOL BLOCKS & PULSE VOLTAGES

BIT #1 (sign)	BIT #2 (magnitude)	QUATERNARY SYMBOL	PULSE VOLTAGE
0	0	-3	-2.50 V
0	1	-1	-0.83 V
1	0	+3	+2.50 V
1	1	+1	+0.83 V

3.4.3 Prior to the adoption of an American standard line code for transmission of the BRI over a digital subscriber line (DSL), a variety of line codes were evaluated for use. 2B1Q was found to be superior in meeting the requirements of typical loops in North America. Other signal processing techniques are used along with this code to further enhance digital transmission over loop facilities. They include scrambling, echo cancellation and adaptive equalization.

3.4.4 The standardized line code for BRI ISDN has its peak spectral energy at an approximate frequency of 40 kHz, as compared to 80 kHz for an AMI code. The lower frequency, or spectral components, minimize loss over the largely inductive loop plant. The baud rate (or symbol rate) of 2B1Q is 80 kilobaud. This results from the use of one symbol per two bits of data times the 160 kb/s bit rate (1/2 x 160 kb/s). The use of 2B1Q over copper loop facilities is designed to produce a bit error rate (BER) of less than 10^{-7}.

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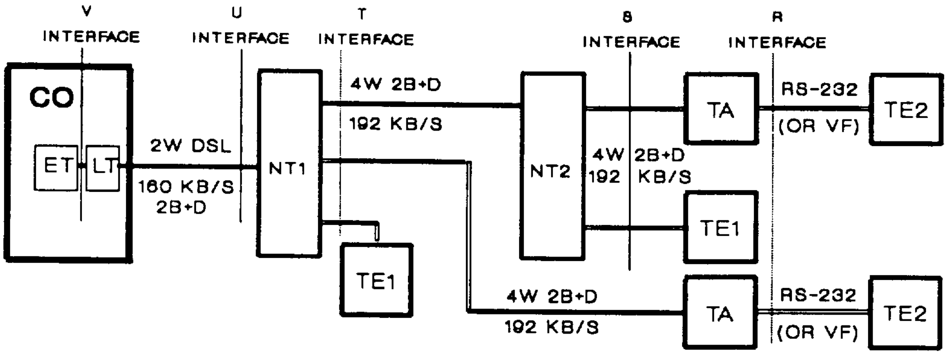
[1] ANSI Standard No. T1.601-1988, *ISDN Basic Access Interface for Use on Metallic Loops for Application to the Network Side of the NT.*

3.5 ISDN Architecture & Functional Groups

3.5.1 BRI ISDN consists of a number of reference points and functional groups between the CO and the subscriber's terminal equipment that are used for information transfer over the network. The functional groups are used to define the specific functions that are performed between each reference or access point. The reference points, located between functional groups, are where the ISDN signals are defined. This section will describe the principal components of this network, their functions and their respective reference points. The discussion will center around Figure 3.

FIGURE 3
ISDN INTERFACE REFERENCE MODEL



KEY

DSL	- DIGITAL SUBSCRIBER LINE
ET	- EXCHANGE TERMINATION AT CO SWITCH OR EQUIVALENT
LT	- LINE TERMINATION AT CO SWITCH OR EQUIVALENT
NT1	- NETWORK TERMINATION TYPE 1 (OSI LAYER 1)
NT2	- NETWORK TERMINATION TYPE 2 (OSI LAYERS 1, 2 & 3)
TA	- TERMINAL ADAPTER (ADAPTS A TE2 TO AN ISDN INTERFACE)
TE1	- TERMINAL EQUIPMENT TYPE 1 (ISDN INTERFACE)
TE2	- TERMINAL EQUIPMENT TYPE 2 (NON-ISDN INTERFACE)

3.5.2 As a general overview of the BRI interface, the two-wire DSL operates bidirectionally between the CO and the subscriber's premises at a rate of 160 kb/s. At the subscriber end, a network termination (NT) device converts the two-wire facility to four-wire to provide a passive bus-type connection to subscriber terminal equipment.

3.5.3 More specifically and as illustrated in Figure 3, a BRI ISDN begins at the CO where the DSL is affixed to the Line Termination (LT). The LT is essentially equivalent to the line card of the switch.[2] The actual termination of a DSL at the CO end is defined at the Exchange Termination (ET), which is the connection to the switching network. It is at this point that access to either packet-switched or circuit-switched networks is

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[2] The LT may also be located at any form of remote terminal (RT) extension of the CO, such as a digital loop carrier system, concentrator terminal or remote switching terminal.

provided. The reference point between the LT and the ET (physically located at the backplane of the CO or RT line card frame) is known as the V-interface, shown at the extreme left of Figure 3.

3.5.4 At the CO, the LT contains a master digital transceiver that is largely a mirror image of a slave digital transceiver located at the subscriber's end of the DSL. The subscriber's transceiver is contained within the NT. Both the LT and NT transceivers contain multiplexers and demultiplexers to combine and separate the 2B+D channels. The digital transceivers also perform a number of important signal processing capabilities to ensure accurate transmission of the digital signal over loop facilities.

3.5.5 To deal with reflections at cable plant impedance discontinuities (such as bridged taps or gauge changes) and to provide for bidirectional transmission, the receivers contain a hybrid with echo canceling capability. This feature removes echoes and crosstalk by comparing the transmitted and received bitstreams and canceling undesirable echoed signals, resulting in the overall elimination of the undesirable components and restoration of the original signal. Additionally, the receivers contain a post adaptive equalizer that assesses the impedance characteristics of different loop facilities and adjusts for the expected loop distortion factors. It then reshapes the incoming digital pulses to their original form based upon the expected distortion. Scrambling (temporary rearrangement of a bitstream to avoid repetitive patterns) is also employed as a further measure to reduce crosstalk within the paired cable. In summary, several relatively sophisticated signal processing techniques are used to ensure accurate delivery of the 160 kb/s signal.

3.5.6 Figure 3 shows the DSL extending from the CO to the subscriber's premises and terminating at the NT. The interface or reference point between the DSL and the NT is termed the U-interface. Physically, it is located by mutual agreement between the LEC and the subscriber.

3.5.7 The basic rate ISDN reference model provides for the division of the NT into two separate functional components, known as NT1 and NT2. (NT can refer to an NT1 or an NT2, or both.) An NT1 provides minimal functionality by establishing and maintaining an OSI (Open Systems Interconnection) Layer 1 connection, which involves only the basic physical/electrical connection and related communication protocols between each end of the DSL. An NT2 is optional and is used only when higher layer OSI functions (Layers 1, 2 and 3) are required. (OSI Layers are discussed in the following section, 3.6.) Only NT1s will be used in most BRI applications; NT2s will see use in higher capacity installations, particularly where the higher bandwidth PRI form of ISDN is required.

3.5.8 The NT1 is similar to network channel terminating equipment, or NCTE. As previously mentioned, it is a slave transceiver which operates under the control of the LT master transceiver located at the CO. The NT1 performs the conversion from the U-interface to the T-interface, which is used only for direct connection to subscriber or customer premises equipment (CPE) that is ISDN-compatible. The T-interface is a 4-wire interface and operates at a bit rate of 192 kb/s in each direction to facilitate the connection of multiple CPE devices in a bus configuration.

3.5.9 The reference point between the NT1 and the optional NT2 is also termed the T-interface. The NT2 interfaces directly to ISDN terminal equipment. This interface is known as the S-interface. It is essentially equivalent to the four wire T-interface. Because of the commonalties between the S and T-interfaces, sometimes both reference points are collectively termed the S/T-interface. NT2 devices can include appropriately-equipped PBXs, LANs (local area networks), ACDs (automatic call distributors), multiplexers and terminal controllers.

3.5.10 ISDN-compatible CPE is referred to as Terminal Equipment Type 1, or TE1. Non ISDN-compatible equipment is known as Terminal Equipment Type 2, or TE2. If TE2 is to be used with ISDN, it requires a conversion between the CPE and the T-interface of the NT1. This conversion is performed by a device known as Terminal Adapter, or TA. TAs can either be standalone devices or add-on component boards for existing data or voice terminal equipment. Certain TAs have the capability to transform, for example, an IEEE RS-232 data port of a personal computer and a standard two-wire voice frequency interface into the four-wire 192 kb/s T-interface for direct connection to the NT1. The interface point between the TA and the TE2 is referred to as to the R-interface.

3.5.11 In terms of ownership, it is expected that an LEC would provide the DSL network facilities up to the U-interface, *excluding* the NT1. The subscriber would be responsible for providing and maintaining the NT1 and the NT2 (if needed), any TAs and the TE1 or TE2 CPE devices.

3.6 OSI Layer Protocols

3.6.1 The OSI or Open Systems Interconnection reference model is integral to the information transfer aspects of ISDN. This section will generally describe the OSI structure and its role for ISDN.

3.6.2 The OSI model was developed by the International Standards Organization (ISO) to provide a common, yet flexible, framework to facilitate the transfer of message, signaling and management information in different data communications systems. It has since been adopted for use in telecommunications.

3.6.3 The basis for the OSI model is a seven layer hierarchy of information transfer operations. Each layer is defined in terms of its specific functions. The means of providing these functions within each layer are not specifically defined; they are left up to individual designers or users. The important aspect with respect to OSI standardization is that the defined functions are performed by each layer and that the proper information is passed between layers. This flexibility is the essence of the OSI model and is what makes it desirable from an information transfer perspective among different equipment or systems. Table 3 shows the OSI model and briefly describes the function of each of the seven layers.

TABLE 3
OSI SEVEN LAYER ARCHITECTURAL MODEL

Layer	Function	Description
7	**APPLICATION**	PROVIDES GENERAL PROCEDURES AND AGREEMENTS BETWEEN COMMUNICATION PARTNERS FOR AUTOMATED OR MANUAL PROCESSES INVOLVING COST ALLOCATIONS, ACCESS, SECURITY, SERVICE QUALITY, DATA SYNTAX & OTHER RESPONSIBILITIES.
6	**PRESENTATION**	PROVIDES FOR GENERAL REPRESENTATION OR SYNTAX OF THE INFORMATION BEING EXCHANGED INCLUDING TRANSFORMATION (ENCRYPTION, DECRYPTION, COMPRESSION, EXPANSION), CHARACTER CONVERSIONS, FORMATTING, ETC.
5	**SESSION**	PROVIDES FOR THE OVERALL MANAGEMENT OF A DATA OR INFORMATION EXCHANGE SESSION FROM CONNECTION TO RELEASE, INCLUDING ORGANIZATION, SYNCHRONIZATION OF DIALOG, & EXCEPTION REPORTING.
4	**TRANSPORT**	PROVIDES FOR THE TRANSPARENT TRANSFER OF DATA OR INFORMATION THROUGH OPTIMAL USE OF RESOURCES, MINIMAL COST & SERVICE QUALITY CONSIDERATIONS, ALL INDEPENDENT FROM NETWORK OR OTHER ROUTING CONSIDERATIONS
3	**NETWORK**	PROVIDES THE MEANS TO ADEQUATELY ESTABLISH, MAINTAIN & TERMINATE CONNECTIONS AMONG A VARIETY OF NETWORK RESOURCES, RELIEVING THE TRANSPORT LAYER OF NETWORK-SPECIFIC DETAILS.
2	**DATA LINK**	PROVIDES THE FUNCTIONAL AND PROCEDURAL MEANS TO ESTABLISH, MAINTAIN AND RELEASE A CONNECTION, INCLUDING ERROR CONTROL, FRAMING AND SYNCHRONIZATION.
1	**PHYSICAL**	PROVIDES FOR THE ELECTRICAL & MECHANICAL CHARACTERISTICS NEEDED TO ESTABLISH A DATA CONNECTION, SUCH AS BIT RATE, CHANNEL STRUCTURE, TIMING, ERROR RATE, ETC.

3.6.4 Each OSI layer uses the services and information provided by the lower layers in conjunction with its own functions; it then provides further processing and furnishes information through its upper interface to a higher level layer, where it is used to perform that layer's functions.

3.6.5 For the BRI ISDN, the network provides, at a maximum, only the three lowest layers of the OSI model. These layers (numbered 1 through 3) are referred to as the lower layer functions; layers 4 through 7 are referred to as the higher layer functions. Most BRI applications will only use the Layer 1 services.

3.7 Powering

3.7.1 In theory, power for BRI ISDN service to the NT can be provided either over the network or locally by the subscriber. It is anticipated, however, that in the U.S. the NT end of a DSL will be locally powered using commercial power sources with a battery backup, both provided by the subscriber. A low power consumption mode at the NT is provided internationally through CCITT (International Telegraph and Telephone Consultative Committee) Recommendation I.430 (ISDN User-Network Interfaces: Layer 1). But due to an apparent industry preference for customer powering in the U.S., this feature was not adopted in ANSI T1.605.[3]

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[3] ANSI Standard No. T1.605-1989. *ISDN Basic Access Interface for S and T Reference Points (Layer 1 Specification).*

3.8 DSL Activation/Deactivation

3.8.1 A DSL may be operated in one of two modes: continuous activation or activation upon call request. In the U.S., it is expected that most DSL facilities will be continuously activated from time of system turn-up. The reasoning is that the expected delay and complexity involved in startup on a request basis would be unsatisfactory to a subscriber, in spite of the potential NT power consumption savings that could result from the deactivated mode.

3.9 Sealing Current

3.9.1 In standard analog, circuit-switched POTS (plain old telephone service) loops, a steady state DC current flows through the subscriber pair when initiated by an off-hook action at the CPE. The current is used for signaling purposes (to detect an off-hook condition by the CO switch) and to provide a limited amount of network-supplied power to operate CPE. A side benefit of this current flow is that it causes the DC resistance of the loop to be minimized at splice joints. Without occasional current flow, these joints tend to oxidize producing a significant increase in loop resistance, leading to resistive unbalances. This can cause increased circuit noise. In fact, for special service circuits not requiring DC current for signaling, a common practice is to apply a DC current around 10 milliamperes to ensure minimum resistance through the splice points in the loop. This is called a sealing current.

3.9.2 With BRI ISDN, signaling is performed digitally over the D-channel and, in general, all powering will be local. As a result, no DC current flow will occur in the DSL and, therefore, splicing resistance will not be minimized. This will be a problem for long loops in particular. No specific solution has yet been developed where loop resistance becomes excessive. (See Section 4.1 for loop resistance recommendations.) One option is to use a DC termination on the NT1 that will permit a continuous loop current to be supplied from the LT at the CO. However, this is not desirable from a CO battery capacity and energy cost perspective. Application of a pulsed DC current from the CO is a second solution since splice resistance drops rapidly following a current pulse and maintains its minimum value for some time following the termination of current flow.

3.10 U-Interface Frame Structure

3.10.1 The digital bitstream between the CO and the subscriber for the BRI U-interface has a rate of 160 kb/s and uses the 2B1Q line code, previously described in Section 3.4. The organization or frame structure for this segment of an ISDN connection is based upon a frame that contains 240 bits, or 120 quaternary symbols[4] (quats). This frame passes in a nominal time period of 1.5 milliseconds (ms), giving the 160 kb/s bit rate. The frames are further organized into superframes, which each contain eight standard frames. The superframes are 12 ms in duration. The frame and superframe are depicted in Figure 4.

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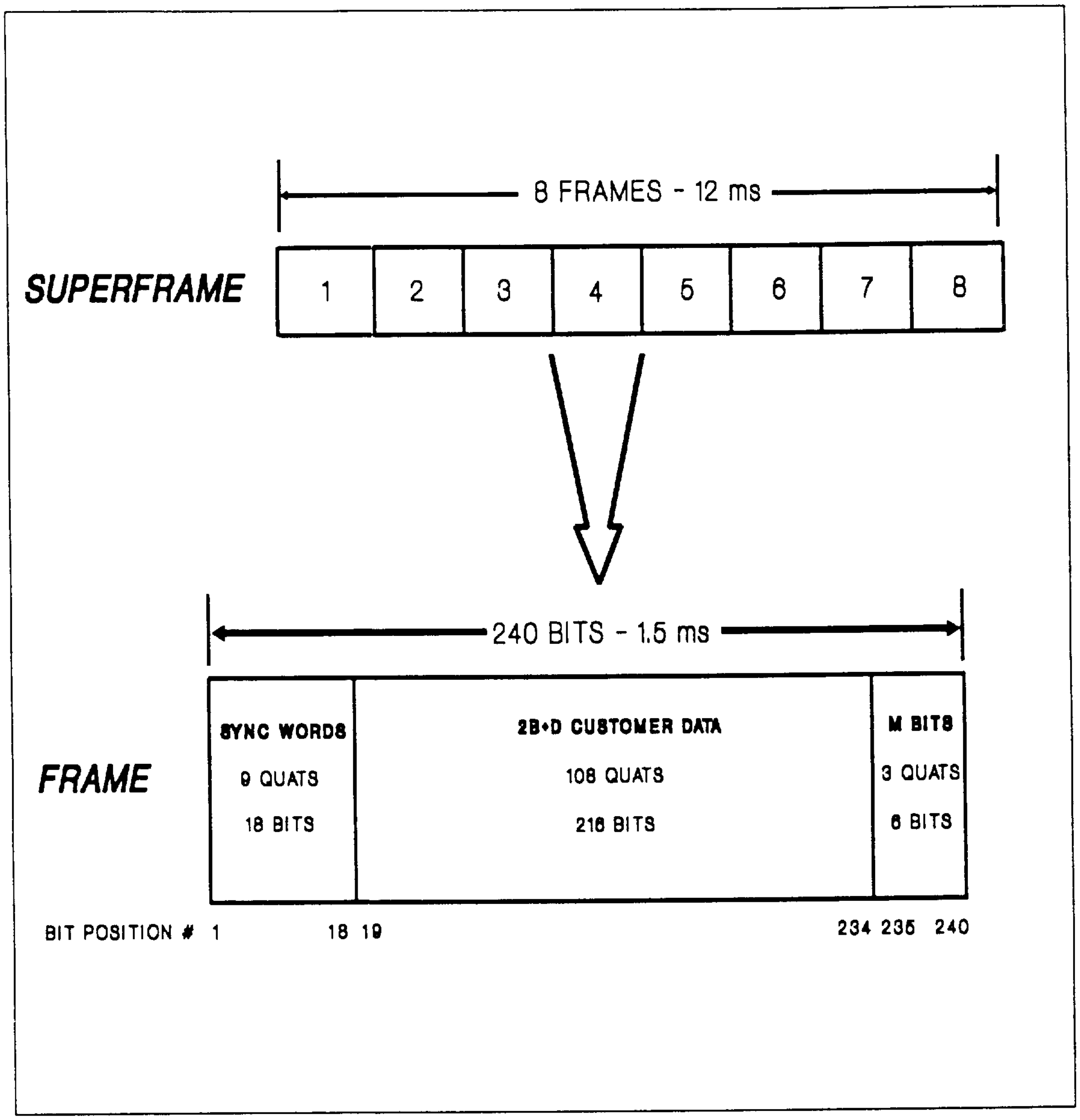
[4] Each quaternary symbol, or quat, for the 2B1Q line code (i.e. +3, +1, -1 and -3) consists of two bits, as shown in Table 2.

FIGURE 4
U-INTERFACE FRAME STRUCTURE



3.10.2 As Figure 4 shows, each frame contains 9 quats for synchronization, 108 quats for the 2B+D user data and 3 quats for maintenance or overhead. The overhead bits are sometimes referred to as M bits; they are organized on a superframe basis, giving 24 quats or 48 bits per superframe for a variety of functions. These include: an embedded operations channel[5] (EOC) at 2 kb/s that utilizes 24 bits, a cyclic redundancy check[6] (CRC) using 12 bits, and far end block error (FEBE) detection by the CRC using one bit. The remaining eleven bits within each superframe are for miscellaneous overhead and status functions (such as powering and activation); some are reserved for future overhead use.

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[5] The embedded operations channel (EOC), which is part of the 16 kb/s M-channel, supports communication needs between the LT at the CO and the NT at the subscriber.

[6] The cyclic redundancy check (CRC) is an error checking procedure that performs mathematical calculations on transmitted and received signals.

4. ISDN PROVISIONING

4.1 Loop Limitations

4.1.1 Because of the relatively high bit rate used by the BRI for loop purposes, loop limitations have been developed to ensure the integrity of the transmitted data pulses. These requirements[7] were designed so that approximately 99% of the twisted pair, *non-loaded* loops in North America could be used for BRI ISDN provisioning without modification. Loaded loops do not comply because they do not permit adequate transmission of the digital signal. This is because the load coils act as low pass filters having an upper cutoff around 3 kHz, significantly attenuating the 2B1Q signal, whose spectral energy peaks near 40 kHz. The principal loop specifications are noted in Table 4.

TABLE 4
BRI LOOP LIMITATIONS

CHARACTERISTIC	LIMITATION
Maximum Loss @ 1004 Hz	8 dB
Maximum Loss @ 40 kHz	42 dB
Maximum DC Resistance	1300 Ω
Maximum Length (nominal)*	5.5 km (18 kf)
Loading	None Permitted
Bridged Taps-Sum	≈1.5 km (5 kf) Max.

* Based upon several combinations of 22, 24 and 26 gauge cable. The precise maximum length for a given situation is based upon the particular cable gauges and lengths of both the loop and associated bridged taps. **Maximum loss and resistance values are the determining factors.**

4.2 Loop Extension Options

4.2.1 As Table 4 indicates, the ISDN BRI can only be reliably offered on metallic loops with a nominal length of 5.5 km (18 kf) or less and without loading coils. Because many rural areas contain subscribers outside this region, additional methods must be employed to satisfactorily offer ISDN at a greater range. As with analog loops, electronic devices can also be used with ISDN to permit significant extension of a loop's range. Several options are depicted in Figure 5.

4.2.2 One option in Figure 5 includes digital line repeaters that would regenerate the 2B1Q signal over the DSL, similar in function to T1 span line equipment. These are technically feasible and are not precluded by ISDN technology plans. However, it is not expected that they will be

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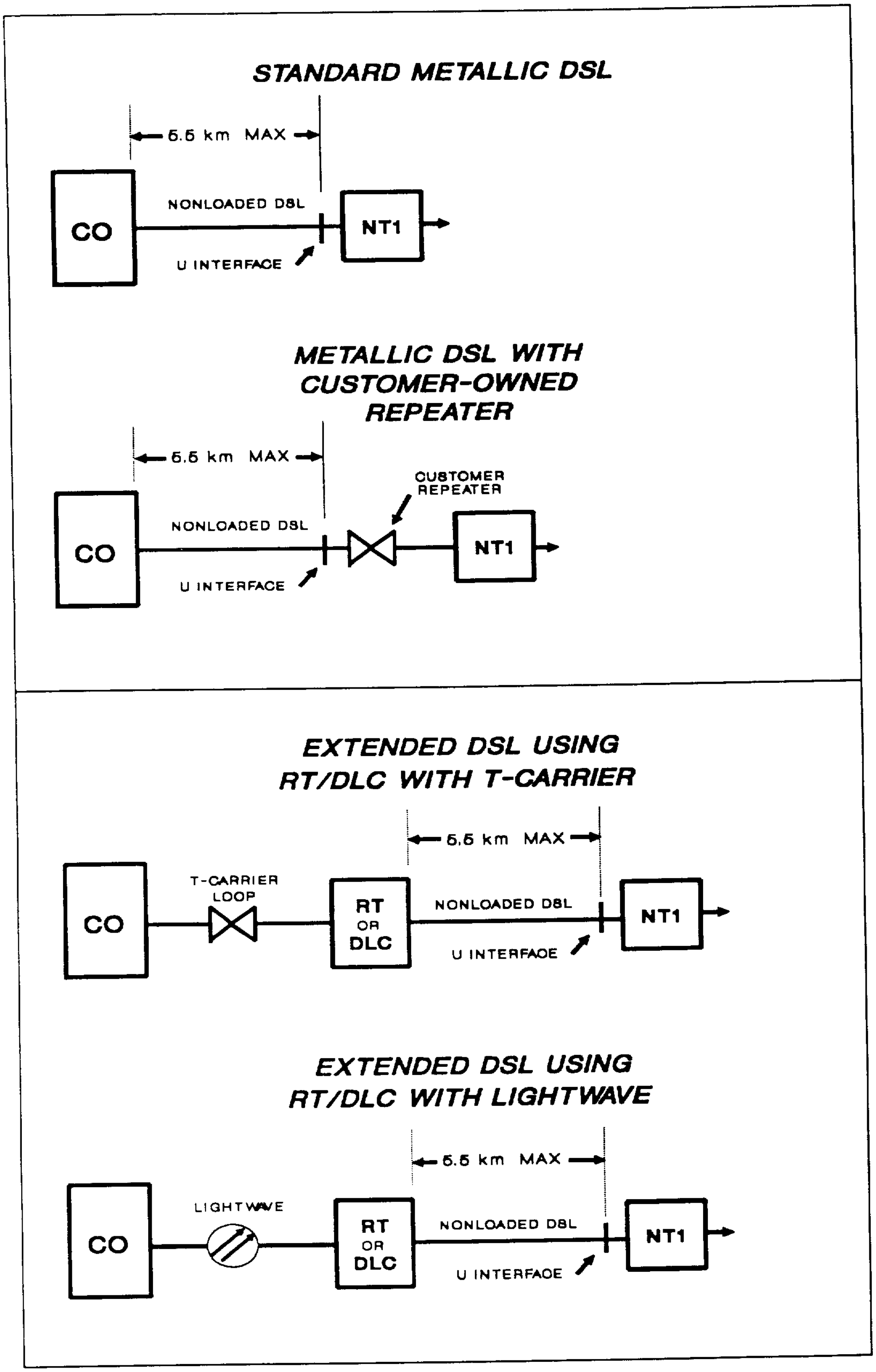
[7] As specified in ANSI Telecommunications Standard ANSI T1.601-1988.

FIGURE 5
OPTIONS FOR DEPLOYING ISDN



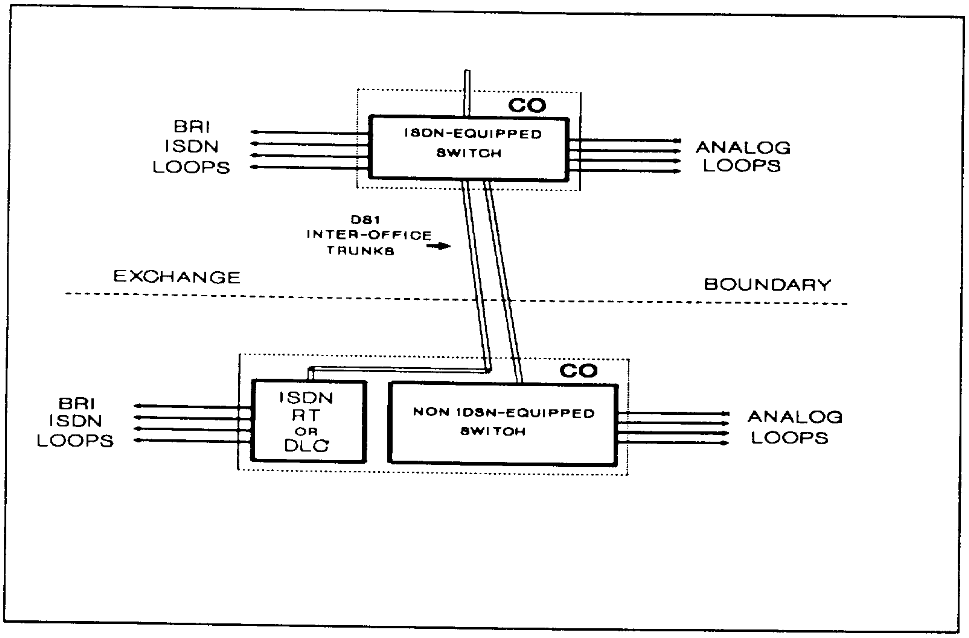
widely used by LECs, except in applications where economics suggest that they are the only viable alternative. DSL repeaters could also be used by certain subscribers as CPE to extend the range from the U-interface to the NT1 in campus-type environments where the plant is owned and maintained by the customer. Consequently, the deployment of electronic devices such as digital loop carrier (DLC), concentrator or remote terminals (RTs) is viewed as the primary option available, where economically justified, to facilitate widespread provisioning of BRI ISDN. It should also be noted that the transmission systems (whether T-carrier or lightwave) used to connect the DLCs or RTs to the CO will require 3 DS0 channels *per DSL* to provide for transport of the entire 2B+D signal.

4.2.3 Electronic devices used to extend the range of the 2B1Q signal cannot be of the same type used in conventional analog plant; they must be ISDN-compatible and be designed to operate and interface with an ISDN-compatible CO switch. DLC and RT plant of this type are beginning to emerge now that ISDN standards are becoming finalized.

4.3 Overlay Networks

4.3.1 As ISDN is initially provisioned, many exchanges (particularly smaller, rural exchanges) will not have a sufficient number of subscribers to justify the upgrade of the CO equipment and the outside plant facilities to ISDN compatibility within that exchange. For example, the CO switch technology serving that exchange may not even have the capability to be equipped to offer ISDN, and switch replacement at that time would cause a significant economic penalty. Or, the small number of subscribers desiring ISDN may not justify the hardware and software additions that are necessary for an ISDN-capable switch. In spite of these considerations, options exist that would permit BRI ISDN to be deployed in these situation. Figure 6 depicts an option known as overlay networks.

FIGURE 6
EXAMPLE OF ISDN OVERLAY NETWORK



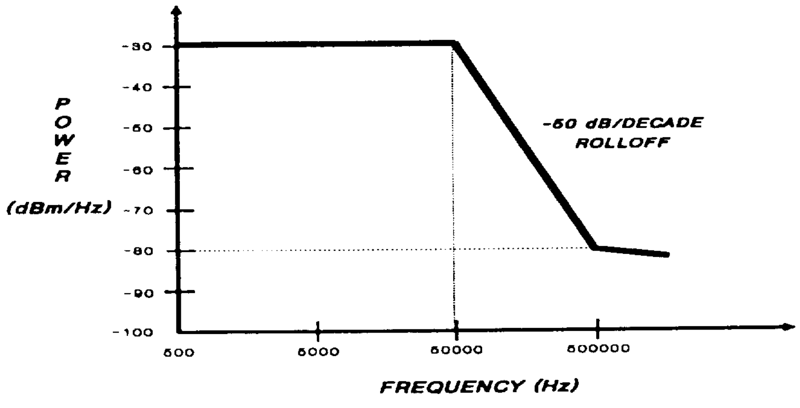
4.3.2 Figure 6 shows the deployment of ISDN through the extension of facilities from an IDSN-equipped exchange to serve portions of a nearby, *non* ISDN-equipped exchange. The use of either DLCs or RTs served from the ISDN exchange makes this deployment possible. This solution is similar to that utilized for DSL loop extension where ISDN facilities are needed beyond their maximum metallic range, as discussed in the section 4.2.

4.3.3 The overlay concept may even be extended one step further. If the 5.5 km maximum loop limitation does not permit reaching the desired subscriber locations from the overlay network as in Figure 6, electronic loop extension may be employed as previously discussed. This generally requires that the RT and its associated DLC both have ISDN capabilities.

4.4 Interference to Other Loop Transmission Systems

4.4.1 The 2B1Q signal used for transmission of the BRI ISDN is of a relatively high power level and broad bandwidth. Figure 7 shows the maximum spectral parameters, in terms of dBm per Hz, as defined by current standards. While this signal is not expected to cause interference to voice frequency signals, it may cause problems with analog station carrier systems in certain applications. This is due to the overlap and interaction of the station carrier frequencies with that of the frequencies resulting from use of the DSL line code.

FIGURE 7
MAXIMUM POWER SPECTRUM DENSITY OF 2B1Q SIGNAL



4.4.2 Analog station carrier systems typically operate in the frequency band range from 8 kHz to 160 kHz. The peak energy of the 2B1Q signal is at 40 kHz with the upper reaches of its fundamental and harmonic components extending beyond 40 kHz. With the information provided in Figure 7, over a 6 kHz bandwidth (typical for station carrier) it can be calculated that the maximum power from the 2B1Q signal can be as high as approximately +8 dBm, or roughly 6 milliwatts.[8] Crosstalk coupling (specifically, NEXT), if both systems are contained within the same cable at sufficient proximities, could cause the high output 2B1Q signal to interfere with the lower level receive signal of the station carrier.

4.4.3 Preliminary calculations suggest that placement of both the analog carrier and the ISDN 2B1Q systems within the same small cable, or within the same cable binder groups of larger cables, will likely result in intolerable noise conditions on the station carrier. Depending on cable size and NEXT characteristics, placement of the systems in non-adjacent binder groups of larger cables may provide acceptable operating conditions. Use of screened cable would likely present no problems with noise interference to the station carrier.

4.4.4 While laboratory testing is complete, practical operating experience has yet to be gained to learn the exact extent and under what conditions that DSL and station carrier systems can co-exist within a single cable. Certain newer analog carrier systems may be compatible with the 2B1Q signal. As BRI ISDN, or equivalent digital loop transmission schemes, begin to be deployed on rural networks, more information will become available and it is expected that more specific operating recommendations will then be furnished.

4.5 Central Office Equipment Considerations

4.5.1 In addition to numerous transmission considerations, provision of BRI ISDN within an exchange or service area requires that significant enhancements be made at the CO switch. This section will briefly highlight BRI ISDN from a switching systems perspective in order to round out the discussion. It should be noted that differences exist between the BRI and PRI forms of ISDN in terms of the needed CO additions and configurations. Details on the central office aspects of ISDN provisioning will be left to other, more CO-specific documents.

4.5.2 To offer ISDN CO switch capability, several additions are required. First, the switch must be digital and, from a software perspective, the generic software residing in the switch must be replaced or upgraded to one having BRI ISDN capability. Some, but not all, CO vendors currently offer BRI ISDN software and hardware upgrades, or have announced release dates for such products in the near future.

4.5.3 Secondly, the analog line equipment serving those subscribers desiring ISDN must be replaced with those designed for 2B1Q operation and other functions needed for DSL operation. Fundamental differences exist between the standard analog line card and the DSL card in terms of signaling, supervision, battery, test, etc. Some switch vendors have previously produced "ISDN" line cards that employed a nonstandard and proprietary line code known as alternate mark inversion, or AMI. Since that time, the 2B1Q code has been officially adopted in the U.S. as the

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[8] -30 dBm equals 10^{-6} watts/Hz. Over a 6 kHz spectrum the composite energy is 6000 Hz x .001 milliwatts per Hz, equaling 6 mW. This equates to roughly +8 dBm.

standard basic rate line code through ANSI Telecommunications Standard T1.601-1988. AMI-type line cards are not compatible with the 2B1Q standard used on NT (network termination) equipment.

4.5.4 Because the BRI ISDN contains the ability to access either packet-switched or circuit-switched networks, capability for this feature needs to be provided. Hardware additions such as a packet switching unit or packet handler are integral to these functions.

4.5.5 If it is desired to offer ISDN services beyond the exchange in which the ISDN subscribers reside, then Signaling System #7 (SS7) also will need to be installed at the ISDN serving office. This is necessary because ISDN operates on a common channel signaling basis whereby signaling information for trunking purposes is transmitted on separate channels, unlike conventional trunks that utilize in-band signaling. Implementation of SS7 will additionally require compatible software, hardware and SS7 communication links to other switching offices.

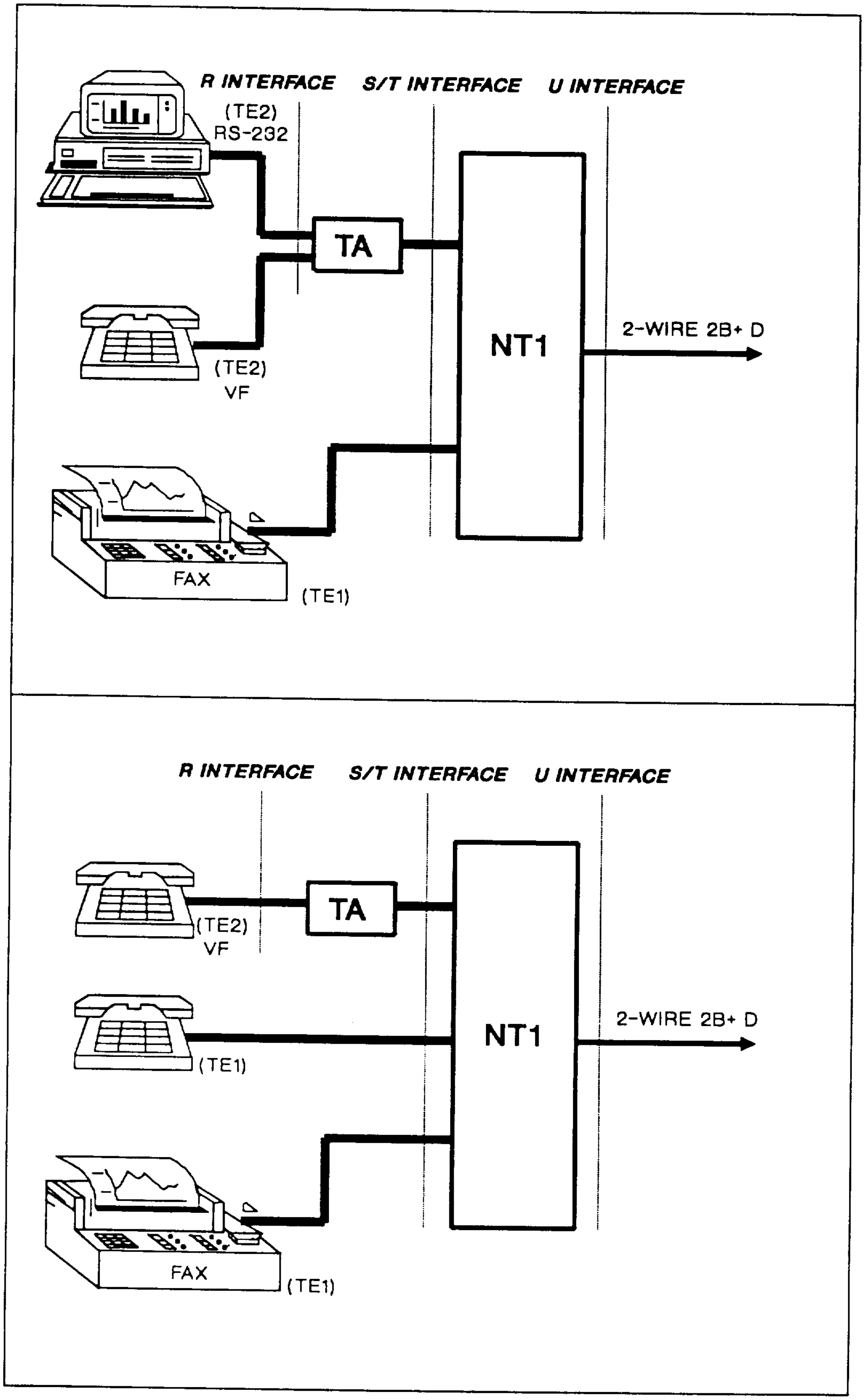
5. ISDN APPLICATIONS

5.1 This section will briefly describe some potential applications for which BRI ISDN technology may be used. Although these applications can be largely characterized as being the responsibility of an ISDN subscriber, a general understanding of basic subscriber uses is considered beneficial to the network provider.

5.2 As discussed in Section 2, the BRI form of ISDN can be portrayed as simply a form of digital multiplexing, or pair gain. This view will likely be shared by many ISDN subscribers in response to this new transport technology. They will see an ISDN DSL as an opportunity to simultaneously connect to a standardized interface and operate several data or voice communication devices with only one telephone line. Subscribers will also expect to realize economic benefits commensurate with the use of this single DSL as compared to several, separate voice and data subscriber lines.

5.3 The specific characteristics of a subscriber's application will, in large part, depend upon to what extent the communication devices or CPE and their associated communications software are directly ISDN-compatible. If they are not, use of TAs will be required. CPE that is compatible may be connected directly to the 4-wire S/T-interface. Non ISDN-compatible devices must be connected using TAs, which provide an interface from standard data or voice outputs to the S/T-interface. The configurations in Figure 8 show two possible applications with voice, facsimile and personal computer terminal equipment. The uppermost figure depicts a single TA having both voice and data inputs, thereby facilitating the use of the two non-ISDN terminals.

FIGURE 8
BRI ISDN APPLICATIONS



6. RECOMMENDATIONS

6.1 Subscriber demand for BRI ISDN at this time appears to be rather limited. Although several dozen, well publicized trials are currently underway nationally, many of these trials are with large organizations using PRI ISDN. It is particularly difficult to determine when BRI ISDN may see interest, application and growth in rural areas. In spite of this uncertainty, many REA borrowers may want to consider planning for their loop networks and CO equipment now for the capability of providing BRI ISDN to their subscribers in the future.

6.2 Because of the strict loop limitations over which ISDN operates, minimizing loop length in anticipation of BRI offerings is a primary consideration. The desire to be well positioned for future ISDN provisioning should, of course, be balanced with the economic considerations that may accompany such positioning. Positioning now for BRI ISDN could translate into increased up-front costs in certain instances, although in some cases this cost penalty may be small. For example, DLC or RT installations can now be used to minimize loop lengths in preparation for future ISDN deployment. These designs should be compared to the traditional all copper physical loops to determine cost differences. In any event, each situation must be individually assessed. It is possible that higher up-front costs initially can ultimately translate into lower life-cycle costs.

6.3 The following loop plant recommendations are offered to those LECs wishing to plan for ultimate provisioning of BRI ISDN.

1) Adopt a maximum nominal loop length planning goal of 5.5 km (18 kf).

Note - the nominal 5.5 km maximum length is affected by gauge and bridged tap considerations. The determining factors are the maximum resistance and maximum loss values as shown in Table 4.

Where currently economically justified, strategically place DLC/RT units to permit loops to meet this length limitation. Where placement of DLC/RTs cannot be currently justified, locate serving area interface (SAI) splice points so that *future* placement of DLC/RTs will permit loops to meet this maximum length requirement.

2) Strive to eventually eliminate all loaded loops.

Limit use of load coils by using the methods described in 1), above.

3) Strive to eventually eliminate all loop extension equipment.

Limit maximum DC loop resistance to 1300 ohms by using the methods described in 1), above.

4) Minimize use and length of bridged taps.

Bridged taps should be avoided to the maximum practical extent. Where elimination is not possible, bridged taps should be limited to a maximum of 1.5 km, total.

5) Deploy any new analog station carrier systems with discretion.

Future provision of BRI ISDN could either render this plant obsolete and/or create operational problems if the carrier system is not designed to be compatible with the 2B1Q signal.

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