

## DIGITAL SPAN LINES

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#### 1. GENERAL

1.1 This section provides REA borrowers, consulting engineers and other interested parties with information and recommendations on digital transmission systems. The section specifically covers digital span lines. Ancillary equipment such as automatic protection switches (APS) and span line interrogation are briefly covered also. Refer to TE&CM Section 950 for an overview and summary discussion on digital transmission, and refer to TE&CM Section 951 for a glossary of digital transmission terminology. Digital terminals, multiplexers, terminal maintenance systems and alarms are covered in TE&CM Section 954.

1.2 Digital span lines are used to transport digital bit streams between terminal locations. In telephony applications, span lines are generally used to transport digital bit streams between ends of digital carrier terminal equipment (channel banks), digital central office equipment, and integrated digital carrier-concentrator equipment. For the purpose of this discussion, a digital span line consists of telephone cable pairs and the necessary equipment to transmit a digital bit stream between two points. Unless otherwise indicated, a span line generally refers to a T1 type span line operating at 1.544 megabits per second (Mb/s). Digital span line equipment generally consists of span terminating equipment and line repeaters. Ancillary equipment includes housings, automatic protection switches, span line interrogation, order wire and similar equipment. The term ancillary equipment is used to describe the support hardware and subsystems that are a secondary part of the system, but are not part of the primary digital transmission and regeneration process. Digital span lines are generally arranged to accommodate 24 voice channels (or data equivalent) at 1.544 Mb/s, or multiples of 24 channels. Certain interface criteria are specified or otherwise implied by equipment specifications, application, or commonly used terminology. REA Specification PE-60 outlines some of these requirements including the 1.544 Mb/s bit stream with defined

characteristics such as pulse density, height, width and shape. Additional interface information is outlined in AT&T Advisory No. 34, Interconnection Specification for Digital Cross-Connects.

## 2. SPAN LINE TECHNIQUES AND CHARACTERISTICS

2.1 Span Concept: Digital transmission systems applied to paired telephone cables are built on a modular span concept. A span line is essentially a string of regenerators between two locations (generally central office buildings) with a specified interface at each end. A span is the sum of all span lines between these two locations. Figure 1 illustrates the span concept. Span lines are established between CO buildings A-B, B-C and C-D. For direct digital transmission paths between other points, span lines are patched through intermediate points. For example, to provide direct service between office A and office D, span lines are patched through offices B and C. The specified interfaces allow span lines to be joined on a universal basis, and can be patched automatically or manually into other span lines. For instance, if service between A and D were lost because of a span line failure between B and C, other (spare) span lines between B and C could be patched (automatically or manually) at B and C to complete the operating transmission path between A and D. Spare span lines are generally included in digital transmission system applications for that purpose.

2.1.1 The T1 span line operates at 1.544 Mb/s. This bit rate is called DS1, or digital signal at the first level. Span lines are terminated with a specified universal interface or crossconnect point at each end. The DSX1 is the specified interface for T1 span lines and other DS1 system modules. The pulse stream bit rate and the pulse density, height, width and shape are defined by the term DSX1. Span lines are "lossless" lines in that all input levels and output levels are the same. Spare span lines can be patched (automatically or manually) at DSX1 locations because of this apparent zero-loss line and universal interface.

2.2 Span Line Equipment: Figure 2 illustrates a typical arrangement of channel bank, automatic protection switch (APS), and T1 type span line equipment. Span line equipment is usually categorized broadly as span terminating equipment (inside equipment) and line repeaters (outside equipment). The DSX1 interface jacks are generally considered part of the span terminating equipment. The functional parts of T1 type span line equipment will be outlined.

2.2.1 Span Terminating Equipment: Span terminating equipment is illustrated in Figure 3. It generally consists of a span power converter, an office repeater (receive regenerator only), line access units (DSX1 jacks), equalizer and attenuator pads for cable and DSX1 interface, protective devices and associated hardware.

2.2.1.1 Span Power: Span line power supplies may be large dc-dc converters that are common for several span lines. However, in rural telcos, it is likely that a small span power converter will be an integral part of the span terminating equipment dedicated to one span line. The most common line powering voltage is +130 volts to the transmit side and -130 volts to the receive side of the span line. This provides 260 volts for the simplex power loop. Span power current is adjusted and maintained at a fixed value (constant current) with a current regulator in the transmit (positive) line side. To improve system operation during electrical surge conditions, REA requires current limiting to 200 mA in both sides of the line. This is generally provided by a threshold limit circuit in the receive side and the current regulator in the transmit side. As the simplex loop current passes through the repeater, a fixed voltage is established and regulated by a zener diode to power that repeater (Figures 4A and 5). In effect, the zener diode acts as the local power supply for the repeater. The office repeater is generally powered by a zener diode in the span power loop as illustrated in Figure 3. The power test points (generally 10 ohm resistors) are used to measure the dc span line loop current, and the ac induction current in the span line.

2.2.1.2 Office Repeater: The office repeater is essentially one-half of a line repeater. It contains a receive regenerator only.

2.2.1.3 Line Access Units: A T1 type span line is terminated in DSX1 jacks. These DSX1 jacks may be integral to the span terminating equipment for each span line, or may be large DSX1 jackfields located separate from the span terminating equipment.

2.2.1.4 Equipment Protection: Office repeaters and associated electronic hardware are protected in much the same manner as line repeaters. The multistage protection consists of shunt high voltage gaps such as gas tubes (not shown), series current limiting resistors (R), and shunt low voltage devices such as varistors or zener diodes. The functions of these devices are discussed further in Paragraph 2.2.2.5 covering line repeater protection.

2.2.1.5 Miscellaneous: Equalizer and attenuator pads located in the span terminating equipment and/or separate DSX1 jackfields are used to provide proper levels at the DSX1, inside equipment, and outside plant interface. The office repeater also contains an interrogation circuit in the regenerator output transformer. The interrogation circuit is omitted from the office repeater illustrated in Figure 3, but is included in the line repeater illustrated in Figure 4A.

2.2.2 Line Repeater: A T1 type digital line repeater contains two regenerators, a power supply, interrogation circuits and electrical protection. Figure 4A illustrates a typical line repeater and Figure 4B shows an expanded view of the regenerator.

2.2.2.1 Regenerator: The heart of the digital line repeater is the regenerator. In a present day digital repeater, much of the regenerator is contained in one integrated circuit. Figure 4B illustrates a typical regenerator. It consists of an automatic line build out (ALBO) network, equalizer and amplifier to boost and reshape the incoming pulses. This is followed by a threshold detector and a balanced pulse regenerator. A clock extracts pulses for precise timing and a peak detector feedback loop controls the amplification and equalization (shaping).

2.2.2.2 As the pulses are transmitted along the cable, they become weak and distorted. Controlled by a peak detector in a feedback loop, the ALBO, equalizer and amplifier use analog techniques to amplify and reshape the weak incoming signal. The amplifier output signal is then at a level and shape that can be viewed as pulses. The regenerator will then sample the incoming signal at 1,544,000 times per second (for DS1) to determine if there is a pulse or a no-pulse condition at each timing interval. If there is a pulse present at the input, a new pulse will be regenerated at the output. The decision level is controlled by a threshold detector within the regenerator. The 1.544 Mb/s sampling rate is controlled by a precise clock (tuned circuit) which is driven by pulses extracted from the incoming signal. So that the repeater clocks will not drift in frequency due to a long absence of pulses, a limit is placed on the number of consecutive zeros (no-pulse condition) that can be transmitted by terminal equipment. No more than 15 consecutive zeros are transmitted at the DS1 rate. Terminal equipment is generally designed to transmit a large pulse density during idle or low activity conditions to minimize clock drift or timing jitter.

2.2.2.3 Repeater Power Supply: Digital line repeaters are powered by a constant current simplex loop as illustrated in Figure 5. As the current passes through the line repeater, a zener diode establishes a constant voltage drop to power the repeater electronic circuits. (Refer to Figure 4 for a more detailed illustration of the line repeater.) Depending on the model, repeaters require 60, 100 or 140 mA simplex loop current. The voltage drop across each line repeater is about 8 to 12 volts, depending on the span loop current and the specific model repeater. The span line power is fed from each end of the system (central offices or other locations) on a simplex basis (tip and ring of a pair in parallel) to a power loop point, and return. The trend is toward lower current. Where there is a mixture of repeaters in a span line, the low current repeaters can be operated at the higher current values. The repeaters must function properly with induced 60 hertz ac longitudinal current in the cable pairs and repeaters. REA specifications require that T1 type digital repeaters function properly with 50 mA rms of ac. (This equates to a peak value of 70.7 mA for a 60 hertz sine wave, and may exceed the dc powering current.) A large value capacitor is placed across the zener diode to improve the immunity to 60 hertz current in the repeater.

2.2.2.4 Repeater Protection: The multilevel protection incorporated into a digital line repeater serves as an example of the electrical protection used with a wide variety of electronic equipment. This is illustrated in Figure 4A. High voltage gap devices (A) are used to limit the voltage across the line terminals. There are usually 350 volt 2 element or 3 element gas tubes. Series resistors (B) provide current limiting for lightning and electric system fault currents flowing through the repeaters. These resistors are usually 5.6 ohms each. Low voltage limiting devices (C) are placed across the input and output of sensitive electronic circuits. These are usually zener diodes or varistors. The high voltage gaps and series resistors are coordinated; as the surge current through the repeater increases, the series resistors provide enough voltage drop across the repeater to activate the high voltage protector gaps which bypass large surge currents around the repeater or to ground. Voltage differences at repeater inputs and outputs (due to current differences in tip and ring conductors) are low voltage limited or clamped to minimize damage to sensitive electronic circuits within the repeater.

2.3 Automatic Protection Switch: An automatic protection switch (APS) "protects" the digital system from failure by switching traffic to a spare span line in the event of a failure in the systems main span line (Figure 2). APS were developed initially for high density analog radio systems to achieve very high service reliability. The inherent nature of digital systems provided for low cost APS systems to protect small channel quantities. Digital APS systems are available for paired cable systems, optical fiber systems and radio systems. They are arranged to protect in levels or groups, beginning at the basic DS1 bit rate. This discussion will be limited to APS applied to T1 type span lines (DS1). Similar techniques are used at higher bit rates.

2.3.1 APS systems monitor the incoming DS1 line signal for errors (bipolar violations). When the predetermined error rate is exceeded, the APS causes the traffic on the primary or main span line to be transferred to a spare span line automatically. Thus, the digital bit stream is transferred to an alternate path when the main path becomes unusable.

2.3.2 Early APS used simple error detection techniques, used mechanical relays for the switching paths, and required manual restoration. Several problems surfaced with these early APS. Simple error detection may cause the bit stream to be prematurely switched due to a momentary disturbance (lightning surges, etc.). Once the switch is made, the spare span line is no longer available for backup of other span lines if manual restoration is required -- even if the main line is operating satisfactory. Relay switches require a relatively long switching interval (5 to 50 milliseconds) leaving the main and spare line repeaters without incoming pulses to maintain proper gain (ALBO repeaters). In the absence of incoming pulses, the increased repeater gain may cause the repeater to respond to

pulses from other span lines via near end crosstalk coupling and generate excessive errors. A transfer may be initiated, but may be inhibited before transfer at both ends is completed.

2.3.3 Improvements were made, and available APS ranged from simple relay switches to high speed electronic systems. With improved characteristics, relay switches were used with varying degrees of success in terminal-to-terminal applications. All relay switches lacked some of the characteristics necessary for universal interface and sectional application. The gap in costs between the relay and electronic APS began to narrow. A review of the technical and economic considerations led to an REA specification for a universal APS applied on a sectional basis.

2.3.4 REA Specification PE-60c covers a universal APS for T1 span lines. The specification requires a high level of error detection, fast transfer and automatic restoral. The term "universal" refers to the requirement that the APS can be placed between span lines and channel banks without external control signals (such as a clock, transfer command, etc.). There is no requirement for a universal "language" (command signals in the DS1 bit stream) that would ensure end-to-end compatibility. Industry agreement could not be reached in this area. However, the two APS now on the REA List of Materials are end-to-end compatible.

2.3.5 Requirements for APS are outlined in REA Specification PE-60c and in the AT&T "T1 Outstate Automatic Protection Switching Requirements". Some of the APS characteristics are noted here. The DSX1 is the standard interface. Control signals are contained in the DS1 bit stream. The switching elements are semiconductors. Errors are monitored on the main and spare line. Transfer is initiated after the main line is determined to be faulty and the spare line is determined to be satisfactory. Automatic restoral to the main line is required when the main line becomes satisfactory for traffic. The APS will not initiate transfer due to a brief "burst" of errors. Transfer is rapid. "Keep-alive" bit streams are supplied to all span lines not carrying traffic except during the very short transfer period. The keep-alive signal is generated within the APS, and is substituted for an absent DS1 line signal. A channel bank failure will not initiate a transfer. Each section of the "protected" span line stands alone. Incoming bipolar violations are removed, resulting in a violation-free output signal. In a string of several protected sections, only the faulty section will be transferred. The other spare lines remain available for protection of other span sections. Priority of line transfer is assigned by the operating telco. As a maintenance tool, the APS provides an alarm and registers a local indication of failure and transfer.

2.3.6 Since the APS removes bipolar violations, span line interrogation must be done on a section-by-section basis. It is not possible to interrogate through an intermediate APS location at this time. The APS does make provision for maintaining the interrogation bipolar violation patterns in a looped mode. Both the transmit and receive regenerators can be interrogated from either end of a section with a looped interrogation system and APS wired for the looping mode.

2.4 Span Line Interrogation: Digital line repeaters and office repeaters contain interrogation circuits so that they can be tested from a distant location. This is an out-of-service test. This capability is provided by a third winding in the repeater output transformer (see Figure 4A). A digital bit stream containing specific bipolar violation patterns is generated at the central office and transmitted down the span line. The bipolar violation patterns are coupled into the third winding of the repeater output transformer and passed through a voice frequency filter (see Figure 6). There are 12 frequencies associated with the bipolar violation patterns. Each repeater location (up to 12) uses a filter tuned to a different voice frequency. Additional interrogation pairs or other techniques are used for more than 12 interrogation locations, or for looped interrogation. In most cases of span line troubles, the faulty repeater can be determined from the central office.

2.4.1 Interrogation Signal: A span and repeater test set generates a digital bit stream with a controlled pattern of bipolar violations. The pattern consists of (a) positive trios and negative trios; (b) positive trios followed by a signal without bipolar violations; and (c) negative trios followed by a signal without bipolar violations (see Figure 7). The positive and negative trios are discussed to illustrate the interrogation process.

2.4.2 The test set consists of a pulse generator and a voice frequency selective voltmeter (receiver). The pulse generator output is connected to the transmit side of the span line, and provides the span line driving signal (Figure 6). The test set receiver is connected to a fault location pair; this is a voice frequency cable pair (loaded or nonloaded). The pulse generator output is a 1.544 Mb/s line signal consisting of trios of pulses with a large quantity of bipolar violations. These are transmitted in specific patterns of positive trios (positive-negative-positive) and negative trios (negative-positive-negative) as illustrated in Figure 8. The low frequency characteristics of this signal are contained in the rate by which the pattern alternates from positive trios to negative trios. If this signal is passed through a voice frequency filter, the 1.544 Mb/s bit stream would be eliminated and a voice frequency signal would remain.

2.4.3 If the repeaters are operating properly, the trios will be regenerated and transmitted to the next repeater. A portion of the repeater output is coupled into the third (interrogation) winding. This signal is filtered and connected to the fault location cable pair. At the central office, the fault location pair is measured for a receive level at one of the 12 voice frequencies corresponding to filters A-M. Each repeater is tested by transmitting and measuring each of the 12 frequency patterns in sequence. A faulty repeater is detected by no received signal, or by a low receive level at its corresponding filter frequency. The 12 frequencies are:

<u>Filter</u>	<u>Hertz</u>	<u>Filter</u>	<u>Hertz</u>
A	832	G	1722
B	928	H	2008
C	1049	J	2193
D	1206	K	2413
E	1340	L	2680
F	1508	M	3017

2.4.4 For interrogating more than 12 repeaters, or for looped interrogation (both directions from one end), additional fault pairs and/or amplified directional filters are used. The amplified filters have become rather standard in rural areas. They not only double the number of repeaters that can be interrogated with one fault pair, they amplify the interrogation signal to improve the signal-to-noise ratio on the fault pair. Figure 9 illustrates the use of two fault pairs and Figure 10 illustrates the amplified fault filter for looped interrogation. Either technique can be used to interrogate up to 12 repeaters in both directions from either end, or can be used to interrogate up to 24 repeaters in one direction only. More fault pairs can be used to increase the number of repeaters to be interrogated.

2.4.5 Repeaters cannot be interrogated through an APS location because the bipolar violations are removed. The APS provides for automatic looping in the presence of large quantities of bipolar violations to accommodate looped interrogation.

2.5 Equipment Evolution: This discussion will address digital span line equipment evolution as applied to paired telephone cables.

2.5.1 T1: The original digital transmission system was developed for inter-office trunks for application to existing exchange telephone cables. Extensive research by the Bell System resulted in a practical transmission system at 1.544 Mb/s with 24 voice channels. It was designated the T1 system, and is the basic building block for digital transmission systems used in North America. (T1 designates the Western Electric equipment and DS1 designates the 1.544 Mb/s bit rate.)

2.5.1.1 A T1 system transmits 50 percent duty random bipolar pulses with each successive pulse alternating in polarity (alternate bipolar pulses) as illustrated in Figure 11. Consecutive pulses of the same polarity constitute a bipolar violation in T1 transmission systems. Other digital systems may contain intentional bipolar violations provided by the equipment design. (Note: A 50 percent duty pulse describes a pulse where one-half of the duty cycle is allotted to the pulse and the other half is allotted to a zero level condition for separation of pulses in a bit stream.) A T1 signal can have no more than 15 consecutive zeros in a bit stream to maintain clock synchronization and minimize jitter (timing variations).

2.5.1.2 Early model T1 type repeaters did not contain the automatic line build out (ALBO) network illustrated in Figure 4B. Instead, a special digital span line test set was used to measure the cable loss between repeaters. A fixed line build out (LBO) network was inserted in

both receive sides of the repeater corresponding to the measured cable loss in each receive side. The LBO networks were provided in 2.4 dB steps, and provided a sloped loss to build the cable out to a full loss section (nominal 31 dB). This provided for a  $31 \pm 4$  dB loss between repeaters, regardless of the cable length.

2.5.1.3 Early model repeaters used discrete components and had minor operational problems such as oscillation in the absence of an input signal. There were also additional application restrictions for these discrete component repeaters such as no impedance discontinuity (i.e., cable type or gauge change) within 3 dB of the repeater. Most of the repeater regenerator is now contained in a single integrated circuit designed for low current operation. The T1 type line repeater is perhaps the key component in a T1 span line. This complex device has evolved into a compact and inexpensive unit with a history of reliable service.

2.5.2 T2: The Bell System later developed the T2 system to operate on special cables at 6.312 Mb/s with 96 voice channels. The 96 channels of the T2 system may originate in as many as four different locations of 24 channels each over separate T1 lines. Each of the T1 systems may operate from independent 1.544 Mb/s clocks. The slight differences in bit rates result in nonsynchronized signals being fed into a multiplexer. The multiplexer inserts an extra 136,000 bits to maintain a 6.312 Mb/s synchronized rate from the four random 1.544 Mb/s inputs. These extra bits are discarded when the signal is demultiplexed. (Multiplexing is described in TE&CM Section 954.)

2.5.2.1 A T2 system transmits 50 percent duty bipolar pulses, but with deliberate bipolar violations. Higher density systems use scrambling or zero substitution techniques to avoid long groups of zeros or repetitive patterns in the transmitted signal. T2 uses a bipolar with six zero substitution (B6ZS) code to provide frequent clock synchronization pulses and avoid a long string of zeros. A special code is substituted for six consecutive zeros. Bipolar violations included in the code are used by the receive terminal to restore the signal to its original condition.

2.5.3 T1C: T1C is an intermediate level span line with a bit rate greater than T1 but less than T2. T1C refers to a digital transmission system (or span line) that operates at 3.152 Mb/s with 48 voice channels. The cable transmission characteristics must be significantly better for T1C than for T1. T1C was designed to be applied to very large cables (i.e., 900 pairs or more) for use in large metropolitan areas, or for use in two-cable applications. Cable near end crosstalk requirements for T1C were not met with standard screened cables (equivalent of two cables for digital systems) at that time. "Improved" screened cables were then developed for T1C application.

2.5.3.1 A T1C system transmits 50 percent duty bipolar pulses in the same manner as T1, but at a higher rate. The 3.152 Mb/s line rate provides for combining two asynchronous T1 lines plus 64,000 bits for synchronization.

2.5.4 Other 48 Channel Systems: Independent manufacturers also provide alternative 48 channel span lines that can be applied to exchange cables and standard screened cables as now used by REA borrowers. These alternative systems compress the 48 channel information into a span line signal that requires cable transmission characteristics only slightly better than T1 and significantly less than T1C. These alternative 48 channel systems are unique, and are not compatible with T1C. Two of these encoding techniques are briefly described.

2.5.4.1 A ternary encoded system uses a 4 binary to 3 ternary (4B3T) code to reduce the T1C line rate. The 3.152 Mb/s bipolar pulses are converted into 2.364 Mb/s pulses with a large quantity of bipolar violations in the bit stream.

2.5.4.2 A modified duobinary encoded system divides the T1C stream into two alternative bit streams, and then interleaves the two signals in a duobinary format. A T1C system transmits pulses of 158 nanoseconds duration of the 317 nanoseconds time slot allotment (50 percent duty). A T1 systems transmits pulses of 324 nanoseconds duration of the 648 nanoseconds time slot allotment -- also 50 percent duty, but approximately twice as wide. The duobinary system takes advantage of the "dead time" between pulses. One hundred percent duty pulses are transmitted (317 nanosecond pulses in a 317 nanosecond time slot). The two bit streams are interleaved each 317 nanoseconds, and the resultant combined output pulses may be either 158 or 317 nanoseconds wide (one or two time periods) before returning to zero. The duobinary signal transports the T1C information rate but with a power spectrum similar to that of a T1 system.

2.5.4.3 These alternative 48 channel span lines were developed to be retrofitted into existing T1 span line designs. The system crosstalk requirements are slightly greater than for T1 systems, and each application must be reviewed before a decision is made to convert from T1 to an alternative system. (T1C is not a retrofit system because of higher crosstalk requirements.)

### 3. PRESENT DAY EQUIPMENT.

3.1 The vast majority of present day digital span line equipment is T1 type equipment applied to exchange telephone cables. There are also higher bit rate systems in service on exchange and special telephone cables, but in relatively small quantity at this time. The characteristics of these digital transmission systems are described in Paragraph 2. The following is a tabulated summary of these span line characteristics.

<u>Equipment Type</u>	<u>Information Bit Rate (Mb/s)</u>	<u>Span Line Rate (Mb/s)</u>	<u>Application Comments</u>
T1	1.544	1.544	Exchange Cable
T1C	3.152	3.152	Special Cable or 2 Cable
Ternary	3.152	2.364	Exchange Cable-Retrofit
Mod. Duobinary	3.152	3.152 (Mod)	Exchange Cable-Retrofit

3.2 The T1 span line is the basic building block of digital transmission systems used in North America. T1 type span lines have become the standard for digital transmission systems in rural areas, and have been used since 1962 in REA borrowers' systems. T1 type systems are provided by almost all independent manufacturers of digital transmission and switching equipment. Typical applications in REA borrowers' systems generally favor T1 type span lines over other techniques. Terminated with a DSX1 interface, T1 type span lines can be used with a wide variety of digital trunk and subscriber channel banks, digital host and remote central office equipment, digital subscriber line concentrators, and for high speed digital data services. T1 type span lines can also be used to extend service from higher density radio, lightwave or coaxial cable digital transmission systems.

3.2.1 T1 type span lines can be applied to exchange cables without undue concern if the cable meets REA specification requirements and span line engineering guidelines are followed. Because T1 type span lines are economical and in wide use, REA cable specifications (screened and non-screened) generally emphasize T1 type digital span lines. Cable considerations are outlined in Paragraph 4, repeater spacing guidelines are covered in Paragraph 5, and power considerations are covered in Paragraph 6. T1 type span lines can be applied to cables with low density analog station carrier. This is discussed in Paragraph 7.

3.3 Higher density digital span lines impose increased transmission requirements on cable facilities over that of T1 span lines. The increased requirements are modest for two systems of independent manufacturers using ternary encoding or modified duobinary encoding to provide 48 channels. In many applications, these systems can be retrofitted into existing 24 channel T1 type span lines to double the capacity. Other systems such as T1C type span lines are designed primarily for new cable routes. T1C type span lines impose much higher transmission requirements, and must be used in two-cable applications or applied to special cables. These special cables for T1C application are not presently covered in REA specifications, but guidelines are being developed for the use of T1C cables and equipment. Refer to paragraph 7.7 for information and recommendations on 48 channel span lines.

#### 4. CABLE CONSIDERATIONS

4.1 Span line engineering for T1 type systems is based on the research by H. Cravis and T. V. Crater of Bell Telephone Laboratories. The results of this research were published in the March 1963 issue of The

Bell System Technical Journal entitled "Engineering of T1 Carrier System Repeated Lines". The major contributions of this work were to quantify a large volume of statistical data and to establish simplified guidelines for the application of T1 systems to exchange telephone cable. The following guidelines for T1 span line design are for voice service only, and not for digital data service (DDS).

4.1.1 The span is established as a basic engineering unit. Span line engineering guidelines are based on a maximum of 3 spans in tandem. The overall maximum bit error rate objective for digital systems in voice service is  $10^{-6}$ . This provides for a maximum bit error rate of  $3 \times 10^{-7}$  for each span (Figure 12). For reasons that are discussed later the error rate is further divided to provide for  $10^{-7}$  bit error rate for each end section and  $10^{-7}$  bit error rate for the remainder of the span line (Figure 13).

4.1.2 The design frequency for T1 span lines is 772 kHz and the design temperature is 100°F for buried cables and 140°F for aerial cables. Maximum span line section loss values of 35 dB, 33.5 dB, 32 dB, and others are often cited; but confusion may exist as to the circumstances under which each apply.

35 dB: The highest loss to be encountered on any pair in a section at the highest operating temperature is established at 35 dB.

33.5 dB: The maximum allowable section loss based on the average of all cable pairs in a cable section at the highest operating temperature is generally established at 33.5 dB; this allows for a 1.5 dB increase for the worst one percent cable pair.

32 dB: The maximum allowable section loss based on the average of all cable pairs in a cable section at a nominal 55°F operating temperature calculates to be approximately 32 dB for buried cable (and approximately 31 dB for aerial cable).

4.1.3 Engineering Loss: For the ease of span line design, engineering loss values at 55°F, 100°F and 140°F were developed for various cable types. Design charts are generally based 33.5 dB as a maximum loss (average of pairs) at 100°F for buried cable and 140°F for aerial cable. Typical telephone cable engineering loss values are shown in Figure 22.

4.1.4 The 33.5 dB maximum section length is based on the repeater (regenerator) performance. The maximum section length also depends on signal-to-noise degradation due to crosstalk and other noise. A maximum length of 23 dB has been established for end sections in a noisy environment (i.e., CO switching noise). For one cable operation, it may be necessary to reduce the section lengths to offset the poorer signal-to-noise margin caused by near end crosstalk (NEXT) coupling from other cable pairs. There are engineering guidelines for minimum section loss and for maximum level differences for span line route junctions between repeater locations. Unless stated otherwise, the following discussion refers to span line design as applied to trunk systems. Additional factors must be

considered for subscriber systems.

4.2 Terminal Noise Considerations: Terminal locations are generally considered as noisy environment locations. This is especially the case where pairs within a cable are used for voice frequency service that terminate at that location. Impulses from rotary dialing and ringing voltages are coupled into digital span lines, reducing the system signal-to-noise margin. One-third of the signal-to-noise impairment is assigned to each end section and one-third is assigned to the remainder of the span line (Figure 13). A maximum loss of 23 dB has been established for end sections due to office noise. Crosstalk must also be considered, but it is unlikely that crosstalk will reduce the maximum permissible loss further.

4.2.1 Where separate cables are used for digital transmission systems and are routed to avoid impulses from switching and other noise sources, the full 33.5 dB section loss is permitted. The lower impulse noise from electronic and digital central offices further reduce terminal noise concern. Some telcos have been successful in establishing maximum loss sections for all cable sections by careful planning. While this engineering approach is permitted, the shorter end sections will result in only a small cost increase for typical rural systems (one additional repeater location). This is generally a good investment in margin for the future.

4.3 Crosstalk Considerations: Figure 14 illustrates crosstalk coupling paths for digital systems in telephone cables. A cable section between repeater location X and Y is reviewed. A digital bit stream transmitted by System 1 at repeater X is coupled into the remaining five pairs illustrated. It is coupled into pairs 3 and 5 as far end crosstalk (FEXT). It is also coupled into pairs 2, 4 and 6 as near end crosstalk (NEXT). Note that the potential interference is not only to other digital systems in the same cable, but is also a potential for interference to the same system in the reverse direction. As the signals travel from repeater X to repeater Y, the signal levels of all three systems are attenuated equally. Thus, FEXT is "equal level" crosstalk. As long as engineering guidelines are followed, FEXT is considered in the basic system design and need not be considered further in application engineering. (FEXT is considered when engineering for taps between repeater locations.)

4.3.1 The maximum repeater spacing due to crosstalk is determined by the following formula.

$$L_d = (m - s - 32 - 10 \log n)$$

Where:  $L_d$  = Repeater section loss in dB at highest operating temperature (100°F or 140°F)

$m$  = Mean value of near end crosstalk (NEXT) coupling loss in dB at 772 kHz

$s$  = Standard deviation of  $m$

$n$  = Number of T1 systems in the cable

Note that only NEXT values of  $m-s$  are identified in this formula. The  $-32$  includes a 6 dB reduction in the value of  $m$  to provide for variations in cable manufacturing and for FEXT. The  $-32$  is for chart values of  $m-s$ . For measured values of  $m-s$ , use  $-29$  instead of  $-32$ .

4.3.2 The formula for maximum repeater spacing is often shown as follows.

$$L_d = (m-s - 32 - 10 \log n) \frac{1}{f_t}$$

In this case,  $L_d$  is the loss at 55°F instead of the highest temperature, and  $f_t$  is a conversion factor for temperature. This method is used when attenuation values are provided at 55°F,  $f_t$  values are provided for each cable type, and maximum section losses are provided for each cable type at 100°F and 140°F. For simplicity, this discussion provides attenuation values at 100°F and 140°F for repeater spacing calculations.

4.3.3 The terms  $m$  and  $s$  are described for a better understanding. The near end coupling of wire pairs in cable is determined by measuring the coupling loss of all pair combinations. This comprises a large volume of measurements. There are 66 combinations in a 12 pair cable, 153 combinations in an 18 pair cable, 300 combinations in a 25 pair cable, etc. Because of this large volume,  $m-s$  values have been quantified and charts developed for span line engineering. The mean value is the arithmetic average of the near end crosstalk couplings of all of the individual combinations, and is identified as  $m$ . The deviation of this distribution of individual values is calculated by standard statistical methods (Figure 15). One standard deviation ( $s$  or sigma) is the range from the mean value of a "normal distribution" which encompasses 34 percent of the observations of the statistical sample. Emphasis is placed on the "poorer" values of crosstalk coupling. A total of 84 percent of the combinations are likely to be "better" than the statistical  $m-s$  value and 16 percent are likely to be "poorer". These low (poor) values of NEXT primarily contribute toward the total interference into other digital transmission systems in the same cable.

4.3.4 From the basic research by the Bell System, the statistical characteristics of cable were summarized. With emphasis on simplicity, charts were developed to determine span line maximum repeater spacings based primarily on cable NEXT and attenuation (engineering loss). Similar charts are used by the entire telephone industry. In 1968, REA and independent cable manufacturers verified that cable from non Western Electric sources displayed similar statistical NEXT characteristics. Later REA cable specifications included 772 kHz NEXT and attenuation requirements to assure satisfactory performance of T1 type digital systems.

4.3.5 Minor variations generally exist in published engineering data. These differences in data cause confusion; but a close examination will often indicate that the effects of these data differences are minimal. The data for NEXT in Figure 20 and engineering loss in Figure 22 are representative of telephone cable characteristics.

4.3.6 In 1969, an improved cable for digital transmission systems was developed by Superior Cable Corporation and Continental Telephone Laboratories. The new cable contained a metal tape between compartments within the cable to improve the NEXT isolation. This cable construction was called a T Screen cable. It was called a screen because it provided additional crosstalk isolation over a standard (non screened) cable. But it did not provide the complete isolation of completely shielded units within a cable, or provided by two separate cables. It did provide the isolation required so that the T1 span line engineering guidelines for separate cables could be followed. This economical approach to cable manufacturing for digital transmission system application was adopted by other cable manufacturers. A series of improvements followed and resulted in additional crosstalk isolation for higher density digital systems. A variety of these cable types are now available. Engineers should review the published crosstalk data for applications above the DS1 rate.

4.4 Cable Construction: Examples of non screened cable construction are shown in Figure 16. Other cable construction types exist, but those shown in Figure 16 are representative of the plastic insulated conductor cables used by rural telephone companies. A brief review of cable construction types will aid in understanding and utilizing the span line engineering charts. Cables manufactured by independent manufacturers are generally in layers of cable pairs to form units. Cable sizes of 25 pairs or less are generally constructed in layers to form a single unit. Cable sizes above 25 pairs are generally constructed in units of 12 or more pairs each. A 25 pair cable might be constructed in three units of 8, 8 and 9 pairs; but it is much more likely to be layer construction to form a single 25 pair unit. Figure 20 shows typical m-s crosstalk values in common use for exchange type PIC cables. Within unit values are given from 6 pair to 25 pair units. Adjacent unit and non adjacent unit values are also given. A unit is considered to be adjacent if the dividing line touches in any way. For example, all units within a 50 pair cable (Figure 16) are considered adjacent; however, greater crosstalk isolation is expected between opposite units (1-12 versus 26-37) than in close adjacent units (1-12 versus 13-25). Non adjacent units provide much greater crosstalk isolation than adjacent units, regardless of cable size.

4.4.1 Examples of screened cable construction are shown in Figure 17.

This construction is much the same as non screened cables except that a metal "screen" divides the cable core into two separate compartments. Consecutive pair numbers are maintained on each side of the screen with the lower numbers on one side and higher numbers on the other side. This tends to encourage the use of symmetrical compartment halves. Thus, the screened cables may contain a different makeup of units that non screened cables of the same size.

4.4.2 Screened cables meeting the requirements of REA cable specifications provide for 100 percent utilization of cable pairs for T1 type span lines at maximum repeater spacing. The screen provides the necessary crosstalk isolation so that calculations for NEXT are unnecessary in span line application engineering. Figure 18 shows several types of screen in use. All are designed to meet T1 span line requirements. Extended screens

and D screens provide additional crosstalk isolation over that of the original T Screen. Cables with integrated shields and screens provide more crosstalk isolation than separate ungrounded screens. Cables with integrated shields and screens are intended for higher bit rate span lines such as T1C.

4.5 Cable Selection: Where new cable routes are being constructed for the exclusive use of digital transmission systems, the use of filled core, screened buried cables is recommended. In the case of new construction, a review of long term projected needs and service may warrant consideration of improved cables that will support higher density digital systems such as T1C. In rural areas, most digital systems are applied to existing cables or new cables with a mixture of voice frequency and carrier system application. Thus, digital system application may be a secondary consideration in the selection of new cables. In the case of existing cables, it becomes a matter of making the best use of what is available. For long term stability the use of filled buried cables for digital system application is highly recommended.

4.5.1 New Cables: Where new cables are being installed, it is recommended that screened cables be considered for all trunk and subscriber routes that are candidates for digital system application in the future. A review of current technology trends leads to the conclusion that all backbone cable routes are candidates for digital system application. The incremental cost differential between screened and non screened cables in the 25 to 100 pair sizes could be further justified as digital services become cost effective at the subscriber level. (Non screened cables of 100 pairs and larger may provide for a limited number of digital systems to be applied to non adjacent cable units with reasonable NEXT isolation, depending on the core construction.)

4.5.2 Existing Cables: Options for selection are limited with existing cables. The primary objectives are to select cables and pairs or units in cables to maximize repeater spacing and minimize problems from moisture and NEXT. Where two cables exist along a route, it may be practical to use both cables to eliminate NEXT effects. Where dissimilar cables have been installed along subscriber routes, it may be impractical or undesirable to use both cables. Examples are air core versus filled, age differences, gauge differences, different pedestal access points, and possible splicing problems.

4.5.3 Pair and Unit Selection: The selection of cable pairs and cable units is directed toward the reduction of near end crosstalk between transmit and receive pairs. (This is in contrast to far end crosstalk as the primary consideration for analog carrier application.) The selection of pairs and units is done to separate high level signals from low level signals. The use of electrical barriers such as separating shields and screens provide adequate NEXT isolation for maximum repeater spacing. Where electrical barriers are not provided, physical separation of pairs becomes a primary factor to provide NEXT isolation. (The judicious

selection of differing pair twist lengths is used in the manufacture of cable to improve crosstalk isolation of pairs that are in close proximity.)

4.5.3.1 Figure 19 illustrates the selection of cable pairs and cable units to minimize the effects of NEXT. Cables of 25 pair and smaller are generally constructed as one unit in these small cables. Thus, the two directions of transmission must be placed within the same unit. Repeater spacing must be reduced to offset the effects of NEXT. It is not possible to provide physical separation where a large number of the pairs are used for digital systems. Where only a small number of systems (i.e., 4 or 5 systems) are applied within a 25 pair cable, some NEXT improvement may be obtained by selecting pairs separated as far as possible (Figure 19A). Adjacent units offer some NEXT improvement over that of transmit and receive pairs within the same unit (Figure 19B). For larger cables, non adjacent units should be selected to separate transmit and receive directions whenever possible (Figure 19C). The optimum NEXT isolation is provided by separate cables or by screened cables to separate transmission directions (Figure 19D).

4.5.3.2 Splicing to digital repeater housing cable stubs can be confusing. Remember that the objective is to separate high levels from low levels--and not necessarily separate east from west. High levels (repeater output) within the repeater cable stub may be in the same unit for both east and west directions. Repeater housing cable stubs consisting of two cables, each screened, provide for four isolated compartments to minimize confusion. One cable stub can be spliced to the "east" cable and the other spliced to the "west" cable with screens to separate high and low levels.

4.5.4 Pair Quantities: The following discussion illustrates the cable pair requirements for digital transmission systems and for maintenance. All present and projected future span line requirements must be included in repeater spacing calculations. This includes spare span lines as well as main span lines with traffic.

4.5.4.1 Maintenance pairs for interrogation and order wire (voice frequency pairs) may be assigned at random, and are not included in repeater spacing calculations. The illustrations will indicate only one pair for interrogation. Additional pairs may be necessary because of system length, or because of route junctions and other factors.

4.5.4.2 Two cable pairs (one transmit and one receive) are required for each main and each spare span line, one pair for order wire, and one pair (or more) for interrogation. (A spare span line is recommended for trunk systems and where 48 or more subscribers are affected by a failure on the main span line.) The following chart illustrates the pair requirements for 24 channel systems without spare span lines and with one spare span line along the route.

<u>Systems</u>	<u>Tx &amp; Rec</u>	<u>O. W.</u>	<u>Inter*</u>	<u>Total Pairs</u>	
				<u>No Spare</u>	<u>One Spare</u>
1	2	1	1*	4	6
2	4	1	1*	6	8
3	6	1	1*	8	10
4	8	1	1*	10	12
5	10	1	1*	12	14
6	12	1	1*	14	16
10	20	1	1*	22	24

\*Note: More pairs may be required.

The "get started" costs in terms of cable pair requirements are high for digital systems when order wire, interrogation and spare span lines are included. Six or more pairs are generally required to place the first 24 channel system in service. This is a circuit to cable pair ratio of 4. For 10 systems or 240 channels, the ratio improves to 10. For "skinny" route subscriber systems, the necessity for spare span lines may be questionable.

4.5.4.3 When digital span lines are used for the transmission path between digital central offices and remote switches, or between the office and subscriber end of digital subscriber line concentrators, spare span lines may not be required. For a decision to be made, certain technical characteristics of these systems must be known. Many digital remote switches and concentrators are designed for a minimum of two span lines with the capability of shifting traffic to the remaining span line when one fails. Traffic capacity will be degraded during the failed condition, but service will be maintained. Some systems may require spare span lines and perhaps external automatic protection switching to maintain a link between all subscribers served by a remote switch or concentrator.

## 5. REPEATER SPACING GUIDELINES

5.1 The following are guidelines for T1 type span line repeater spacing for voice service only. The requirements for digital data service (DDS) and higher density span lines are more severe. Refer to paragraph 7.7 for information on 48 channel span lines. These guidelines are based on the assumption that the cable has been tested and found to be satisfactory for digital span lines service. Certain limitations outlined in Paragraph 4 must be considered when the guidelines are applied.

5.1.1 Repeater spacing guidelines generally cover three basic areas. They are near end crosstalk (NEXT), end sections and route junctions. NEXT must be considered for all cable sections, but is a primary concern for cable sections between repeaters. End sections that are subjected to switching noise are subject to further limitations.

Route junctions that cause level differences must also be considered. The minimum repeater section loss is normally 9 dB. The minimum section loss for end sections can be shorter than 9 dB by using the attenuator and equalizer pads in the span terminating equipment.

5.2 General Recommendations: The following repeater spacing guidelines are based on the use of engineering charts to determine the maximum loss at 772 kHz at the highest temperature (100° for buried cable or 140°F for aerial cable). The maximum section loss (normal cable average) between repeaters is 33.5 dB and the maximum end section loss is 23 dB. (Note the discussion in paragraph 4.2.1 on full end sections.) There is some margin included for statistical variations in cable parameters and other factors. However, it is recommended that repeater sections be engineered for slightly less than 33.5 dB and 23 dB for the following reasons.

- a. Cable pair loss should be verified by measurement at 772 kHz if engineered for 33.5 dB.
- b. In the evolution of digital systems in telephony, it is highly probable that systems will exceed three spans in tandem.
- c. There is a possibility that higher density span line equipment will be considered for future application (i.e., duobinary or ternary systems).
- d. Road moves and other unplanned changes may increase the loss of some sections.
- e. Digital subscriber systems require additional consideration.

5.2.1 Between Repeaters: It is recommended that the maximum spacing between repeaters be limited to no more than 31 or 32 dB. If higher density systems are being considered for future use, more margin may be necessary.

5.2.2 CO End Sections: It is recommended that the first repeater from the central office be located at the first loading coil point (2250 or 3000 feet). This will provide margin for the future.

5.2.3 Subscriber End Sections: Subscriber terminal locations are generally treated the same as central offices. If it is practical, engineer the subscriber terminal end sections the same as CO end sections; that is, locate the first repeater about 2250 to 3000 feet from the terminal. If that is not practical, engineer the subscriber end section to no more than 23 dB, recognizing that these may have to be reconsidered later.

5.3 Maximum Repeater Spacing: The charts in Figure 20, 21 and 22 are used to determine the maximum repeater spacing for one cable operation. For two cable or screened cable operation, use the chart in Figure 22 only (omit Figure 20 and 21) and engineer to a maximum of 33.5 dB.

5.3.1 From Figure 20, determine the m-s near end crosstalk (NEXT) coupling loss for each different type of cable used in the span line. Find the m-s crosstalk value that corresponds to each cable construction type. Repeat this procedure for each span section of different cable construction. Note: Where several cable sizes and gauges are encountered in any one repeater section, the lowest m-s crosstalk value is used to determine that cable section length.

5.3.2 From Figure 21, determine the maximum repeater spacing in dB. Enter the chart at the bottom for the number of span lines or systems ("N") in that cable section. Follow the vertical line until it crosses the m-s crosstalk value determined from Figure 20. At the intersect point, follow the horizontal line to the left. Read the maximum repeater spacing in dB. Repeat this procedure for each span section of different cable construction or different number of systems. It is important to estimate the ultimate maximum number of systems because as the number increases, the repeater spacing decreases. Count all span lines; that is, include all main plus spare span lines.

5.3.3 From Figure 22, determine the maximum repeater spacing in length. For buried cable, use the engineering loss values at 100°F; for aerial cable use the values at 140°F. Divide the maximum dB loss value determined from Figure 21 by the engineering loss value for the appropriate cable gauge and type found in Figure 22. The result is the maximum repeater spacing length in kilofeet.

5.3.4 Remember to limit end sections to a maximum of 23 dB. No section should be less than 9 dB loss. For existing cable routes, repeaters will likely be placed at existing access points such as loading points or existing pedestal locations. Repeater locations should be chosen for easy access and clearance for maintenance activities.

5.4 Route Junctions: Attention must be given to the location of repeaters at or near route junctions so that undesirable level differences are controlled. If it is practical, it is recommended that a repeater location be established at each route junction. This simplifies the engineering because each section from the junction can then be engineered separately without regard to the sections in other directions. With the small system sizes in rural areas, it is generally practical to locate repeaters at each junction.

5.4.1 Figure 23 shows common route junction considerations. The ideal solution is to establish a repeater location at route junctions (Figure 23A). Where this cannot be done, repeaters in each section located at equal distances (in dB loss) from the junction will accomplish the same objective. The determination of repeater locations for route junctions other than a repeater at the junction or equally spaced repeaters from the junction can become involved. This complexity is caused by the very large combinations of cable construction types and span line quantities that can exist in system applications. Shorter repeater sections will improve the signal-to-noise caused by NEXT in one cable operation, but will not improve the FEXT effects. The following are brief guidelines on route junctions to avoid the necessity of detailed calculations.

5.4.2 One Location: Where direct service to one location is involved (Figure 23B), the first repeater back from the junction toward A is the controlling factor since it is common to both systems. The repeater location from the junction to the first repeater toward B must be nearly equal in loss to that from the junction to repeater toward C; and the normal rules concerning maximum loss between repeaters must be satisfied. The location of the repeater toward A is independent of the repeaters toward B and C, so long as the section loss between these repeaters is nearly equal.

5.4.3 Multiple Locations: Because of the additional complications involved in calculations for this arrangement, a simple recommendation is made. Every attempt should be made to establish a repeater location at the junction. If this cannot be accomplished, repeater locations should be established at nearly equal distances (in dB loss) from the junction in each section (Figure 23C).

5.5 Repeater Spacing Examples: The following are typical examples of calculations for T1 type span line maximum repeater spacing. The charts in Figures 20, 21 and 22 are referenced.

5.5.1 Calculate the maximum repeater spacing for 4 main span lines plus one spare span line (5 systems) applied to a buried filled 25 pair 22 gauge cable (BJF 25-22).

Step 1: Figure 20: 22 gauge, transmit and receive within same 25 pairs: NEXT (m-s) = 63 dB. (Transmit and receive pairs should be separated if practical.)

Step 2: Figure 21: 5 systems, 63 dB (m-s) NEXT: Maximum loss = 24 dB.

Step 3: Figure 22: 22 BJF = 4.19 dB/kF (100<sup>0</sup> for buried cable).

Maximum length = max loss ÷ dB/kF = 24 ÷ 4.19 = 5.73 kF

Step 4: Figure 22: End sections must be limited to 23 dB maximum.

Maximum length =  $23 \div 4.19 = 5.49$  kF (It is suggested that the first repeater from a central office be placed at the first loading point for additional margin.)

5.5.2 Calculate the maximum repeater spacing for 9 main span lines plus one spare span line (10 systems) applied to a buried filled 50 pair 24 gauge cable (BJF 50-24).

Step 1: Figure 20: 24 gauge, transmit and receive in adjacent 12 or 13 pair units: NEXT (m-s) = 69 dB.

Step 2: Figure 21: 10 systems, 69 dB (m-s) NEXT: Maximum loss = 27 dB.

Step 3: Figure 22: 24 BJF = 5.17 dB/kF ( $100^{\circ}$  for buried cable). Maximum Length = max loss  $\div$  dB/kF =  $27 \div 5.17 = 5.22$  kF.

Step 4: Figure 22: End sections must be limited to 23 dB maximum (preferably shorter). Maximum length =  $23 \div 5.17 = 4.45$  kF.

5.5.3 Calculate the maximum repeater spacing for 9 main span lines plus one spare span line (10 systems) applied to a buried filled screened 25 pair 22 gauge cable (BJF 25-22H).

Step 1: Figure 22: Screened cables can be treated as two cables. The maximum loss is 33.5 dB at  $100^{\circ}$ F. 22 BJF = 4.19 dB/kF at  $100^{\circ}$ F. Maximum length =  $33.5 \div 4.19 = 8.00$  kF. (Margin is recommended.)

Step 2: Figure 22: End sections must be limited to 23 dB maximum (preferably shorter). Maximum length =  $23 \div 4.19 = 5.49$  kF.

## 6. SPAN POWER CONSIDERATIONS

6.1 Span line power is generally provided in combinations of -48 or -130 volts and +130 volts. These provide 48, 140, 178 or 260 volts (sometimes higher) for the span line. The calculation for the required span line voltage becomes a simple matter of adding up the voltage drops or equivalent resistances due to (a) span power regulator, (b) office and line repeaters, and (c) cable pairs. The repeaters may require from 60 mA to 140 mA, depending on the specific repeater and application.

6.1.1 Figure 24 contains typical characteristics of span line power components. An attempt has been made to approximate span line equipment and cable characteristics. These values can be used to estimate the required span line power. A final determination should be made based on the specific equipment from the manufacturer's published charts.

6.1.2 Each of the elements are considered separately, and then combined to determine the powering voltage requirements. The span terminating unit contains a power supply, a current regulator, and an office repeater. The current regulator is actually a current regulator in one line side and a current limiter in the other line side. For the sake of discussion, about 10 volts is dropped across each, or 20 volts total. The office repeater requires approximately 10 additional volts. Thus, 30 volts is required for the span terminating equipment. (Note: The office repeater could be powered separately, but it is more common to include it in the line repeater simplex loop for economic reasons.) This 30 volts has been converted into resistance equivalent values at 60, 100, and 140 mA in Figure 24A. The line repeaters require a voltage drop of 9.5, 10.0 and 10.5 volts at 60, 100 and 140 volts, respectively. This is shown as 158, 100, and 75 ohms in Figure 24A. Where the power is provided at one end only, include resistance value for the span termination unit at the distance office without power. The above values would apply at 100°F or 140°F because the derived values are primarily determined by a voltage drop. Cable resistance is affected by temperature. Figure 24B shows cable resistance at 100°F and 140°F. The values shown are simplex loop values in common use in digital carrier applications. The loop resistance values in TE&CM Section 406 are slightly different, but could be used by dividing the loop resistance by two and correcting for temperature. (The simplex loop resistance for the two pairs is one-half that of a one pair loop.) Figure 24C shows the maximum equivalent simplex loop resistances for corresponding span power voltages.

6.1.3 Span power is fed on a simplex basis over the span line transmit pair out to a looping point and returns on the receive pair. When the span line is powered from both ends, the looping point is generally chosen to be at the exchange boundary, or near the midpoint between the two powering locations. If span power is required at only one end, looping is accomplished in the span terminating equipment at the distant end. Note that current is in all sections of cable and equipment. This provides a "sealing current" for more reliable operation.

6.2 Span Power Example: The following is a typical calculation for span power for a buried cable trunk route. The trunk route is approximately 18 miles long and consists of 18 line repeaters over 15 kF of 24 gauge cable and 80 kF of 22 gauge cable. The simplex current is to be 100 mA; a calculation will first be made to determine if the system can be powered from one end only. (See Figure 24 for typical equivalent resistance values for equipment and cable.)

15 kF 24 gauge (100°F)	15 x 26.8 =	402 Ohms
18 kF 22 gauge (100°F)	80 x 16.8 =	1344
18 Line Repeaters	18 x 100 =	1800
1 Span Term (W/Power)	1 x 300 =	300
1 Span Term (No Power)	1 x 140 =	<u>140</u>

Equivalent Resistance = 3986 Ohms

The equivalent resistance of 3986 ohms exceeds the 3080 ohm maximum shown in Figure 24 for powering from one end. A calculation is now made to determine the span power requirements when powered from both ends.

15 kF 24 gauge (100 <sup>0</sup> F)	15 x 26.8 = 402 Ohms
80 kF 22 gauge (100 <sup>0</sup> F)	80 x 16.8 = 1344
18 Line Repeaters	18 x 100 = 1800
2 Span Term (W/Power)	2 x 300 = <u>600</u>

4146 Ohms

The span power voltage should be set at +130 and -130 volts at one end. The distant end should be set at +48 and -130 volts or +130 and -130 volts depending on the exact looping point and desired margin in span power current.

## 7. RECOMMENDATIONS

7.1 Recommendations on the engineering and selection of digital transmission systems, ancillary hardware and cables have been included along with the general discussion of these items in Paragraph 4.5 and parts of Paragraph 5. The key points from those recommendations are briefly summarized here, along with other general recommendations on digital transmission systems. All recommendations refer to T1 type span line unless noted otherwise. Brief recommendations on T1C and other 48 channel span lines are outlined in paragraph 7.7.

7.2 General: Digital span lines are expected to form the backbone plant for trunk and subscriber service in rural areas during this decade. Lower density digital systems applied to paired cable at the exchange level can easily and economically be connected into the trunk network to provide a wide array of digital services as these systems and services evolve. Because of the expected impact of digital technology on communications systems and services, planning for the future is recommended. Digital span lines should be established to provide for the well defined present service needs, but also provide for future, less defined service needs to the extent economical and practical.

7.2.1 Perhaps the most crucial economic decision is the choice between retaining existing cables for digital systems, or the installation of new facilities. A major factor in this determination is the estimated timetable for future service needs versus the estimated timetable for technology evolution. Optical fiber systems may become economically practical at rates below the DS3 level (672 channels) in the future, perhaps even DS2 (96 channels) or lower. If new cables are installed for digital span lines, the possible future use of higher bit rate systems such as T1C should be considered. However, it may be highly advantageous to use existing cables and existing technology to the extent practical until these emerging technologies are better defined.

7.2.2 The T1 type span lines in widespread use today can be mixed in cables with analog station carrier. This is because of their dissimilar power versus frequency characteristics. The low density analog station carrier and the more sophisticated digital carrier have their unique application advantages for subscriber service. The ability to use both types in the same cable also provides for an orderly transition from analog to digital systems along a cable route, if and when the need exists. Lower bit rate digital systems are expected to be used for subscriber service in the future. Lower bit rate systems (below 1.544 Mb/s) have the potential of causing interference into analog station carrier applied to the same cable. The implementation of low bit rate systems along routes with station carrier must be well planned to avoid premature obsolescence of equipment.

7.3 Cable Recommendations: The following summarizes recommendations for the selection of new cables, the use of existing cables, and the selection of units and pairs within the cable.

7.3.1 New Cable: Where new cable routes are being constructed for the exclusive use of digital transmission systems, the use of filled core, screened buried cable is recommended. Consideration should be given to selecting cables with improved characteristics for applying higher density systems such as TIC. Where new multipurpose cables are being installed, filled core buried cable is recommended; consideration should be given to using screened cable for backbone plant, especially in the smaller sizes lacking non adjacent units (generally the 25 to 100 pair range).

7.3.2 Existing Cables: Make sure the cables are satisfactory for digital system application. Use filled core buried cables of 25 pair and larger if possible. The use of air core buried cables for digital systems may be questionable, especially in smaller sizes.

7.3.3 Unit and Pair Selection: Units and pairs are selected for maximum NEXT isolation between transmit and receive pairs as illustrated in Figure 19. For screened cables (Figure 19D), the transmit and receive pairs are isolated by the screen. For non screened cables, isolation is provided by physical separation. Non adjacent units (Figure 19C) are best and adjacent units (Figure 19B) are second best. Where transmit and receive pairs must exist within a unit, physical separation between transmit and receive pairs is suggested to the extent practical (Figure 19A).

7.3.4 Repeater Spacing: Repeater spacing is determined at 100°F for buried cable and 140°F for aerial cable. Except where limited by NEXT, the maximum repeater spacing is 33.5 dB between repeaters and 23 dB for end sections. To provide future margin, it is recommended that the spacing between repeaters be limited to no more than 31 or 32 dB, and that the first repeater from the central office be placed at the first loading point (2250 or 3000 feet). Where NEXT is a factor in repeater spacing, the spacing is determined based on the ultimate system quantities to be used in the future.

7.4 Mixed Digital and Analog: In general, digital carrier and compandored analog station carrier can be applied within the same cable. (All multichannel station carrier utilize compandors to meet the noise requirements of REA specifications. One-channel types may contain compandors, but generally do not.)

7.4.1 The following criteria apply to the mixing of digital trunk and subscriber carrier with analog station carrier in small cables.

- A. The analog station carrier systems must contain full range compandors that provide approximately 25 to 30 dB compandor advantage. All multichannel station carrier systems on REA's List of Acceptable Materials now meet this requirement.
- B. The digital trunk and subscriber carrier systems must use an encoding that limits the power on the span line at frequencies below 150 kHz. All D2, D3 and D4 encoded trunk and subscriber carrier are expected to meet this criterion. The REA List of Materials now contains footnotes in the listing of digital trunk and subscriber carrier systems concerning these compatibility considerations.

7.4.2 The guidelines above are based on digital systems transmitting random bipolar signals of 1.544 Mb/s or higher; or transmitting repetitive patterns with a high pulse density to limit the power below 150 kHz. Certain digital systems may transmit pulse streams with bipolar violations, low density repetitive patterns, or lower bit rates. Pulse streams with these characteristics can shift the power to a lower frequency and cause interference with analog station carrier in the same cable. The effects of each of these systems must be evaluated before mixing in cables with station carrier. Digital span lines carrying traffic between digital central offices and remote switches, between digital concentrator terminals, and other systems can generally be mixed in cables with analog station carrier. However, each system should be reviewed to confirmed that the potential for interference does not exist.

7.5 Alternate Paths: Digital transmission systems are generally very reliable. Additional reliability can be achieved by the use of alternate paths and automatic rerouting. Factors such as the quantity of subscribers affected by failure and the response time to restore service influence decisions on the need for and the degree (quantity or technique) of alternate paths required. The ultimate is to provide alternate routes between terminal locations. A more common level of alternate paths is obtained through the use of spare span lines and automatic protection switches (APS). The APS function may be included in the design of digital offices, remotes and concentrators. Spare span lines and APS are generally recommended for trunk systems and for subscriber

systems where the loss of a span line affects 48 or more subscribers. Where two or more span lines share traffic and the loss of a span line degrades traffic but does not isolate an office or area, spare span lines and APS are not generally recommended except for unusual circumstances.

7.6 Equipment Selection: There is a wide variety of equipment and hardware available. Since the specific equipment must be chosen to satisfy the individual circumstances and economics, only generalized suggestions are offered. In general, it is recommended that equipment be chosen that meet industry standards for compatibility. This encourages competition and provides alternative sources for the purchase of systems and hardware. At this time, the economics generally favor T1 type span lines, especially for digital subscriber systems. As energy costs increase, more attention should be given to equipment power requirements. The added reliability and ease of maintenance afforded by spare span lines, APS, interrogation, order wire, patching jacks, testing jacks, and other ancillary equipment and hardware should be compared to the rising maintenance personnel costs.

7.6.1 Repeater and terminal housings can constitute a large investment. Repeater housing are available in small and large sizes, pressurized and vented types, and with various cable stub types and lengths. When pressure type housings are used, they should be vented unless positive pressure is maintained. Water can build up inside housing that are not vented. This is due to cyclic temperatures and restricted air flow. Negative pressure can bring moisture inside the housing but positive pressure may not expell the trapped water.

7.7 Higher Density Span Lines: There is a small, but growing interest in TIC and other 48 channel span lines for rural applications. The following are interim recommendations on the selection and application of these systems. The use of 48 channel span lines should be based on economics, considering the present and long term communication requirements. TIC types are primarily intended for new cable application; and the other 48 channel types are intended for retrofit applications to existing cables. Limited information is available on the application of TIC and other 48 channel span lines at this time. Thus, the brief information and recommendations outlined here must be supplemented by manufacturer's descriptive information, application guidelines and specifications.

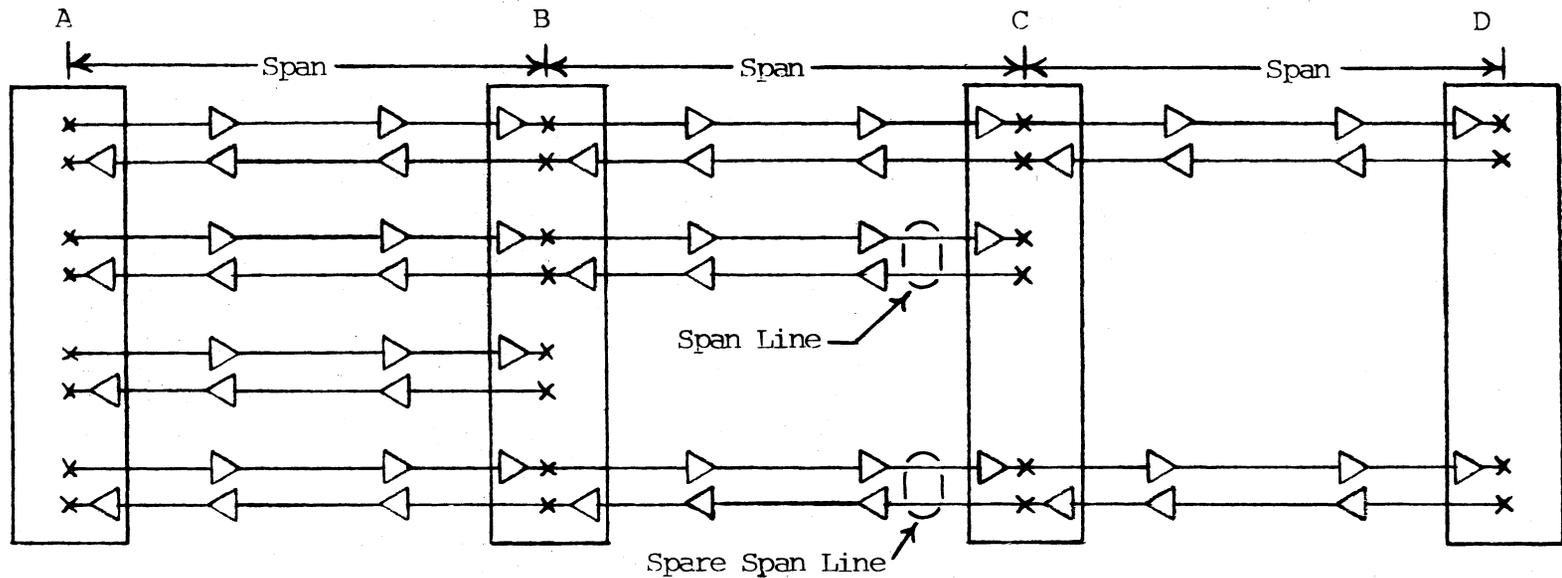
7.7.1 TIC Type Span Lines: The most significant economic impact of TIC applications is likely to be the installation of new cables, especially where existing cables can support growth using T1 equipment types or other alternatives. A route by route study should be made. Advanced planning will be necessary for the installation of new cables. TIC type systems may be justified on trunk routes interfacing a connecting company, but not necessarily on all trunk routes within a system.

7.7.1.1 REA is developing limited specifications and guidelines for TIC screened cables, equipment and application. The primary cable specification need is for improved near end crosstalk isolation across the screen, and to impose some attenuation limits at 1.576 MHz. Screened cables for TIC application require about 20 dB additional near end crosstalk isolation over screened cables for T1 applications.

7.7.1.2 TIC and T1 systems are designed for essentially the same maximum repeater spacing length. Assuming that the TIC crosstalk requirements are met, a system carefully designed for T1 repeater spacing will usually meet TIC application limits also. The TIC maximum design section loss is 54 dB at 1.576 MHz for the worst pair at the highest temperature. End sections are designed for 37 dB maximum loss. Because cable attenuation characteristics at 1.576 MHz are not well established at this time, a small margin of safety is recommended for TIC repeater spacing. Cables for TIC should be dedicated to digital carrier service only; there should be no voice frequency switched pairs in the same cable. Special care should be taken in the routing of TIC cables at the central office to avoid impulse noise coupling into TIC cable pairs.

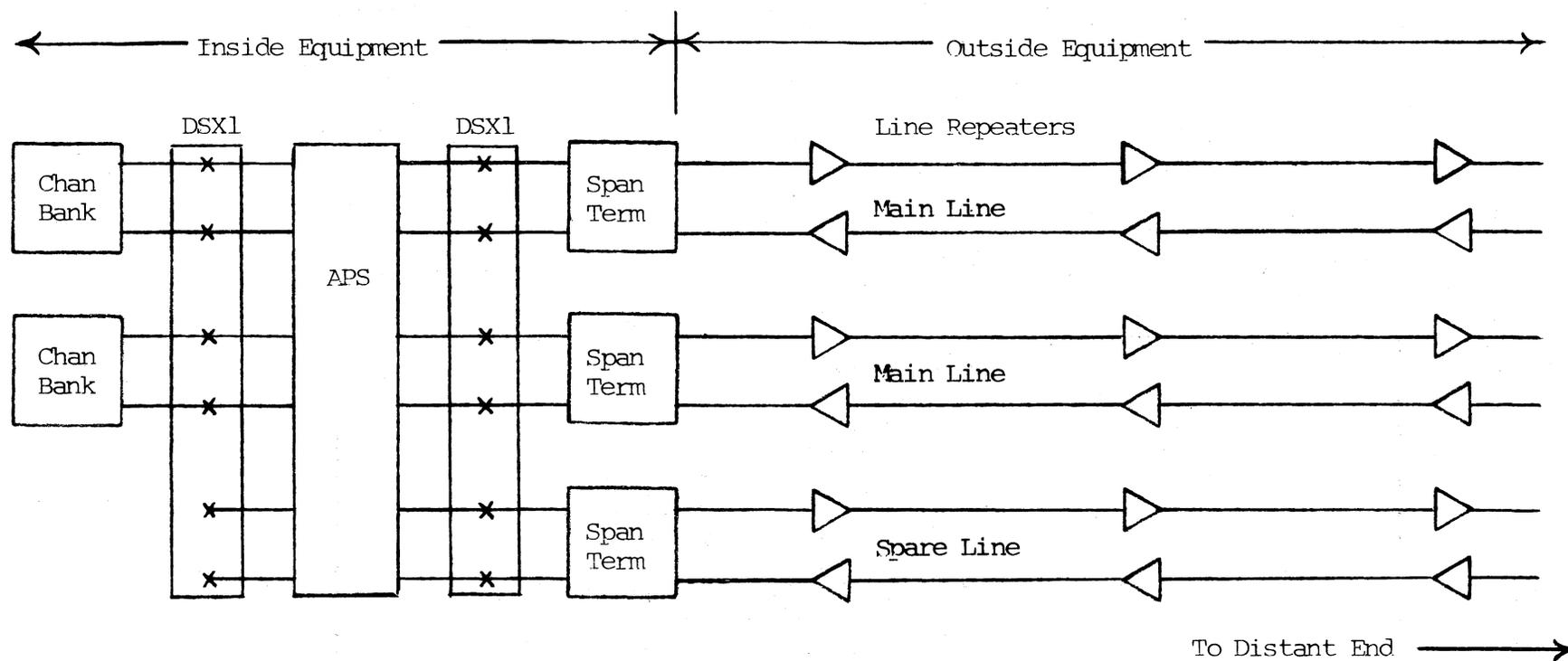
7.7.2 Other 48 Channel Span Lines: Ternary and duobinary encoded 48 channel span lines can be used to expand the capacity of some existing routes and avoid costly new cable installations. These systems might be chosen as an interim measure, or may be planned and used as a long term solution to additional circuit requirements. These ternary and duobinary span lines are designed for essentially the same maximum repeater spacing as for T1 systems. A system designed for T1 application on a conservation basis will usually be satisfactory as a retrofit application for a ternary or duobinary span line. However, these systems do require a small improvement in cable transmission requirements (near end crosstalk and attenuation), as compared to T1 applications. Since each of these systems are unique, specific engineering and application requirements should be established in consultation with the manufacturer before equipment is purchased and installed.

FIGURE 1  
SPAN CONCEPT



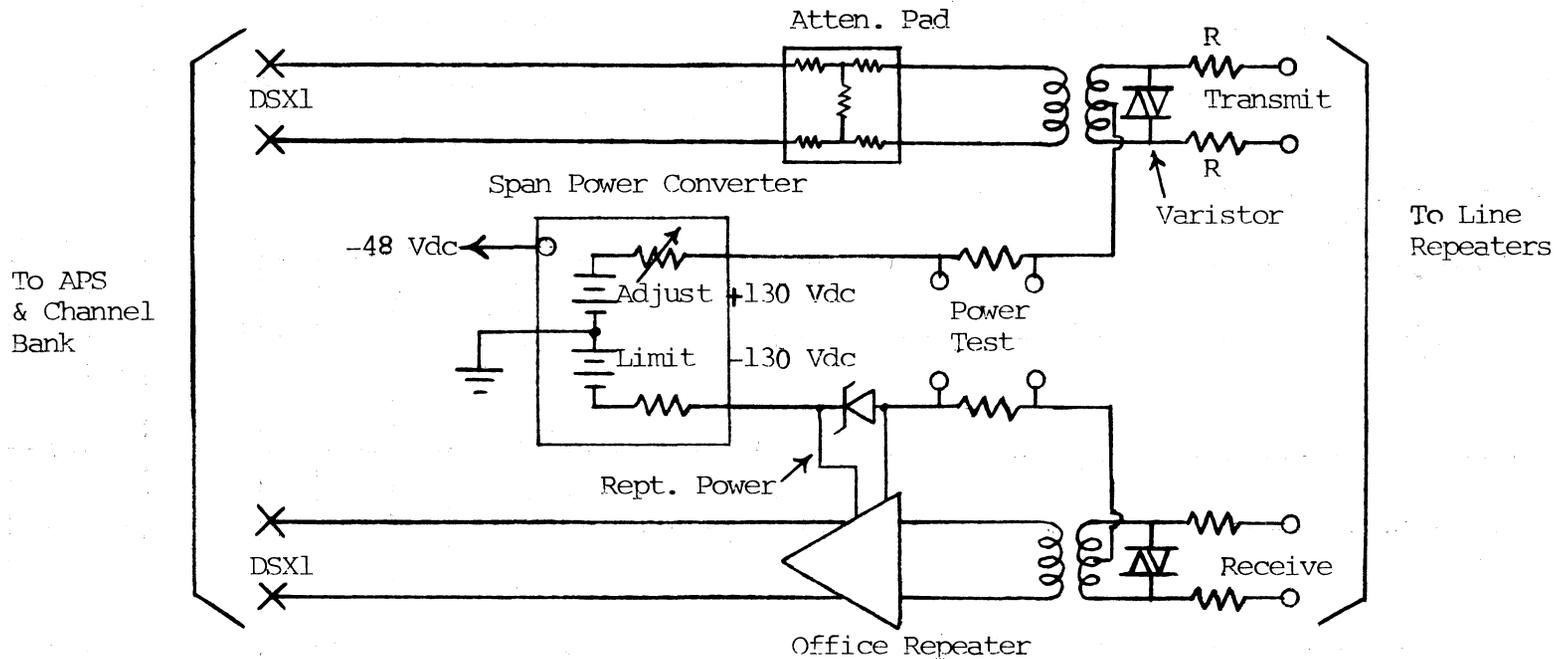
- NOTES:
1. A span line is essentially a string of regenerators between two locations.
  2. A span is the sum of all span lines between two locations.
  3. Span lines are terminated with a specified universal interface at each end. The DSX1 is the specified interface for T1 span lines and other DSL system modules. Span lines are "lossless" lines in that the input levels and output levels at all locations are equal. Spare span lines can be patched (manually or automatically) at DSX1 locations because of this universal interface.

FIGURE 2  
SPAN LINE EQUIPMENT



- NOTES:
1. This illustration shows a typical arrangement of channel banks, automatic protection switch (APS) and T1 type span line equipment. These equipment types interface at a DSX1 point.
  2. Span line equipment includes span terminating equipment (inside equipment) and line repeaters (outside equipment). The DSX1 interface jacks are generally considered part of the span terminating equipment.

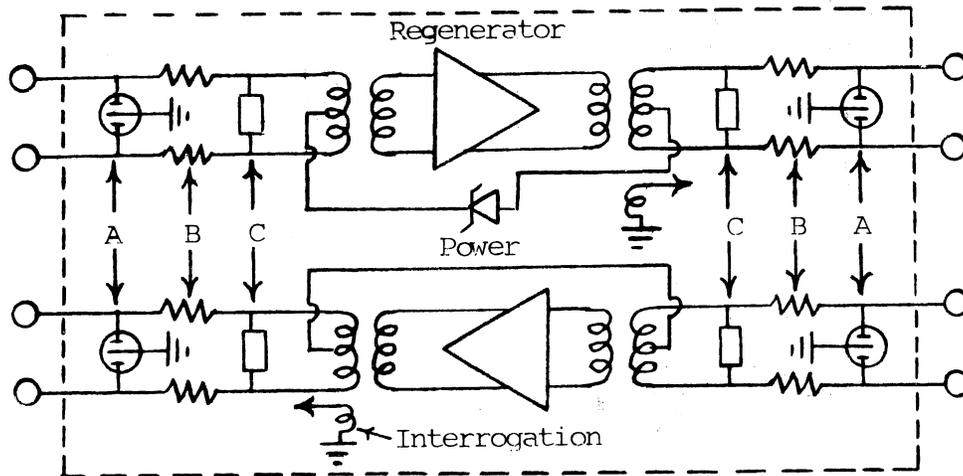
FIGURE 3  
SPAN TERMINATING EQUIPMENT



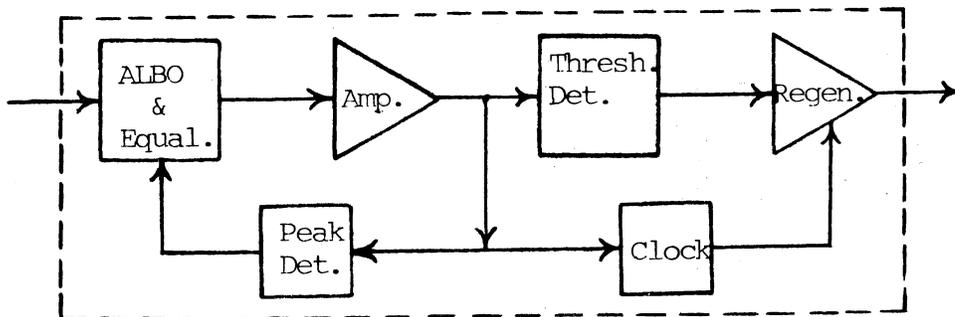
- NOTES:
1. Span termination equipment generally consists of a span power converter, an office repeater (receive only), line access units (DSX1 jacks), attenuator pads, protective devices and associated hardware.
  2. The span power converter is generally an integral part of the span terminating equipment providing +130 and -130 volts (or other voltages) for only one span line. Span power current is generally adjusted in the transmit side; REA requires current limiting in both sides of the line.
  3. The power test points (10 ohm resistors) are used to measure the dc span line loop current and the ac induction in the span line.
  4. The office repeater consists of a receive regenerator only. The office repeater is generally powered by the span power loop (the same as line repeaters).
  5. Resistors (R) and varistors (or zener diodes) face the outside plant in the transmit and receive lines to provide low voltage protection for the office repeater electronics.

FIGURE 4  
DIGITAL LINE REPEATER

A. Line Repeater



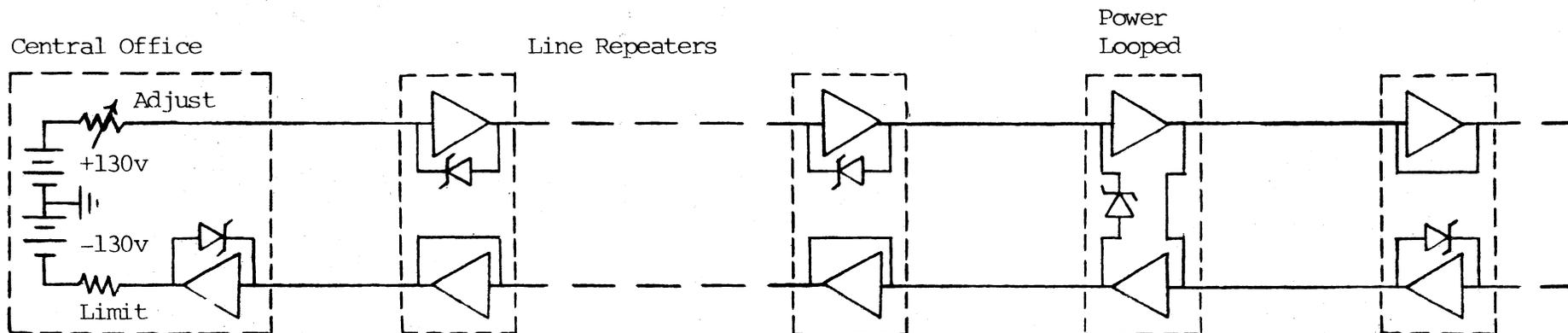
B. Regenerator



- Notes:
1. A typical digital line repeater consists of two regenerators, power, interrogation and protection.
  2. The internal power supply generally consists of a zener diode and filter capacitor.
  3. Protection consists of (A) high voltage gaps, (B) current limiting and (C) low voltage protection.
  4. A third winding in the repeater output transformer is used for the interrogation of each repeater.
  5. A typical regenerator consists of an automatic line build out (ALBO) network, equalizer and amplifier to boost and reshape the incoming signal. This is followed by a threshold detector and a balanced regenerator. A clock extracts pulses for precise timing and a peak detector feedback loop controls the amplification and equalization.

FIGURE 5

DIGITAL SPAN LINE POWER



- NOTES:
1. Span line power is generally provided in combinations of -48 or -130 volts and +130 volts. This provides for 48, 130, 178 or 260 volts (sometimes higher) for the span line.
  2. The voltage drop across each repeater is about 8 to 12 volts, depending on the span line loop current (60 to 140 mA) and the specific model repeater.
  3. The span line power is fed from each end of the system (central offices or other locations) on a simplex basis (tip and ring of a pair in parallel) to a power loop point and return.

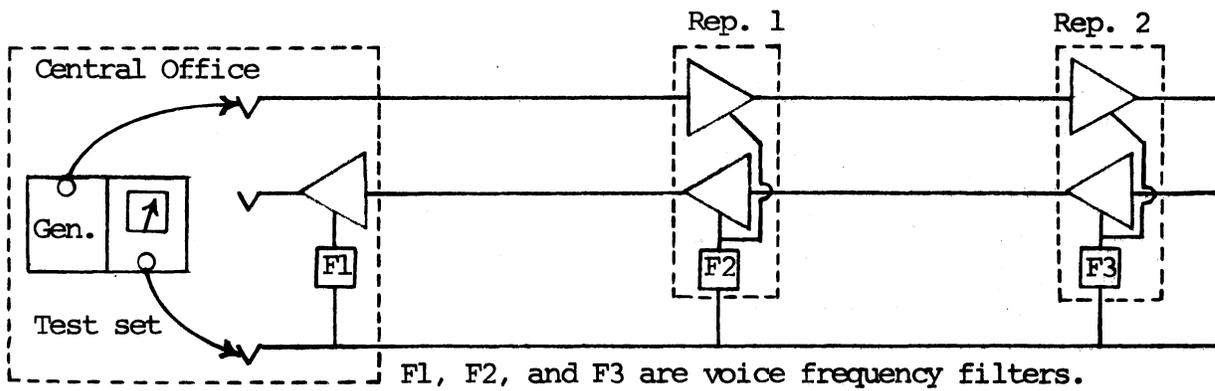
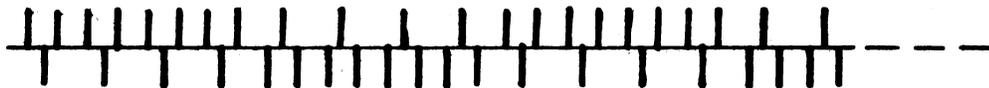
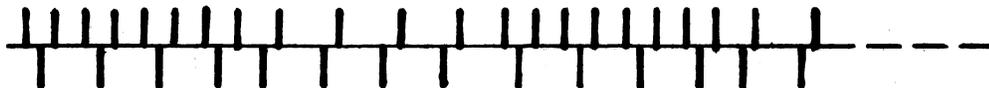


FIGURE 7  
INTERROGATION PULSES

A. Positive and Negative Trios



B. Positive Trios and Alternate Bipolar

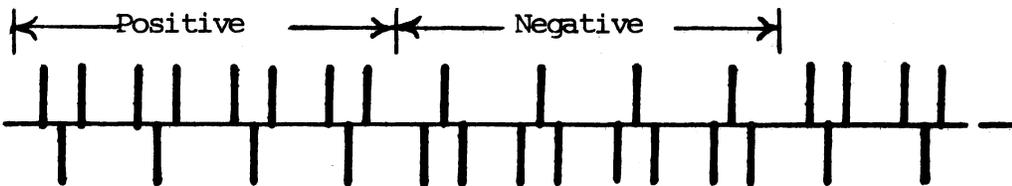


C. Negative Trios and Alternate Bipolar



FIGURE 8  
FILTERED INTERROGATION PULSES

A. Pulse Stream (Trios)



B. Filtered Pulses



FIGURE 9  
 LOOPED INTERROGATION WITH TWO FAULT PAIRS

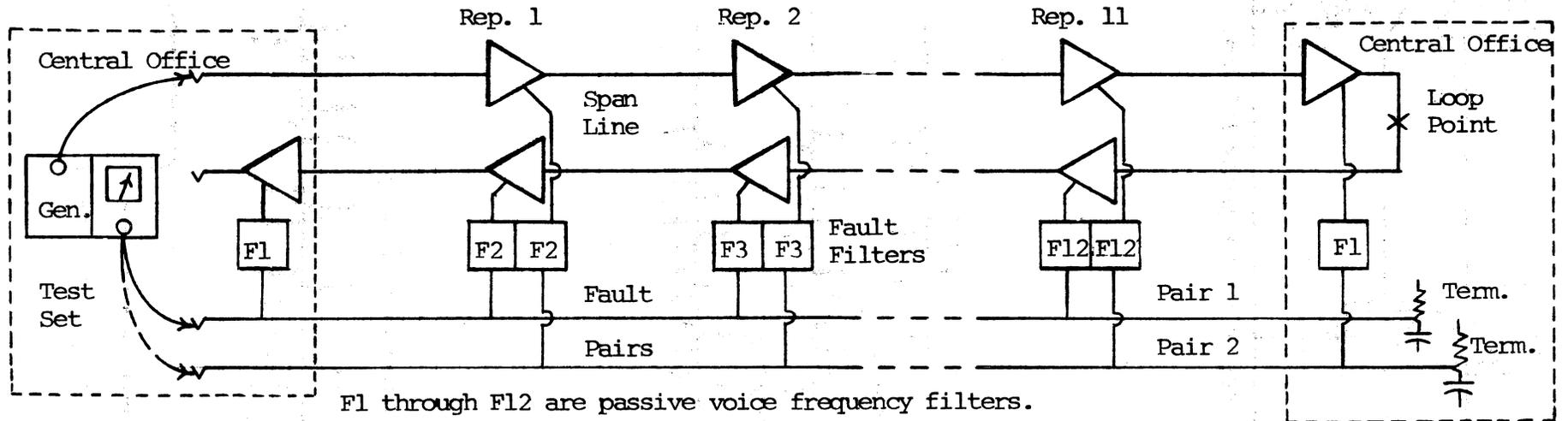


FIGURE 10  
 LOOPED INTERROGATION WITH AMPLIFIED FAULT FILTERS

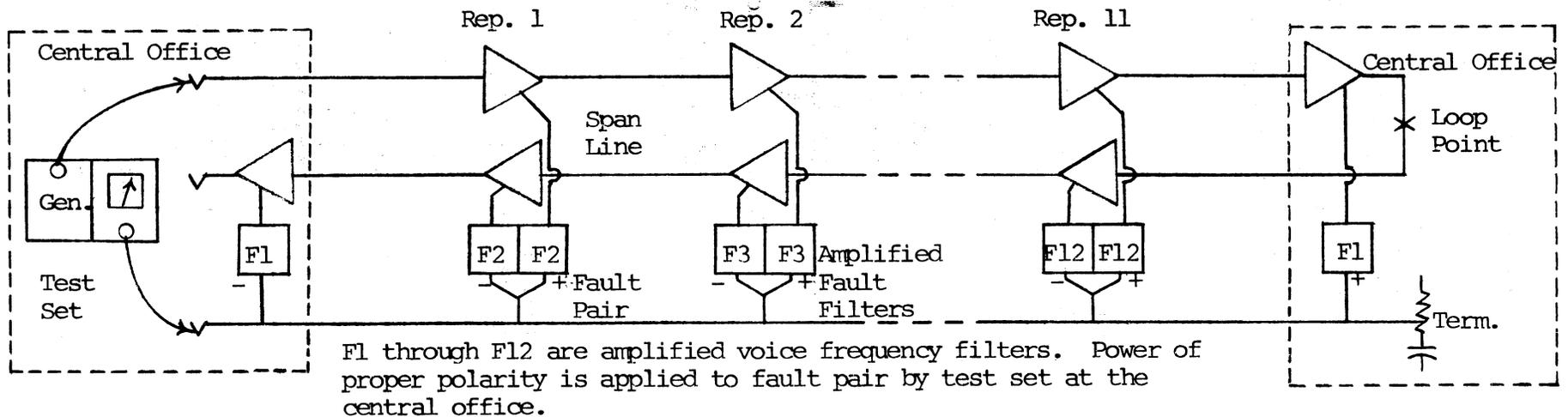
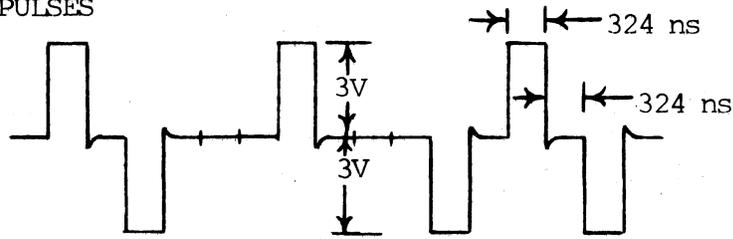


FIGURE 11

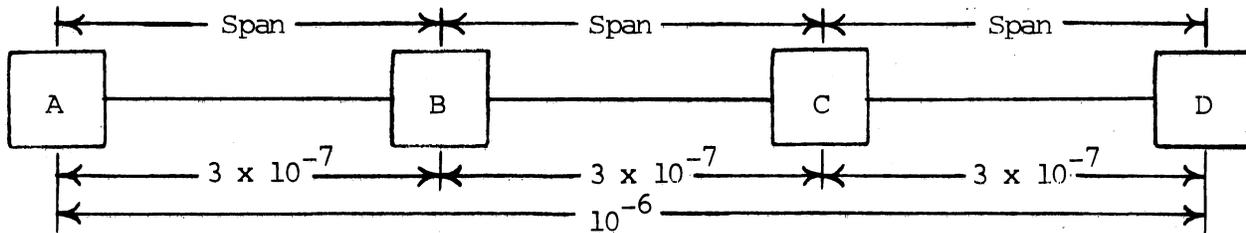
ALTERNATE BIPOLAR PULSES



NOTE: Example of 50 percent duty alternate bipolar pulses at a DSX1 interface (equipment output).

FIGURE 12

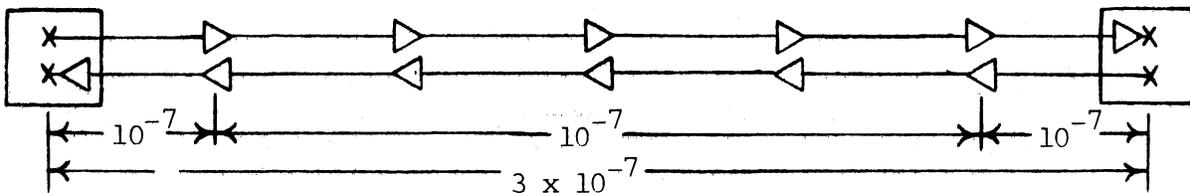
SYSTEM ERROR RATE



- NOTES:
1. The overall maximum error objective for digital systems is  $10^{-6}$ .
  2. Span line engineering guidelines are based on a maximum error rate of  $3 \times 10^{-7}$  for each span, based on the assumption of a maximum of three spans in tandem.

FIGURE 13

SPAN LINE ERROR RATE



NOTE: One-third of the span line error rate is assigned to each end section, and the remaining one-third is assigned to the remainder of the span line.

FIGURE 14

CROSSTALK COUPLING

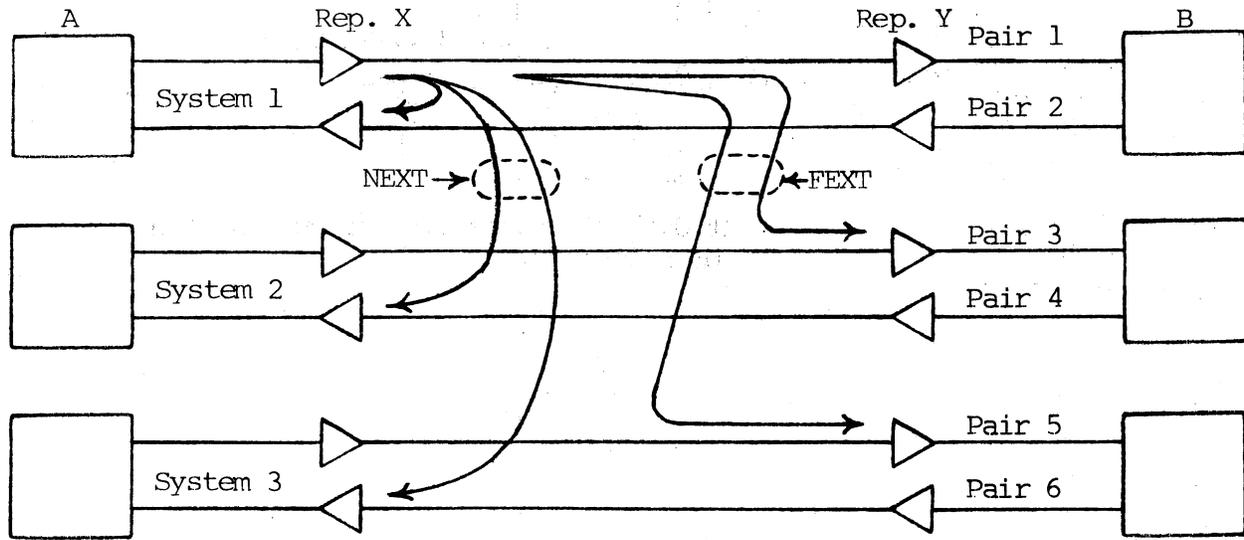
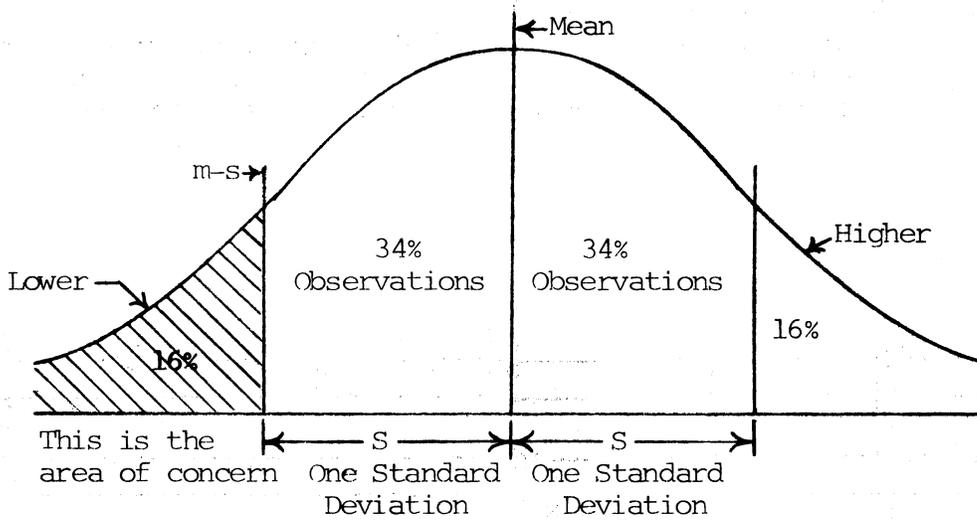


FIGURE 15

STANDARD DEVIATION

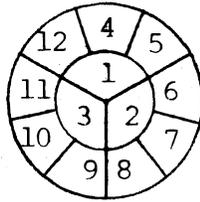


**NOTE:** For digital span line design, the statistical cable crosstalk characteristics at 772 kHz are expressed as "mean" (arithmetic average) and "mean minus one standard deviation" (m-s). Only 16 percent of the individual values would be expected to fall below the calculated m-s value.

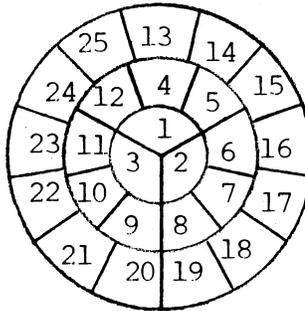
FIGURE 16

EXAMPLES OF CABLE CONSTRUCTION (NON SCREENED)

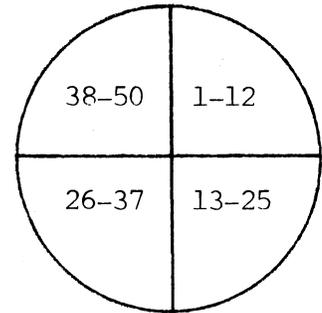
12 Pair  
(13 Pair Similar)



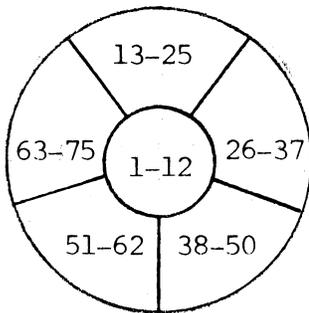
25 Pair  
(18 Pair Similar)



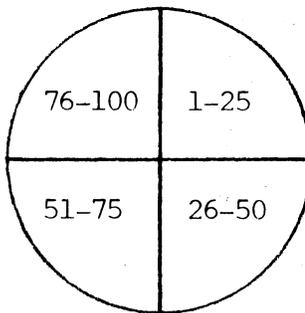
50 Pair



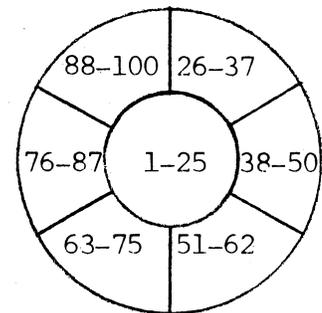
75 Pair



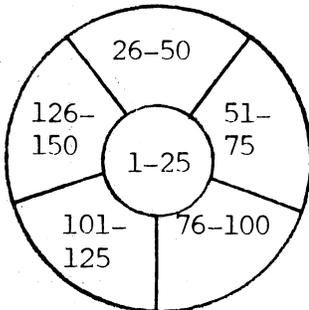
100 Pair



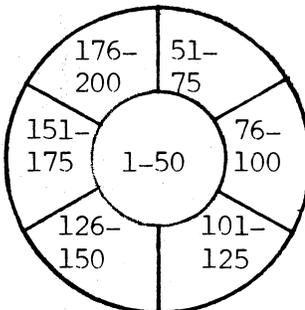
100 Pair



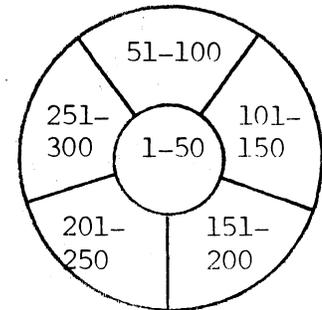
150 Pair



200 Pair



300 Pair

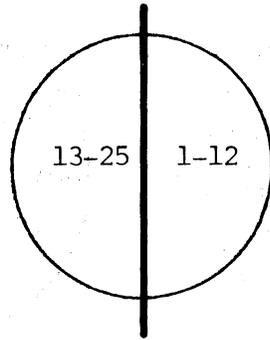


NOTE: Larger cables are made up of units composed of 12, 13, 25 or 50 pairs as shown above.

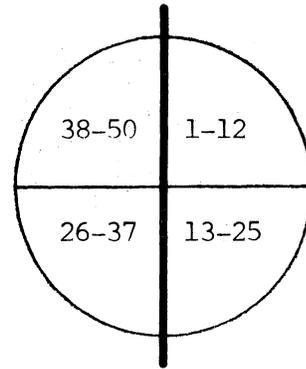
FIGURE 17

EXAMPLES OF SCREENED CABLE CONSTRUCTION

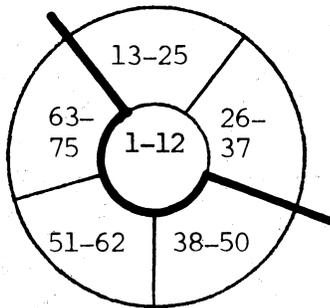
12-25 Pair  
(25 Pair Shown)



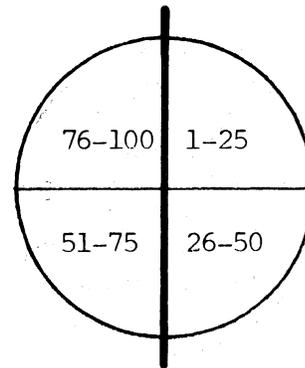
50 Pair



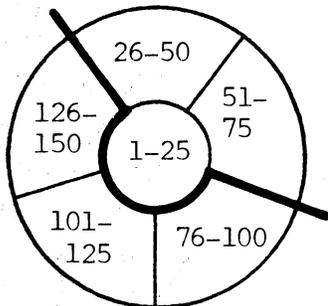
75 Pair



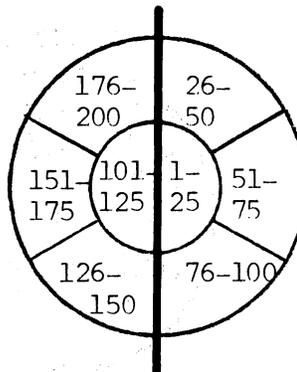
100 Pair



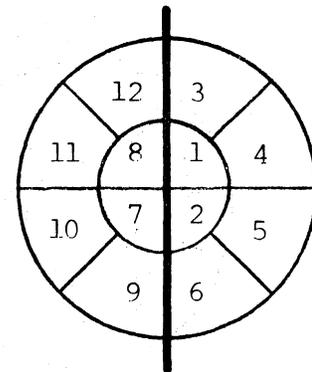
150 Pair



200 Pair



300 Pair

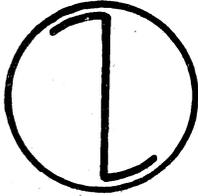


12-25 Pair  
Units

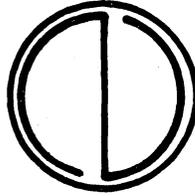
NOTE: Screened cables are generally constructed in **symmetrical halves**. Consecutive unit and pair numbers are maintained on each side of the screen.

FIGURE 18  
CABLE INTERNAL SCREENS AND SHIELDS

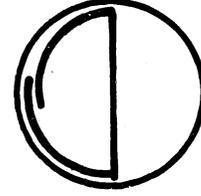
A. T Screen



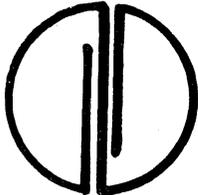
B. Extended T Screen



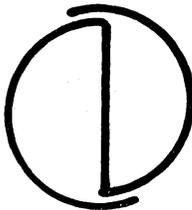
C. D Screen



D. Dual D Screen



E. Super T Screen



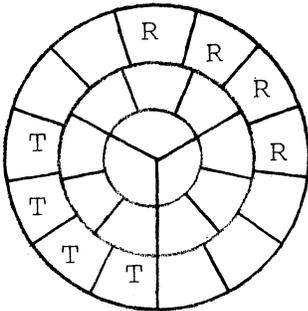
NOTE:

A, B and C are ungrounded screens; shields are separate and grounded. D and E are integrated shields and screens which are grounded.

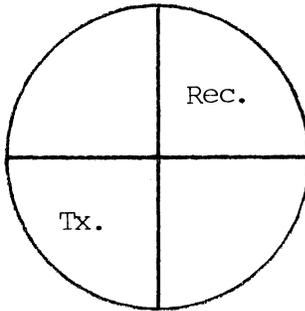
FIGURE 19

SELECTION OF CABLE PAIRS AND UNITS

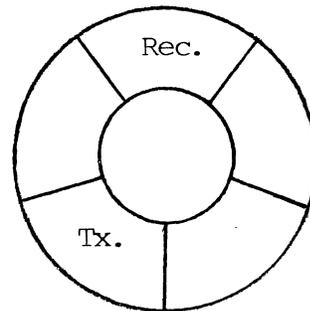
A. 25 Pair



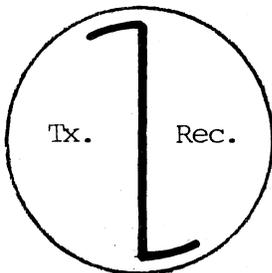
B. 50 Pair



C. Larger Cables



D. Screened Cables



NOTES: Cable pairs should be selected for maximum NEXT isolation between transmit and receive pairs. Screened cables are preferred (D) or non adjacent units in larger cables (C). Adjacent unit pairs (B) offer some improvement over pairs within the same unit (A).

FIGURE 20

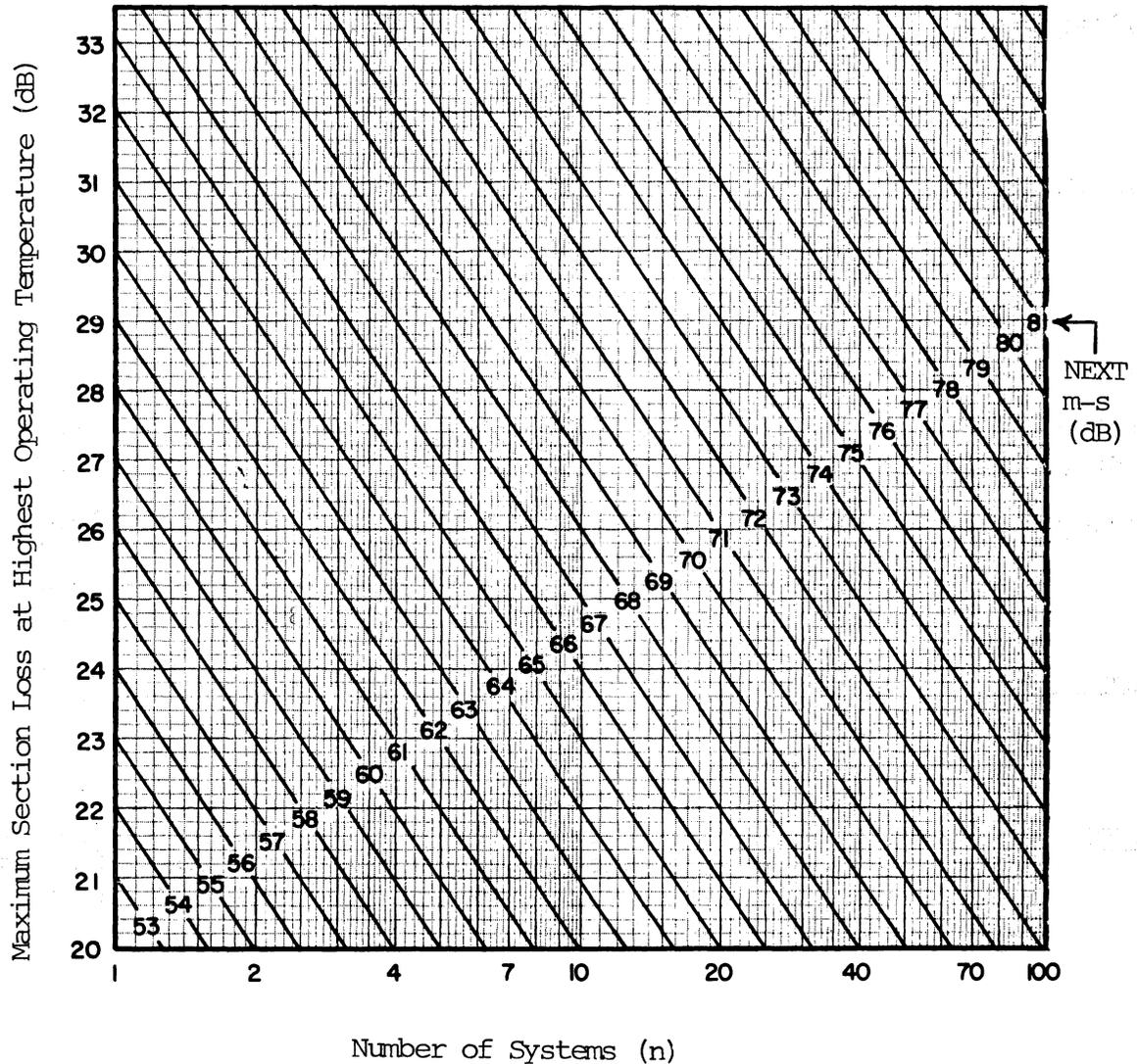
NEAR END CROSSTALK LOSS AT 772 KHz

<u>Cable or Unit Size</u>		<u>NEXT: m-s (dB)</u>			
		<u>19 Ga</u>	<u>22 Ga</u>	<u>24 Ga</u>	<u>26 Ga</u>
Pairs	6, 8 or 9 Pair Unit	55	57	58	59
Within	12 or 13 Pair Unit	57	59	60	61
Unit	18 or 25 Pair Unit	61	63	64	65
Pairs in	8, 9, 12 or 13 Pair Units	66	68	69	70
Adjacent	25 Pair Units	67	69	70	71
Units					
Pairs in	8, 9, 12, 13 or				
Non Adjacent	25 Pair Units	82	84	85	86
Units					

- NOTES:
1. The near end crosstalk values cited are typical values at 772 kHz for filled core and air core plastic insulated conductor cables in common use (0.083  $\mu$ F/mile).
  2. m-s = MEAN VALUE minus ONE STANDARD DEVIATION of the mean near end crosstalk in dB.
  3. Cable pairs should be assigned to provide the maximum isolation between transmit and receive directions of transmission if possible. If cable makeup is unknown, use the worse case condition to determine the maximum repeater spacing.

FIGURE 21

MAXIMUM LOSS CHART FOR ONE CABLE OPERATION



NOTE: The maximum loss in dB for one cable operation is determined by the maximum number of systems (n) to be applied (ultimate quantities) and the NEXT determined from Figure 20.

FIGURE 22

CABLE ENGINEERING LOSS DATA AT 772 kHz

A. Cable Loss in dB/Kilofeet at 772 kHz

<u>Cable Construction</u>	<u>Cable Gauge</u>	<u>Reference (55°F)</u>	<u>Buried Cable (100°F)</u>	<u>Aerial Cable (140°F)</u>
<u>Filled Core</u>	19	2.94	3.09	3.23
	22	3.99	4.19	4.37
	24	4.92	5.17	5.39
	26	6.30	6.59	6.86
<u>Air Core</u>	19	3.18	3.32	3.43
	22	4.39	4.58	4.75
	24	5.58	5.72	5.87
	26	7.48	7.66	7.82

B. Cable Length in Kilofeet for 23 dB and 33.5 dB Loss

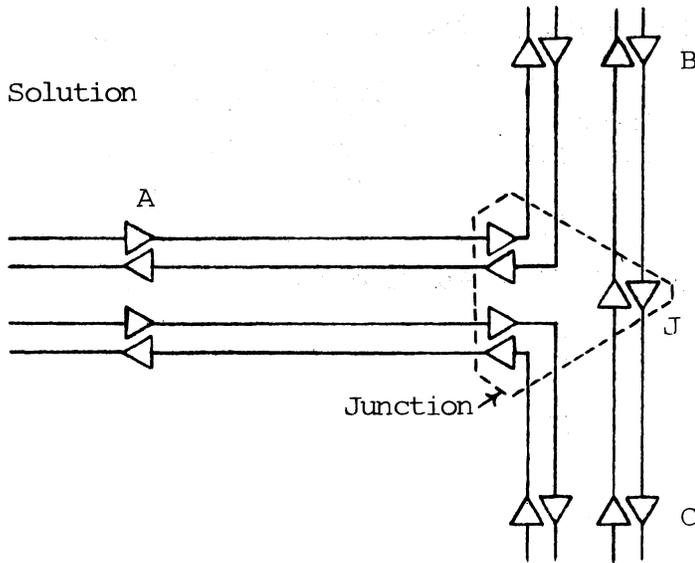
<u>Cable Construction</u>	<u>Cable Gauge</u>	<u>Buried Cable (100°F)</u>		<u>Aerial Cable (140°F)</u>	
		<u>23 dB</u>	<u>33.5 dB</u>	<u>23 dB</u>	<u>33.5 dB</u>
<u>Filled Core</u>	19	7.4	10.8	7.1	10.4
	22	5.5	8.0	5.3	7.7
	24	4.4	6.5	4.3	6.2
	26	3.5	5.1	3.4	4.9
<u>Air Core</u>	19	6.9	10.1	6.7	10.0
	22	5.0	7.3	4.8	7.1
	24	4.0	5.9	3.9	5.7
	26	3.0	4.4	2.9	4.3

NOTE: The engineering loss values cited are typical values at 772 kHz for filled core and air core plastic insulated conductor cables in common use (0.083  $\mu$ F/mile). Refer to manufacturer's data for more precise values and for other cable types.

FIGURE 23

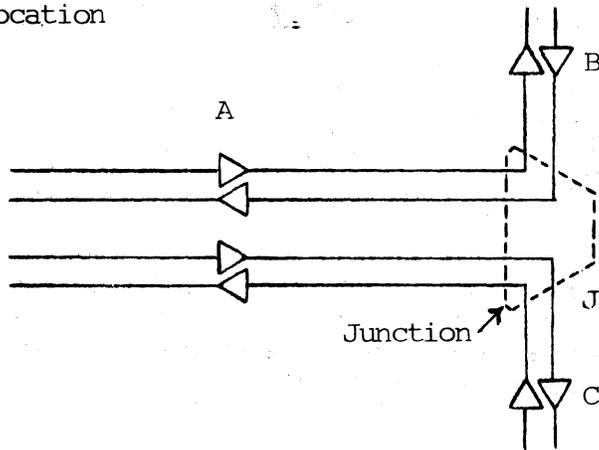
ROUTE JUNCTIONS

A. Ideal Solution



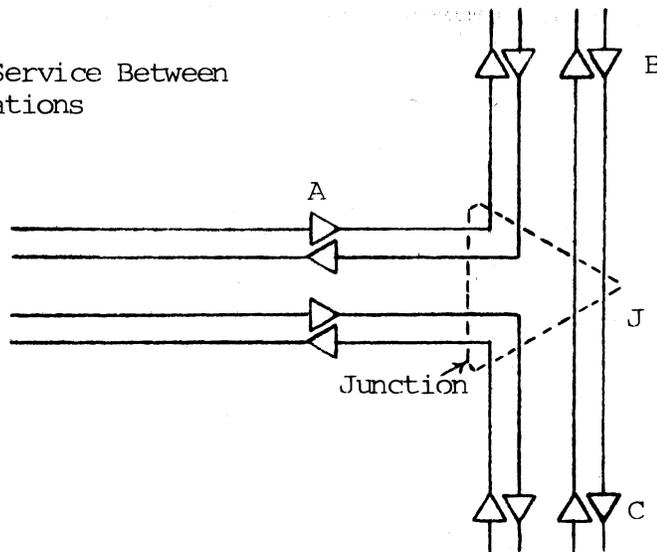
When a repeater is located at the junction, sections A-J, B-J and C-J are independent of each other.

B. Direct Service From One Location



Sections B-J and C-J should be nearly equal (in dB). Section A-J is a separate consideration.

C. Direct Service Between All Locations



Sections A-J, B-J and C-J should all be nearly equal (in dB).

FIGURE 24

SPAN POWER CONSIDERATIONS

A. Equivalent Resistance of Equipment in Ohms

	<u>60 mA</u>	<u>100 mA</u>	<u>140 mA</u>
Span Terminating Unit/With Power	500	300	214
Span Terminating Unit/Without Power	200	140	100
Line Repeater	158	100	75

B. Cable Simplex Loop Resistance in Ohms Per Kilofeet

<u>Gauge</u>	<u>100°F</u>	<u>140°F</u>
19	8.4	9.2
22	16.8	18.3
24	26.8	29.2
26	42.6	46.7

C. Equivalent Resistance in Ohms  
(Supply Voltage Divided by Line Current)

<u>Volts</u>	<u>60 mA</u>	<u>100 mA</u>	<u>140 mA</u>
48	800	480	343
130	2167	1300	929
178	2967	1780	1271
260	4333	2600	1857
308	5133	3080	2200

NOTE: The resistance values shown are representative values for discussion purposes and for estimating span power requirements. A final determination should be made based on the specific manufacturer's equipment from that manufacturer's published charts.