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The Application of Various Digital Subscriber Line (xDSL) Technologies to ITS: Traffic Video Laboratory Assessments

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ABSTRACT

Various digital subscriber line (xDSL) technologies are those methods used to implement high-speed data services (e.g., 2 Mbps Frame Relay) on a twisted pair (wire) communications medium. They are also considered strong candidates for rapidly deploying Intelligent Transportation Systems (ITS) services over existing communications infrastructure. For example, xDSL technologies provide the potential to integrate full motion traffic video over the twisted pair currently used by many traffic control systems.

Commercially available xDSL products and services exist, and field trials have occurred for the more popular applications, including Internet access and video on-demand. However, ITS applications such as freeway surveillance video are untested. Although xDSL technologies offer great potential for ITS, they remain largely unknown to the transportation industry, and further evaluation is required. This paper summarizes some features of these technologies and a successful Federal Highway Administration (FHWA) proof-of-concept test to assess their application to ITS.

Suggested Keywords: digital subscriber line (DSL), traffic video, Intelligent Transportation Systems (ITS)

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EXECUTIVE SUMMARY

INTRODUCTION

Various digital subscriber line (xDSL) technologies are methods used to implement high-speed data services on a twisted pair (wire) communications medium. They are also candidates for rapidly deploying Intelligent Transportation Systems (ITS) services over existing communications infrastructure. However, as emerging technologies, they remain largely unknown to the transportation industry, and proof-of-concept studies are needed to establish their application within ITS. This paper documents a Federal Highway Administration (FHWA) concept study devised to establish, demonstrate, and evaluate the use of xDSL technologies within ITS, particularly traffic video applications (e.g., traffic management, incident detection).

This study was not an effort to evaluate the relative performance of vendor specific xDSL equipment that is based on a particular modulation technique or adheres to a particular standard. It was also not a comparative technical or financial study of the many video transmission systems (e.g., fiber, coaxial, wireless) or the types of video they support (e.g., analog, digital, packetized). It was a feasibility study to determine whether xDSL technologies could be used for traffic video, and if so, how they might be applied.

The complete study is being conducted in two phases: an initial laboratory testing phase that was performed in Mitretek's Advanced Telecommunications Laboratory (ATL), and a supplemental field testing phase. Both phases include various qualitative and quantitative assessments to determine if our concept systems function properly, and if so, over what distances, with what impairments, at what data rates, and with what quality.

The laboratory assessments have been completed and comprise the basis for the findings in this report. While the focus of our activity is the application of xDSL to traffic video, this document also provides essential background information and general understanding of the technologies.

BACKGROUND

Telephone companies have long been developing methods of providing new high-bandwidth services to the home, and several strategies have been pursued to increase bandwidth of the "last mile", such as fiber-to-the-curb (FTTC) and hybrid fiber-coax (HFC). These are not yet practical for most individual end users, but xDSL technologies can provide such services during this – perhaps 20 year – transition period.

As the telephone companies continue developing xDSL technologies and services, the devices being created might also be used to support high-speed data-intensive applications for ITS. Like the telephone companies, state Departments of Transportation (DOTs) have an enormous investment – and usually an extensive existing infrastructure –

in twisted pair connectivity. This provides an interesting alternative for DOTs that may be planning to lease communications or install fiber-optic systems.

Twisted pair wire has much greater bandwidth available (over 1 MHz) than is typically used (approximately 4 kHz). xDSL technologies utilize this available bandwidth and attain greater data rates by taking advantage of breakthroughs in error correction coding, modulation, equalization, echo cancellation, and digital signal processing techniques. The various technologies support symmetric and/or asymmetric communication. Some use most all of the twisted pair bandwidth, while others share the bandwidth with existing communications (e.g., plain old telephone service [POTS]).

There are over 13 forms of DSL technology, hence the variable ‘x’ in xDSL. Each has its distinct advantages and target applications. Among others, the asymmetric forms include: Asymmetric DSL (ADSL), Rate Adaptive DSL (RADSL), and Very-high-bit-rate DSL (VDSL). Symmetric forms include: High Bit Rate DSL (HDSL), Single-pair HDSL (S-HDSL), Symmetric DSL (SDSL), and HDSL Version 2 (HDSL2).

The development of new DSL technologies and the enhancement of those noted above is extremely rapid. By the time this document is released, many changes in these technologies will have occurred, including the line coding techniques on which they are based and the standards to which they adhere.

Although xDSL is often referred to as a service, it is more appropriately identified as a transport technology that enables high-speed services (e.g., Frame Relay and Asynchronous Transfer Mode (ATM)). xDSL technologies can also be used to provide clear channels without enabling any particular service – an approach we used in our concept study.

THE CONCEPT: xDSL-BASED TRAFFIC VIDEO

Although traffic video is a current interest of many DOTs and the scope of this particular effort, other high-speed and data-intensive transportation applications can be supported by the xDSL technologies. The US National ITS Architecture depicts a number of potential applications, most of which involve roadside and remote access systems.

In their application to traffic video, xDSL technologies provide the ability to multiplex video transmissions over the existing twisted pair infrastructure currently used by DOTs for freeway management and traffic control. This particular example is the essence of our concept study.

CONCEPT SYSTEMS

To establish and evaluate our concept of xDSL-based traffic video, we required both base system components and DSL system components, the latter of which is highlighted in Figure ES-1.

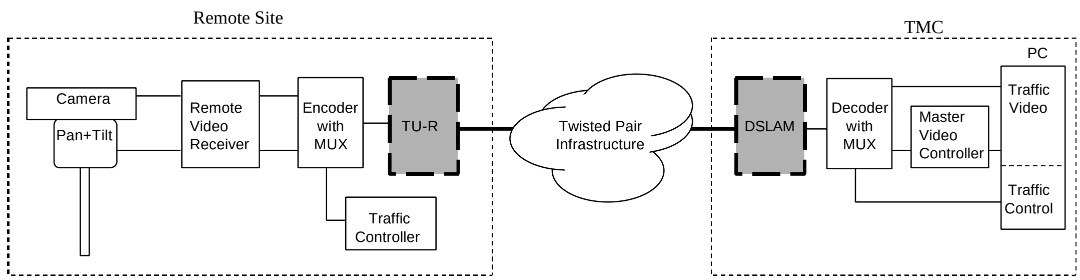

Figure ES-1. xDSL-Based Concept Prototype

Base system components provide the common functionality of digital traffic video systems in use today and comprise the traffic video and traffic control equipment to which particular xDSL technologies are applied. They also allow one to account for various equipment configurations and infrastructure conditions when evaluating the performance of the prototypes. Along with a personal computer, these base systems include the following:

- A traffic video component (camera, pan & tilt unit, video receiver, video controller)
- A traffic controller component
- A twisted pair simulator component
- A video encoder/decoder "codec" component

xDSL system components provide the means of communication between base system components in the field, and those at a TMC or communications hub. As part of a complete system, they were introduced to the base system components creating concept prototypes, such as that illustrated in Figure ES-1. Although we consistently illustrate our concept with a single-camera system, it is possible to integrate multiple-camera systems on a single DSL circuit.

CONCEPT PROTOTYPES

Different communication infrastructures and twisted pair availability create different scenarios in which to use xDSL-based traffic video systems – each more amenable to different solutions. With no unused (or spare) pairs available for dedicated use, an ADSL system could be used to provide video transmissions and camera control on the same twisted pair currently used for field device telemetry – without disturbing this baseband communication. With more than one spare twisted pair available, other xDSL systems offer potential solutions.

Several prototypes were considered for our study, but while most xDSL technologies offer a solution, particular aspects of some make them more or less feasible as a part of our concept systems, including: infrastructure limitations, equipment interfaces, and technology lifecycle and availability. In an attempt to represent various deployment scenarios, our approach was to consider one each of the more viable symmetric and asymmetric DSL solutions – SDSL and RADSL respectively.

Regardless of the enabling DSL technology, the concept remains the same, “provide integrated traffic video and traffic control over twisted pair wire”. Any specific solution is subject to the requirements of and the restrictions upon those implementing the system. The solutions we have selected are sufficient for the purpose of our lab study, and they comprise the basis for our two concept prototypes.

PROTOTYPE EVALUATIONS

Having established the concept prototypes, we devised a methodology to assess their performance. Evaluating the SDSL and RADSL prototypes within a laboratory environment involved:

- Creating a laboratory traffic video source (i.e., the traffic event our camera will view)
- Formulating various twisted pair infrastructure scenarios (e.g., an ANSI #6 configuration) over which our prototypes will operate
- Determining various system parameter settings (e.g., the xDSL line rate) with which our prototypes will operate

Once these issues were resolved, we were able to conduct the evaluations. Quantitative assessments involved: xDSL modem performance and error statistics, xDSL modem information rate (i.e., throughput), video motion (i.e., video frame rate), and traffic controller operational status. Qualitative observations involved perception of the received video quality.

CONCLUSIONS

Our conclusions were derived from not only our assessments, but also the process of establishing the concept prototypes. This includes developing an understanding of xDSL technologies, traffic video systems, and field device communications. Each of which has an impact on how the prototypes were designed, and how they might be deployed.

The prototypes operate as expected within the limitations of their component systems, particularly the xDSL systems. The xDSL systems used in both prototypes performed well and functioned consistently when operating below their maximum distance-throughput values (e.g., 21,000 feet at 2048 kbps). As with most digital communication technologies, they perform almost flawlessly until reaching these particular thresholds, then they fail. Within these bounds, the video quality can be improved or worsened at the expense or benefit of video motion. The compromise becomes an issue of preference.

The prototypes have shown that xDSL-based traffic video systems will work. The circumstances under which they will work and the performance of those that do will vary with implementation, but the concept is sound. Although commercially available xDSL equipment and services now exist, they were not specifically intended for applications such as traffic video. If choosing to deploy an xDSL solution, along with user requirements, there will be some additional infrastructure-, equipment-, operational-, and service-related issues to address. Ultimately, these considerations will be influenced by where and for whom the system is deployed.

While conducting over 600 different laboratory test cases, we could not possibly construct the endless number of scenarios one might encounter in the field. Furthermore, precisely duplicating realistic field conditions with any one of the test cases was unlikely. Therefore, we are currently conducting field-testing activities to validate our laboratory work and to demonstrate the concept prototypes in a true operational environment. Two sites have been selected for field study activities, one within the city of Alexandria, Virginia, and the other within the city of Fairfax, Virginia. The results of these efforts will be documented as an addendum to a revised version of this report.

xDSL technologies show great potential for their application to ITS. Although our focus is limited to traffic video, the numbers and types of high-speed data-intensive applications will grow and subsequently increase the demand on transportation communication systems. The ability to support such applications on existing infrastructure can significantly speed system deployment and provide substantial cost savings. It provides an alternative to those with communications problems that originate from financial constraint or infrastructure limitations. It also provides an option for those planning to lease or install new communication systems. Our studies effectively demonstrate this concept and have helped establish the value of xDSL technologies within the transportation domain.

SECTION 1

INTRODUCTION

Various digital subscriber line (xDSL) technologies are methods used to implement high-speed data services on a twisted pair (wire) communications medium. They are also candidates for rapidly deploying Intelligent Transportation Systems (ITS) services over existing communications infrastructure. However, as emerging technologies, they are rapidly evolving and remain largely unknown to the transportation industry, and proof-of-concept studies are needed to establish their application within ITS. As part of a Federal Highway Administration (FHWA) task, Mitretek Systems is conducting such studies.

1.1 PURPOSE

Commercially available xDSL products and services exist, and systems are in place to support the more popular residential applications, including Internet access and video on-demand. However, ITS applications such as freeway surveillance video are untested. This paper documents a Mitretek concept study devised to establish, demonstrate, and evaluate the use of xDSL technologies within ITS, particularly traffic video applications (e.g., traffic management, incident detection). Results of this effort can be used to identify potential solutions for ITS applications that were previously perceived unfeasible due to financial constraint or communications infrastructure limitations.

1.2 SCOPE

While this study effectively demonstrates the concept of using xDSL technologies to support various ITS applications, the scope of this particular effort features the use of xDSL for traffic video. Emphasis was placed on evaluating the operation and performance of end-to-end xDSL-based traffic video systems – our concept systems. This study was not an effort to evaluate the relative performance of vendor specific xDSL equipment that is based on a particular modulation technique or adheres to a particular standard. It was also not a comparative technical or financial study of the many video transmission systems (e.g., fiber, coaxial, wireless) or the types of video they support (e.g., analog, digital, packetized). It was a study to determine whether xDSL technologies could be used for traffic video, and if so, how they might be applied.

Our xDSL concept studies are being conducted in two phases: an initial laboratory testing phase that was performed in Mitretek's Advanced Telecommunications Laboratory (ATL), and a supplemental field testing phase. Both of which include various qualitative and quantitative assessments to determine if our concept systems function properly, and if so, over what distances, with what impairments, at what data rates, and with what quality.

The laboratory assessments have been completed and comprise the basis for the findings in this report. The field assessments will validate our laboratory work and demonstrate the system concept in an operational environment. Documentation of the field studies will comprise an addendum to a revised version of this report. While the focus of our activity is the application of xDSL to traffic video, this document also provides essential background information and general understanding of the technologies.

1.3 ORGANIZATION

This document is divided into six additional sections, and four appendices:

- Section 2 provides background on the xDSL technologies
- Section 3 explains the general application of xDSL technologies to ITS as well as our specific application to traffic video
- Section 4 introduces components of the concept systems
- Section 5 describes our concept prototypes
- Section 6 describes our evaluation methodology and provides results from the evaluation of our concept prototypes
- Section 7 offers brief conclusions as a result of this effort
- Appendices A and B document specific findings from the prototype evaluations
- Appendix C provides a detailed description of the components introduced in section 4
- Appendix D illustrates twisted pair loop configurations used in our assessments

SECTION 2

BACKGROUND

Today's telephone networks serve millions of homes and businesses, but they were primarily designed for what is know as plain old telephone service (POTS). With advancements in communications technologies, these networks have undergone several upgrades to enhance both the capacity and the quality of service over their backbone segments. However, circumstances are much different for the existing local loops – the "last mile" connections that are currently dominated by twisted pair wire.

Telephone companies have long been developing methods of providing new high-bandwidth services to the home, and several strategies have been pursued to increase bandwidth of the "last mile", including fiber-to-the-curb (FTTC) and hybrid fiber-coax (HFC). Unfortunately, such technologies are not yet practical for individual end users. Due to the sheer volume of installed twisted pair, the time and associated costs required to upgrade the existing "last mile" connections are enormous. It is estimated that telecommunications carriers can replace a maximum of 4% of the subscriber connections annually. Therefore, xDSL technologies have been proposed as an interim solution to bring high bandwidth services to the home or business during this – perhaps 20 year – transition period.

As the telephone companies continue developing xDSL technologies and services, the devices being created might also be used to support high-speed, data-intensive applications for ITS. Like the telephone companies, state Departments of Transportation (DOTs) have an enormous investment – and usually an extensive existing infrastructure – in twisted pair connectivity. This provides an interesting alternative for DOTs that may be planning to lease communications or install fiber-optic systems. The ability to provide for transportation services on existing twisted pair wires using xDSL can significantly speed system deployment as well as provide substantial cost savings. Field trials have occurred for residential applications (e.g., Internet access, video on-demand), but transportation applications such as those identified in this paper are untested.

2.1 VARIOUS DIGITAL SUBSCRIBER LINE (xDSL) TECHNOLOGIES

Subscriber lines are the twisted pair connections between customer premise equipment (CPE) and the central office (CO) that enable both POTS and high-speed access services without the need for repeaters. Individual subscriber lines are combined into sub-distribution, distribution, sub-feeder, and feeder cables (with as many as 3600 pair) until they are eventually connected at the CO. Data exchanged between the xDSL CPE and the CO is concentrated by a digital multiplexer and passed through the transport system to the local access network (Figure 2-1).

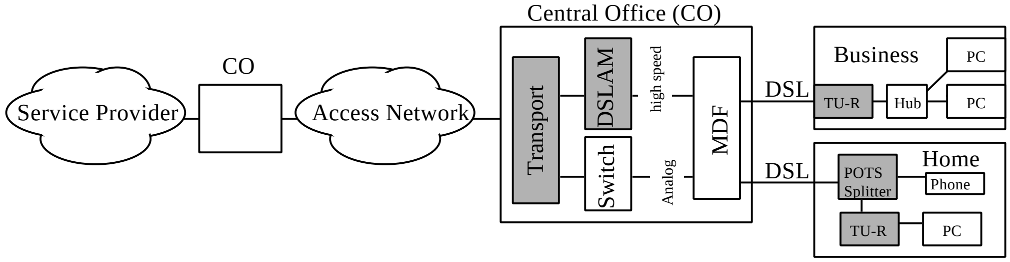

Figure 2-1. xDSL System Configuration

System components within a common xDSL system include:

- **Transceiver Unit - Remote (TU-R):** This CPE provides end users an interface (e.g., 10BaseT, V.35, ATM-25, etc.) to the DSL loop. The TU-R is commonly referred to as an ATU-R due to early associations with asymmetric DSL technologies.
- **POTS Splitters:** These are either active or passive devices used in conjunction with those xDSL technologies that allow for simultaneous high-speed data transmissions and 4 kHz baseband communications (e.g., POTS). New 'splitterless' xDSL technologies eliminate the need for this separate piece of equipment.
- **Digital Subscriber Line Access Multiplexer (DSLAM):** This device resides within the CO and concentrates the data traffic from multiple DSL loops onto the local access network. Most DSLAMs offer backhaul services for packet, cell, and/or circuit based applications; some provide cell and/or packet multiplexing capabilities as well.
- **Transceiver Unit - CO (TU-C):** Although not shown in Figure 2-1, this device is the counterpart to the TU-R and provides the interface between the CO and the DSL loop. A DSLAM is a TU-C with multiplexing and other advanced capabilities.
- **Transport System:** This system provides a local access network transmission interface (e.g., T1, T3/E3, OC-1, OC-3, and STS-1) for the DSLAM.

2.1.1 What Do DSL Technologies Do?

The existing telecommunications network is designed to optimize the voice grade bandwidth of approximately 4 kHz, as illustrated in Figure 2-2.

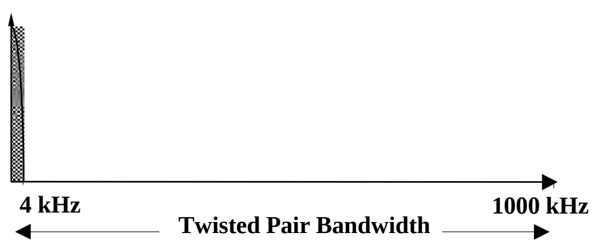

Figure 2-2. Twisted Pair Frequency Spectrum

Conventional modems (i.e., voice grade baseband modems) transmit signals through the switching network without alteration; the network treats them like voice signals. The data rates achieved by these modems are now approaching a theoretical maximum, but copper wire can pass much higher frequencies and subsequently allow much greater data rates. The xDSL technologies utilize this available bandwidth and attain greater data rates by taking advantage of breakthroughs in error correction coding, modulation, equalization, echo cancellation, and digital signal processing.

xDSL technologies can support both symmetric and asymmetric data rates. Some use most all of the twisted pair bandwidth, while others share the bandwidth with existing communications.

2.1.2 Types of xDSL Technologies

The xDSL technologies evolved from two different markets: a consumer market aimed primarily at the home user; and a commercial market aimed at the business environment. Each technology has its distinct advantages and target applications. The following summarizes some of the more common asymmetric and symmetric types.

The asymmetric xDSL technologies include:

- **Asymmetric DSL (ADSL):** ADSL uses a single twisted pair. It is designed to support downstream (CO to CPE) rates ranging from 1.544 Mbps at distances up to 18,000 feet to 8.448 Mbps at distances of 9000 feet or less. Upstream (CPE to CO) data rates range from 16 kbps to 640 kbps. The spectrum used by ADSL is well above 4 kHz, leaving any POTS undisturbed.

- **Rate Adaptive DSL (RADSL):** RADSL, a variant of ADSL, also uses a single twisted pair. RADSL modems assess the quality of the line and automatically adjust the number of modulation levels or the use of sub-bands (depending on line coding method) to match the modem speed with maximum line capacity (i.e., a RADSL modem will adjust to the highest data rate the line can accommodate at a given time). While RADSL modems have an auto-rate adaptive mode, they also support manual configuration, including symmetric operation. Depending on line length and quality, asymmetric data rates range from 1-12 Mbps on the downstream link, and 0.128-1 Mbps on the upstream link. Symmetric data rates range from 1-2 Mbps.

- **Very-high-bit-rate DSL (VDSL):** VDSL is an adaptation of ADSL used to transmit very high asymmetric bit rates (e.g., 30-51 Mbps downstream) over very short distances – usually less than 1000 feet. Some newer variants of VDSL have been designed to support symmetric rates ranging from 2-4 Mbps over much longer distances.

The symmetric xDSL technologies include:

- **High Bit Rate DSL (HDSL):** HDSL was one of the first DSL technologies fielded and is primarily used by telecommunications companies for infrastructure. HDSL provides symmetric data rates of 1.544 Mbps over two twisted pair up to 12,000 ft in length. HDSL is currently the most widely used xDSL technology. There are over one half million installations, most of them used to deploy repeaterless T1's.

- **Single-pair HDSL (S-HDSL):** S-HDSL, like HDSL, is a telecommunications company infrastructure technology, but as the name indicates, only a single twisted pair is used. Consequently, the data rate is limited to 768 kbps – ½ that of HDSL.

- **Symmetric DSL (SDSL):** SDSL represents a family of symmetric rate lines (e.g., 384, 768, 1544, and 2048 kbps) that are implemented over a single twisted pair. This technology was intended to support symmetric services such as frame relay and two-way video teleconferencing. At a T1 data rate, SDSL can reach distances well beyond 10,000 feet.

- **HDSL Version 2 (HDSL2):** HDSL2 has the same data rate as HDSL but uses a single twisted pair. This DSL technology has new features designed for simplifying the implementation of the telecommunications company infrastructure.

Most of the symmetric technologies use line codes that have spectral energy overlapping the voice frequency band; therefore, they usually require dedicated twisted pair and can not be used to support simultaneous communication in the voice frequency band (e.g., POTS, voice grade modem operation).

Additional versions of xDSL are currently emerging. As an example, some providers will offer low-speed **ISDN DSL (IDSL)** and/or **consumer DSL (CDSL)** for residential markets or applications. IDSL is ISDN without the telephone switch. In other words, the two B channels of an ISDN basic rate interface (BRI) are multiplexed to give a dedicated 128 kbps circuit for data only (no voice). This data service is then directed to a WAN, rather than a switched network, allowing IDSL to work well in a digital loop carrier (DLC) system. CDSL is a low-cost 1 Mbps version of DSL developed by Rockwell International. A technology called **universal DSL (UDSL)**, similar to CDSL, has also recently been developed.

The development of new DSL technologies and the enhancement of those noted above is extremely rapid. By the time this document is released, many changes in these technologies will have occurred, including the line coding techniques on which they are based and the standards to which they adhere. While the changes are more often beneficial, it will be important to follow them as they impact the use of xDSL as an enabling technology.

2.1.3 Line Codes

Advancements in signal processing and line coding have significantly increased the data rates achieved by older line coding techniques such as alternate mark inversion (AMI) and 2-binary 1-quarternary (2B1Q). Two line codes have emerged as the most common methods for supporting xDSL technologies. Unlike 2B1Q, the following codes can be used at pass-band and operate over a wide range of frequencies.

- **Carrierless Amplitude and Phase (CAP):** CAP modulation is a version of QAM in which incoming data modulates a single carrier that is transmitted down a telephone line. The carrier itself is suppressed before transmission (it contains no information, and can be reconstructed at the receiver), hence the adjective “carrierless”. CAP splits the data into two bit streams and alters both symbol rate and modulation levels to change the bit rate. CAP also uses frequency division multiplexing to eliminate the need for echo cancellation techniques.

- **Discrete Multitone (DMT):** DMT is a version of multicarrier modulation in which incoming data is collected and then distributed over a large number of subcarriers, each of which uses a form of QAM modulation. DMT modems divide the downstream bandwidth into 256 channels of 4 kHz each, and can transmit up to 15 bits/Hz in each channel. The modems can adapt to different impairments in different lines by evaluating the signal-to-noise ratio (S/N) in each subchannel and sending more data in those with higher quality. DMT upstream and downstream channels overlap; therefore, echo cancellation techniques are needed. **Discrete Wavelet Multitone (DWMT)**, a recent variant of DMT, provides better subchannel isolation by using a digital wavelet transform instead of the Fourier transform used in standard DMT.

There are also a few new “splitterless” line coding techniques, including “G.Lite” – another variant of DMT specified by the International Telecommunications Union (ITU). These new methods are designed to operate so that a splitter is not required as part of the CPE. This supposedly allows true plug-and-play installation and reduces end-user installation costs; however; it comes at the expense of reduced line capacity.

2.1.4 Standards

Like most modern technologies, xDSL is subject to standards conflicts. The American National Standards Institute (ANSI) has been publishing standards for the xDSL technologies through its T1E1.4 committee. DMT was the first technique developed for ADSL service, and the first to demonstrate this support. It was therefore selected by the committee as the official ADSL standard (T1.413). ANSI has since been asked to standardize the CAP modulation for ADSL.

CAP has the backing of several telephone companies, was deployed first, and is used more than DMT. Some argue this effectively makes CAP the defacto ADSL standard.

The ANSI committee has also established a working group to develop a RADSL standard; one that focuses on data services as opposed to bit synchronous services – the focus of the ADSL standard. The group is still considering proposals, and they are updating the original DMT standard to reflect the need for data services. Similarly, most other xDSL technologies are based on variations of the two coding techniques and have yet to be standardized.

2.1.5 Impairments

The public switched telephone network (PSTN) was designed for voice transmissions that were limited to frequencies below 4 kHz. To achieve the dramatic increase in data rates provided by xDSL technologies, the available spectrum above 4 kHz is used. However, higher frequency operation comes at a penalty; higher attenuation and increased crosstalk.

- **Attenuation:** Supporting higher data rate services requires the use of higher frequencies; higher frequency signals attenuate faster and therefore result in shorter loop distances. Attenuation can be reduced by using lower resistance wire (e.g., 19 AWG, which is common in many DOT environments), or can be compensated with more sophisticated modulation techniques.

- **Crosstalk:** Energy transmitted on a twisted pair will radiate onto adjacent pairs creating coupling of energy called crosstalk. Higher frequency signals have greater energy and therefore create more crosstalk. Symmetric forms of DSL can be severely limited by this impairment.

The maximum data rates and distances associated with the xDSL technologies are often based on continuous runs of good quality wire. Unfortunately, this is not usually the case with existing twisted pair. There are several impairments imposed by an existing communications infrastructure that can affect the performance of xDSL. The connection from an end user to a CO can involve a complex mesh of feeder and distribution cables resulting in a series of wire gauge changes, splices, and bridged taps. There is also the potential for loading coils on the loop. All of these impairments will result in either shorter distances or lower data rates for xDSL services.

- **Loading Coils:** Telephone companies routinely used loading coils to modify the electrical characteristics of the loop and improve the performance of voice circuits over longer distances. The coils severely attenuate frequencies used by xDSL technologies and subsequently make these lines unsuitable. The telecommunication companies that make use of loading coils estimate as many as 20% of the loops are loaded.

- **Splicing:** A common length of wire delivered by the manufacturers is 500 feet, so splices are common at increments of this distance. The splices cause harmonics and reflections along the loop, and the more splices, the more likely the data rate or distance will need to be reduced.

- **Bridged Taps:** Any portion of a loop that is not in the direct path between a CO and the CPE can be classified as a bridged tap. Like splices, bridged taps will generate harmonics and reflections and subsequently reduce the effective data rate or distance.

Amplitude modulation (AM) radio interference is another potential impairment to xDSL performance. The AM radio band falls in the same frequency range used by xDSL downstream channels, and radio stations within close proximity to a cable run can inject in-band interference.

Understanding impairments to xDSL technologies is important to transportation engineers. Leased lines will be exposed to most all of these impairments. xDSL services are now available for lease, and the lines offered for transportation applications must be suitably screened. Lines owned by a DOT, depending on how they are installed, may be subjected to few of these impairments, and high bandwidth ITS applications might be more practical to implement.

2.2 xDSL ENABLED SERVICES

Although xDSL is often referred to as a service, it is more appropriately identified as a transport technology that enables high-speed services. Services that can be provisioned using the xDSL technologies include: T1 and Digital Data Service (DDS), Internet Protocol (IP), Frame Relay, and Asynchronous Transfer Mode (ATM).

- **T1 or DDS:** These services can be implemented between the CPE and CO where a DSLAM would provide direct connection with a network access provider’s WAN. The symmetric xDSL technologies are most practical to provision these services.

- **IP:** This service can be implemented in several fashions with xDSL technologies; one of which could utilize a network access protocol between the TU-R and the DSLAM where data would be placed onto a frame relay or ATM permanent virtual circuit (PVC) and sent across the access network. Another similar implementation could be used for IP layer data, but this approach would require routers within the access network. One could also implement an ATM solution (for IP) which would extend an ATM PVC through the DSLAM, over the DSL link, and to a TU-R with networking functions. However, the protocols necessary for this last approach are still under development.

- **Frame Relay:** This service can be used to carry data between the CPE and CO where it is concentrated in the DSLAM before being sent across the access network. Since Frame Relay is often used for LAN interconnection with nearly equivalent upstream and downstream data rates, the most practical implementation would involve a symmetric xDSL technology.

- **ATM:** This service, in addition to supporting IP services, can also be the intended end user service. ATM technologies would need to be integrated into both the TU-R and the DSLAM, and PVCs would be used between the service provider and the end user across the local access network.

Each of these services can be implemented with xDSL technologies and subsequently used to support ITS applications. Alternatively, the xDSL technologies can be used to provide clear data channels without enabling any particular service – an approach we used in our concept study.

SECTION 3

ITS APPLICATIONS

The greatest value of xDSL technologies for ITS is their utility in locations with existing twisted pair. For example, xDSL technologies provide the ability to multiplex traffic video signals over the existing twisted pair infrastructure currently used by DOTs for freeway management and traffic control.

3.1 GENERAL ITS APPLICATIONS

Although traffic video is a current interest of DOTs, other high-speed and data-intensive transportation applications can be supported by the xDSL technologies. The US National ITS Architecture depicts a number of potential applications particularly suited for the DSL technologies, most of which involve roadside and remote access systems.

- **Roadside Systems:** The ITS roadside systems include: roadway subsystems (e.g., variable message signs, CCTV cameras, traffic controllers), commercial vehicle checkpoint subsystems, parking management subsystems, and toll collection subsystems. Each of these subsystems includes functions that require distribution to the roadside to support direct surveillance, information provision, and control plan execution. All of these subsystems interface with one or more of the center systems (e.g., a traffic management subsystem (TMS)) that govern operations.

- **Remote Access Systems:** The ITS remote access systems include: remote traveler support subsystems and personal information access subsystems. Except for kiosks, a majority of the equipment for these subsystems is typically owned and operated by the traveler, such as personal computers, PDAs, etc. These subsystems interface with an information service provider (e.g., one of the center subsystems) to access traveler information.

With further development of ITS, the numbers and types of transportation related applications will grow and subsequently increase the demand on communications systems. The ability to support these applications on existing infrastructure would provide significant benefit to many transportation agencies.

3.2 TRAFFIC VIDEO APPLICATIONS

Currently, traffic management centers use several types of roadside devices (e.g., ramp meters and loop detectors) for operations such as freeway surveillance, traffic management, and incident detection. Most of these roadside operations involve a central to remote controller configuration connected via voice grade modems over twisted pair wire. DOTs, like the local exchange carriers, own an extensive infrastructure of twisted pair wiring supporting such communications. Additionally, many DOTs are now going to great expense to implement either coaxial cable or fiber optics systems to enhance these traffic management and freeway surveillance operations with video. From a communications point of view, these closely resemble the applications for which xDSL technologies were originally intended.

3.3 THE CONCEPT – xDSL FOR TRAFFIC VIDEO

Figure 3-1 illustrates one possible configuration for using an xDSL technology to add traffic video to an existing twisted pair; one that is currently used to support communications for a traffic signal controller. In this instance, we illustrate the use of an asymmetric technology, such as RADSL.

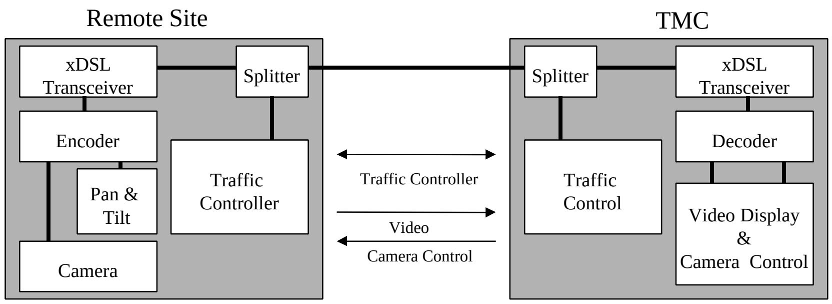

Figure 3-1. Traffic Video & Traffic Control Using xDSL

The existing controller communications is undisturbed and connected via passive splitters. If either xDSL modem fails, only the video functions are lost. The downstream channel (remote to TMC in this particular application) is used for the video, while the upstream channel (TMC to remote) is used for control of the camera's pan, tilt, and zoom functions. A variable rate encoder is used to digitize and compress the analog video and integrate that signal with any video control communication. A decoder at the TMC reverses this process. The maximum distance from the camera to TMC depends on not only the xDSL system settings (e.g., line rate), but also the twisted pair conditions (e.g., wire gauge, impairments) and other unique attributes of the communications infrastructure.

While most existing traffic control and freeway management devices communicate over twisted pair, their supporting communications architectures vary. Communications architectures for traffic control systems fall into three major classifications:

- A centralized architecture where only one level of traffic related computation occurs prior to the signals reaching the field controller. This architecture is most often utilized in urban and densely populated suburban environments.

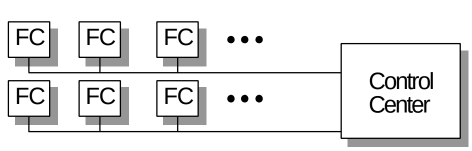

Figure 3-2. Centralized Traffic Control Architecture

- A distributed architecture where multiple levels of traffic related computation exist in the field, and a field master (FM) plays a mediating role between the control center and field controllers (FC). Commonly referred to as “closed loop”, this architecture is more often used in rural environments. Another form of this architecture (often found in urban and suburban environments and along major freeways) utilizes a high-speed backbone with communication hubs.

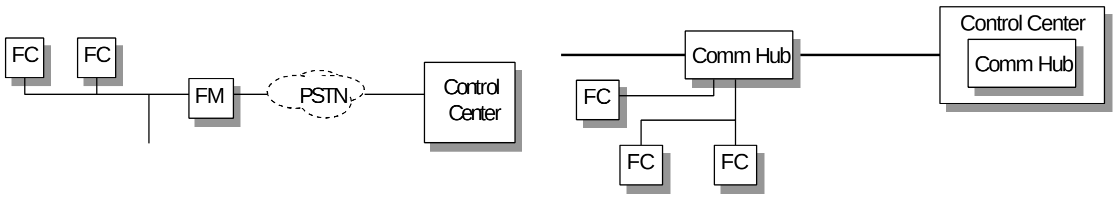

Figure 3-3. Distributed Traffic Control Architectures

- A hybrid architecture has system features and characteristic of both centralized and distributed architectures.

While the configuration in Figure 3-1 illustrates the use xDSL for traffic video, it is only an example. The communications infrastructure could be used to support most any field device (e.g., ramp meter, dynamic message sign) connected by twisted pair wire, not just traffic controllers. Additionally, the traffic video system does not require the RADSL technology. It could utilize one of the other xDSL technologies. The supporting system design would be different than that illustrated in Figure 3-1, but the concept would remain the same. The termination point for the xDSL circuit might actually be an intermediate communications hub such as that shown in Figure 3-3. In this instance, the xDSL equipment would be located at the hub; the decoder and video control and display equipment would remain at the TMC; and communications services (e.g., a SONET) along the backbone facilities would be used to complete the circuit between hub and TMC. Options such as these are more thoroughly discussed in the following sections.

Again, the scope of this particular effort is focused on the use of xDSL technologies for traffic video. Emphasis is placed on the operation and performance of the end-to-end traffic video system. In our particular study, we are not using xDSL to provide a communication service (e.g., ATM). Instead, we are using the xDSL technologies to provide clear channel communications for digital video and data between equipment located at a remote site and a TMC-type facility (or communications hub depending on communications infrastructure, system design, etc.). While this is one particular application of the technology, xDSL could also be used to provide networked video (i.e., “video over IP”), such as that being done by Nestor, Inc. as part of a “Photo Red Light” project in Vienna, VA.

As previously noted, the first part of our concept study was performed in the laboratory. To emulate xDSL-based traffic video systems within different communication architectures, we had to develop flexible base systems; systems that would allow us to account for various line conditions and system component configurations. Once established, we introduced xDSL technologies into these base systems to create concept prototypes.

SECTION 4

CONCEPT SYSTEMS COMPONENTS

The prototypes created to establish and evaluate our concept comprise base system components and DSL system components. The base system components are used to construct select conditions in which the prototypes will be tested. The xDSL system components provide our means of communications between base system components in the field, and those at a TMC or communications hub.

4.1 THE BASE SYSTEMS

After conducting various product surveys, we acquired the components used in the laboratory base systems. They comprise the traffic video and traffic control equipment to which particular xDSL technologies were applied. Along with a personal computer, these base systems include the following:

- A traffic video component with camera, pan & tilt unit, remote video receiver, and master video controller
- A traffic controller component
- A twisted pair simulator component
- A video encoder/decoder "codec" component

The base system can be configured as illustrated in Figure 4-1 – a configuration used to evaluate those xDSL technologies that allow for simultaneous high-speed data and 4 kHz baseband communication, such as RADSL. We refer to this configuration as base system #1.

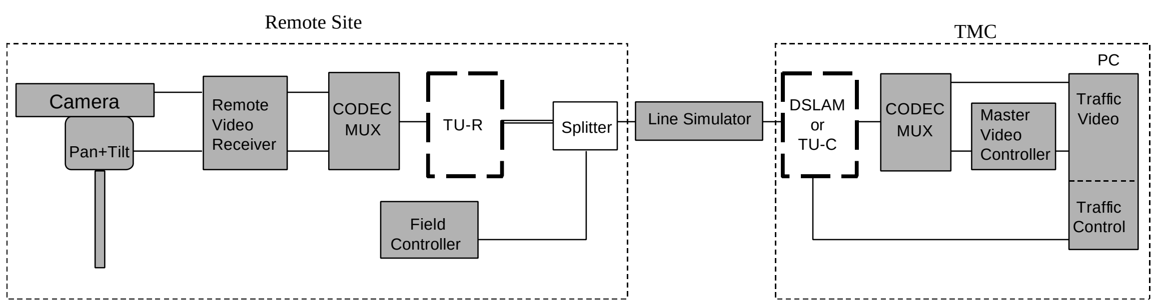

Figure 4-1. Base System #1 Configuration

If the termination point for the xDSL circuit happens to be an intermediate communications hub, the xDSL equipment would be placed at the hub location, and the decoder and video control/display equipment would be located at the TMC. A communications service (e.g., a SONET) along the backbone facilities would be used to complete the circuit between hub and TMC.

Alternatively, the base system can be configured as illustrated in Figure 4-2 – a configuration used to evaluate those xDSL technologies that utilize baseband portions of the twisted pair spectrum for high-speed data communication, such as HDSL. We refer to this second configuration as base system #2. In this case, traffic control communications must be integrated with the video signal before being passed to the TU-R.

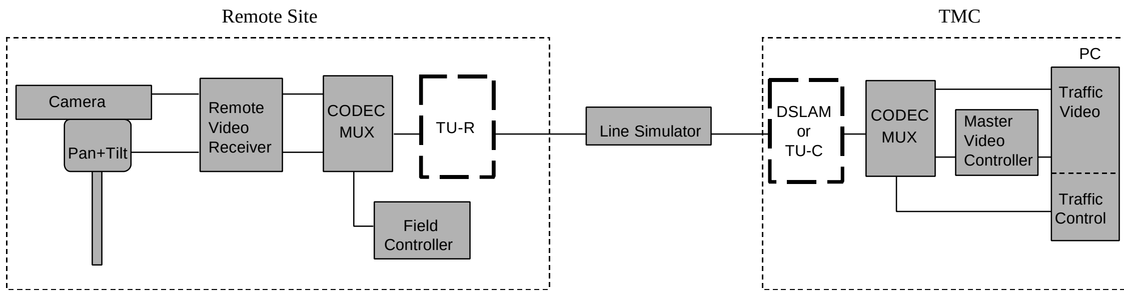

Figure 4-2. Base System #2 Configuration

As before, if the termination point for the xDSL circuit happens to be an intermediate communications hub, the xDSL equipment would be placed at the hub location.

These base systems provide the common functionality of digital traffic video systems in use today. At the remote site, the camera and pan & tilt systems are controlled by the remote video receiver. The video receiver passes analog video between the camera and the encoder, and it provides full duplex video control data between the pan & tilt and camera units and a communications multiplexer within the encoder. The encoder compresses and digitizes the analog video signal accordingly, multiplexes this with any video control data and provides this integrated data stream to the xDSL modem at the remote site.

There are two different methods used by these base systems to provide traffic controller (field device) communications. One exchanges traffic control data via an xDSL splitter (i.e., using a base system #1 configuration), and the other integrates the traffic control data via the encoder's multiplexer (i.e., using a base system #2 configuration). The remote xDSL modem exchanges data with its counterpart at the TMC facility or communications HUB (this process is more thoroughly discussed in sections 4.2, 5.1.1, and 5.2.1).

To emulate the various twisted pair line conditions between these sites, we used a twisted pair simulator. At the TMC, the data stream is provided to the decoder. The decoder decompresses the video signal and returns it to an analog form, and any multiplexed video or traffic control data is separated. Traffic control data is sent to a traffic control device – in our case a desktop computer using a DOS based controller application. The video control data is passed to the master video controller, which is in turn governed by the same desktop computer. The analog video signal is passed to a monitoring device, either the desktop computer (with a video capture board) or video monitor.

Using these two base systems, we will attempt to emulate as closely as possible the conditions under which our xDSL-based traffic video systems must operate. These conditions will also be representative of those found within the different communication architecture configurations. Precisely duplicating specific real-world scenarios was impractical, but our subsequent field tests should address any apparent discrepancies as the result of laboratory conditions.

Appendix C more completely describes the equipment we used to establish the base systems. If one were to use equipment other than that we selected, the general concept would remain the same.

4.2 THE xDSL SYSTEMS

The components addressed in the previous section, and described in Appendix C, provide for the systems around which particular xDSL technologies could be applied. As part of our complete concept system, xDSL components were introduced into these base systems (Figure 4-3 and Figure 4-4) to evaluate their application to traffic video.

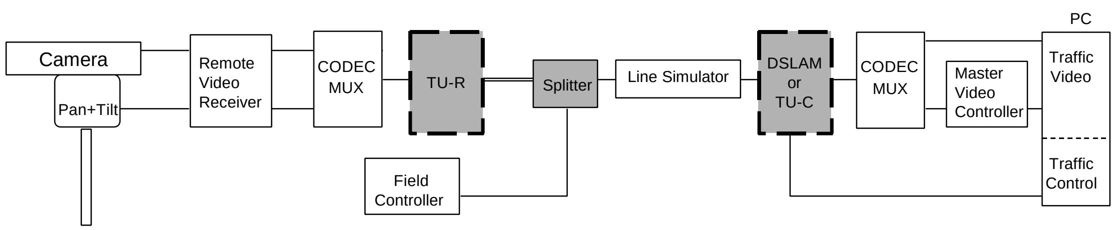

Figure 4-3. xDSL Equipment in a Base System #1 Configuration

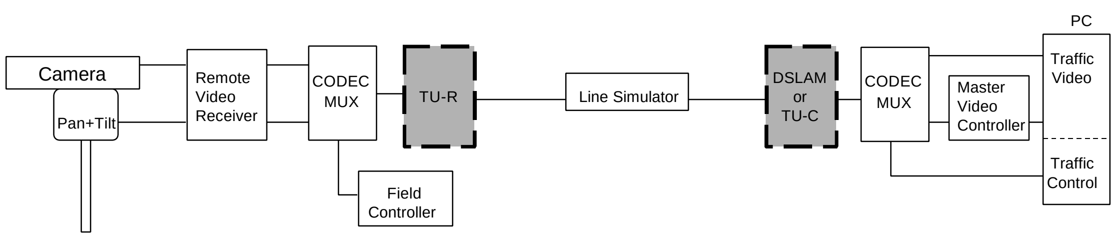

Figure 4-4. xDSL Equipment in a Base System #2 Configuration

The encoder exchanges data with the remote site xDSL modem (i.e., the TU-R). The modem in turn communicates with its counterpart at the TMC facility or communications hub, and the data is then exchanged with the decoder. The xDSL modems, each by their own methods, are merely passing raw data between encoder and decoder.

Different traffic control communication architectures and twisted pair availability create different scenarios in which to use such systems – each more amenable to different solutions. With no unused (or spare) pairs available for dedicated use, a RADSL system could be used to provide video transmissions and camera control on the same twisted pair currently used for the traffic controller telemetry – without disturbing this baseband communication. With more than one spare twisted pair available, other xDSL systems offer potential solutions.

There are many xDSL systems, each of which can be used with one of the aforementioned base systems. The following sections briefly describe how symmetric and asymmetric DSL technologies would be used as part of our concept systems. Although we consistently illustrate our concept with a single-camera system, it is possible to integrate multiple-camera systems on a single DSL circuit. Details of the xDSL system components that we used in our concept prototypes are described later in this document (sections 5.1.1 and 5.2.1).

4.2.1 Symmetric DSL

There are several forms of symmetric DSL (e.g., HDSL, VDSL, and SDSL). Since most symmetric systems require the use of a dedicated pair, these solutions would be used in instances where at least one spare twisted pair is available. They would also be used in a base system #2 type configuration. Within limitations of the specific component, one could implement a symmetric solution in any of the traffic control communications architectures described in section 3. The following illustrations depict symmetric solutions as they apply to centralized and distributed high-speed backbone architectures, Figure 4-5 and Figure 4-6 respectively.

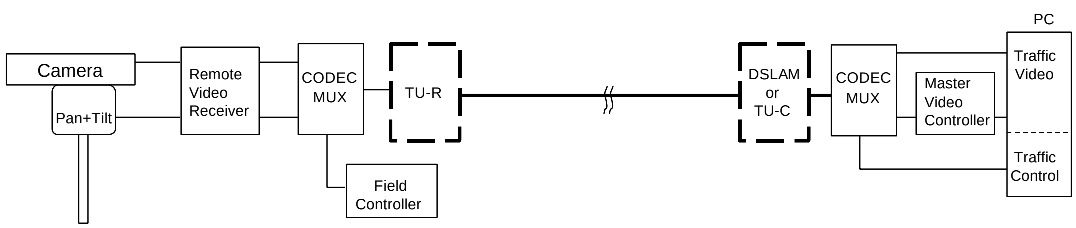

Figure 4-5. Symmetric DSL in a Centralized Architecture

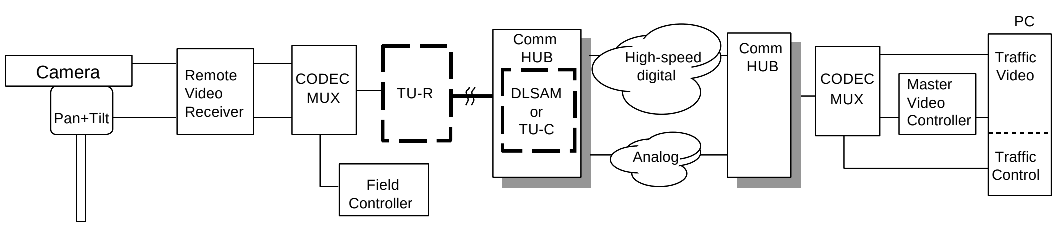

Figure 4-6. Symmetric DSL in a Distributed Architecture (High-speed Backbone)

Components other than those used in the xDSL systems or either base system, such as the communications hub or the communications “clouds”, are implementation specific communications facilities. Use of these facilities for a specific solution would depend on their availability within a region or to a particular user, agency, or municipality. For example, if relying on a communications service provider, they must not only have the proper equipment at the communications hub (or CO), but provide the selected xDSL service as well.

Many symmetric systems use equipment that can operate back-to-back, in other words, similar devices (TU-R and TU-C) functioning in a stand-alone mode at either end of a circuit (CO or CPE side). This allows end-to-end implementations without the need for more complex DSLAM equipment at the TMC or intermittent communications hub. A DSLAM provides the capability to multiplex several circuits; an advantage only if more than one remote site is supported (i.e., more than one circuit is required).

Although rare, some manufacturers have symmetric DSL systems that allow for simultaneous 4 kHz baseband communication (i.e., they employ splitters). However, the availability of such products is scarce and sporadic. These products are usually custom designed for a specific application and have particular communications interfaces. If available, these systems could be implemented using the base system #1 configuration.

4.2.2 Asymmetric DSL

As with symmetric DSL, there are also several forms of asymmetric DSL (e.g., ADSL, RADSL). An asymmetric solution is well suited for instances where no spare twisted pair are available for dedicated use, one that would utilize a base system #1 type configuration. However, these technologies could also be used for situations in which one or more spare twisted pair is available.

Within limitations of the specific components, an asymmetric solution could be implemented in any one of the traffic control communications architecture described in section 3. The following illustrations depict such solutions as they apply to a centralized architecture, Figure 4-7, and two distributed architectures, Figure 4-8 and Figure 4-9 respectively.

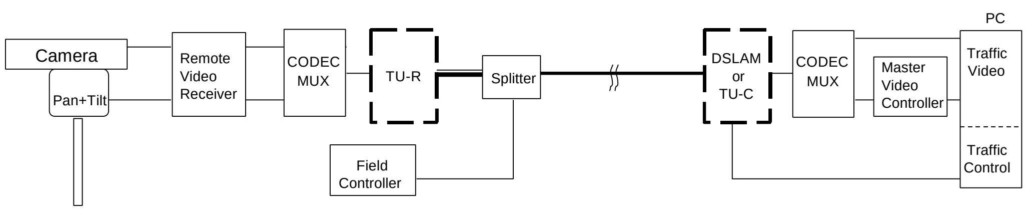

Figure 4-7. Asymmetric DSL in a Centralized Architecture

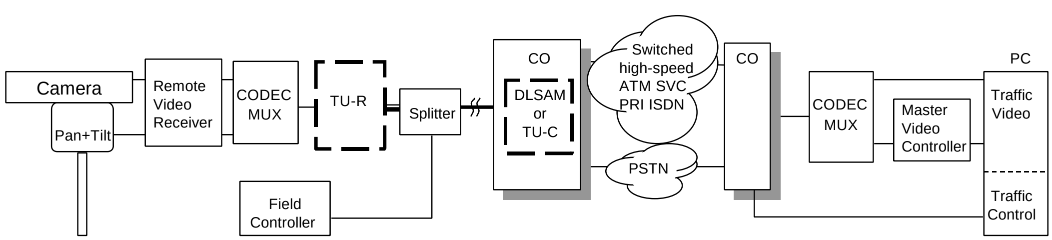

Figure 4-8. Asymmetric DSL in a Distributed Architecture (Closed Loop)

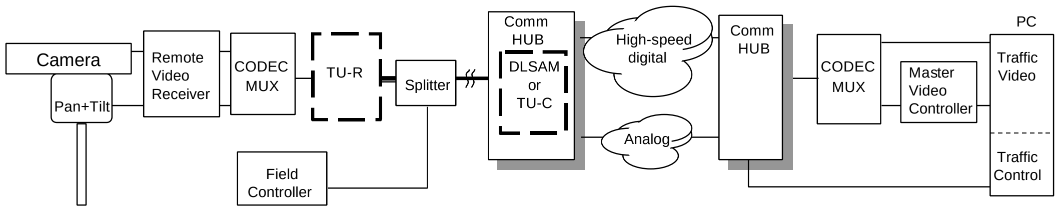

Figure 4-9. Asymmetric DSL in a Distributed Architecture (High-speed Backbone)

Since most asymmetric DSL equipment does not operate back-to-back, a DSLAM is normally used at the TMC or intermittent communications hub. Components other than those used in either the base systems or xDSL systems are implementation specific and restricted by availability.

Asymmetric DSL technologies are designed to provide a large downstream capacity (i.e. to the remote location), but since traffic video is a collection (not dissemination) process, one is compelled to use the asymmetric equipment in one of two ways. The first of which would be to swap CPE and CO equipment (i.e., move the TU-R to the TMC or communications hub location and move the DSLAM to the remote site). However, this approach makes little sense as it would be too costly and inefficient. The second option would be to optimize upstream throughput (i.e., from the remote location) and operate the modems in a symmetric mode – a function currently available to only the rate adaptive DSL technologies (i.e., RADSL). This would severely underutilize the potential downstream capacity of an asymmetric system, but our particular application would not require much more than 9.6 kbps for either traffic video or traffic control communications.

In either instance (i.e., using symmetric or asymmetric technologies), these systems are the focus of our concept studies. Together with the base system components, they form the basis of our xDSL-based traffic video prototypes.

SECTION 5

CONCEPT PROTOTYPES

Section 4 defined the base system components and introduced potential xDSL systems that together, as part of a complete system, comprise our concept prototypes. Several prototypes were considered for our study, but while most xDSL technologies offer a solution, particular aspects of some make them more or less feasible as a part of our concept systems. These aspects include:

- Infrastructure Limitations: Existing twisted pair wire is a valuable commodity and its availability will dictate one's xDSL solution. The need for fewer twisted pair reserves communication resources, so an HDSL prototype, which requires two twisted pair, was not considered as part of our study.
- Equipment Interfaces: Most asymmetric equipment (targeted for home Internet access) use a 10/100BaseT RJ-45 type interface and are designed to process packetized data. Recall that we are sending a serial data stream, but not packetized data, and therefore require serial interfaces (e.g. RS-530, V.35) between the xDSL units and the codecs. Therefore, many asymmetric DSL products could not be used.
- Technology Lifecycle: The xDSL industry and associated technologies are developing rapidly. Even within the timeframe of this study, many DSL technologies have become outdated and have been superseded by newer versions (e.g., HDSL2 for HDSL, RADSL for ADSL). While RADSL technologies are similar to and based upon ADSL technologies, RADSL provides more provisioning and implementation flexibility as well as greater data rates and line quality compensation.
- Technology Availability: Some xDSL technologies have only recently gone from concept to product. For example, there are now some rate-selectable HDSL products that operate on a single twisted pair (but not S-HDSL as described in section 2). Such devices might provide comparable or even better solutions than those that we selected for our prototypes, but they were not available at the time our prototypes were established. A VDSL-based prototype might also provide an attractive solution for remote locations within close proximity to the TMC or communications hub, but there was no VDSL equipment on the market at the time.
- Equipment Loans: The aforementioned aspects helped establish feasible technical solutions. However, we needed to identify vendors that were willing to provide certain equipment (e.g., xDSL units, twisted pair simulator) for our studies – and to do so within a reasonable time frame.

In an attempt to represent various deployment scenarios, our approach was to consider one each of the more viable asymmetric and symmetric solutions. The restrictions noted above were the primary factors influencing our selection and led us to develop our concept prototypes around the SDSL and RADSL technologies. Most existing HDSL technologies offered little if any benefit over an SDSL solution; they also required at least two dedicated twisted pair. Additionally, existing HDSL equipment did not meet our base system interface requirements. Therefore, we selected SDSL as a symmetric solution. For an asymmetric solution, RADSL technologies offer all the features of ADSL and more. VDSL equipment was not available; if it were, its functionality would have been very distanced limited. Therefore, we selected RADSL as an asymmetric solution.

Regardless of the enabling DSL technology, the concept remains the same, “provide integrated traffic video and traffic control over twisted pair wire”. Any specific solution is subject to the requirements of those implementing the system. The solutions we have selected are sufficient for the purpose of our studies, and they form the crux of our two concept prototypes.

5.1 SDSL PROTOTYPE

The SDSL prototype uses a base system #2 configuration and SDSL equipment as shown in Figure 5-1. This prototype is applicable in either a centralized or distributed architecture and is well suited for instances in which spare (or unused) twisted pairs are available. If no pairs are available, the prototype provides the flexibility to integrate applications currently using a twisted pair with the video and camera control transmissions.

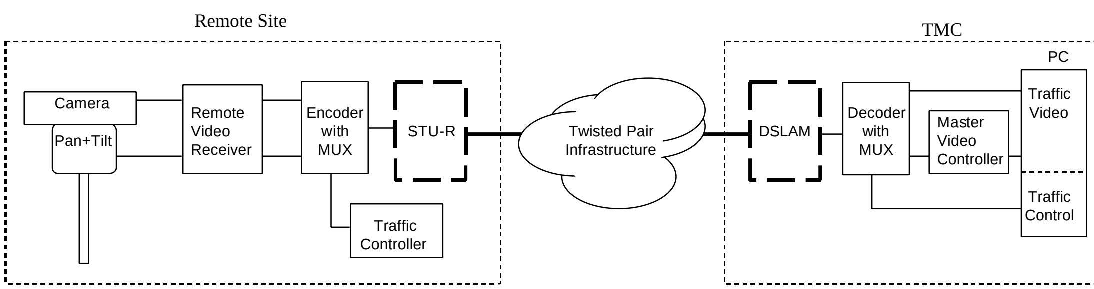

Figure 5-1. SDSL Prototype

The remote site component of the SDSL prototype is constructed as follows.

- The camera uses a single 39-pin connector for multiple interfaces to the remote video receiver: an RS-170 interface for analog video, an RS-422 interface for DSP camera control, and an analog interface for mechanical camera control.
- The pan & tilt unit has a 14-pin analog interface for communications with the remote video receiver.
- The remote video receiver has an RS-170 BNC interface for analog video to the encoder and an RS-232 interface for full duplex camera control communications with the encoder’s multiplexer (user port #1)
- The traffic controller has an RS-232 interface for full duplex communications with the encoder’s multiplexer (user port #2).
- The encoder has an RS-530 to V.35 interface for integrated communications with the remote SDSL unit (STU-R), which is in turn connected to the twisted pair infrastructure.

The TMC component of the SDSL prototype is constructed as follows.

- The twisted pair is connected to the DSLAM, which has a V.35 to RS-530 interface for integrated communications with the decoder.
- The decoder has an RS-170 BNC interface for analog video to both the PC's video capture board and a video monitor. The decoder's multiplexer has two RS-232 interfaces; one for camera control communications with the master video controller and the other for traffic controller communications with the PC.
- The master video controller also has an RS-232 interface for full duplex communications with the PC.
- The PC houses Cohu's CAMS 2.0 software, a windows-based application that will manage and control video system equipment through a graphical user interface (GUI). The PC also contains Eagle's Monitor and Report Console (MARC) software, a DOS-based application that provides for telemetry between the PC and the traffic controller.

Earlier we described the function of the base system components; refer to section 4.1 and Appendix C. The function of the SDSL system is to provide the communications between those base system components at the remote site and those at the TMC site (or the transmission facilities at an intermediate communications hub). SDSL systems use a single twisted pair, and as implied by name, they provide symmetric communications. The specific SDSL equipment used for this prototype was selected as a result of the aspects discussed on page 5-1. Other SDSL equipment might also have worked for this prototype; regardless, the concept remains the same.

Equipment

- DSLAM: Paradyne Corporation's Hotwire 8600 DSLAM chassis. This unit houses up to three line cards and supports a stackable design configuration for future growth. A 50-pin punch-down block provides access to the twisted pair infrastructure. Each individual line card provides the DTE interface(s). Our SDSL prototype utilized the following line cards:

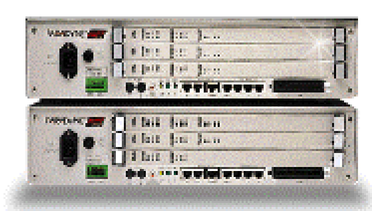

Figure 5-2. SDSL Prototype's DSLAM

- Hotwire management communications controller (MCC) card: This card manages all of the DSL cards within the DSLAM chassis providing alarm monitoring, system status, port status, etc. Only one MCC card is needed per stack (with a maximum of six chassises per stack).

- Hotwire 8775 termination unit: Paradyne Corporation's Multirate Symmetrical Digital Subscriber Line (M/SDSL) line card. This card uses a CAP line coding technique operating over the 3 kHz to 400 kHz portion of a twisted pair's frequency spectrum. The card has four DTE ports, each providing for a symmetric communications channel; each for a separate twisted pair. The card can automatically configure a channel for the maximum throughput supported by the associated local loop. Throughput is also selectable in increments of 64 kbps to a maximum of 2048 kbps (E1).

- STU-R: Paradyne Corporation's Hotwire 7975 termination unit. This stand-alone unit has functions similar to those of the 8775 M/SDSL line card, but it has only one DTE port. It is the line card's counterpart in the field. This unit can also be connected back-to-back without the need of a DSLAM (i.e., with another 7975 unit functioning as an STU-C).

Figure 5-3. SDSL Prototype's M/SDSL Line Card and STU-R

Component Testing

Before integrating the SDSL and base systems, we installed and configured the SDSL equipment as an individual system. The M/SDSL line card (via DSLAM) was connected to the STU-R with a short test wire. The DSLAM, M/SDSL line card, and STU-R were appropriately configured and powered. We then verified synchronization and proper communications between the units with management statistics provided by the MCC card via terminal session.

The twisted-pair simulator was introduced in place of the test wire, and we again verified synchronization and proper operation as twisted pair infrastructure configurations were varied. All tests were successful and indicated no problems with our SDSL system.

Prototype Testing

Once operational, we introduced the SDSL system to the base system components. This only required connecting DTE ports between STU-R and encoder, and between DSLAM and decoder.

As a complete system, the only concern with this integration was the synchronization between codecs over the new digital subscriber line. Proper clocking is required to maintain synchronization between the codecs. We used the SDSL system to source the clock, but our original attempt to integrate the SDSL system failed. After properly configuring the M/SDSL line card, STU-R, and codec DTE ports (e.g., receive and transmit clock polarity, DTR and RTS leads, etc.) we were able to synchronize the codecs.

The video signal was successfully transmitted; camera control functions were operational; and traffic controller telemetry was accurate and continuous. SDSL system parameter settings (e.g., throughput) were changed, and the prototype remained operational. Base system parameter settings affecting video motion and video quality were changed, and the prototype remained operational. The simulated twisted pair infrastructure was changed; the SDSL modems compensated for the change, and the prototype returned to operation.

We did not exhaustively test all possible SDSL and base system parameter settings. Once convinced that all components were operating properly, we were ready for evaluation of the prototype. This evaluation is discussed in section 6.2.1 and Appendix A.

5.2 RADSL PROTOTYPE

The RADSL prototype uses a base system #1 configuration and RADSL equipment as shown in Figure 5-4. This prototype is applicable in a centralized architecture as well as either form of distributed architecture (closed loop or high-speed backbone). It is well suited for instances in which no spare (or unused) twisted pair is available. It can provide video transmissions while isolating and preserving applications (e.g., traffic controller telemetry) currently using the twisted pair.

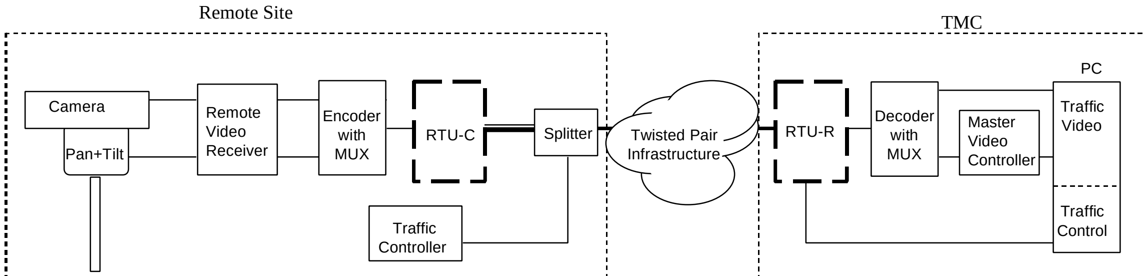

Figure 5-4. RADSL Prototype

The remote site component of the RADSL prototype is constructed as follows.

- The camera, pan & tilt unit, remote video receiver, and encoder are interconnected as they were with the SDSL prototype – a common part of the two base system configurations.
- The encoder has an RS-530 to RS-422 interface for integrated video and camera control communications with the remote RADSL unit (in this case, the RTU-C), which is in turn connected to the twisted pair infrastructure.
- The traffic controller has an RS-232 interface with a standard voice grade modem (not shown), which is in turn connected to the RTU-C via a passive splitter. Controller telemetry is completely isolated from video transmissions and camera control communications. Should the RADSL modems fail, traffic controller telemetry remains operational.

The TMC component of the RADSL prototype is constructed as follows.

- The twisted pair is connected to the RTU-R, which has an RS-422 to RS-530 interface for integrated video to and camera control communications with the decoder. By way of a passive splitter, the RTU-R is connected to a voice grade modem (not shown), which has an RS-232 interface with the PC.
- The decoder has an RS-170 BNC interface for analog video to both the PC's video capture board and a video monitor. The decoder's multiplexer utilizes one RS-232 interface for camera control communications with the master video controller.
- The master video controller and the PC are configured as they were for the SDSL prototype – another common part of the two base system configurations.

Earlier we described the function of the base system components; refer to section 4.1 and Appendix C. Like the SDSL system, the function of the RADSL system is to provide the communications between those base system components at the remote site and those at the TMC site. RADSL systems also use a single twisted pair, but these systems provide asymmetric communications.

While it would have been convenient to build the RADSL prototype around the DSLAM used in the SDSL prototype (i.e., using a RADSL line card in the chassis); this was not a practical solution. RADSL technologies are designed to provide a large downstream capacity (DSLAM to TU-R). For our particular application to traffic video, this would require one to place the TU-R at the TMC site and the DSLAM at the remote site. As discussed previously, this approach (i.e., placing DSL multiplexing equipment at the remote site) makes little sense.

Using a RADSL line card and leaving the DSLAM at the TMC site, one could optimize upstream throughput (i.e., TU-R to DSLAM) and operate the modems in a symmetric mode. This would probably yield results similar to those of the SDSL prototype. However, this too was not possible since Paradyne's RTU-R does not have the serial DTE interface required by our codecs. This is not uncommon though. As noted earlier, RADSL was designed for consumer markets and residential applications where the DTE is most often a PC requiring a 10/100BaseT RJ-45 type interface.

Therefore, we decided to base the RADSL prototype on modems that could operate back-to-back – small stand-alone RTU-C and RTU-R units with serial interfaces. As described previously, the RTU-C is located at the remote site. Unlike placing a DSLAM at the remote site, this configuration is a practical solution allowing large asymmetric downstream throughput to the TMC.

As with the SDSL prototype, the specific RADSL equipment used for this prototype was selected as a result of the aspects discussed on page 5-1, and in particular, because it provided the appropriate interface to the codecs. WaiLAN Communications Inc. was the only manufacturer we found to offer such equipment. With the proper interfaces, other RADSL equipment might also have worked for this prototype.

Equipment

- RTU-R: WaiLAN Communications' AGATE 700. This device also uses a CAP line coding technique. According to the manufacturer, it can provide line rates up to 7.1 Mbps downstream and 1 Mbps upstream depending on the twisted pair infrastructure. The unit has high- and low-speed serial DTE interfaces for downstream and upstream channels respectively. It also has an RJ-11 interface for connection to the twisted pair infrastructure. Terminal sessions across a standard management interface allow one to configure the unit as a remote unit – an RTU-R.

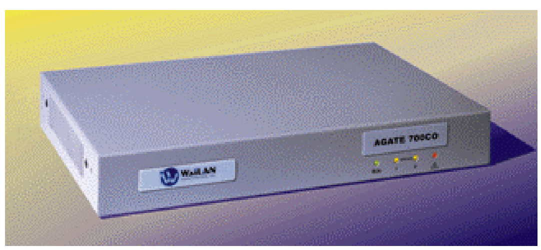

Figure 5-5. RADSL Prototype's TU-C and TU-R

- RTU-C: WaiLAN Communications' AGATE 700. This is the same device as that used for the TU-R; however, it is configured as a CO device – an RTU-C.

Component Testing

Before integrating the RADSL and base systems, we installed and configured the RADSL equipment as an individual system. After being appropriately configured, the RTU-C and RTU-R were connected with a test wire. The units were powered, and we verified synchronization and proper communications with terminal sessions across the standard management interfaces.

As with the SDSL prototype, the twisted-pair simulator was introduced in place of the test wire. We again verified synchronization and proper operation as twisted pair infrastructure configurations were varied. All tests were successful and indicated no problems with our RADSL system.

Prototype Testing

Once operational, we introduced the RADSL system to the base system components by connecting DTE ports between RTU-C and encoder and between RTU-R and decoder. We used the RADSL system to source the clock, but like our original attempt to integrate the SDSL system, this also failed. After properly configuring the RTU-R, RTU-C, and codec DTE ports, we were able to synchronize the codecs. These adjustments were slightly more complicated than those required for the SDSL prototype, but sensible in retrospect.

Once the prototype was functioning, the video signal was successfully transmitted; camera control functions were operational; and traffic controller telemetry was accurate and continuous. RADSL system parameter settings were changed, and the prototype remained operational. Base system parameter settings affecting video motion and video quality were changed, and the prototype remained operational. The simulated twisted pair infrastructure was changed, and while the RADSL modems and codecs temporarily lost synchronization, traffic controller telemetry continued without any disruption. Once the RADSL modems compensated for the infrastructure change, the prototype was again fully operational.

We did not test all possible RADSL and base system parameter settings. Once convinced that the systems were operating properly, we were ready for evaluation of the prototype. This evaluation is discussed in section 6.2.2 and Appendix B.

SECTION 6

CONCEPT PROTOTYPE EVALUATIONS

Having established the concept prototypes, we devised a methodology to evaluate these prototypes within our laboratory. Again, this was not a detailed analysis on the relative performance of vendor specific xDSL equipment – equipment that is based on a particular modulation technique or adheres to a particular standard. It was a study to determine if and how xDSL technologies, and in particular our concept prototypes, could be used for traffic video.

6.1 METHODOLOGY

Our approach to evaluating the SDSL and RADSL prototypes within a laboratory environment involved the following activities:

- Creating a laboratory traffic video source (i.e., the traffic event our camera will view)
- Formulating various twisted pair infrastructure scenarios over which our prototypes will operate
- Determining various system parameter settings with which our prototypes will operate
- Identifying particular quantitative and qualitative observations by which our prototypes will be assessed

Once these issues were resolved, we were able to conduct the evaluations.

6.1.1 Laboratory Traffic Video

Since this study was conducted inside Mitretek facilities, we needed to create a traffic video source. This source was produced by using the laboratory's 52" large screen monitor to display traffic video footage recorded from locations along Interstate 66 in Northern Virginia. The video was filmed during moderately dense (but not congested) traffic conditions, during daylight hours, and while the roadways were dry. Since our efforts were not an attempt to assess performance under various environmental or traffic conditions, this footage served as a good source against which our prototypes could be tested.

Although not ideal, this approach was our best attempt at viewing live traffic. It offered somewhat degraded video quality (e.g., VCR resolution, sync pulse aberrations, ambient laboratory light), but all of our assessments are relative to this one source. It was the most efficient alternative and proved to be more than sufficient for assessing the feasibility and relative performance of our prototypes. Video quality will improve when conducting the subsequent field study, but under identical system settings, this improvement will only be due to a live traffic source.

6.1.2 Twisted Pair Infrastructure Scenarios

There are an endless number of twisted pair infrastructures that one might encounter in the field, and nearly as many that one could emulate. Using the twisted pair simulator component, as shown in Figure 6-1, we formulated as many possible scenarios as time and simulator component would permit.

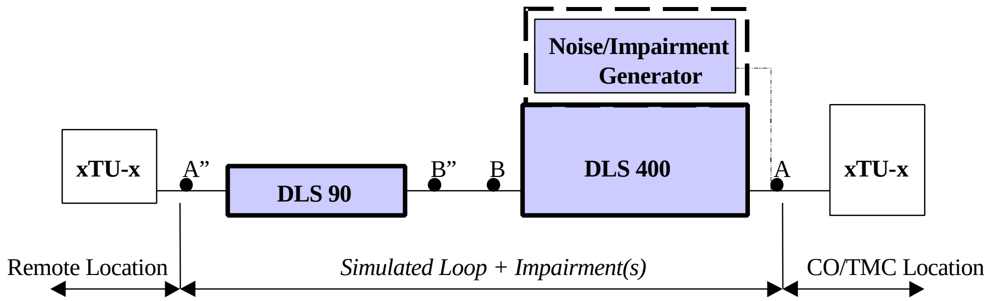

Figure 6-1. Twisted Pair Simulator Component

We configured this broad range of scenarios to be moderately representative of the environment and to emulate, as closely as possible, the communications medium between points A and B – termination points of the xDSL circuit at the remote site and either the TMC or communications hub. The simulator component’s graphical user interface (GUI) (Figure 6-2) was used to create and change our scenarios (e.g., MID-CSA #2 to ANSI #3).

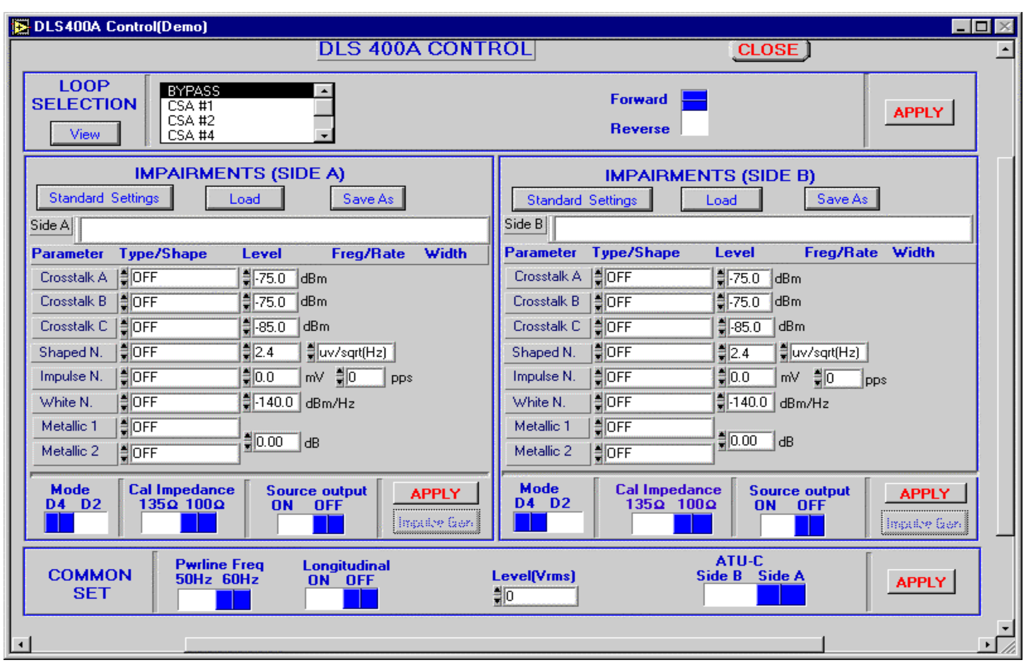

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Figure 6-2. Twisted Pair Simulator GUI

Formulation of some scenarios was restricted due to availability of the DLS 400, which was on a ten-day consignment. Others were restricted due to limitations of the simulation component. Although the scenarios we created could not be identical to existing traffic control communications infrastructures, they are as close as we could achieve in a laboratory environment. They are certainly more than sufficient to demonstrate the feasibility of our concept.

The following scenarios were established for our lab assessments. Refer to Appendix C, specifically section C.1.4, and Appendix D for further description and illustration.

Point-to-point Scenarios

As illustrated by Figure 6-3, these configurations are logically point-to-point in nature and variable in distance. While many scenarios could be emulated, we merely selected distances in increments of one mile until we reached the maximum distance allowed by the simulation component – 27, 350 feet or slightly over 5 miles.

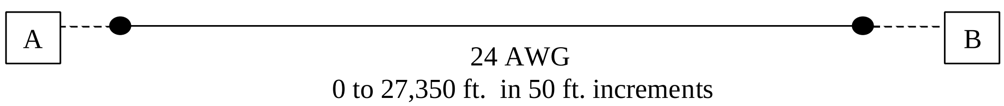

Figure 6-3. Variable Distance 24 AWG Scenarios

The following eight point-to-point scenarios were used.

- 24 AWG at 1, 2, 3, 4, and 5 miles
  Note: The 2-mile scenario was actually a 1.75-mile scenario. This approximation was a test that could be conducted by the DLS 90 alone. This concession allowed more efficient use of our time with the DLS 400.

- 26 AWG at 1, 2, and 3 miles
  Note: The 4 and 5 miles scenarios were not created since the DLS 90 was configured as a 24 AWG unit. The DLS 400 alone could only reach 3 miles.

Standard Configuration Scenarios

These fixed infrastructure scenarios include configurations such as ANSI #6 (Figure 6-4), a point-to-multipoint single twisted pair of different gauge wire with 500 foot taps at 16,500 and 17,500 feet from what would be a TMC or communications hub (i.e., point "B").

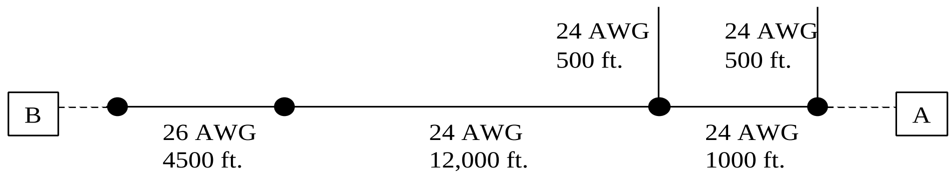

Figure 6-4. ANSI # 6 Scenario

This is one of many common local loop configurations found in North America and those that have been (or soon will be) specified by ANSI for testing xDSL transmissions. While the simulation component is capable of over 30 such standard configurations, we selected six of them. To push the functional limits of our prototype, we diverted from the standard and created another six scenarios augmenting these configurations with an extended loop distance (Figure 6-5).

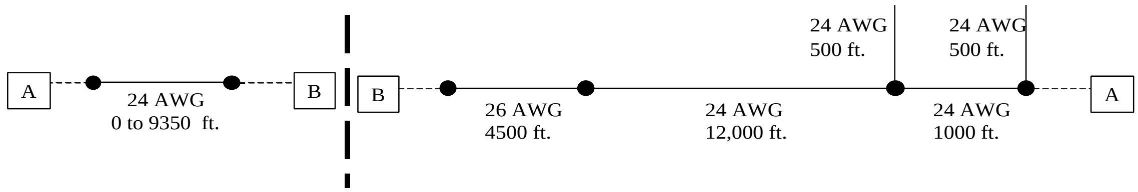

Figure 6-5. Augmented ANSI # 6 Scenario

The following ten scenarios (standard and augmented) were used. Refer to Appendix D for illustration of these configurations.

- MID-CSA #2
- ANSI #3
- ANSI #6
- ANSI #9
- ANSI #13
- MID-CSA #2 with a 9350 ft. extension
- ANSI #3 with a 9350 ft. extension
- ANSI #6 with a 9350 ft. extension
- ANSI #9 with a 9350 ft. extension
- ANSI #13 with a 9350 ft. extension

Impairment Scenarios

These scenarios include both point-to-point and standard configurations, but have impairments introduced onto the line. As shown in Table C-2, several such impairments can be introduced. However, most of these were established to test LEC systems with thousands of circuits (e.g., xDSL, ISDN, T1) in hundreds of twisted pair bundles. They are not necessarily applicable to a traffic control communications infrastructure, particularly those owned by DOTs or local municipalities. If applicable, most impairments (e.g., impulse noise) have very little impact. Additionally, if leasing the service from a provider (i.e., using the LEC to provision the xDSL circuit), the quality of the line would most likely be guaranteed, and any impairments would be corrected by the provider.

Near-end cross talk (NEXT) is one impairment that we believe could affect our prototypes in a traffic control communications environment. NEXT would only have significant impact at locations where several circuits converge (i.e., within cable bundles, etc.), such as the TMC or communications hub. To emulate such instances, NEXT would be introduced at the associated node (A or B).

While many forms of NEXT could be introduced, we selected those that would have notable effect on the prototype being tested. For the SDSL prototype, the most closely related form of NEXT available from the DLS 400 was HDSL NEXT. For the RADSL prototype, the most closely related form available was ADSL NEXT. The intensity of the impairment is directly proportional to the number of disruptive circuits (disruptors) at the node of interest. In our case, we used 24 disruptors – more than sufficient to represent any such configuration in which these prototypes would be deployed.

We could have created an infinite number of scenarios with permutations of the many configurations and impairment selections, but again, with limited time we selected those we felt most realistic. The following eight impairment scenarios were used. The prototype under evaluation determined the type of NEXT introduced.

- MID-CSA #2 with NEXT
- ANSI #3 with NEXT
- ANSI #6 with NEXT
- ANSI #9 with NEXT
- ANSI #13 with NEXT
- 24 AWG at 1 mile with NEXT
- 24 AWG at 2 miles with NEXT
- 24 AWG at 3 miles with NEXT

While limited by time, we were also forced to make a reasonable guess at what actual traffic control communications infrastructures might resemble. We could not account for all scenarios, but we were able to create an acceptable pool from which to select. Ultimately, the configuration will depend on the specific site of deployment, hence the purpose of our subsequent field testing activities.

6.1.3 Systems Parameter Settings

Each prototype has a number of variable system parameters. Some involve their xDSL system component while others involve base system components.

xDSL System Parameters

The xDSL systems' variable parameters are noted in sections 5.1.1 and 5.2.1. That of particular interest to our effort is the system information rate (i.e., throughput), which is defined as the rate of the xDSL transmission (i.e., the line rate) less the xDSL overhead. The throughputs we used for the xDSL systems in each of the prototypes are as follows:

- SDSL System: 384, 768, 1152, 1536, and 2048 kbps
- RADSL System: 1544 and 2304 kbps

While the SDSL system offers symmetric throughputs in increments of 64 kbps, we selected fairly common ¼ T1 increments (384 kbps) and the E1 rate (2048 kbps). The RADSL system's throughputs were limited to approximate T1 and 1½ T1 rates – each with an associated upstream line rate of 672 kbps.

Base System Parameters

For the purpose of this study, the most benign base system component is the traffic controller. The function of this unit was to provide nominal field controller telemetry – a communications link to verify proper and continual controller operation during our evaluation process. Therefore, we did not alter controller telemetry parameters. The unit was configured to communicate asynchronously at 1200 bps when used with either prototype. The means of connectivity between controller and TMC differed with prototype (i.e., the SDSL prototype uses a base system #2 configuration requiring a trivial portion of the total xDSL throughput for controller telemetry), but the configuration had no bearing on an individual prototype's performance.

Variations in some video system component settings could impact performance slightly. However, these settings are not applicable in the video system's standard operational mode.

The most significant base system component to influence the performance of the prototypes is the video encoder/decoder (codec), and in particular, the encoder's resolution, quantization, and screen cropping parameter settings. Each can be manipulated to improve video quality at the expense of video motion, or vise versa.

The encoder settings were configured via terminal session, as illustrated in Figure 6-6.

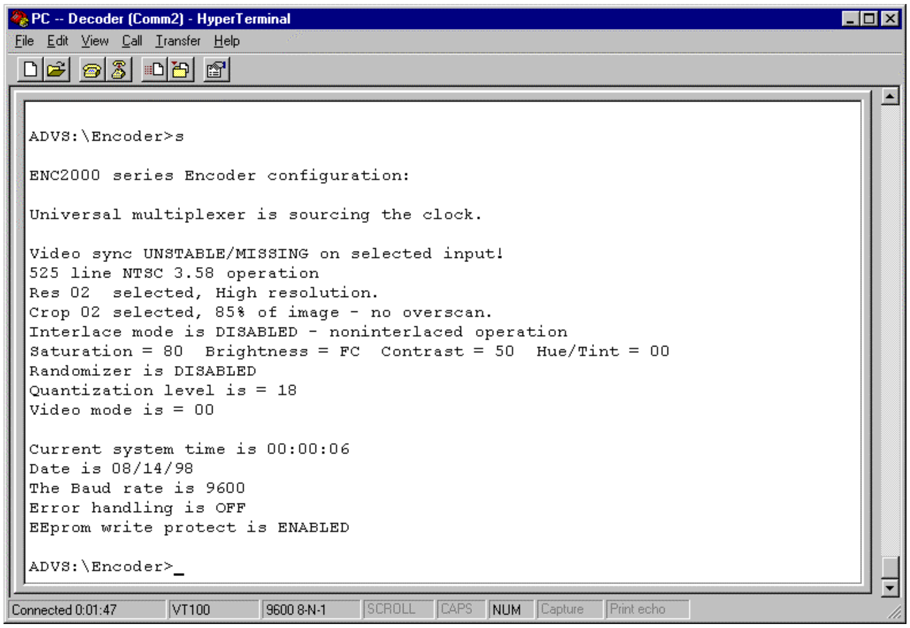

Figure 6-6. Terminal Session to the Encoder

- The encoder has a vertical resolution of 480 lines/frame at 60 Hz. The horizontal resolution is variable and was set to one of three possible values.

    - Resolution = High: 560 pixels/line (laser disc quality)
    - Resolution = Standard: 280 pixels/line (VCR quality)
    - Resolution = Low: 140 pixels/line

    The resolution setting is indirectly proportional to the achievable frame rate (video motion).

- The encoder's quantization factor (q-factor) defines the relative quantization level – an element affecting the distinction between individual pixels. While there are 256 valid q-factor settings, we selected the following values.

    - q-factor = 18: no noticeable distinction between pixels
    - q-factor = 28: little noticeable distinction between pixels
    - q-factor = 38: noticeable distinction between pixels

    The q-factor has a direct relationship to the amount of compression achieved and is directly proportional to the achievable frame rate.

- The encoder's screen cropping factor determines the number of pixels per video frame that are included in the image being compressed (i.e., it defines the region of view in which most image processing occurs). There are six available cropping settings from which to choose, but we selected the more common.

  - Screen cropping factor = 85% standard video: The entire visible image area is processed, excluding the over-scanned areas around the edges of the picture (some monitors display blanked video around the edged – a normal procedure)
  - Screen cropping factor = 63% standard video: The center window of the screen is processed

  Although not quite as noticeable, the screen cropping factor is indirectly proportional to the frame rate.

Many more codec permutations could be created by introducing variations on additional parameters (e.g., saturation, brightness, contrast, tint), but such parameters have relatively little impact on video quality and video motion compared to resolution, quantization, and screen cropping. While we couldn't possibly review all permutation of these three parameters either, we selected an adequate range with which to demonstrate the concept. Additionally, parameters and parameter settings are particular to this device and would be different for other codec systems.

When considering the video encoding used in our prototypes, it's important to recall that this effort is not a performance evaluation of the codec system or the M-JPEG encoding scheme that it employs. It is not a comparison of technical issues such as M-JPEG vs. H.261 or MPEG1, or interframe vs. intraframe encoding. These issues are independent of the xDSL transmission technology and considerations for those implementing such systems. Our focus is placed on the transmission technology – xDSL. From the perspective of this particular project, the codecs and other base system components are interchangeable with similar devices on the market. We selected the prototype component systems for reasons discussed in section 4. For technical comparisons and costing analyses, we refer you to documents such as:

- *ITS Telecommunications: Public or Private? A Cost Trade-off Methodology Guide*, Pub. No. FHWA-JPO-97-0014.
- *A Case for Intelligent Transportation System (ITS) Telecommunications Analysis*, Pub. No. FHWA-JPO-97-0015.
- *ITS Telecommunications Requirements, Options, and Policy Implications*, prepared by Volpe NTSC for the FHWA ITS JPO.

Baseline Parameter Settings

Some of the decisions on system parameter settings were affected by earlier studies of compressed video for traffic video. The FHWA telecommunications analysis[1] discusses the quality of video to support real-time traffic operations for Maryland's Chesapeake Highway Advisory Routing Traffic (CHART) system. Using an H.261 encoding scheme, researchers were able to obtain 15 frames per second over leased fractional T1 lines. The analyses suggest that compressed video transmitted at 384 kbps would be sufficient to perform CHART operator job functions. CHART officials subsequently selected this rate as a minimum requirement for compressed video.

Our studies do not attempt to confirm or dispute the validity of this requirement. We did however use the results from this study to establish a baseline for our compressed video transmissions – a baseline that was used to identify the lower bound on our system parameter settings. With the xDSL modem-pair information rate (i.e., throughput) set to 384 kbps, we were able to achieve 15 frames per second with the following encoder settings: q-factor = 38, resolution = Low, and cropping factor = 63 percent. Within a twisted pair infrastructure scenario, we started observations at this lower limit and worked toward higher quality video.

We could have created an endless number of permutations with additional encoder settings (e.g., q-factor, cropping, as well as saturation, brightness, contrast, and tint) or xDSL system settings (e.g., BER threshold, S/N margins, etc.) However, our objective was to demonstrate the feasibility of xDSL transmission systems and not to exhaustively evaluate every system permutation. We manipulated those parameters that have the most significant impact on video quality and video motion and selected ranges within those items to adequately demonstrate the concept. The selected permutations of the system settings noted above and the twisted pair infrastructure scenarios described in section 6.1.2 comprise the more than 600 test cases we devised for our evaluation.

[1] "A Case for Intelligent Transportation System (ITS) Telecommunications Analysis", pub. No. FHWA-JPO-97-0015

6.1.4 Quantitative and Qualitative Observations

For each of more than 600 different test cases established, we conducted limited qualitative and quantitative observations of each concept prototype.

Quantitative Observations

Our quantitative observations include the following:

- xDSL modem performance statistics, as illustrated in Figure 6-7
  - MrGn: The near-end and far end receiver signal margin, or the received signal to noise ratio (SNR) less a relative receiver SNR reference value (dB)
  - XmtPW: The near-end and far-end transmit signal power level (dBm)
  - RxGn: The near-end and far-end receiver gain level (dB)

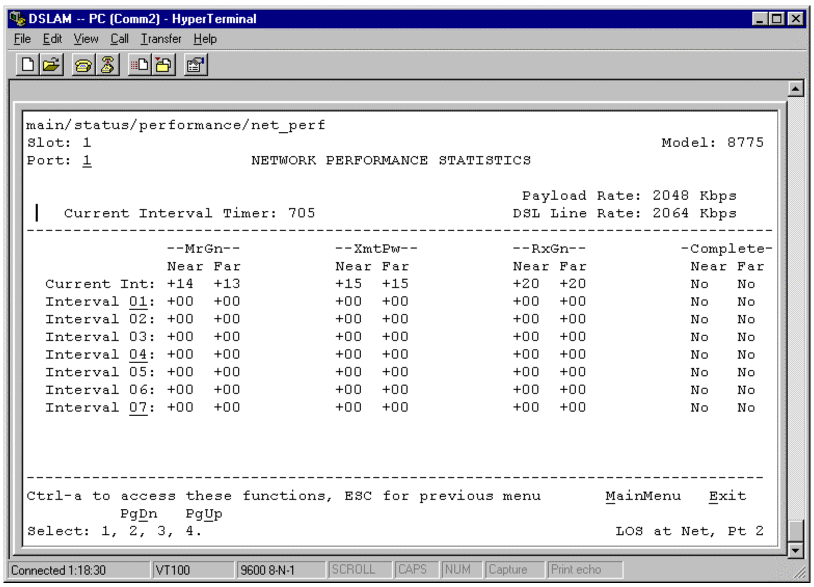

Figure 6-7. xDSL Modem Performance Statistics

- xDSL modem error statistics, as illustrated in Figure 6-8.

  - ES: Errored seconds, or the seconds during which one or more extended super frame (ESF) error events occurred
  - SES: Severely errored seconds, or the seconds during which more than 320 CRC error events or at least 1 out-of-frame (OOF) events occurred
  - FEBE: Far end block errors, errors reported by the remote equipment

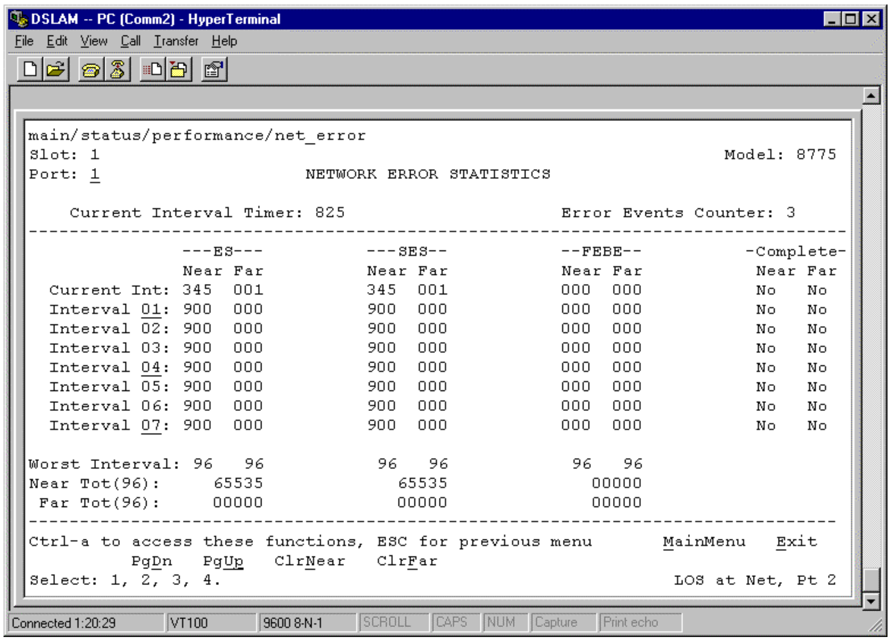

Figure 6-8. xDSL Modem Error Statistics

Statistics for a single test case offer little information, but a collection of such statistics clearly illustrate relative performance of the concept prototype under varying conditions. Sophisticated features of the DSLAM permitted collection of this data for the SDSL prototype, but similar data was not available from the RADSL TU-C or TU-R (i.e., the RADSL prototype).

The modem information rate (i.e., throughput) and its constituent video signal and control data throughput were also collected. This information was the only modem performance data available for the RADSL prototype.

- Video Motion: The received video frame rate (frames per second or f/s) was collected for both prototypes via the codec component (Figure 6-9). Video motion refers to the smoothness of subject motion. Full motion is defined as 30 f/s in the US, but the level of video motion required for a given application is subjective and not an issue of this study.

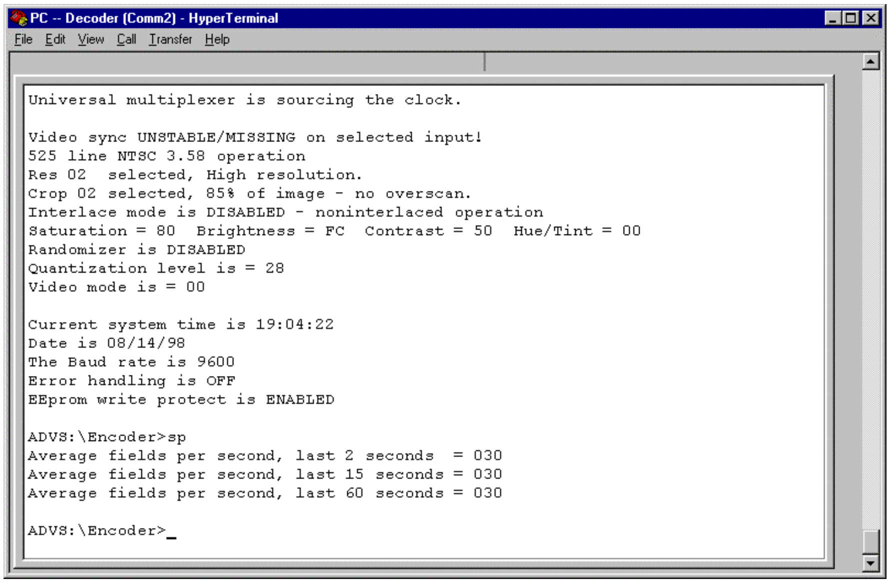

Figure 6-9. Video Motion Statistics

- Traffic Control Operations: A simple observation to determine if there was accurate and continual telemetry between our PC and our traffic controller. This observation was conducted for both prototypes by monitoring the telemetry from the traffic controller GUI (Figure 6- 10).

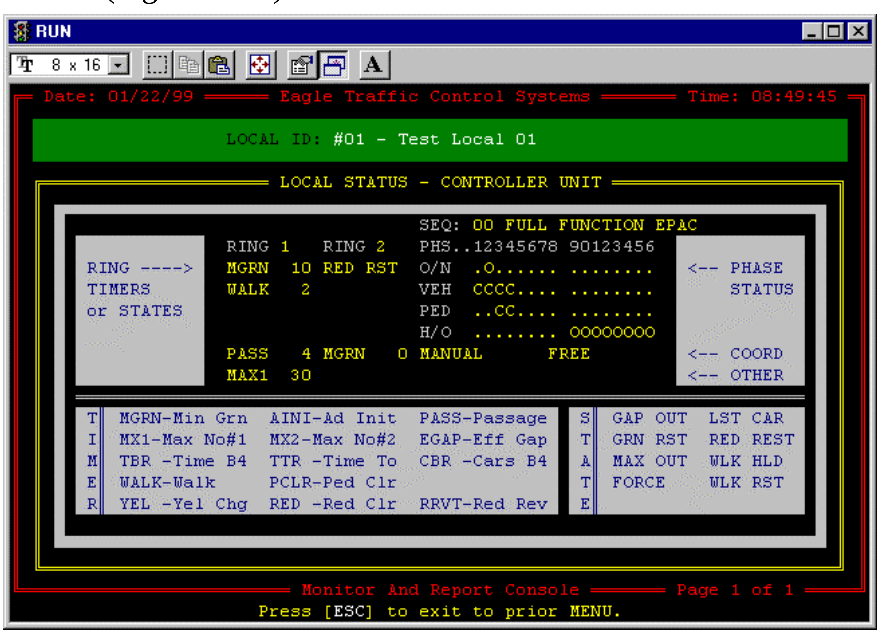

Figure 6-10. Traffic Controller GUI

Qualitative Observations

Our only qualitative observation was a perception of the received video image. For each test case, we provided a limited and subjective assessment of the video quality. Video quality refers to the perceived video resolution – a function of encoder resolution, q-factor, and cropping settings as well as pixel tint, saturation, brightness, and contrast values. We identified the video quality from each test case as one of nine relative values from "poor-" to "good+".

While such assessments are normally conducted among large test groups, we were limited to two researchers. As with most individuals, we held a highly subjective opinion on the quality of the video, which originated from a less than optimal video source (refer to section 6.1.1, Laboratory Traffic Video). Regardless, this assessment was fairly consistent, was relative to our baseline video quality (established as discussed in section 6.1.3), and provided some perspective on system performance.

Having established the criteria that we will use to observe the prototypes, we then conducted our assessments.

6.2 LABORATORY ASSESSMENTS

For each of the prototypes, we configured the system components with our baseline settings – xDSL modem throughput is 384 kbps and encoder q-factor, resolution, and screen cropping factors are 38, low, and 63 percent, respectively. We started observations at this lower limit and worked toward higher quality video adjusting xDSL and base system parameter settings as discussed in the methodology (Section 6.1). Each permutation creating one of more than 600 test cases. Observations were conducted in groups identified by infrastructure scenario.

- Point-to-point scenarios: These are used to assess twisted pair infrastructure configurations that are logically point-to-point in nature and variable in distance and wire gauge. We looked at several 24 AWG scenarios in detail. We also did a comparative analysis with limited 26 AWG scenarios to determine how the performance of the prototypes would be affected by different wire gauges.

- Standard configuration scenarios: While loop configurations representative of various DOT cable plants might be point-to-point in nature, others (or those being leased) might be more like standard loop configurations, such as those defined by ANSI. Our standard configuration scenarios are used to assess the prototypes' performance in such environments.

- Impairment scenarios: These scenarios include both point-to-point and standard configurations, but have impairments introduced onto the line. In some deployments, NEXT can be one of the more significant (and likely) impairments for xDSL-based systems in a traffic control communications environment. These scenarios incorporate the more realistic form of this impairment for the particular prototype being tested.

As explained in the methodology, our quantitative observations included: xDSL modem performance and error statistics, modem information rate (i.e., throughput), traffic controller telemetry, and video motion. Our qualitative observations involved video quality.

6.2.1 SDSL Prototype

This section presents brief results from the evaluation of our SDSL prototype as used with the predefined system parameter settings and within the noted twisted pair infrastructure scenarios. Specific findings from these assessments are provided in Appendix A.

Point-to-Point Scenarios – 24 AWG

The following information summarizes qualitative and quantitative observations from the various test cases using the point-to-point variable length 24 gauge twisted pair wire scenarios. Results are grouped by increasing SDSL modem throughput.

- SDSL throughput = 384 kbps

  Video quality and video motion observations are summarized in Tables 6-1 and 6-2.

Table 6-1 - Video Quality; SDSL Throughput = 384 kbps

Encoder Settings			Twisted Pair Loop Reach (Distance) [miles]				
Video Quantization Factor	***Video Resolution***	***Screen Cropping Ratio***	1	2	3	4	5
38	Low	63%	*Poor-*	*Poor-*	*Poor-*	*Poor-*	*Poor-*
38	Low	85%	*Poor-*	*Poor-*	*Poor-*	*Poor-*	*Poor-*
38	Standard	63%	*Fair-*	*Fair-*	*Fair-*	*Poor+*	*Fair-*
38	Standard	85%	*Fair-*	*Fair-*	*Fair-*	*Fair-*	*Poor+*
38	High	63%	*Good-*	*Good-*	*Good-*	*Good-*	*Good-*
38	High	85%	*Good-*	*Good-*	*Good-*	*Fair+*	*Good-*
28	Low	63%	*Poor*	*Poor*	*Poor*	*Poor*	*Poor*
28	Low	85%	*Poor*	*Poor-*	*Poor*	*Poor*	*Poor*
28	Standard	63%	*Fair*	*Fair*	*Fair*	*Fair-*	*Fair*
28	Standard	85%	*Fair+*	*Fair*	*Fair-*	*Fair*	*Fair-*
28	High	63%	*Good*	*Good*	*Good*	*Good*	*Good-*
28	High	85%	*Good*	*Good*	*Good*	*Good*	*Good-*
18	Low	63%	*Fair-*	*Poor+*	*Poor+*	*Poor+*	*Poor+*
18	Low	85%	*Poor+*	*Poor+*	*Poor+*	*Poor*	*Poor*
18	Standard	63%	*Fair+*	*Fair+*	*Good-*	*Good-*	*Fair+*
18	Standard	85%	*Fair+*	*Fair+*	*Fair+*	*Fair+*	*Good-*
18	High	63%	*Good*	*Good*	*Good*	*Good*	*Good-*
18	High	85%	*Good*	*Good*	*Good*	*Good*	*Good*

Observations reveal that regardless of q-factor and screen cropping settings, the encoder's resolution must be at or above the "standard" setting in order to achieve a fair to good quality video.

Table 6-2. Video Motion (f/s); SDSL Throughput = 384 kbps

Encoder Settings			Twisted Pair Loop Reach (Distance) [miles]				
Video Quantization Factor	***Video Resolution***	***Screen Cropping Ratio***	1	2	3	4	5
38	Low	63%	*15*	*15*	*15*	*15*	*15*
38	Low	85%	*15*	*15*	*15*	*15*	*15*
38	Standard	63%	*10*	*10*	*10*	*10*	*10*
38	Standard	85%	*8*	*9*	*10*	*10*	*9*
38	High	63%	*6*	*6*	*6*	*7*	*6*
38	High	85%	*5*	*6*	*5*	*6*	*6*
28	Low	63%	*15*	*13*	*10*	*14*	*14*
28	Low	85%	*15*	*12*	*12*	*12*	*14*
28	Standard	63%	*8*	*8*	*9*	*8*	*8*
28	Standard	85%	*8*	*8*	*7*	*8*	*7*
28	High	63%	*5*	*5*	*5*	*6*	*5*
28	High	85%	*4*	*5*	*5*	*4*	*5*
18	Low	63%	*10*	*10*	*10*	*10*	*10*
18	Low	85%	*10*	*10*	*10*	*11*	*10*
18	Standard	63%	*7*	*7*	*7*	*6*	*6*
18	Standard	85%	*7*	*6*	*6*	*6*	*6*
18	High	63%	*4*	*3*	*4*	*5*	*3*
18	High	85%	*3*	*3*	*4*	*3*	*3*

The prototype achieves a maximum of 15 f/s at certain distances, but only when the encoder resolution setting is "low" and the q-factor is "28" or better, which yields poor video quality. A good video quality is obtained at a rate of approximately 7 f/s.

- SDSL throughput = 768 kbps

  Specific observations (similar to those in Tables 6-1 and 6-2) are tabulated in Appendix A.

  As expected, video quality at this throughput is consistent with that at 384 kbps. In order to achieve a fair to good video quality, the encoder resolution setting must be at or above "standard". Video motion observations reveal an improvement in achievable frame rate. The prototype was able to achieve 30 f/s in many test cases, but at the expense of video quality. Good video quality is possible with a rate of approximately 10 f/s. The 5 mile distance is no longer possible at 768 kbps; the SDSL prototype can only support this throughput at distances of less than approximately 4.5 miles.

- SDSL throughput = 1152 kbps

  Specific observations are tabulated in Appendix A.

  In these instances, video quality observations are again consistent with those made at 384 kbps. The video motion observations reveal a great deal of improvement in frame rate. The prototype is able to achieve 30 f/s more frequently, again at the expense of video quality. Fifteen (15) f/s can also be achieved while maintaining good video quality, but only with select encoder settings. Arranging for the best video quality (i.e., encoder resolution and q-factor settings of “high” and “18” respectively), the frame rate drops within the range of 10 f/s. We also noted that the maximum operational distance at 1152 kbps is approximately 4 miles.

- SDSL throughput = 1536 kbps

  Specific observations are tabulated in Appendix A.

  As expected, the video quality observations are again consistent with earlier observations. Fair to good video quality requires an encoder resolution setting at or above “standard”. The prototype is able to achieve between 15 and 30 f/s under most system parameter settings and can maintain the better video quality within this range. As in the previous case, the maximum operational distance at this throughput is 4 miles – a result of using an identical line rate of 1552 kbps for both 1152 and 1536 kbps throughputs. Obviously, a higher throughput at the same line rate is advantageous – better performance.

- SDSL throughput = 2048 kbps

  Specific observations are tabulated in Appendix A.

  As in all the earlier test cases, the video quality observed follows the same trend. Fair to good video quality requires an encoder resolution setting at or above “standard”. The lowest frame rate observed is 15 f/s, but this is only when the video is of its highest quality. The maximum operational distance at this throughput is approximately 3.75 miles, a notable reduction as compared to the distance of at least 5 miles achieved at 384 kbps. This illustrates the inter-dependence of distance and throughput and defines one of the system’s distance-throughput thresholds for these particular scenarios.

General observations of the SDSL prototype within the 24 AWG point-to-point scenarios are as follows:

- <u>SDSL performance and error statistics</u>: These statistics (as defined in section 6.1.4) allowed us to assess the operation of the SDSL equipment as infrastructure and system parameter settings varied. As distance between the SDSL units increased, near-end and far-end transmit powers remained constant while the receiver gains increased to compensate for a dropping SNR. This trend continued regardless of system throughput. As the distance extended to the systems current threshold, we observed the SNR drop toward zero. The SDSL modems remained synchronized, but we began to notice a great deal of communication errors (FEBE, ES, and SES). We would occasionally notice video 'tiling' effects and intermittent frame loss.

- SDSL modem information rate (throughput): Although this was a predetermined system parameter setting, we monitored real-time throughput for any significant deviation – perhaps due to modem compensations. No significant or sustained deviations were observed.

- Traffic control operations: As long as the SDSL modems were able to achieve and maintain synchronization for a given test case, traffic controller telemetry was accurate and continual. As distance and throughput increased, so did the instances in which the synchronization failed.

- Video motion: The frame rate was affected by the available system throughput – the greater the throughput the smoother the motion. For any given throughput, the motion was also affected by the prototype's encoder settings (e.g., resolution, q-factor, screen cropping). Values set to achieve better video quality subsequently reduced motion. However, with sufficient throughput, the quality was optimized without noticeably affecting the motion. For details, refer to Appendix A.

- Video quality: The quality was based primarily on the prototype's encoder settings and remained independent of the system throughput. Throughput had no significant impact on the quality until the system reached a distance-throughput threshold and failed. Refer to Appendix A for details.

Point-to-Point Scenarios – 24 vs. 26 AWG

The following information compares qualitative and quantitative observations from the various test cases using point-to-point variable length scenarios of both 24 and 26 gauge twisted pair wire. Although a more complete set of test cases was performed, we present only the observations from those using the best-case base system parameter settings (i.e., screen cropping ratio = 63%, video resolution = high, video quantization factor = 18). These are all that were required to illustrate the relative performance of the prototype as it was affected by wire gauge. Due to limitations of the twisted pair simulator, comparisons were limited to a distance of 3 miles.

The detailed results for these test cases can be found in Appendix A. Here (Table 6-3) we summarize only those observations for video motion. Video quality is always good since we were reviewing best-case base system parameter settings.

Table 6-3. Video Motion (f/s); 24 vs. 26 AWG

Wire Gauge	Throughput [kbps]	Twisted Pair Loop Reach (Distance) [miles] 1	2	3
24 AWG	384	4	3	4
	768	7	7	7
	1152	10	10	10
	1536	10	10	11
	2048	15	15	15
26 AWG	384	3	3	3
	768	7	7	7
	1152	10	10	10[2]
	1536	10	11	10[3]
	2048	15	15	NR

NR = No Result – the SDSL modems did not operate over the respective wire gauge for the given distance throughput value.

There was no notable difference in video motion observations. However, at a distance of 3 miles and a throughput of 2048 kbps, the SDSL modems (and consequently the traffic controller telemetry) failed to operate over the 26-gauge wire. In other words, the maximum distance at which the SDSL prototype functions at 2048 kbps over 26 AWG is somewhere between 2 and 3 miles. As expected, the wire gauge does affect the loop reach, and hence the achievable distance throughput thresholds.

Although often found in DOT cable plants, we did not experiment with 19 gauge wire. Limitations of the twisted pair simulator allowed more flexibility with 24 and 26 AWG scenarios. However, theory predicts and our results indicate that 19 AWG will provide better performance and longer loop reach than either 24 or 26 AWG scenarios.

General observations of the SDSL prototype in the 24 vs. 26 AWG point-to-point scenarios are as follows:

- SDSL performance and error statistics: As with the earlier point-to-point test cases, the near-end and far-end transmit powers remained constant while the receiver gains increased to compensate for a dropping SNR – regardless of throughput. The only difference for those test cases using 26 AWG was the distance-throughput values at which the SDSL prototype failed to operate. When reaching a distance at which the prototype could no longer support 2048 kbps (i.e., one of its distance-throughput thresholds) the SNR dropped to almost zero and a great deal of communication errors occurred. However, using 24 AWG at the same distance and the same line rate did not generate any of these error statistics; the operation of the modem was normal. Consequently, these statistics verify the dependence of loop reach on the wire gauge. They also help identify the maximum distance at which the prototype can support a given throughput, or the maximum throughput for a given distance.

[2] Observations: intermittent frame loss; occasional tiling due to modem operation around 0 SNR
[3] Observations: intermittent frame loss; frequent tiling due to modem operation at 0 SNR

- SDSL modem information rate (throughput): Again, although a predetermined system parameter setting, we monitored real-time throughput for any significant deviation. No significant or sustained deviations were observed.

- Traffic control operations: As long as the modems were able to achieve and maintain synchronization, traffic controller telemetry was accurate and continual. At a distance approaching 3 miles and with an SDSL throughput of 2048 kbps, the video signal was lost when using 26 AWG, so was the traffic control telemetry.

- Video motion: As with previous point-to-point test cases, the frame rate was affected by the available system throughput – the greater the throughput the smoother the motion. For any given throughput, the motion was also affected by the prototype's encoder settings. Refer to Appendix A for details.

- Video quality: The quality depends on the prototype's encoder settings; refer to Appendix A. Throughput has no significant impact on the quality until the system reaches a distance-throughput threshold and fails completely.

Standard Configuration Scenarios

A complete set of test cases was performed using the standard configuration scenarios, but we present only the observations from those using the best-case base system parameter settings. These results adequately illustrate the performance of the prototype as it was affected by different standard configurations.

Detailed results for these test cases can be found in Appendix A. Here we summarize only those observations for video motion. Video quality is always good since we were reviewing best-case base system parameter settings.

As shown in Table 6-4, the SDSL prototype was found to work in only four of the ten standard configuration scenarios: MID-CSA #2, augmented MID-CSA #2, ANSI #6, and ANSI #13. The operation of the prototype within these configurations was limited to the lesser throughputs. Each allows the prototype to sustain 384 kbps, but only the MID-CSA # 2 configuration supported throughputs up to 2048 kbps.

Table 6-4. Video Motion (f/s); Standard Configuration Scenarios

SDSL Throughput [kbps]	Twisted Pair Loop Configurations: MID-CSA #2	MID-CSA #2 + 9,350 ft.	ANSI #3	ANSI #3 + 9,350 ft.	ANSI #6	ANSI #6 + 9,350 ft.	ANSI #9	ANSI #9 + 9,350 ft.	ANSI # 13	ANSI #13 + 9,350 ft.
384	3	3	NR	NR	3	NR	NR	NR	3	NR
768	6	NR	NR	NR	NR	NR	NR	NR	NR	NR
1152	10	NR	NR	NR	NR	NR	NR	NR	NR	NR
1536	12	NR	NR	NR	NR	NR	NR	NR	NR	NR
2048	15	NR	NR	NR	NR	NR	NR	NR	NR	NR

NR = No Result – the SDSL modems did not operate over the respective configuration for the given throughput.

The standard configurations we selected were rather complex and lengthy, and our results indicate that many were obviously too demanding. This is an issue if cable plants are more complicated than those similar to the MID-CSA configuration (see Appendix D). Fortunately, many transportation communication infrastructures are similar to the point-to-point scenarios addressed earlier. In retrospect, it would have been beneficial to review some of the less demanding infrastructures, but limited time with the twisted pair simulator equipment restricted our testing activity. Regardless, results show that some standard configurations will limit deployment options.

General observations of the SDSL prototype in the standard configuration scenarios are as follows:

- SDSL performance and error statistics: Similar to previous instances, these statistics showed modem receiver gains were increased to compensate for low SNRs. If possible, these adjustments allowed the prototype to operate at the given throughput within the particular configuration. In cases where the SDSL equipment could not synchronize, we observed a great number of communications errors (i.e., FEBE, ES and SES) indicating that we had attempted operation beyond the distance-throughput threshold.

- SDSL modem information rate (throughput): While monitoring real-time throughput, there were no instances of significant or sustained deviations from the preset values.

- Traffic control operations: If the SDSL modems were able to achieve and maintain synchronization, traffic controller telemetry was accurate and continual.

- Video motion: As with previous cases, the frame rate was affected by the available system throughput. Each of the standard configurations we used (and even those we didn't) support an associated maximum throughput. The greater this value, the greater the frame rate and the smoother the motion. For any given throughput, the motion was also affected by the prototype's encoder settings. For more specific information, refer to Appendix A.

- Video quality: Since quality is based on the prototype's encoder settings and remains independent of system throughput, standard configurations themselves do not affect the quality unless they impose an effective loop distance greater than that supported by the prototype, at which point the system fails completely. Refer to Appendix A.

Impairment Configuration Scenarios

For the SDSL circuits, the most closely related form of near-end cross talk (NEXT) available from the twisted pair simulator was HDSL NEXT. We used 24 disruptive HDSL circuits for each of these test cases – more than sufficient to represent any such configuration in which these prototypes would be deployed.

As with the standard configuration scenarios, a complete set of test cases were evaluated. Again, we present only the observations from those using the best-case base system parameter settings. These are all that were required to illustrate the relative performance of the prototype as it was affected by NEXT. The detailed results for the impairment configuration scenarios can be found in Appendix A. Here (Table 6-5) we summarize only those observations for video motion. Video quality is always good since we were reviewing best-case base system parameter settings.

There are two loop configurations that prohibit the SDSL prototype from functioning properly when NEXT is introduced, ANSI #3 and ANSI #9.

Table 6-5. Video Motion (f/s); Impairment Configuration Scenarios

SDSL Throughput [kbps]		Twisted Pair Loop Configurations							
		MID-CSA #2	ANSI #3	ANSI #6	ANSI #9	ANSI # 13	1mile	1.75miles (~2 miles)	3 miles
	384	3	NR	4	NR	3	4	3	3
	768	6	NR	NR	NR	NR	7	7	7
	1152	10	NR	NR	NR	NR	10	10	NR
	1536	15	NR	NR	NR	NR	15	15	NR
	2048	15	NR	NR	NR	NR	15	15	NR

NR = No Result – the SDSL modems could not operate over the respective configuration or distance for the given throughput while NEXT was injected.

When compared to standard configuration scenarios, there were no noticeable changes with respect to video motion or video quality – as expected. If the prototype is operational, video motion and quality observations are nearly identical. The distance-throughput threshold has been reduced with the introduction of NEXT, but the system is still operating below this value.

Performance and error statistics show the noise is affecting the system, but the SDSL modems compensate. The consequences of this compensation can't be seen until the system reaches a distance-throughput threshold; one that has been reduced by the impairment. This is clearly illustrated by comparing results from Tables 6-5, A-6, A-8, and A-10 where loop distance is three miles and throughput is at or above 1152 kbps (the line rate is at or above 1152 kbps).

General observations of the SDSL prototype when operating in the impairment configuration scenarios are as follows:

- SDSL performance and error statistics: As stated earlier, these statistics show the affect of NEXT on system performance. When comparing statistics collected for the earlier 3-mile point-to-point scenarios (identical with the exception of NEXT; see Tables A-6, A-8, and A-10), we noticed that the prototype is now unable to provide more than 768 kbps. This new threshold is explained by these performance and error statistics.

- <u>SDSL modem information rate (throughput)</u>: There were no instances of significant or sustained deviations from the preset throughput values.

- <u>Traffic control operations</u>: Again, if the SDSL modems were able to achieve and maintain synchronization, traffic controller telemetry was accurate and continual.

- <u>Video motion</u>: As with all other test cases, the frame rate was affected by the system throughput – the greater the throughput the smoother the motion. The impact of NEXT limits the throughput at any given distance, or within any specific configuration. This in turn restricts the range of video motion. For any achievable throughput, the motion was also affected by the prototype's encoder settings. For more specific information, refer to Appendix A.

- <u>Video quality:</u> The quality is based primarily on the prototype's encoder settings and remains independent of the system throughput. Therefore, NEXT has no impact on video quality until the system reaches a new reduced distance-throughput threshold and subsequently fails. Refer to Appendix A

6.2.2 RADSL Prototype

This section presents some brief results from the evaluation of our RADSL prototype as used with the predefined system parameter settings and within the noted twisted pair infrastructure scenarios. Specific findings from these assessments are provided in Appendix B.

Point-to-Point Scenarios – 24 AWG

The following information summarizes qualitative and quantitative observations from the various test cases using the point-to-point variable length 24 gauge twisted pair wire scenarios. Results are grouped by increasing RADSL modem downstream throughput.

- RADSL downstream throughput = 1544 kbps

Video quality and video motion observations are summarized in Tables 6-6 and 6-7.

Table 6-6. Video Quality; RADSL Downstream Throughput = 1544 kbps

Encoder Settings			**Twisted Pair Loop Reach (Distance) [miles]**			
Video Quantization Factor	***Video Resolution***	***Screen Cropping Ratio***	1	2	3	3.5[4]
38	Low	63%	Poor-	Poor-	Poor-	Poor-[5]
38	Low	85%	Poor-	Poor-	Poor-	Poor-
38	Standard	63%	Fair-	Fair-	Fair-	Fair-
38	Standard	85%	Fair-	Fair-	Fair-	Fair-
38	High	63%	Good-	Good-	Good-	Good-
38	High	85%	Good-	Good-	Fair+	Fair+
28	Low	63%	Poor	Poor	Poor	Poor
28	Low	85%	Poor	Poor	Poor-	Poor
28	Standard	63%	Fair+	Fair+	Fair+	Fair
28	Standard	85%	Fair	Fair	Fair	Fair
28	High	63%	Good	Good	Good	Good
28	High	85%	Good	Good	Good	Good
18	Low	63%	Poor+	Poor+	Poor+	Poor+
18	Low	85%	Poor+	Poor+	Poor+	Fair-
18	Standard	63%	Good-	Fair+	Good-	Fair+
18	Standard	85%	Fair+	Fair+	Fair+	Fair+
18	High	63%	Good	Good	Good	Good
18	High	85%	Good	Good	Good	Good

Observations indicate that in order to achieve a fair to good video quality, the encoder resolution setting must be at or above "standard", as with the SDSL prototype.

[4] At a 4 miles the RADSL modems did not operate at 1544 kbps; we collected results at 3.5 miles instead.
[5] Significant tiling and video frame loss observed – specific cause unknown.

Table 6-7. Video Motion; RADSL Downstream Throughput = 1544 kbps

Codec Input Settings			Distance (mile)			
Video Quantization Factor	***Video Resolution***	***Screen Cropping Ratio***	1	2	3	3.5[6]
38	Low	63%	30	30	30	30
38	Low	85%	30	30	30	30
38	Standard	63%	30	30	30	30
38	Standard	85%	30	30	30	30
38	High	63%	15	15	15	15
38	High	85%	15	15	15	15
28	Low	63%	30	30	30	30
28	Low	85%	30	30	30	30
28	Standard	63%	30	30	30	30
28	Standard	85%	30	30	30	28
28	High	63%	15	15	15	15
28	High	85%	15	15	15	15
18	Low	63%	30	30	30	30
18	Low	85%	30	30	30	30
18	Standard	63%	15	15	15	15
18	Standard	85%	15	15	15	15
18	High	63%	15	15	15	12
18	High	85%	13	12	12	10

Most frame rate observations varied from 15 to 30 f/s, the lowest frame rate observed was 10 f/s, but this is only when the video was of its highest quality. The maximum distance over which the RADSL modems would operate at 1544 kbps was approximately 3.5 miles.

- RADSL downstream throughput = 2304 kbps

The specific observations (similar to those in Tables 6-6 and 6-7) are tabulated in Appendix B.

In all cases, the video quality observations followed a similar trend. Fair to good quality video requires an encoder resolution setting at or above “standard”.

As with the SDSL prototype at this approximate throughput, the lowest frame rate observed is 15 f/s, but again, only when the video is of its highest quality. The maximum distance at which the RADSL modems would properly function dropped to approximately 3 miles, which illustrates the relation between distance and throughput and identifies one of this system’s distance-throughput thresholds.

[6] At a 4 miles the RADSL modems did not operate at 1544 kbps; we collected results at 3.5 miles instead.

General observations of the RADSL prototype within the 24 AWG point-to-point scenarios are as follows:

- RADSL performance and error statistics: Not applicable; sophisticated features of the DSLAM permitted collection of this data for the SDSL prototype, but similar data was not available from the RADSL TU-R or TU-C (i.e., the RADSL prototype)

- RADSL modem information rate (throughput): As with the SDSL prototype, this was a predetermined system parameter setting, but we monitored real-time throughput for any significant deviation – perhaps due to modem compensations. Only minor and unsustained deviations were observed.

- Traffic control operations: Even if the RADSL modems were not able to achieve or maintain synchronization for a given test case, traffic controller telemetry was accurate and continual. This result was expected since the RADSL prototype is configured on a base system #2 configuration – one that uses a splitter to isolate controller telemetry.

- Video motion: As in the tests with the SDSL prototype, the frame rate was affected by the available system throughput – the greater the throughput the smoother the motion. For any given throughput, the motion was also affected by the prototype's encoder settings (e.g., resolution, q-factor, screen cropping). Values set to achieve better video quality subsequently reduced motion. However, the RADSL prototype's high throughput settings were sufficient to allow optimization of video quality without noticeably affecting the motion. For details, refer to Appendix B.

- Video quality: The quality was based primarily on the prototype's encoder settings and remained independent of the system throughput. Throughput had no significant impact on the quality until the system reached a distance-throughput threshold and failed. Refer to Appendix B for details.

Point-to-Point Scenarios – 24 vs. 26 AWG

The following information compares qualitative and quantitative observations from the various test cases using point-to-point variable length scenarios of both 24 and 26 gauge twisted pair wire. Although a more complete set of test cases was performed, we present only the observations from those using the best-case base system parameter settings (i.e., screen cropping ratio = 63%, video resolution = high, video quantization factor = 18). These are all that were required to illustrate the relative performance of the prototype as it was affected by wire gauge.

The detailed results for these test cases can be found in Appendix B. Here (Table 6-8) we summarize only those observations for video motion. Video quality is always good since we were reviewing best-case base system parameter settings.

Table 6-8. Video Motion (f/s); 24 vs. 26 AWG

Wire Gauge	Downstream Throughput [kbps]	Twisted Pair Loop Reach (Distance) [miles] 1	2	3
24 AWG	1544	15	15	15
	2304	15	15	15
26 AWG	1544	15	15	15
	2304	15	15	NR

NR = No Result – the RADSL modems did not operate over the respective wire gauge for the given distance throughput value.

There was no notable difference in video motion observations. However, at a distance of 3 miles and a throughput of 2304 kbps, the RADSL failed to operate over the 26 AWG. Due to the prototype's configuration, traffic controller telemetry remained operational. The maximum distance at which the RADSL prototype functions at 2304 kbps over 26 AWG is somewhere between 2 and 3 miles. As expected, the wire gauge affects loop reach and therefore the achievable distance throughput thresholds.

General observations of the RADSL prototype in the 24 vs. 26 AWG point-to-point scenarios are as follows:

- RADSL performance and error statistics: Not applicable; as noted previously, this data was not available for the RADSL prototype.

- RADSL modem information rate (throughput): Again, although a predetermined system parameter setting, we monitored real-time throughput for any significant deviation. Only minor and unsustained deviations were observed.

- Traffic control operations: Again, regardless of whether the RADSL modems achieved or maintained synchronization, traffic controller telemetry was accurate and continual. This was the expected result.

- Video motion: As with previous point-to-point test cases, the frame rate was affected by the available system throughput – the greater the throughput the smoother the motion. For any given throughput, the motion was also affected by the prototype's encoder settings. Refer to Appendix B for details.

- Video quality: The quality depends on the prototype's encoder settings; refer to Appendix B. Throughput has no significant impact on the quality until the system reaches a distance-throughput threshold and fails to operate.

Standard Configuration Scenarios

A complete set of test cases was performed using the standard configuration scenarios, but we present only the observations from those using the best-case base system parameter settings. These results adequately illustrate the performance of the prototype as it was affected by different standard configurations.

Detailed results for these test cases can be found in Appendix B. Here we summarize only those observations for video motion. Video quality is always good since we were reviewing best-case base system parameter settings.

As shown in Table 6-9, the RADSL prototype was found to work in only three of the ten standard configuration scenarios: MID-CSA #2, augmented MID-CSA #2, and ANSI #13. Each of these configurations allows the RADSL prototype to sustain both 1544 and 2304 kbps.

Table 6-9. Video Motion (f/s); Standard Configuration Scenarios

		Twisted Pair Loop Configurations									
		MID-CSA #2	MID-CSA #2 + 9,350 ft.	ANSI #3	ANSI #3 + 9,350 ft.	ANSI #6	ANSI #6 + 9,350 ft.	ANSI #9	ANSI #9 + 9,350 ft.	ANSI # 13	ANSI #13 + 9,350 ft.
RADSL Downstream Throughput [kbps]	1544	15	15	NR	NR	NR	NR	NR	NR	15	NR
	2304	15	15	NR	NR	NR	NR	NR	NR	15	NR

NR = No Result – the RADSL modems did not operate over the respective configuration for the given throughput.

As stated previously, the standard configurations we selected were rather complex and lengthy, and our results indicate that many were too demanding. Less demanding configurations might have provided more data, but limited time with the twisted pair simulator equipment restricted our testing activity. Regardless, results show that some standard configurations will limit deployment options.

The SDSL prototype functioned within the MID-CSA#2, augmented MID-CSA#2, ANSI #6, and ANSI #13. The RADSL prototype could accommodate all of these except one, the MID-CSA #6. A RADSL solution might have functioned within this configuration at a lower throughput, but that was not an option with this particular RADSL equipment.

Noticeably different is the throughput maintained by the RADSL prototype within these configurations. Where the SDSL prototype could not support throughputs beyond 384 kbps, the RADSL prototype supported the full 2304 kbps. Perhaps this is an indication that RADSL – either the specific equipment or the technology – could be more accommodating to the bridged tap impairments in these standard configurations. This is difficult to determine since the prototypes were obviously operating near their effective distance-throughput thresholds and performance statistics were unavailable for the RADSL prototype.

General observations of the RADSL prototype in the standard configuration scenarios are as follows:

- RADSL performance and error statistics: Not applicable; as noted previously, this data was not available for the RADSL prototype.

- RADSL modem information rate (throughput): While monitoring real-time throughput, there were only minor and unsustained deviations were observed.

- Traffic control operations: As expected, traffic controller telemetry was accurate and continual – regardless of whether the RADSL modems achieved or maintained synchronization.

- Video motion: As with previous cases, the frame rate was affected by the available system throughput. Each standard configuration supports an associated maximum throughput. The greater this value, the greater the frame rate and the smoother the motion. For any given throughput, the motion was also affected by the prototype's encoder settings. For more specific information, refer to Appendix B.

- Video quality: Since quality is based on the prototype's encoder settings and remains independent of system throughput, standard configurations themselves do not affect the quality unless they limit the effective loop distance at which the prototype will operate. At this point, the system fails and the video transmissions are lost. Refer to Appendix B.

Impairment Configuration Scenarios

For the RADSL circuits, the most closely related form of near-end cross talk (NEXT) available from the twisted pair simulator was ADSL NEXT. We used 24 disruptive ADSL circuits for each of these test cases – more than sufficient to represent any such configuration in which these prototypes would be deployed.

As with the standard configuration scenarios, a complete set of test cases were evaluated. However, we present only the observations from those using the best-case base system parameter settings. These are all that were required to illustrate the relative performance of the prototype as it was affected by NEXT. The detailed results for the impairment configuration scenarios can be found in Appendix B. Here (Table 6-10) we summarize only those observations for video motion. Video quality is always good since we were reviewing best-case base system parameter settings.

There are three loop configurations that prohibit the RADSL prototype from functioning properly when NEXT is introduced, ANSI #3, ANSI #6, and ANSI #9.

Table 6-10. Video Motion (f/s); Impairment Configuration Scenarios

		Twisted Pair Loop Configuration							
		MID-CSA #2	ANSI #3	ANSI #6	ANSI #9	ANSI # 13	1mile	1.75 miles (~ 2 miles)	3 miles
RADSL Downstream Throughput [kbps]	1544	15	NR	NR	NR	14	15	15	15
	2304	15	NR	NR	NR	15	15	15	15

NR = No Result – the RADSL modems could not operate over the respective configuration or distance for the given throughput while NEXT was injected.

When compared to standard configuration scenarios, there was no noticeable change with respect to video motion. The frame rate was still 15 f/s for all test cases. However, at 2304 kbps and within the ANSI #13 and 3-mile point-to-point scenarios, the video quality was impaired with occasional 'tiling' and intermittent frame loss. We also noticed occasional codec errors. It's clear that the system was operating just below a new distance-throughput threshold that had been reduced by the introduction of NEXT.

General observations of the RADSL prototype when operating in the impairment configuration scenarios are as follows:

- <u>RADSL performance and error statistics</u>: Not applicable; as noted previously, this data was not available for the RADSL prototype.

- <u>RADSL modem information rate (throughput)</u>: There were only minor and unsustained deviations from the preset throughput values.

- <u>Traffic control operations</u>: Again, traffic controller telemetry was accurate and continual in all test cases, even if the RADSL modems could not achieve or maintain synchronization.

- <u>Video motion</u>: As with all previous test cases, the frame rate was affected by the system throughput. The impact of NEXT limits the throughput at any given distance, or within any standard configuration, which subsequently restricts the range of video motion. For any achievable throughput, the motion was also affected by the prototype's encoder settings.

- Video quality: The quality is based primarily on the prototype's encoder settings and remains independent of the system throughput. Therefore, ADSL NEXT has no impact on video quality until the system exceeds a new reduced distance-throughput threshold and fails.

SECTION 7

CONCLUSIONS

This section provides brief conclusions derived from not only our assessments, but also the process of establishing the concept prototypes. This includes developing an understanding of xDSL technologies, traffic video systems, and field device communications. Each of which has an impact on how the prototypes were designed, and how they might be deployed. We also briefly discuss our subsequent field studies and alternatives to xDSL for traffic video.

7.1 LABORATORY ASSESSMENTS

The laboratory assessments have shown the concept of the xDSL-based traffic video to be sound. The prototypes operate as expected within the limitations of their component systems, particularly the xDSL systems. The xDSL systems used in both prototypes performed well until reaching their maximum distance-throughput values (e.g., 21,000 feet at 2048 kbps). As with most digital communication technologies, they function almost flawlessly until reaching these particular thresholds, then they fail.

Many owned infrastructures provide access to twisted pair run directly between remote sites and traffic control facilities (i.e., between TU-R and DSLAM as shown in Figure 7-1). In such instances, an xDSL connection can utilize unlimited twisted pair bandwidth and throughput can be maximized for the physical distance and condition of the line.

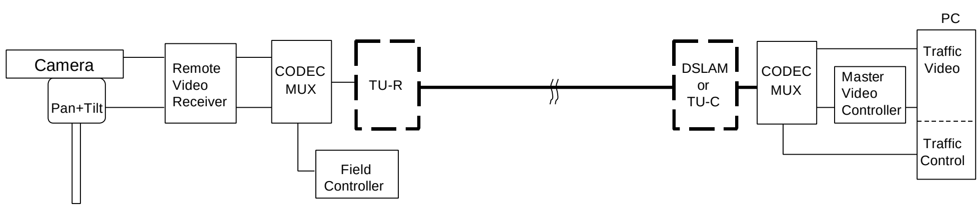

Figure 7-1. Direct Circuit - Centralized Architecture

If establishing an xDSL connection between remote site and communications hub (Figure 7-2), throughput over this tail circuit will be affected by backhaul services (i.e., available capacity along the high-speed backbone). Influenced by technical or financial

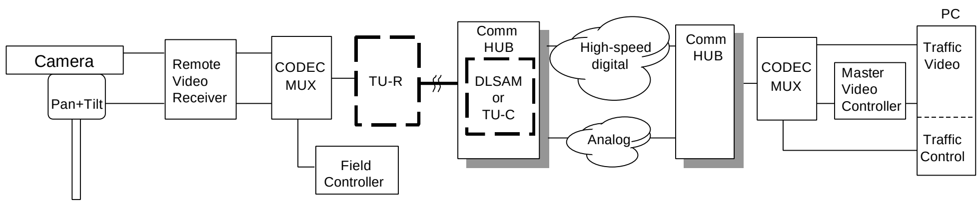

Figure 7-2. Tail Circuit - Distributed Architecture (High-speed Backbone)

considerations or by agency policy, the throughput of the xDSL circuit might be restricted. For example, one might be limited to multiplexing circuits of no more than 348 kbps onto the backbone. In this case, the physical distance between TU-R and DSLAM could be maximized for the accepted throughput and the condition of the line.

In any instance, the prototypes function consistently when operating below their distance-throughput thresholds. Within these bounds (i.e., a given throughput on a line of given distance and under given conditions), the video quality can be improved or worsened at the expense or benefit of video motion. The compromise becomes an issue of preference.

Our prototypes show that xDSL-based traffic video systems will work. However, system designs and infrastructure conditions will dictate the performance one can achieve. Along with user requirements, these are considerations for those implementing such systems. Again, this study is not a comparative technical or financial analysis, but we do present some issues to consider.

7.2 DEPLOYMENT ISSUES

There are many issues involved when deploying a traffic video system, one of which is the choice of communications. Although commercially available xDSL equipment and services now exist, they were not intended for applications such as traffic video. If choosing to deploy an xDSL solution, there will be some additional infrastructure-, equipment-, operational-, and service-related issues to address.

- Infrastructure Related Issues:
  - Twisted Pair Availability: If twisted pair infrastructure is owned, how much is available? If the infrastructure is not owned, can twisted pair (*dry copper*) be leased from the LEC (which is different from leasing an xDSL service)?
  - Distance: How far is the TMC or communications hub from the remote site? Depending on technology, data rate, and wire gauge, the DSLAM (or TU-x) must be located within approximately 30,000 feet of the remote location.
  - Impairments: What infrastructure related impairments (e.g., bridged taps, loading coils) exist?

- Equipment Related Issues:
  - Availability: Will the required xDSL products be commercially available? What interfaces will exist for various product types, and will they be compatible with equipment specific to an ITS application, such as the traffic video codecs?
  - Costs: What recurring and non-recurring equipment costs will one incur if the infrastructure is owned or if leasing additional twisted pair (*dry copper, not an xDSL service*)?
  - Interoperability: Although line coding standards exist, some DSL equipment manufacturers use incompatible upper layer protocols. Most likely, this will not be an issue since xDSL is point-to-point in nature and most will use the same manufacturer's CO and CPE equipment.

- Operational Related Issues:
  - Design: How many cameras need to be connected? What digital compression is used, if any? Will video signals be multiplexed? If so, from how many locations and over what distances? It's possible to integrate multiple-camera systems on a single DSL circuit.
  - Performance: What are the video motion and video quality requirements?

- Service Related Issues:
  - Availability: If intending to lease an xDSL service, will the local provider have that particular service available? If not, what is the probability that the provider will soon deploy such services?

  - Cost: What are the recurring and non-recurring service costs associated with an xDSL solution? What are the costs as compared with other services (e.g., T1, ISDN)? At the beginning of 1998 calendar year, a RADSL tail circuit and ATM backbone service, providing the equivalent outbound bandwidth and four times more inbound as a T1, was priced between $50 and $150 per month, approximately 10 percent the cost of a T1 at that time[7].

Making note of these issues is not intended to discourage an xDSL solution, but rather to suggest that such a solution will likely require some accommodation. Ultimately, these decisions will depend on where and for whom the system is deployed. Although deploying a simple traffic video system, our subsequent field studies exemplify these considerations.

7.3 FIELD STUDIES

The second phase of our study will comprise field testing efforts. While establishing over 600 different laboratory test cases, we could not possibly construct the endless number of scenarios one might encounter in the field. Furthermore, precisely duplicating realistic field conditions with any one of the test cases was unlikely. Even with the use of a sophisticated twisted pair simulator, we can only guess at the conditions in any given field environment. Therefore, we will establish field testing activities to validate laboratory work and to demonstrate the concept prototypes in a true operational environment. The field tests should also address any skewed findings because of unrealistic laboratory conditions, such as the degraded quality of the traffic video source.

Two sites were selected for the field study activities, one within the city of Alexandria, Virginia, and the other within the city of Fairfax, Virginia. The locations were selected in part for the willingness of the associated transportation agencies to host these activities. Additionally, both sites are within close proximity of our research facilities and staff, and both have owned infrastructure with direct access to traffic control facilities – ideal conditions for rapid deployment of the concept prototypes. The efforts also have the

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[7] Nelson, David, "Switching ATM in the Service Provider Market", *Telecommunications*, p. 45, March 1998.

attention of local government officials, who believe these studies might be of value to some of their transportation concerns, and the Virginia Department of Transportation (VDOT), which is observing these efforts closely for any insight to similar application within other jurisdictions.

The field studies will be in progress by the time this document is released. Documentation will comprise an addendum to a revised version of this report and will be available by 30 June 1999.

7.4 ALTERNATIVES FOR TRAFFIC VIDEO

The scope of this particular effort is focused on the use of xDSL technologies for traffic video. Our xDSL-based prototypes offer a unique solution for traffic video operations. They do not necessarily offer the most appropriate. Along with the more common communications systems used for traffic video (e.g., coaxial, fiber), some transportation agencies are now utilizing alternative yet well established systems.

There are hardwire communication systems that employ line conditioning and equalization techniques to provide analog video over dedicated twisted pair wires. There are PSTN systems that use the telephone infrastructure to access traffic video cameras via dial-up modems. There are also the newer systems that use license free ISM bands for spread spectrum wireless communications. Satellite and microwave systems are also possibilities. There are even systems that currently use xDSL technologies. The use of the technology is different than ours (these systems use packetized video or "video over IP"), but the enabling technology is xDSL.

In addition, these communication systems can be used to provide for analog or digital video transmissions, the later which can be compressed, packetized, buffered, etc. Depending on user requirements and available resources, one might be more appropriate for a particular transportation agency and their intended application.

This was not a study to evaluate the relative performance of these systems or the types of video transmission they support. There are advantages and disadvantages to each. We merely present them as viable alternatives.

7.5 SUMMARY

The purpose of our concept study was to establish, demonstrate, and evaluate the use of xDSL technologies within ITS, more specifically to decide if and how xDSL technologies could be used for traffic video. We have achieved this objective with the design and assessment of our concept prototypes.

These efforts have shown that xDSL-based traffic video systems will work. The circumstances under which they will work and the performance of those that do will vary depending on system design and infrastructure conditions, but the concept is sound. As our studies progress, we will assess the performance of our prototypes in the field. This will also provide the opportunity to show the systems in operation and demonstrate the concept of xDSL-based traffic video.

xDSL technologies show great potential for their application to ITS. Although our focus is limited to traffic video, the numbers and types of high-speed data-intensive applications will grow and subsequently increase the demand on transportation communication systems. The ability to support such applications on existing infrastructure provides an alternative to those with communications problems that originate from financial constraint or infrastructure limitations. It also provides an option for those planning to lease or install new communication systems. Our studies effectively demonstrate this concept and have helped establish the value of xDSL technologies within the transportation domain.

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APPENDIX A

SDSL PROTOTYPE EVALUATION RESULTS

A.1 POINT-TO-POINT SCENARIOS

These scenarios are used to assess twisted pair infrastructure configurations that are logically point-to-point in nature and variable in distance and wire gauge. While many scenarios could be emulated, we merely selected distances in increments of one mile until we reached the maximum distance allowed by the simulation component – 27, 350 feet or slightly over 5 miles – or until the prototype failed.

A.1.1 Variable Length 24 AWG Twisted Pair

The following information summarizes qualitative and quantitative observations from the various test cases using the point-to-point variable length 24 gauge twisted pair wire scenarios.

A.1.1.a SDSL Modem Information Rate (Throughput) = 384 kbps

- SDSL line rate = 400 kbps
- SDSL throughput = 384 kbps (SDSL line rate less SDSL overhead)
- Codec throughput = 378 kbps (SDSL throughput less codec overhead)

Note: In the SDSL prototype, codec throughput accounts for traffic video, traffic video control, and traffic controller transmissions.

Note: Unless specifically indicated, the traffic controller operations were accurate and continual during these tests.

Table A-1. Video Quality; SDSL Throughput = 384 kbps

Encoder Settings			Twisted Pair Loop Reach (Distance) [miles]				
Video Quantization Factor	***Video Resolution***	***Screen Cropping Ratio***	1	2	3	4	5
38	Low	63%	*Poor-*	*Poor-*	*Poor-*	*Poor-*	*Poor-*
38	Low	85%	*Poor-*	*Poor-*	*Poor-*	*Poor-*	*Poor-*
38	Standard	63%	*Fair-*	*Fair-*	*Fair-*	*Poor+*	*Fair-*
38	Standard	85%	*Fair-*	*Fair-*	*Fair-*	*Fair-*	*Poor+*
38	High	63%	*Good-*	*Good-*	*Good-*	*Good-*	*Good-*
38	High	85%	*Good-*	*Good-*	*Good-*	*Fair+*	*Good-*
28	Low	63%	*Poor*	*Poor*	*Poor*	*Poor*	*Poor*
28	Low	85%	*Poor*	*Poor-*	*Poor*	*Poor*	*Poor*
28	Standard	63%	*Fair*	*Fair*	*Fair*	*Fair-*	*Fair*
28	Standard	85%	*Fair+*	*Fair*	*Fair-*	*Fair*	*Fair-*
28	High	63%	*Good*	*Good*	*Good*	*Good*	*Good-*
28	High	85%	*Good*	*Good*	*Good*	*Good*	*Good-*
18	Low	63%	*Fair-*	*Poor+*	*Poor+*	*Poor+*	*Poor+*
18	Low	85%	*Poor+*	*Poor+*	*Poor+*	*Poor*	*Poor*
18	Standard	63%	*Fair+*	*Fair+*	*Good-*	*Good-*	*Fair+*
18	Standard	85%	*Fair+*	*Fair+*	*Fair+*	*Fair+*	*Good-*
18	High	63%	*Good*	*Good*	*Good*	*Good*	*Good-*
18	High	85%	*Good*	*Good*	*Good*	*Good*	*Good*

Table A-2. Video Motion (f/s); SDSL Throughput = 384 kbps

Encoder Settings			Twisted Pair Loop Reach (Distance) [miles]				
Video Quantization Factor	***Video Resolution***	***Screen Cropping Ratio***	1	2	3	4	5
38	Low	63%	*15*	*15*	*15*	*15*	*15*
38	Low	85%	*15*	*15*	*15*	*15*	*15*
38	Standard	63%	*10*	*10*	*10*	*10*	*10*
38	Standard	85%	*8*	*9*	*10*	*10*	*9*
38	High	63%	*6*	*6*	*6*	*7*	*6*
38	High	85%	*5*	*6*	*5*	*6*	*6*
28	Low	63%	*15*	*13*	*10*	*14*	*14*
28	Low	85%	*15*	*12*	*12*	*12*	*14*
28	Standard	63%	*8*	*8*	*9*	*8*	*8*
28	Standard	85%	*8*	*8*	*7*	*8*	*7*
28	High	63%	*5*	*5*	*5*	*6*	*5*
28	High	85%	*4*	*5*	*5*	*4*	*5*
18	Low	63%	*10*	*10*	*10*	*10*	*10*
18	Low	85%	*10*	*10*	*10*	*11*	*10*
18	Standard	63%	*7*	*7*	*7*	*6*	*6*
18	Standard	85%	*7*	*6*	*6*	*6*	*6*
18	High	63%	*4*	*3*	*4*	*5*	*3*
18	High	85%	*3*	*3*	*4*	*3*	*3*

A.1.1.b SDSL Modem Information Rate (Throughput) = 768 kbps

- SDSL line rate = 784 kbps
- SDSL throughput = 768 kbps (SDSL line rate less SDSL overhead)
- Codec throughput = 756 kbps (SDSL throughput less codec overhead)

Note: In the SDSL prototype, codec throughput accounts for traffic video, traffic video control, and traffic controller transmissions.

Note: Unless specifically indicated, the traffic controller operations were accurate and continual during these tests.

Table A-3. Video Quality; SDSL Throughput = 768 kbps

Encoder Settings			**Twisted Pair Loop Reach (Distance) [miles]**				
Video Quantization Factor	***Video Resolution***	***Screen Cropping Ratio***	1	2	3	4	4.5[1]
38	Low	63%	Poor-	Poor-	Poor-	Poor-	Poor-
38	Low	85%	Poor-	Poor-	Poor-	Poor-	Poor-
38	Standard	63%	Poor	Fair-	Poor	Fair-	Poor+
38	Standard	85%	Fair-	Fair-	Poor+	Poor+	Poor+
38	High	63%	Fair+	Fair+	Fair+	Good	Fair
38	High	85%	Fair+	Good-	Fair	Good-	Fair+
28	Low	63%	Poor	Poor	Poor	Poor	Poor-
28	Low	85%	Poor	Poor-	Poor	Poor	Poor-
28	Standard	63%	Fair-	Fair	Fair-	Fair	Fair-
28	Standard	85%	Fair	Fair	Fair-	Fair-	Fair
28	High	63%	Good-	Good	Good-	Good	Good
28	High	85%	Good-	Good-	Good-	Good	Good
18	Low	63%	Poor+	Poor+	Poor+	Poor	Poor
18	Low	85%	Poor+	Poor+	Poor+	Poor	Poor
18	Standard	63%	Good-	Fair+	Good-	Good-	Fair
18	Standard	85%	Fair+	Fair+	Fair+	Fair+	Fair
18	High	63%	Good-	Good	Good	Good	Good
18	High	85%	Good-	Good	Good	Good	Good

[1] When the length between the SDSL units was set at 5 miles, the modems failed to synchronize; traffic controller and video communications were lost. Thus, results for 4.5 miles were collected instead.

Table A-4. Video Motion (f/s); SDSL Throughput = 768 kbps

Encoder Settings			Twisted Pair Loop Reach (Distance) [miles]				
Video Quantization Factor	***Video Resolution***	***Screen Cropping Ratio***	1	2	3	4	4.5[2]
38	Low	63%	30	30	30	30	30
38	Low	85%	30	30	30	30	30
38	Standard	63%	15	15	15	15	15
38	Standard	85%	15	15	15	15	15
38	High	63%	11	10	10	10	10
38	High	85%	10	10	10	10	10
28	Low	63%	28	27	28	27	28
28	Low	85%	27	27	27	25	25
28	Standard	63%	15	15	15	15	14
28	Standard	85%	12	15	14	15	14
28	High	63%	10	10	10	9	9
28	High	85%	9	10	9	9	8
18	Low	63%	15	15	17	15	15
18	Low	85%	15	15	15	15	15
18	Standard	63%	11	10	10	10	11
18	Standard	85%	10	12	10	10	10
18	High	63%	8	7	7	7	8
18	High	85%	7	6	7	7	6

A.1.1.c SDSL Modem Information Rate (Throughput) = 1152 kbps

- SDSL line rate = 1552 kbps
- SDSL throughput = 1152 kbps (SDSL line rate less SDSL overhead)
- Codec throughput = 1134 kbps (SDSL throughput less codec overhead)

Note: In the SDSL prototype, codec throughput accounts for traffic video, traffic video control, and traffic controller transmissions.

Note: Unless specifically indicated, the traffic controller operations were accurate and continual during these tests.

[2] When the length between the SDSL units was set at 5 miles, the modems failed to synchronize; traffic controller and video communications were lost. Thus, results for 4.5 miles were collected instead.

Table A-5. Video Quality; SDSL Throughput = 1152 kbps

Encoder Settings			Twisted Pair Loop Reach (Distance) [miles]			
Video Quantization Factor	***Video Resolution***	***Screen Cropping Ratio***	1	2	3	4[3]
38	Low	63%	Poor-	Poor-	Poor-	Poor-
38	Low	85%	Poor-	Poor-	Poor-	Poor-
38	Standard	63%	Fair-	Fair-	Fair-	Fair-
38	Standard	85%	Fair-	Fair-	Poor+	Poor+
38	High	63%	Fair+	Good-	Good-	Fair+
38	High	85%	Good-	Fair+	Good-	Good-
28	Low	63%	Poor	Poor	Poor	Poor
28	Low	85%	Poor-	Poor	Poor-	Poor-
28	Standard	63%	Fair	Fair	Fair	Fair
28	Standard	85%	Fair	Fair	Fair+	Fair
28	High	63%	Good-	Good	Good	Good-
28	High	85%	Good	Good	Good	Good
18	Low	63%	Poor+	Poor+	Poor+	Poor
18	Low	85%	Poor+	Poor+	Poor	Poor
18	Standard	63%	Good-	Fair+	Good-	Fair+
18	Standard	85%	Fair+	Fair+	Good-	Fair+
18	High	63%	Good	Good	Good	Good
18	High	85%	Good	Good	Good	Good

Table A-6. Video Motion (f/s); SDSL Throughput = 1152 kbps

Encoder Settings			Twisted Pair Loop Reach (Distance) [miles]			
Video Quantization Factor	***Video Resolution***	***Screen Cropping Ratio***	1	2	3	4
38	Low	63%	30	30	30	30
38	Low	85%	30	30	30	30
38	Standard	63%	30	30	30	30
38	Standard	85%	30	28	30	29
38	High	63%	15	15	15	15
38	High	85%	15	15	15	15
28	Low	63%	30	30	30	30
28	Low	85%	30	30	30	30
28	Standard	63%	15	15	17	15
28	Standard	85%	15	15	15	15
28	High	63%	15	15	12	15
28	High	85%	12	12	12	12
18	Low	63%	30	30	30	30
18	Low	85%	30	30	30	29
18	Standard	63%	15	15	15	15
18	Standard	85%	15	15	15	15
18	High	63%	10	10	10	10
18	High	85%	10	10	10	10

[3] At 4 miles (and regardless of encoder settings) video transmission errors (e.g., tiling) began to occur; the traffic controller communication continued to operate normally. At 4.5 miles, the modems fail to synchronize; the video signal is lost; traffic controller telemetry fails.

A.1.1.d SDSL Modem Information Rate (Throughput) = 1536 kbps

- SDSL line rate = 1552 kbps
- SDSL throughput = 1536 kbps (SDSL line rate less SDSL overhead)
- Codec throughput = 1512 kbps (SDSL throughput less codec overhead)

Note: In the SDSL prototype, codec throughput accounts for traffic video, traffic video control, and traffic controller transmissions.

Note: Unless specifically indicated, the traffic controller operations were accurate and continual during these tests.

Table A-7. Video Quality; SDSL Throughput = 1536 kbps

Encoder Settings			**Twisted Pair Loop Reach (Distance) [miles]**			
Video Quantization Factor	***Video Resolution***	***Screen Cropping Ratio***	1	2	3	4[4]
38	Low	63%	Poor-	Poor-	Poor-	Poor-
38	Low	85%	Poor-	Poor-	Poor-	Poor-
38	Standard	63%	Fair-	Fair-	Fair-	Fair
38	Standard	85%	Fair-	Fair-	Fair-	Fair-
38	High	63%	Fair+	Good-	Good-	Good-
38	High	85%	Good-	Fair+	Fair+	Good-
28	Low	63%	Poor	Poor	Poor	Poor
28	Low	85%	Poor	Poor	Poor	Poor
28	Standard	63%	Fair	Fair	Fair	Fair
28	Standard	85%	Fair	Fair	Fair	Fair
28	High	63%	Good-	Good-	Good	Good
28	High	85%	Good	Good	Good	Good
18	Low	63%	Poor+	Poor+	Poor+	Poor+
18	Low	85%	Poor+	Poor+	Poor+	Poor+
18	Standard	63%	Good-	Fair+	Good-	Good
18	Standard	85%	Fair+	Fair+	Fair+	Good-
18	High	63%	Good	Good	Good	Good
18	High	85%	Good	Good	Good	Good

[4] At 4 miles (and regardless of encoder settings) video transmission errors (e.g., tiling) began to occur; the traffic controller communication continued to operate normally. At 4.5 miles, the modems fail to synchronize; the video signal is lost; traffic controller telemetry fails.

Table A-8. Video Motion (f/s); SDSL Throughput = 1536 kbps

Encoder Settings			Twisted Pair Loop Reach (Distance) [miles]			
Video Quantization Factor	***Video Resolution***	***Screen Cropping Ratio***	1	2	3	4
38	Low	63%	30	30	30	30
38	Low	85%	30	30	30	30
38	Standard	63%	30	30	30	30
38	Standard	85%	30	30	30	30
38	High	63%	15	15	15	15
38	High	85%	15	15	15	15
28	Low	63%	30	30	30	30
28	Low	85%	30	30	30	30
28	Standard	63%	30	30	30	30
28	Standard	85%	30	30	30	30
28	High	63%	15	15	15	15
28	High	85%	15	15	15	15
18	Low	63%	30	30	30	30
18	Low	85%	30	30	30	30
18	Standard	63%	15	15	15	17
18	Standard	85%	15	15	15	15
18	High	63%	13	12	11	10
18	High	85%	12	10	10	10

A.1.1.e SDSL Modem Information Rate (Throughput) = 2048 kbps

- SDSL line rate = 2064 kbps
- SDSL throughput = 2048 kbps (SDSL line rate less SDSL overhead)
- Codec throughput = 2016 kbps (SDSL throughput less codec overhead)

Note: In the SDSL prototype, codec throughput accounts for traffic video, traffic video control, and traffic controller transmissions.

Note: Unless specifically indicated, the traffic controller operations were accurate and continual during these tests.

Table A-9. Video Quality; SDSL Throughput = 2048 kbps

Encoder Settings			Twisted Pair Loop Reach (Distance) [miles]			
Video Quantization Factor	***Video Resolution***	***Screen Cropping Ratio***	1	2	3	3.75[5]
38	Low	63%	Poor-	Poor-	Poor-	Poor-
38	Low	85%	Poor-	Poor-	Poor-	Poor-
38	Standard	63%	Fair-	Fair-	Fair-	Fair-
38	Standard	85%	Fair-	Fair-	Fair-	Fair+
38	High	63%	Good-	Good-	Good-	Good
38	High	85%	Fair+	Good-	Fair+	Good-
28	Low	63%	Poor	Poor	Poor	Poor-
28	Low	85%	Poor	Poor	Poor	Poor
28	Standard	63%	Fair	Fair	Fair	Fair
28	Standard	85%	Fair	Fair	Fair	Good
28	High	63%	Good-	Good	Good-	Good
28	High	85%	Good	Good	Good-	Good
18	Low	63%	Poor+	Poor+	Poor+	Poor
18	Low	85%	Poor+	Poor+	Poor+	Poor
18	Standard	63%	Fair+	Fair+	Good-	Good
18	Standard	85%	Good-	Fair+	Good-	Good
18	High	63%	Good-	Good	Good-	Good
18	High	85%	Good	Good	Good	Good

Table A-10. Video Motion (f/s); SDSL Throughput = 2048 kbps

Encoder Settings			Twisted Pair Loop Reach (Distance) [miles]			
Video Quantization Factor	***Video Resolution***	***Screen Cropping Ratio***	1	2	3	3.75
38	Low	63%	30	30	30	30
38	Low	85%	30	30	30	30
38	Standard	63%	30	30	30	30
38	Standard	85%	30	30	30	30
38	High	63%	30	30	30	15
38	High	85%	30	30	29	15
28	Low	63%	30	30	30	30
28	Low	85%	30	30	30	30
28	Standard	63%	30	30	30	30
28	Standard	85%	30	30	30	29
28	High	63%	15	30	15	15
28	High	85%	15	15	15	15
18	Low	63%	30	30	30	30
18	Low	85%	30	30	30	30
18	Standard	63%	30	30	30	30
18	Standard	85%	30	30	30	27
18	High	63%	15	15	15	15
18	High	85%	15	15	15	15

[5] At a 4 miles, the SDSL modems did not operate at 2048 kbps; we collected results at 3.75 miles instead.

A.1.2 Variable Length Twisted Pair – 24 AWG vs. 26 AWG

The following information compares qualitative and quantitative observations from the various test cases using point-to-point variable length scenarios of both 24 and 26 gauge twisted pair wire. These test cases were used to determine how the performance of the prototype might be affected by different wire gauges.

Although a more complete set of test cases was performed, we have documented only the observations taken from those using the best-case base system parameter settings (i.e., screen cropping ratio = 63%, video resolution = high, video quantization factor = 18). These are all that were required to illustrate the relative performance of the prototype as it was affected by wire gauge.

In these scenarios, the SDSL prototype uses the following modem line rates with associated modem and codec throughputs.

SDSL Line Rate [kbps]	**SDSL Throughput (SDSL line rate less SDSL overhead) [kbps]**	**Codec Throughput (SDSL throughput less codec overhead) [kbps]**
400	384	378
784	768	756
1552	1152	1134
1552	1536	1512
2064	2048	2016

Note: In the SDSL prototype, codec throughput accounts for traffic video, traffic video control, and traffic controller transmissions.

Note: Unless specifically indicated, the traffic controller operations were accurate and continual during these tests.

Table A-11. Video Motion (f/s); 24 vs. 26 AWG

		Twisted Pair Loop Reach (Distance) [miles]		
Wire Gauge	**Throughput [kbps]**	1	2	3
24 AWG	384	4	3	4
	768	7	7	7
	1152	10	10	10
	1536	10	10	11
	2048	15	15	15
26 AWG	384	3	3	3
	768	7	7	7
	1152	10	10	10[6]
	1536	10	11	10[7]
	2048	15	15	NR

NR = No Result – the SDSL modems did not operate over the respective wire gauge for the given distance throughput value.

[6] Observations: intermittent frame loss; occasional tiling due to modem operation around 0 SNR
[7] Observations: intermittent frame loss; frequent tiling due to modem operation at 0 SNR.

A.2 STANDARD CONFIGURATION SCENARIOS

The twisted pair infrastructure configurations used in these scenarios are based on both the European Telecommunications Standards Institute (ETSI) and the American National Standards Institute (ANSI) standards specifications. They comprise ANSI T1.601 test loops conforming to the Revised Resistance Design (RRD) rules as defined in Bellcore SR-TSV-002275, and a subset of RRD loops that conform to Carrier Serving Area (CSA) design rules – CSA and MID-CSA loops. The selection of configurations used in this assessment is discussed in section 6.1.2. Illustrations of those that were selected (those referenced below) are provided in Appendix D.

Although a more complete set of test cases was performed, we present only the observations taken from those using the best-case base system parameter settings (i.e., screen cropping ratio = 63%, video resolution = high, video quantization factor = 18). These are all that were required to illustrate the relative performance of the prototype as it was affected by the standard configurations. The follow information summarizes qualitative and quantitative observations from these test cases.

Note: In the SDSL prototype, codec throughput accounts for traffic video, traffic video control, and traffic controller transmissions.

Note: Unless specifically indicated, the traffic controller operations were accurate and continual during these tests.

Table A-12. Video Quality; Standard Configuration Scenarios

		Twisted Pair Loop Configurations									
		MID-CSA #2	MID-CSA #2 + 9,350 ft.	ANSI #3	ANSI #3 + 9,350 ft.	ANSI #6	ANSI #6 + 9,350 ft.	ANSI #9	ANSI #9 + 9,350 ft.	ANSI # 13	ANSI #13 + 9,350 ft.
SDSL Throughput [kbps]	384	Good	Good	NR	NR	Good	NR	NR	NR	Good	NR
	768	Good	NR	NR	NR	NR	NR	NR	NR	NR	NR
	1152	Good	NR	NR	NR	NR	NR	NR	NR	NR	NR
	1536	Good	NR	NR	NR	NR	NR	NR	NR	NR	NR
	2048	Good	NR	NR	NR	NR	NR	NR	NR	NR	NR

NR = No Result – the SDSL modems could not operate over the respective configuration for the given throughput.

Table A-13. Video Motion (f/s); Standard Configuration Scenarios

SDSL Throughput [kbps]		Twisted Pair Loop Configurations									
		MID-CSA #2	MID-CSA #2 + 9,350 ft.	ANSI #3	ANSI #3 + 9,350 ft.	ANSI #6	ANSI #6 + 9,350 ft.	ANSI #9	ANSI #9 + 9,350 ft.	ANSI # 13	ANSI #13 + 9,350 ft.
	384	3	3	NR	NR	3	NR	NR	NR	3	NR
	768	6	NR	NR	NR	NR	NR	NR	NR	NR	NR
	1152	10	NR	NR	NR	NR	NR	NR	NR	NR	NR
	1536	12	NR	NR	NR	NR	NR	NR	NR	NR	NR
	2048	15	NR	NR	NR	NR	NR	NR	NR	NR	NR

NR = No Result – the SDSL modems did not operate over
the respective configuration for the given throughput.

A.3 IMPAIRMENT SCENARIOS

These scenarios include both point-to-point and standard configurations, but have impairments introduced onto the line. As explained in section 6.1.2, near-end cross talk (NEXT) is an impairment that we believe could affect our prototypes in a traffic control communications environment.

While many forms of NEXT could be simulated, we selected those that would have notable effect on the prototype being tested. For the SDSL prototype, the most closely related form of NEXT available from the DLS 400 was HDSL NEXT. The intensity of the impairment is directly proportional to the number of disruptive circuits (disturbers) at the node of interest. In our case, we used 24 disturbers – more than sufficient to represent any such configuration in which these prototypes would be deployed.

Although a more complete set of test cases was performed, we present only those observations taken from those using the best-case base system parameter settings (i.e., screen cropping ratio = 63%, video resolution = high, video quantization factor = 18). These are all that were required to illustrate the relative performance of the prototype as it was affected by NEXT. The following information summarizes qualitative and quantitative observations from these test cases.

Note: In the SDSL prototype, codec throughput accounts for traffic video, traffic video control, and traffic controller transmissions.

Note: Unless specifically indicated, the traffic controller operations were accurate and continual during these tests.

Table A-14. Video Quality; Impairment Configuration Scenarios

SDSL Throughput [kbps]	Twisted Pair Loop Configurations: MID-CSA #2	ANSI #3	ANSI #6	ANSI #9	ANSI # 13	1 mile	1.75 miles (~2 miles)	3 miles
384	Good	NR	Good	NR	Good	Good	Good	Good
768	Good	NR	NR	NR	NR	Good	Good	Good
1152	Good	NR	NR	NR	NR	Good	Good	NR
1536	Good	NR	NR	NR	NR	Good	Good	NR
2048	Good	NR	NR	NR	NR	Good	Good	NR

NR = No Result – the SDSL modems could not operate over the respective configuration or distance for the given throughput while NEXT was injected.

Table A-15. Video Motion (f/s); Impairment Configuration Scenarios

SDSL Throughput [kbps]	Twisted Pair Loop Configurations: MID-CSA #2	ANSI #3	ANSI #6	ANSI #9	ANSI # 13	1 mile	1.75 miles (~2 miles)	3 miles
384	3	NR	4	NR	3	4	3	3
768	6	NR	NR	NR	NR	7	7	7
1152	10	NR	NR	NR	NR	10	10	NR
1536	15	NR	NR	NR	NR	15	15	NR
2048	15	NR	NR	NR	NR	15	15	NR

NR = No Result – the SDSL modems could not operate over the respective configuration or distance for the given throughput while NEXT was injected.

APPENDIX B

RADSL PROTOTYPE EVALUATION RESULTS

B.1 POINT-TO-POINT SCENARIOS

These scenarios are used to assess twisted pair infrastructure configurations that are logically point-to-point in nature and variable in distance and wire gauge. While many scenarios could be emulated, we merely selected distances in increments of one mile until we reached the maximum distance allowed by the simulation component – 27, 350 feet or slightly over 5 miles – or until the prototype failed.

B.1.1 Variable Length 24 AWG Twisted Pair

The following information summarizes qualitative and quantitative observations from the various test cases using the point-to-point variable length 24 gauge twisted pair wire scenarios.

B.1.1.a RADSL Modem Information Rate (Throughput) = 1544 kbps (Downstream)

- RADSL downstream line rate = 1600 kbps
- RADSL downstream throughput = 1544 kbps (RADSL line rate less RADSL overhead)
- Codec downstream throughput = 1520 kbps (RADSL throughput less codec overhead)

Note: Downstream is defined as CO equipment to CPE -- in this case remote site to TMC. RADSL upstream communications is used for traffic video control transmissions only. The RADSL upstream line rate is 672 kbps.

Note: In the RADSL prototype, codec downstream throughput accounts for traffic video and traffic video control transmissions. Traffic controller telemetry (full duplex) is provided by baseband modems via the splitter.

Note: Unless specifically indicated, the traffic controller operations were accurate and continual during these tests, even if the RADSL modems failed.

Table B-1. Video Quality; RADSL Downstream Throughput = 1544 kbps

Encoder Settings			Twisted Pair Loop Reach (Distance) [miles]			
Video Quantization Factor	*Video Resolution*	*Screen Cropping Ratio*	1	2	3	3.5[1]
38	Low	63%	Poor-	Poor-	Poor-	Poor-[2]
38	Low	85%	Poor-	Poor-	Poor-	Poor-
38	Standard	63%	Fair-	Fair-	Fair-	Fair-
38	Standard	85%	Fair-	Fair-	Fair-	Fair-
38	High	63%	Good-	Good-	Good-	Good-
38	High	85%	Good-	Good-	Fair+	Fair+
28	Low	63%	Poor	Poor	Poor	Poor
28	Low	85%	Poor	Poor	Poor-	Poor
28	Standard	63%	Fair+	Fair+	Fair+	Fair
28	Standard	85%	Fair	Fair	Fair	Fair
28	High	63%	Good	Good	Good	Good
28	High	85%	Good	Good	Good	Good
18	Low	63%	Poor+	Poor+	Poor+	Poor+
18	Low	85%	Poor+	Poor+	Poor+	Fair-
18	Standard	63%	Good-	Fair+	Good-	Fair+
18	Standard	85%	Fair+	Fair+	Fair+	Fair+
18	High	63%	Good	Good	Good	Good
18	High	85%	Good	Good	Good	Good

Table B-2. Video Motion (f/s); RADSL Downstream Throughput = 1544 kbps

Encoder Settings			Twisted Pair Loop Reach (Distance) [miles]			
Video Quantization Factor	*Video Resolution*	*Screen Cropping Ratio*	1	2	3	3.5[3]
38	Low	63%	30	30	30	30
38	Low	85%	30	30	30	30
38	Standard	63%	30	30	30	30
38	Standard	85%	30	30	30	30
38	High	63%	15	15	15	15
38	High	85%	15	15	15	15
28	Low	63%	30	30	30	30
28	Low	85%	30	30	30	30
28	Standard	63%	30	30	30	30
28	Standard	85%	30	30	30	28
28	High	63%	15	15	15	15
28	High	85%	15	15	15	15
18	Low	63%	30	30	30	30
18	Low	85%	30	30	30	30
18	Standard	63%	15	15	15	15
18	Standard	85%	15	15	15	15
18	High	63%	15	15	15	12
18	High	85%	13	12	12	10

[1] At a 4 miles the RADSL modems did not operate at 1544 kbps; we collected results at 3.5 miles instead.
[2] Significant tiling and video frame loss observed – unknown specific cause.
[3] At a 4-miles the RADSL modems did not operate at 1544 kbps; we collected results at 3.5 miles instead

B.1.1.b RADSL Modem Information Rate (Throughput) = 2304 kbps (Downstream)

- RADSL downstream line rate = 2560 kbps
- RADSL downstream throughput = 2304 kbps (RADSL line rate less RADSL overhead)
- Codec downstream throughput = 2270 kbps (RADSL throughput less codec overhead)

Note: Downstream is defined as CO equipment to CPE -- in this case remote site to TMC. RADSL upstream communications is used for traffic video control transmissions only. The RADSL upstream line rate is 672 kbps.

Note: In the RADSL prototype, codec downstream throughput accounts for traffic video and traffic video control transmissions. Traffic controller telemetry (full duplex) is provided by baseband modems via the splitter.

Note: Unless specifically indicated, the traffic controller operations were accurate and continual during these tests, even if the RADSL modems failed.

Table B-3. Video Quality; RADSL Downstream Throughput = 2304 kbps

Encoder Settings			**Twisted Pair Loop Reach (Distance) [miles]**		
Video Quantization Factor	*Video Resolution*	*Screen Cropping Ratio*	1	2	3[4]
38	Low	63%	Poor-	Poor-	Poor-
38	Low	85%	Poor-	Poor-	Poor-
38	Standard	63%	Fair-	Fair-	Fair-
38	Standard	85%	Fair-	Fair-	Fair
38	High	63%	Good-	Good-	Fair+
38	High	85%	Good-	Fair+	Good-
28	Low	63%	Poor	Poor	Poor
28	Low	85%	Poor	Poor	Poor
28	Standard	63%	Fair	Fair	Fair
28	Standard	85%	Fair	Fair	Fair
28	High	63%	Good	Good	Good
28	High	85%	Good	Good-	Good
18	Low	63%	Poor+	Poor+	Poor+
18	Low	85%	Poor+	Poor+	Poor
18	Standard	63%	Good-	Fair+	Fair+
18	Standard	85%	Fair+	Fair+	Fair+
18	High	63%	Good	Good	Good
18	High	85%	Good	Good	Good

[4] At a 4 miles the RADSL modems did not operate at this throughput. We attempted to collect results at 3.5 miles instead, but he modem failed to operate at this threshold as well

Table B-4. Video Motion (f/s); RADSL Downstream Throughput = 2304 kbps

Encoder Settings			Twisted Pair Loop Reach (Distance) [miles]		
Video Quantization Factor	*Video Resolution*	*Screen Cropping Ratio*	1	2	3[5]
38	Low	63%	30	30	30
38	Low	85%	30	30	30
38	Standard	63%	30	30	30
38	Standard	85%	30	30	30
38	High	63%	30	30	30
38	High	85%	30	28	28
28	Low	63%	30	30	30
28	Low	85%	30	30	30
28	Standard	63%	30	30	30
28	Standard	85%	30	30	30
28	High	63%	28	27	28
28	High	85%	15	15	15
18	Low	63%	30	30	30
18	Low	85%	30	30	30
18	Standard	63%	30	30	30
18	Standard	85%	30	30	30
18	High	63%	15	15	15
18	High	85%	15	15	15

B.1.2 Variable Length Twisted Pair – 24 AWG vs. 26 AWG

The following information compares qualitative and quantitative observations from the various test cases using point-to-point variable length scenarios of both 24 and 26 gauge twisted pair wire. These test cases were used to determine how the performance of the prototype might be affected by different wire gauges.

Although a more complete set of test cases was performed, we present only the observations taken from those using the best-case base system parameter settings (i.e., screen cropping ratio = 63%, video resolution = high, video quantization factor = 18). These are all that were required to illustrate the relative performance of the prototype as it was affected by wire gauge.

[5] At a 4 miles the RADSL modems did not operate at this throughput. We attempted to collect results at 3.5 miles instead, but he modem failed to operate at this threshold as well

In these scenarios, the RADSL prototype uses the following downstream modem line rates with associated downstream modem and codec throughputs.

RADSL Downstream Line Rate [kbps]	RADSL Downstream Throughput (RADSL line rate less RADSL overhead) [kbps]	Codec Downstream Throughput (RADSL throughput less codec overhead) [kbps]
1600	1544	1520
2560	2304	2270

Note: Downstream is defined as CO equipment to CPE -- in this case remote site to TMC. RADSL upstream communications is used for traffic video control transmissions only. The RADSL upstream line rate is 672 kbps.

Note: In the RADSL prototype, codec downstream throughput accounts for traffic video and traffic video control transmissions. Traffic controller telemetry (full duplex) is provided by baseband modems via the splitter.

Note: Unless specifically indicated, the traffic controller operations were accurate and continual during these tests, even if the RADSL modems failed.

Table B-5. Video Motion (f/s); 24 vs. 26 AWG

		Twisted Pair Loop Reach (Distance) [miles]		
Wire Gauge	**Downstream Throughput [kbps]**	1	2	3
24 AWG	1544	15	15	15
	2304	15	15	15
26 AWG	1544	15	15	15
	2304	15	15	NR

NR = No Result – the RADSL modems did not operate over the respective wire gauge for the given distance throughput value.

B.2 STANDARD CONFIGURATION SCENARIOS

The twisted pair infrastructure configurations used in these scenarios are based on both the European Telecommunications Standards Institute (ETSI) and the American National Standards Institute (ANSI) standards specifications. They comprise ANSI T1.601 test loops conforming to the Revised Resistance Design (RRD) rules as defined in Bellcore SR-TSV-002275, and a subset of RRD loops that that conform to Carrier Serving Area (CSA) design rules – CSA and MID-CSA loops. The selection of configurations used in this assessment is discussed in section 6.1.2. Illustrations of those that were selected (those referenced below) are provided in Appendix D.

Although a more complete set of test cases was performed, we present only the observations taken from those using the best-case base system parameter settings (i.e., screen cropping ratio = 63%, video resolution = high, video quantization factor = 18). These are all that were required to illustrate the relative performance of the prototype as it was affected by the standard configurations. The follow information summarizes qualitative and quantitative observations from these test cases.

Note: Downstream is defined as CO equipment to CPE -- in this case remote site to TMC. RADSL upstream communications is used for traffic video control transmissions only. The RADSL upstream line rate is 672 kbps.

Note: In the RADSL prototype, codec downstream throughput accounts for traffic video and traffic video control transmissions. Traffic controller telemetry (full duplex) is provided by baseband modems via the splitter.

Note: Unless specifically indicated, the traffic controller operations were accurate and continual during these tests, even if the RADSL modems failed.

Table B-6. Video Quality; Standard Configuration Scenarios

		Twisted Pair Loop Configurations									
		MID-CSA #2	MID-CSA #2 + 9,350 ft.	ANSI #3	ANSI #3 + 9,350 ft.	ANSI #6	ANSI #6 + 9,350 ft.	ANSI #9	ANSI #9 + 9,350 ft.	ANSI # 13	ANSI #13 + 9,350 ft.
RADSL Downstream Throughput [kbps]	1544	Good	Good	NR	NR	NR	NR	NR	NR	Good	NR
	2304	Good	Good	NR	NR	NR	NR	NR	NR	Good	NR

NR = No Result – the RADSL modems did not operate over the respective configuration for the given throughput.

Table B-7. Video Motion (f/s); Standard Configuration Scenarios

		Twisted Pair Loop Configurations									
		MID-CSA #2	MID-CSA #2 + 9,350 ft.	ANSI #3	ANSI #3 + 9,350 ft.	ANSI #6	ANSI #6 + 9,350 ft.	ANSI #9	ANSI #9 + 9,350 ft.	ANSI # 13	ANSI #13 + 9,350 ft.
RADSL Downstream Throughput [kbps]	1544	15	15	NR	NR	NR	NR	NR	NR	15	NR
	2304	15	15	NR	NR	NR	NR	NR	NR	15	NR

NR = No Result – the RADSL modems did not operate over the respective configuration for the given throughput.

B.3 IMPAIRMENT SCENARIOS

These scenarios include both point-to-point and standard configurations, but have impairments introduced onto the line. As explained in section 6.1.2, near-end cross talk (NEXT) is an impairment that we believe could affect our prototypes in a traffic control communications environment.

While many forms of NEXT could be simulated, we selected those that would have notable effect on the prototype being tested. For the RADSL prototype, the most closely related form of NEXT available from the DLS 400 was ADSL NEXT. The intensity of the impairment is directly proportional to the number of disruptive circuits (disturbers) at the node of interest. In our case, we used 24 disturbers – more than sufficient to represent any such configuration in which these prototypes would be deployed.

Although a more complete set of test cases was performed, we present only the observations taken from those using the best-case base system parameter settings (i.e., screen cropping ratio = 63%, video resolution = high, video quantization factor = 18). These are all that were required to illustrate the relative performance of the prototype as it was affected by NEXT. The follow information summarizes qualitative and quantitative observations from these test cases.

Note: Downstream is defined as CO equipment to CPE -- in this case remote site to TMC. RADSL upstream communications is used for traffic video control transmissions only. The RADSL upstream line rate is 672 kbps.

Note: In the RADSL prototype, codec downstream throughput accounts for traffic video and traffic video control transmissions. Traffic controller telemetry (full duplex) is provided by baseband modems via the splitter.

Note: Unless specifically indicated, the traffic controller operations were accurate and continual during these tests, even if the RADSL modems failed.

Table B-8. Video Quality; Impairment Configuration Scenarios

		Twisted Pair Loop Configuration							
		MID-CSA #2	ANSI #3	ANSI #6	ANSI #9	ANSI # 13	1 mile	1.75 miles (~2 miles)	3 miles
RADSL Downstream Throughput [kbps]	1544	Good	NR	NR	NR	Good	Good	Good	Good
	2304	Good	NR	NR	NR	Poor-[6]	Good	Good	Poor-[7]

NR = No Result – the RADSL modems could not operate over the respective configuration or distance for the given throughput while NEXT was injected.

Table B-9. Video Motion (f/s); Impairment Configuration Scenarios

		Twisted Pair Loop Configuration							
		MID-CSA #2	ANSI #3	ANSI #6	ANSI #9	ANSI # 13	1 mile	1.75 miles (~2 miles)	3 miles
RADSL Downstream Throughput [kbps]	1544	15	NR	NR	NR	14	15	15	15
	2304	15	NR	NR	NR	15	15	15	15

NR = No Result – the RADSL modems could not operate over the respective configuration or distance for the given throughput while NEXT was injected.

[6] Video is severely tiled and images are intermittent; great deal of frame loss; codecs attempt to compensate/optimize
[7] Video is severely tiled and images are intermittent; great deal of frame loss; codecs attempt to compensate/optimize

APPENDIX C

BASE SYSTEM COMPONENTS

After conducting various product surveys, we obtained, installed, and tested the components to be used in the laboratory base systems. These components comprise the traffic video and traffic control equipment to which particular xDSL technologies were applied and were used to construct various conditions under which our xDSL-based concept prototypes were evaluated.

The base system can be configured as illustrated in Figure C-1 – a design used to evaluate those xDSL technologies that allow for simultaneous high-speed data and 4 kHz baseband communication, such as RADSL. We refer to this configuration as base system #1.

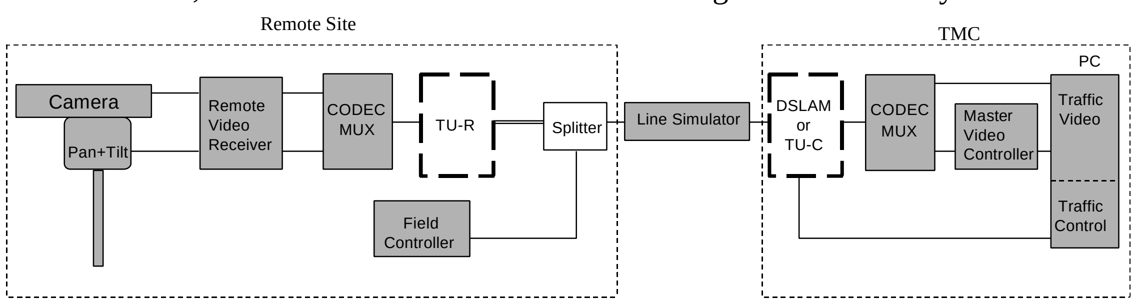

Figure C-1. Base System #1 Configuration

If the termination point for the xDSL circuit happens to be an intermediate communications hub, the xDSL equipment would be placed at the hub location, and the decoder and video control/display equipment would be located at the TMC. A communications service (e.g., a SONET) along the backbone facilities would be used to complete the circuit between hub and TMC.

Alternatively, the base system can be configured as illustrated in Figure C-2 – a design used to evaluate those xDSL technologies that utilize baseband portions of the twisted pair spectrum for high-speed data communication, such as HDSL. We refer to this second configuration as base system #2. In this case, traffic control communications must be integrated with the video signal before being passed to the TU-R. As before, if the termination point for the xDSL circuit happens to be an intermediate communications hub, the xDSL equipment would be placed at the hub location.

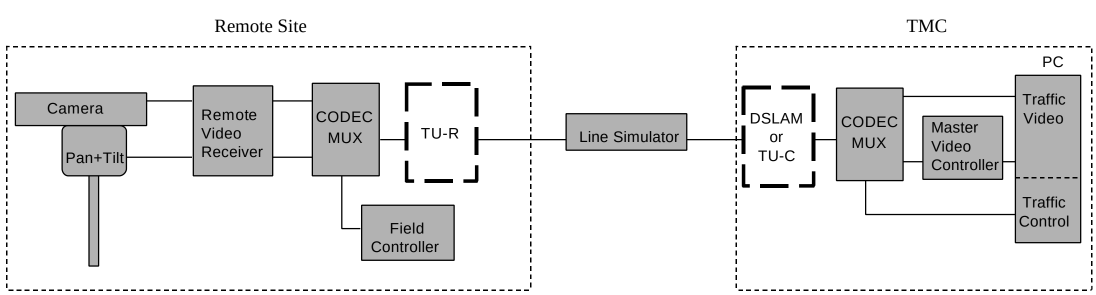

Figure C-2. Base System #2 Configuration

The following sections more precisely describe the equipment we used to establish the base systems. If one were to use equipment other than that we selected, the general concept would remain the same.

C.1.1   Traffic Video Component

The function of the traffic video component is to provide our video source. We made a deliberate attempt to use some of the more common traffic video equipment on the market; that specifically designed for traffic video. This was done to avoid any false conclusions that the video equipment was specifically designed to be used with any of the xDSL system components. This equipment could have been that from most any traffic video system deployed today; the concept would remain the same.

Equipment

The traffic video system, as represented in Figures C-1 and C-2, comprises the following:

- Traffic Camera: Cohu, Inc. 3500 Series High Performance CCD Color Camera with DSP capabilities. This device has several parameter settings that are available on most of today's video camcorders, including an 8:1 digital zoom, auto-back-light compensation, auto-tracking or sample-and-hold white balance, integration and shuttering, etc. The camera uses a single 39-pin connector for multiple interfaces to the remote video receiver: an RS-170 interface for analog video, an RS-422 interface for DSP camera control, and an analog interface for mechanical camera control.

Figure C-3. Traffic Video Camera and Pan & Tilt Unit

- Pan & Tilt Unit: Pelco, Inc. PT570P Medium Duty Pan Tilt. This is one of the more common models used by both Pelco and Cohu. It features worm-gear final drives to minimize backlash and wind-drift and is sealed for all weather use. It uses 120 VAC and has a 40 lb maximum load. The unit has a 14-pin analog interface for communications with the remote video receiver.

- Remote Video Receiver: Cohu, Inc. MPC Receiver within a NEMA-4 rated environmental enclosure. This unit can be mounted on a pole or other location up to 500 feet from the camera site and up to 50 feet (further if using RS-422) from the enclosure with the encoder, TU-R, etc. As described previously, the receiver uses a single 39-pin connector for multiple video and control interfaces with the camera. The receiver has a 14-pin analog interface for communications with the pan & tilt unit, an RS-232 interface for full duplex communication with the encoder's multiplexer, and an RS-170 BNC interface for analog video to the encoder.

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Figure C-4. Pole-mounted Remote Video Receiver, Camera, and Pan & Tilt Unit

- Master Controller: Cohu, Inc. MPC Control Panel. This unit provides an operator interface to the video system and is located within the TMC. It has an integrated control panel that includes: a keypad and a display to enter various camera and monitor selection commands, an integrated joystick to control pan & tilt operation, toggle switches to control camera functions (e.g., zoom), and several LEDs to indicate system status (e.g., camera power, communications error).

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Figure C-5. Master Controller

The Master Controller has a DB9 RS-232 interface for full duplex communication with the dencoder's multiplexer, and a similar interface for communication with the PC. It can be operated by its integrated control panel or Cohu's PC-based Camera Administration & Monitoring Software CAMS™ program (discussed below).

- PC: Dell Dimension desktop personal computer with Pentium™ processor and a Windows 95™ operating system.

Figure C-6. Personal Computer for Traffic and Video Control Operations

The PC houses Cohu's CAMS 2.0 software, a windows based application that will manage and control video system equipment through a graphical user interface (GUI). The software provides the ability to map a complex system and control components by clicking on representative icons displayed within the map. It provides all the functionality of the control panel on the master controller and more (e.g., DSP camera functions such as digital zoom). The PC has full duplex communications with the Master Controller through one of its serial ports (DB9 RS-232).

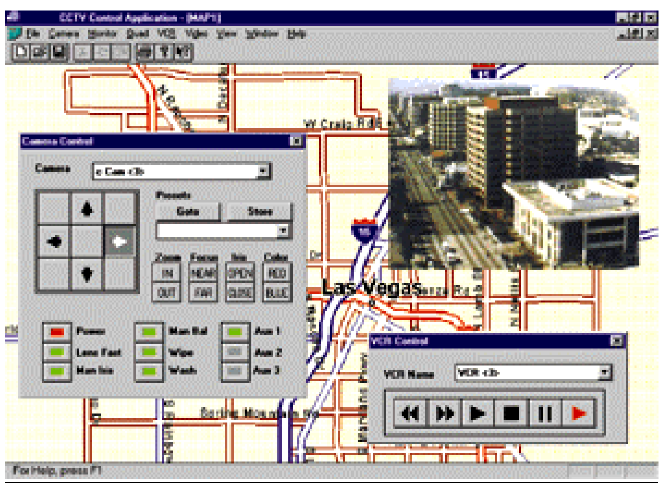


Figure C-7. CAMS GUI

Component Testing

To test the video system independently and verify proper operation of equipment, we connected the camera and pan & tilt unit to the remote video receiver. We then directly connected the remote video receiver to the master controller and the master controller to the PC. We powered these components, entered a default configuration (for a one-camera system) into the master controller, and tested various pan & tilt and camera functions as allowed by the control panel on the master controller. All tests were successful and indicated no problems with our analog video or camera control transmissions.

We later installed the CAMS software on the PC and connected the PC to the master controller. Using the CAMS GUI, we performed various camera and pan & tilt operations. These tests were also successful and indicated no problems with our analog video or camera control transmissions.

Although there are many parameter settings, once we established a suitable video quality baseline (as discussed in Section 6.1, Methodology), we did not adjust these settings – such variations were not essential to our assessments.

C.1.2 Video Encoder/Decoder "codec" Component

Digitization and compression of the video signal and multiplexing of the traffic and camera control communications were handled by two codecs. The codecs are manufactured by Enerdyne Technologies, Inc. (now Boatracs, Inc.), and more specifically described as video encoder and decoder with built-in multipexers. This equipment was selected in part for its use and familiarity within the ITS domain. Additionally, it has interfaces compatible with the rest of our base system components and provides flexibility for the wide range of assessment test cases, as discussed in section 6.1.3.

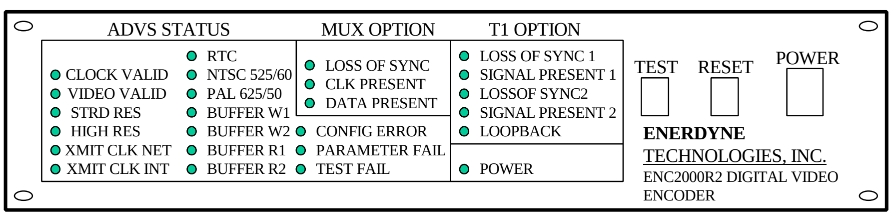
When considering the video encoding used in our prototypes, it's important to recall that this effort is not a performance evaluation of the codec system or the M-JPEG encoding scheme that it employs. It is not a comparison of technical issues such as M-JPEG vs. H.261 or MPEG1, or interframe vs. intraframe encoding. These issues are independent of the xDSL transmission technology and considerations for those implementing such systems. Our focus is placed on the transmission technology – xDSL. From the perspective of this particular project, the codecs and other base system components are interchangeable with similar devices on the market.

Equipment

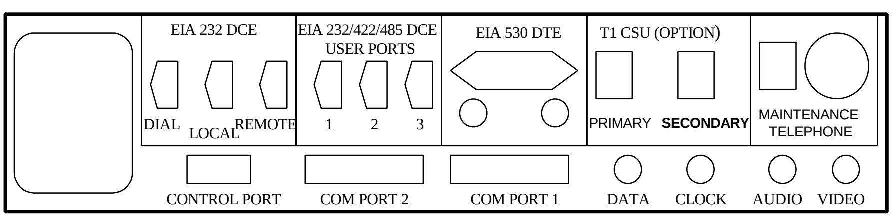
The video encoder/decoder component, as represented in Figures C-1 and C-2, comprises of the following:

- Encoder: Enerdyne ENC2000R2 encoder equipped with the Universal Communications Multiplexer (UCM). This unit digitizes and compresses any of the following analog video signals: NTSC composite (color), PAL composite (color), EIA170 (monochrome), and CCIR (monochrome). The UCM, a single circuit board housed inside the encoder chassis, provides three configurable full-duplex asynchronous serial data channels, a voice communication channel, and control channels. All of which are multiplexed with the compressed video into a single data stream compatible with standard telecommunications interfaces.

  A single video source may be connected at the input video port (VIDEO). The analog board converts the input signal to a digital format where it is compressed by a digital board and routed to the UCM. The UCM combines the compressed video with any serial data that may be present (such as EIA-/RS-232 serial data or digitized voice data) and passes the multiplexed data to the transmission facility. If an external CSU/DSU is utilized, the multiplexed data is available on the DTE serial port compatible with EIA-530 or V.35 telecommunications interfaces, as illustrated in Figures C-8 and C-9. If an optional T1 or dual T1 internal CSU is installed, the DTE serial port is non-functional and the interface to the telecommunications network is via one (T1) or two (dual T1) RJ48 connectors.



The Encoder Front Panel



The Encoder Back Panel

Figure C-8. External Overview of the Video Encoder

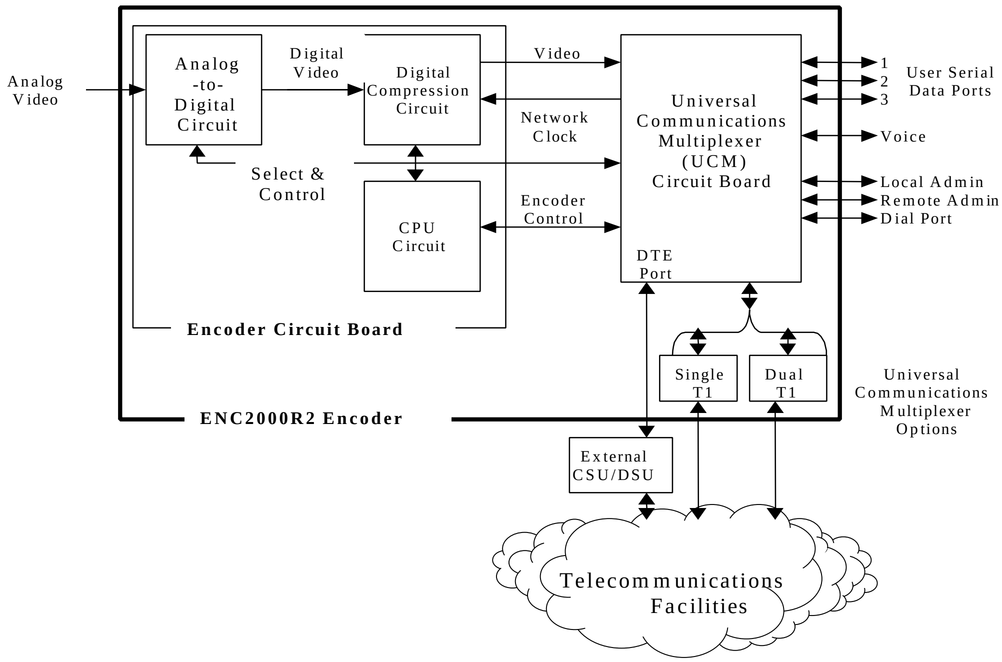


Figure C-9. Functional Block Diagram of the Video Encoder

<u>Decoder</u>: Enerdyne DEC2000R2 decoder similarly equipped with the Universal Communications Multiplexer (UCM). This unit receives digitized video from the encoder via the optional T1 interface or through the DTE port if an external CSU/DSU is used. The UCM on the decoder extracts user data that has been multiplexed with the video signal by the encoder and passes this user data to the three user data ports as appropriate. The UCM also provides the compressed digital video and the network clock signals to the decoder's digital board. Here the video data is decompressed and sent to the CPU as a 24-bit video signal. It is then converted to an NTSC or PAL analog video signal and passed to the output video port (VIDEO) for display (Figures C-10 and C-11).

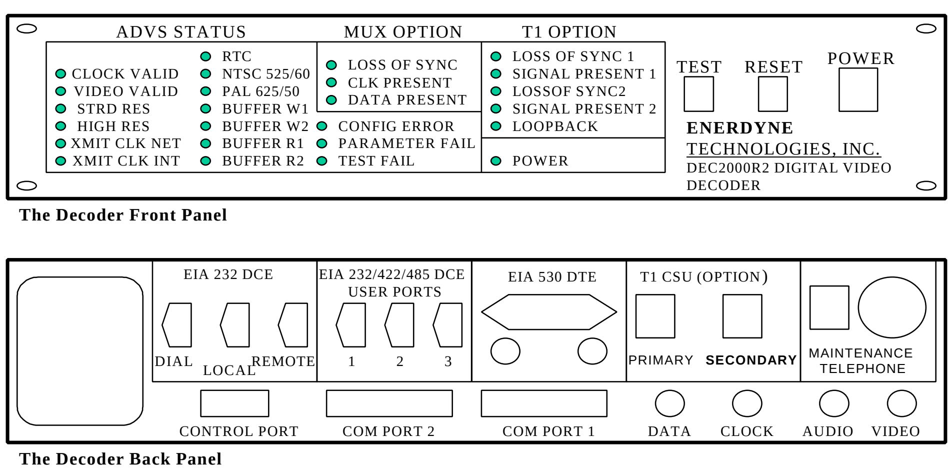


Figure C-10. External Overview of the Video Decoder

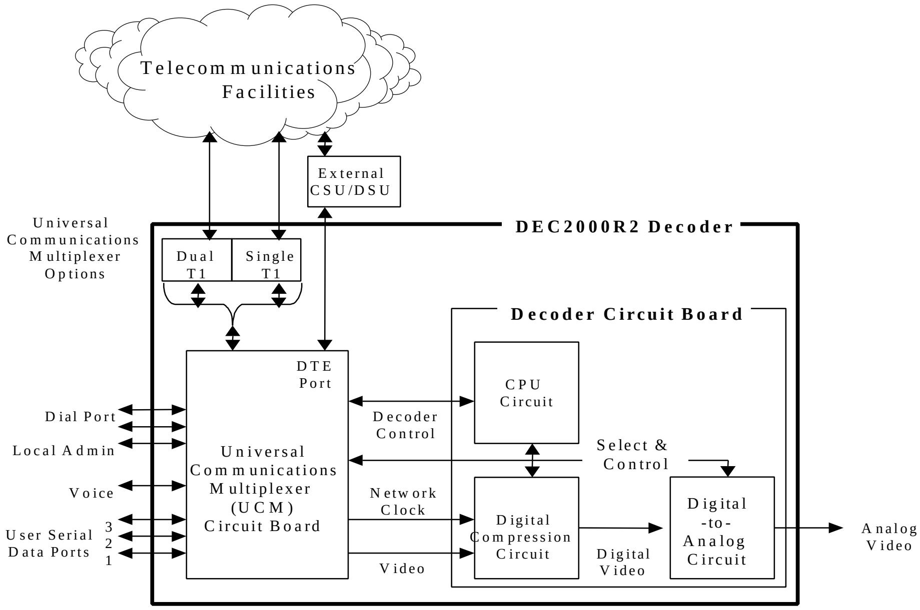


Figure C-11. Functional Block Diagram Representation of the Video Decoder

Component Testing

To inspect the encoder and decoder for proper operation, we used a test cable between these units (connected to the video system as shown in Figure C-12) to run bench testing procedures as outlined in Chapter 5 of the user manual. Refer to the Enerdyne Technologies entry in the Bibliography. All tests were successful and indicated no problems with our digital video transmissions or multiplexed camera control communications.

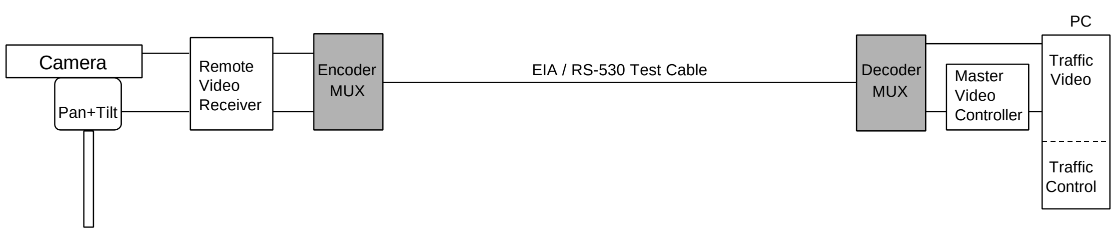


Figure C-12. Bench Testing the Video Codecs

C.1.3 Traffic Controller Component

The function of the traffic controller component is to provide the mechanism for our 4 kHz baseband communications. As with the selection of the traffic video equipment, we made a deliberate attempt to use a fairly common field device; in this instance a NEMA TS2 Type 2 traffic controller from Eagle Traffic Control Systems. This selection was made to demonstrate the proper operation of a true field device within our concept system and to avoid the generalities of using two generic devices (e.g., PCs) for our baseband communications. The field device could have been one of several types (e.g., ramp meter controller, dynamic message sign (DMS)) and from various manufacturers. The concept remains the same.

Equipment

The traffic controller component, as illustrated in Figures C-1 and C-2, comprises of the following:

<u>Traffic Controller</u>: Eagle Traffic Control Systems EPAC300 series controller.

Figure C-13. EPAC300 NEMA TS2 Type2 Traffic Controller

This unit is a fully actuated controller that complies with both NEMA TS 1-1989 and TS 2-1992 actuated controller standards. Interfaces include the standard DB15 SDLC port (port 1), DB25 RS232 terminal port (port 2), as well as DB9 RS232 and FSK modem telemetry ports (ports 3) and the A, B, and C circular ports used for backward compatibility with TS1 devices. This unit also has a backlit LCD and alphanumeric keypad from programming. The EPAC300 communicates with a desktop PC through its telemetry port.

- <u>PC</u>: Dell Dimension desktop personal computer (same as that described previously). The PC is used to emulate basic traffic management functions and houses a demo version's of Eagle's Monitor and Report Console (MARC) software, a DOS-based application that provides for telemetry between the PC and the traffic controller. The software provides the ability to remotely control various aspects of the controller, such as vehicle and pedestrian phases, timing rings, etc. The PC has full duplex communications with the traffic controller through one of its serial ports (DB9 RS232).

- Baseband modems: Boca Research 33.6 kbps voice-grade modems. Although not shown in the base system diagrams, these (and similar) modems are used in instances where dial-up communications is required between the PC and the traffic controller, such as one might have in a 'closed loop' system.

Component Testing

To verify proper operation the traffic controller itself, we merely powered the unit and varied parameters manually using the built-in control panel. To test if we could properly control the unit on a dial-up circuit, as would be used in a closed loop system, we connected the PC and controller via the baseband modems. One connected to the traffic controller's RS232 telemetry port and the other to one of the PC's serial ports. An intermediate PBX was used to provide the necessary telephony. We then dialed the controller and used the MARC software to vary several EPAC300 parameters.

To test if we could remotely control the unit on a dedicated circuit, as would be used in a centralized traffic control architecture, we connected the traffic controller (via its RS232 telemetry port) directly to an encoder user port. The PC (via its serial port) was connected to the associate user port on the decoder. With the codecs functioning, we had a dedicated connection and were able to use the MARC software to vary EPAC300 parameters as before. Since the function of the traffic controller in our study was simply to demonstrate undisturbed and simultaneous field device operation, we did not extensively test the functionality of this traffic controller component.

The only problem encountered while testing the operating the traffic controller telemetry had to due with constructing a test cable and configuring the MARC software for a dedicated connection. This was a consequence of lax documentation on EPAC300 telemetry options. After this configuration issue was resolved, the traffic controller component functioned as required.

C.1.4 Twisted Pair Simulator Component

Two twisted pair simulators, manufactured by Consultronics, were used for our study: the DLS 90 and the DLS 400. Both simulators are used to emulate various twisted pair wire attributes and local loop conditions. The units were selected for two reasons. First, they are equipment that current telecommunications service providers use for testing and prototyping DSL products. Secondly, this expensive and coveted test equipment was available to us for a brief period as part of an arrangement with Consultronics.

Equipment

The twisted pair simulator component, as illustrated in Figures C-1 and C-2, comprises of the following:

Simulator 1: Consultronics DLS 90 twisted pair simulator. The DLS 90 accurately emulates twisted pair copper wires when using frequencies up to 1.5 MHz, and it provides usable simulation when using frequencies up to 2 MHz. These are frequencies well within the range of most xDSL systems. The unit is essentially a processor that can reproduce characteristics of the twisted pair wire using various combinations of simulation circuitry (e.g., resistors, inductors, and capacitors).

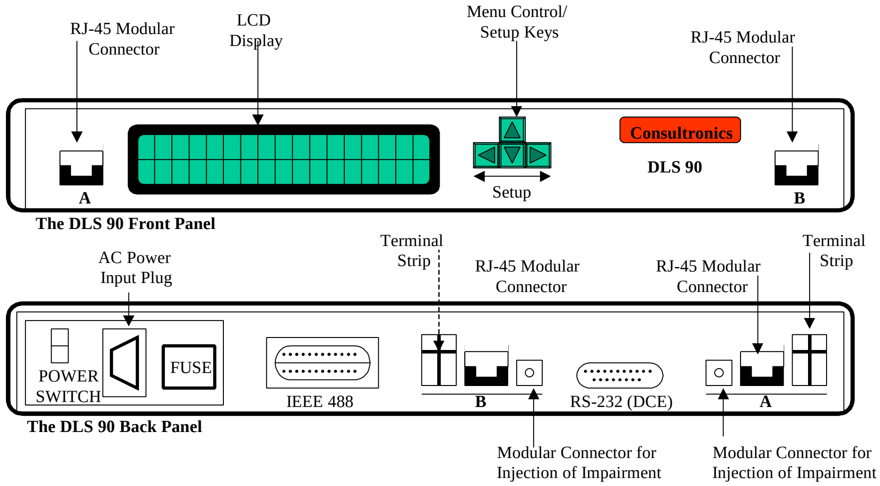


Figure C-14. External Overview of the DLS 90 Twisted Pair Simulator

It can be remotely controlled by a PC connected via serial interface (either IEEE 488 or the RS-232), or by using the control keys the front panel. The DSL 90 can simulate two wire gauges (24 or 26 AWG) used at distances up to 9,350 feet (in increments of 50 feet). An LCD shows the current length and wire gauge.

As shown in Figure C-14, there are interfaces on the DLS 90 labeled side “A” and “B”. These are used to connect the device(s) on either end of the DLS 90. Each side of the simulated wire cable can be accessed from either the RJ-45 connectors on the front or back panel or the terminal strips on the back panel. The RJ-45 connectors and terminal strips on each side are connected in parallel, so any combination of connectors (on one side) can be used. The user can also inject noise impairments on either side by using an external noise generator.

Simulator 2: Consultronics DLS 400 twisted pair simulator. This unit is similar to the DLS 90, but it uses a combination of bantam jacks and CF balanced connectors to connect transmission equipment.

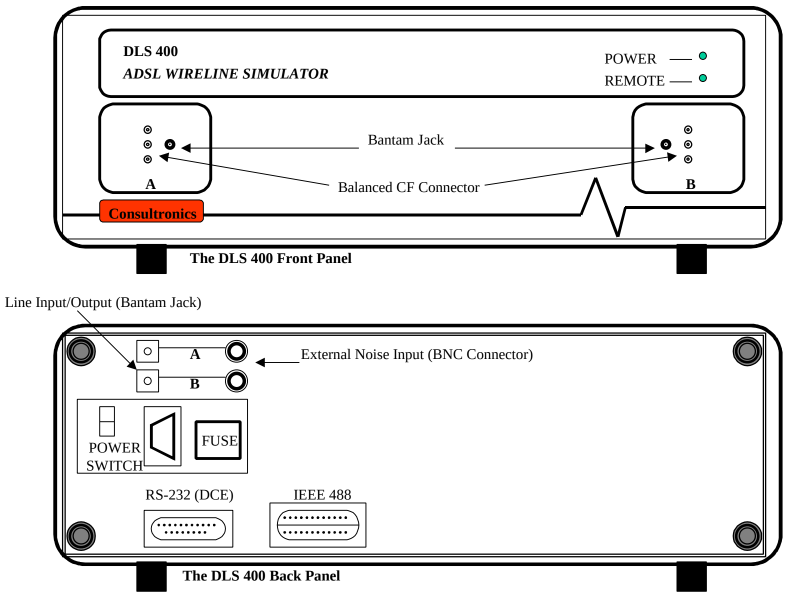


Figure C-15. External Overview of the DLS 400 Twisted Pair Simulator

The DLS 400 is capable of testing various DSL products (e.g., HDSL, ADSL). In addition to variable direct loop distances, it provides over 30 predefined loop configurations of which one could emulate – configurations established according to both the European Telecommunications Standards Institute (ETSI) and the American National Standards Institute (ANSI) standards specifications. These configurations (Table C-1) comprise ANSI T1.601 test loops conforming to the Revised Resistance Design (RRD) rules as defined in Bellcore SR-TSV-002275, and a subset of RRD loops that conform to Carrier Serving Area (CSA) design rules – CSA and MID-CSA loops. Illustrations of those configurations used in our assessments are provided in Appendix D.

Table C–1. Loop Configurations Simulated by the DLS 400

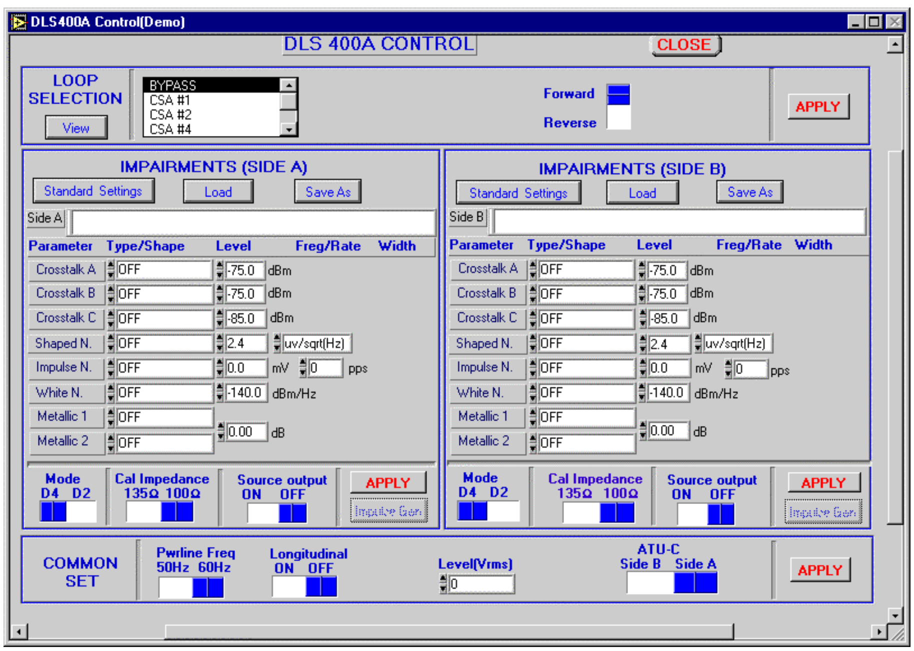
Variable	CSA	MID-CSA	ANSI T1.601
VARIABLE 24 AWG	CSA #0	MID-CSA #0	ANSI #2
VARIABLE 24 AWG + TAP	CSA #1	MID-CSA #1	ANSI #3
VARIABLE 26 AWG	CSA #2	MID-CSA #2	ANSI #4
VARIABLE 26 AWG + TAP	CSA #4	MID-CSA #3	ANSI #5
	CSA #5	MID-CSA #4	ANSI #6
	CSA #6	MID-CSA #5	ANSI #7
	CSA #7	MID-CSA #6	ANSI #8
	CSA #8		ANSI #9
	EXT-CSA #9		ANSI #11
	EXT-CSA #10		ANSI #12
			ANSI #13
			ANSI #15

Some of these configurations include the ability to incorporate additional bridged taps of various wire gauge and length and at various distances from either end of the primary line, side A or B. This DLS 400 also contains a card that can generate a variety of impairments (e.g., crosstalk, white noise) at either end of the line. Table 4-2 lists the various impairments, each defined in the glossary. In addition to the impairments introduced by the DLS 400, externally generated impairments can be injected.

Table C-2. Impairments Generated by the DLS 400

Crosstalk	Shaped Noise	Impulse Noise	Other Noise
T1.601	ETSI BASIC	Cook Pulse	Metallic 1
DSL NEXT	ETSI HDSL	ADSL #1	Metallic 2
HDSL NEXT	FTZ 1TR 200	ADSL #2	Longitudinal
HDSL+ADSL NEXT		Bipolar	White Noise
ADSL NEXT		3-Level	
ADSL FEXT		Unipolar	
ADSL A			
ADSL B			
T1			
E1.AMI			

Like the DLS 90, this unit can be controlled by a PC. However, the DLS 400 comes with a convenient windows-based graphical user interface (GUI) (Figure C-16) that allows the user to vary and monitor the settings (e.g., configuration, impairment type and level).



© Consultronics

Figure C-16. DLS 400 GUI

Component Testing

Each of the simulators was tested individually. Proper DLS 90 operation was verified by connecting the unit between two xDSL units (i.e., CO and CPE) and monitoring link status while varying simulated line distances. A similar procedure was followed for the DLS 400, but included additional status checks while injecting impairments and changing loop conditions (e.g., distance, wire gauge, bridged taps). Each unit functioned properly and impacted the line quality as expected.

The use of the DLS 90 and DLS 400 in series as a single twisted pair simulation component was arranged as shown in Figure C-17. This combination was use to emulate wire line distances up to 27,000 feet. Similar status tests were conducted for the integrated simulation component and again impacted the line quality as expected.

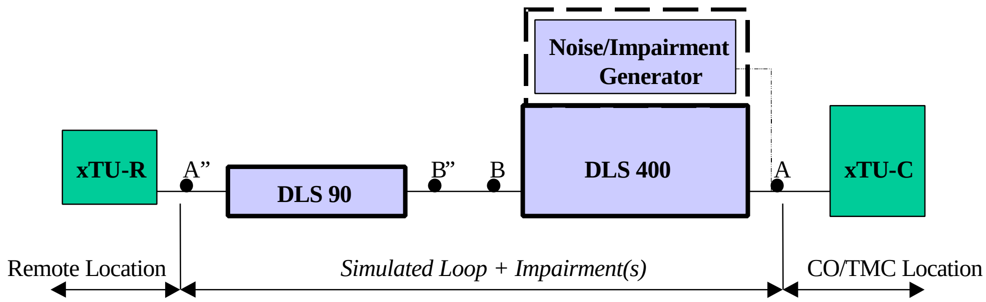


Figure C-17. Twisted Pair Simulator Component

Problems encountered with the DLS units were minor and associated with understanding and establishing system settings. Any such issues were resolved through interaction with the engineers from Consultronics.

APPENDIX D

TWISTED PAIR LOOP CONFIGURATIONS

This appendix provides illustration of those twisted pair loop configurations used in our assessments. All configurations are based on ANSI T1.601 test loops conforming to the Revised Resistance Design (RRD) rules as defined in Bellcore SR-TSV-002275, and a subset of RRD loops that conform to Carrier Serving Area (CSA) design rules – CSA and MID-CSA loops. Some are configured exactly as specified; others are augmentations of these configurations.

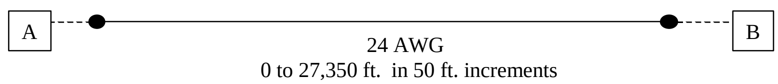


Figure D-1. Variable 24 AWG

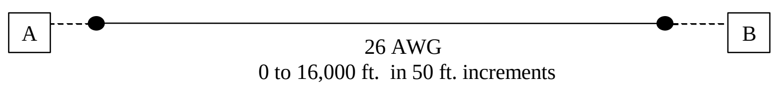


Figure D-2. Variable 26 AWG

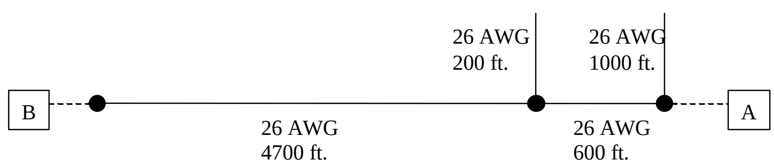


Figure D-3. MID-CSA #2

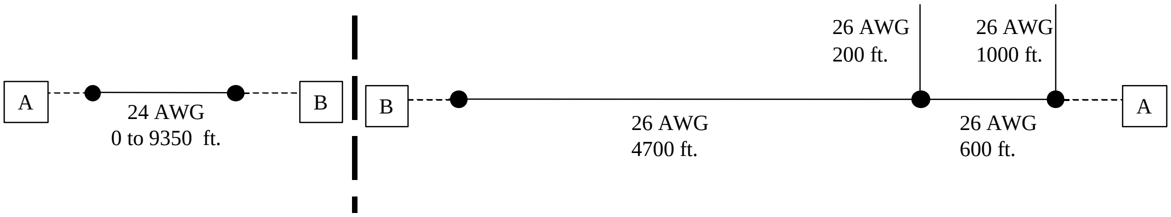


Figure D-4. MID-CSA #2 + Variable 24 AWG

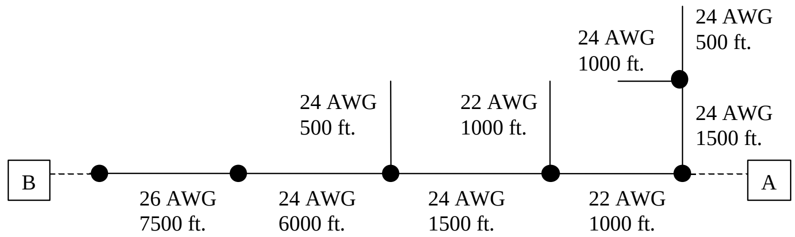


Figure D-5. ANSI #3

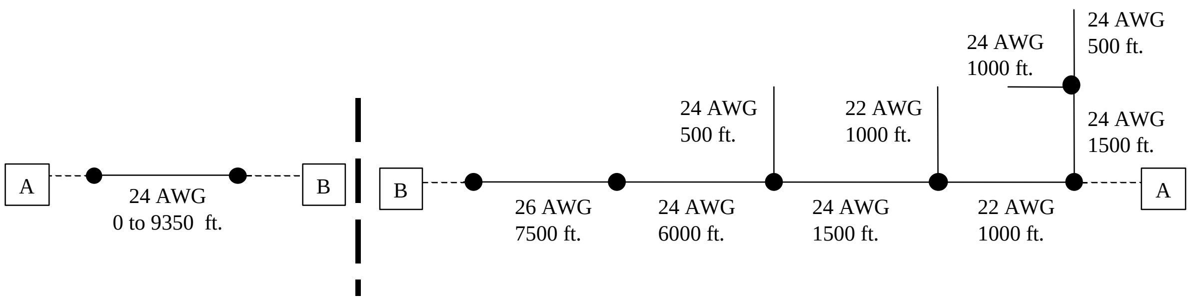


Figure D-6. ANSI #3 + Variable 24 AWG

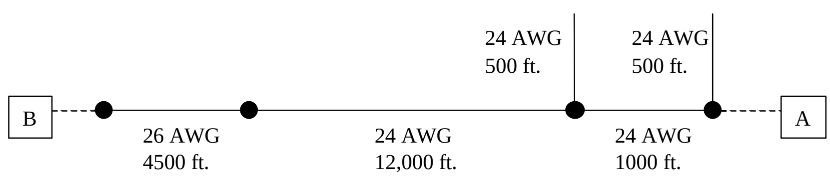


Figure D-7. ANSI #6

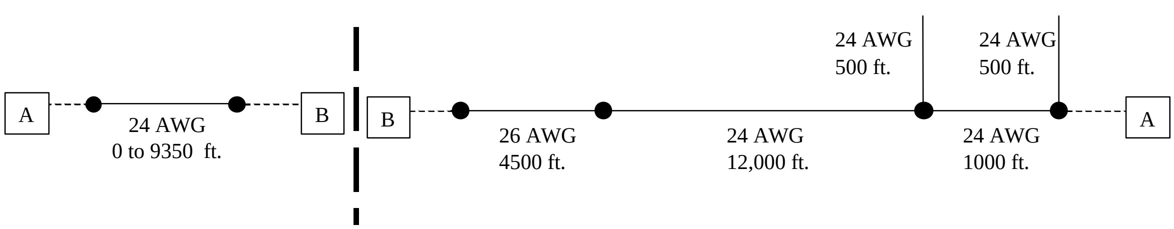


Figure D-8. ANSI #6 + Variable 24 AWG

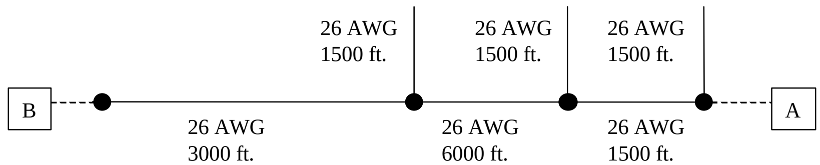


Figure D-9. ANSI #9

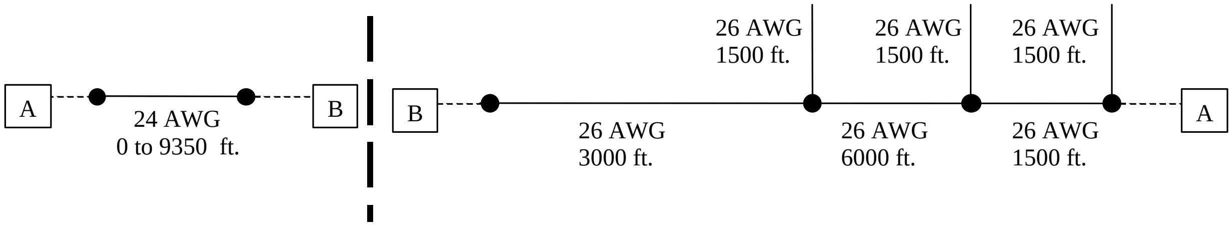


Figure D-10. ANSI #9 + Variable 24 AWG

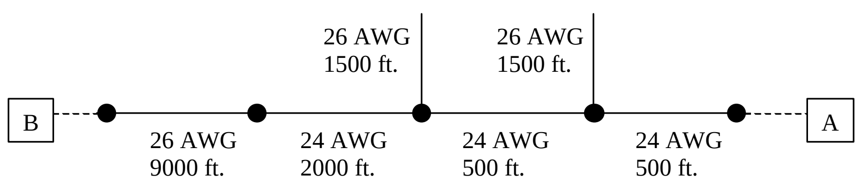


Figure D-11. ANSI #13

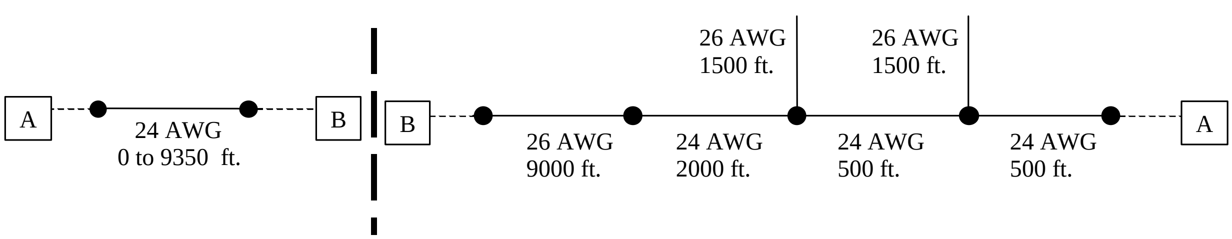


Figure D-12. ANSI #13 + Variable 24 AWG

GLOSSARY

ADSL	Asymmetric Digital Subscriber Line
AM	Amplitude Modulation
AMI	Alternate Mark Inversion
ANSI	American National Standards Institute
ATL	Advanced Telecommunications Laboratory
ATM	Asynchronous Transfer Mode
ATU-C	Asymmetric Transmission Unit- Central Office End
ATU-R	Asymmetric Transmission Unit- Remote End
AWG	American Wire Gauge
BER	Bit Error Rate
CAMS	Camera Administration & Monitoring Software (Cohu, Inc.)
CAP	Carrierless Amplitude Phase Modulation
CCTV	Closed Circuit TV
CDSL	Consumer DSL
CHART	Chesapeake Highway Advisory Routing Traffic
Codec	COder/DECoder
CO	Central Office
CPE	Customer Premises Equipment
CRC	Cyclic Redundancy Check
CSA	Carrier Serving Area, between the Central Office and the home, approximately 12,000 feet in the U.S. phone network
dB	Decibel
dBm	Decibel power level referred to 1 mW
DCE	Data Communication Equipment
DDS	Digital Data Service
DLC	Digital Loop Carrier
DMT	Dual Multi Tone
DOT	Department Of Transportation
DSL	Digital Subscriber Line
DSLAM	DSL Access Multiplexer
DS1	Digital Signal Level 1. Transmission Standard interface for digital data used by T1 transmission lines. DS1 operates at 1.544 Mbps.
DS3	Digital Signal Level 3. Transmission Standard interface for digital data used by T3 transmission lines. DS3 operates at 44.736 Mbps and consists of 28 DS1 channels plus overhead.
DTE	Data Terminal Equipment
DTR	Data Terminal Ready
DWMT	Discrete Wavelet Multitone
E1	European Standard for high-speed digital transmission operating at 2.048 Mbps.
E3	European Standard for high-speed digital transmission operating at 34 Mbps.
ES	Errored Second
ESF	Extended Super Frame

FEBE	Far End Block Error
FEXT	Far End Cross Talk
FTTC	Fiber To The Curb
FTTH	Fiber To The Home
GUI	Graphical User Interface
HDSL	High-bit-rate Digital Subscriber Line
HFC	Hybrid Fiber Coax
IDSL	ISDN DSL
IP	Internet Protocol
ISDN	Integrated Services Digital Network
ITU	International Telecommunications Union
JPEG	Joint Photographic Experts Group
LAN	Local Area Network
LEC	Local Exchange Carrier
LED	Light Emitting Diode
MARC	Eagle's Monitor and Report Console (Eagle TCS, Siemens Inc.)
MCC	Management Communications Controller
MDF	Main Distribution Frame
M-JPEG	Motion JPEG
MPEG	Motion Picture Expert Group
M/SDSL	Multi-rate SDSL
NEXT	Near End Cross Talk
OOF	Out Of Frame
PBX	Private Branch eXchange
PDA	Personal Data Assistant
POTS	Plain Old Telephone Service
PSTN	Public Switched Telephone Network
PVC	Permanent Virtual Circuit
OC-1	Optical Carrier, level 1. The counterpart of STS-1, the basic rate (51.84 Mbps) on which SONET is based. A direct, electrical-to-optical mapping of the STS-1 signal with frame synchronous scrambling. Higher levels of OC-x are multiples of OC-1.
OC-3	Optical Carrier, level 3. A rate of approximately 155 Mbps (3 times one OC-1) at which a signal is transmitted over fiber-optic cable.
QAM	Quadrature Amplitude Modulation
RADSL	Rate Adaptive Digital Subscriber Line
RTS	Request To Send
RTU-C	RADSL Transmission Unit- Central Office End
RTU-R	RADSL Transmission Unit- Remote Office End
S-HDSL	Single-pair HDSL
SDSL	Symmetric Digital Subscriber Line
SES	Severed Errored Second
SNMP	Simple Network Management Protocol
SNR	Signal to Noise Ratio
SONET	Synchronous Optical Network

STS-1	Synchronous Transport Signal, level 1. The basic rate of transmission, 51.84 Mbps, of a SONET frame carried on an electrical interface.
STU-C	SDSL Transmission Unit- Central Office End
STU-R	SDSL Transmission Unit- Remote Office End
SVC	Switched Virtual Circuit
T1	An AT&T digital T-carrier facility used to transmit a DS-1 formatted digital signal at 1.544 Mbps
T3	An AT&T digital T-carrier facility used to transmit a DS3-formatted digital signal at approximately 45 Mbps.
TMC	Traffic Management Center
TMS	Traffic Management Subsystem
UDSL	Universal DSL
VDSL	Very high bit rate Digital Subscriber Line
V.35	ITU-T standard for a high-speed, 34-pin, DCE/DTE interface.
WAN	Wide Area Network
2B1Q	2 Binary 1 Quarternary