

# **xDSL Tutorial**

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# 1 -- General Information

## 1.1) Introduction

With the rapid growth of xDSL technology many people feel confused by what exactly “xDSL technology” means. Adding to the confusion, there are a swarm of acronyms and jargon. The intent of this paper is to alleviate some of the uncertainty by explaining what the terms mean and to give resources on where to find more information. Technical information and the applicable standards have been included where appropriate.

This paper is divided into three basic sections. The first contains general information about DSL, which includes some broad definitions and explanations of general concepts of DSL. The second section addresses various types of DSL individually, highlighting the major features that set a particular type apart from the rest. At the end of this paper is a quick reference guide which contains a list of common acronyms and internet links which are associated with xDSL topics.

## 1.2) What is DSL and why do people use it?

DSL stands for Digital Subscriber Line, and the ‘x’ in xDSL means there are many different varieties of DSL (HDSL, ADSL, etc.). DSL and xDSL are generic terms for all types of Digital Subscriber Lines.

Digital Subscriber Lines are nothing more than high-speed digital communications lines. In the past few years, the computer industry has seen a huge upswing in information sharing technologies. New business collaboration software, multimedia applications, and even standard internet browsing, have created a huge demand for more speed. DSL technology is fulfilling much of this need.

DSL offers several key advantages over other high speed communications solutions. The foremost of these is price. The greatest savings come from the fact that **DSL runs on existing copper lines**. This fact alone has many wonderful consequences. Unlike fiber optics and other communication lines, no new cables need to be installed for existing buildings. By using the existing copper infrastructure, the capital costs for upgrading to DSL service is quite low. Telephone companies and other service providers can easily adapt their current services to use DSL.

Another advantage is in the way the information is handled in the network. Most DSL systems allow voice transmission simultaneously with data traffic. DSL helps carriers reduce congestion on their voice-switching systems. The data traffic is directed to a packet-based data network, while the voice information is sent to the Public Switch Telephone Network (PSTN).

Besides price, the most relevant feature of DSL to most consumers is that it is fast, much faster than an analog modem (**modulator/demodulator**). Today’s fastest 56 kilobit per

second (kbps) modems are just about to the theoretical limit of analog modem technology, so progress towards faster analog solutions will be slow if not impossible. Conversely, DSL is already much faster than 56 kbps. Two Megabits per second is a readily achievable and is more than 30 times faster than a standard 56k modem. (\* For information on the units of measure for data please refer to the note at the end of this paper.)

### **1.3) Why so many types and what's the difference?**

Why so many types? Short answer: People have different needs. Longer answer: Most xDSL technologies are used to provide internet access of some sort, but what is needed from that service varies greatly from case to case. The needs of a home user with only one or two computers on a line are quite different from the needs of a business network running collaboration software or web server/file server.

So what sets each type apart? There are a few key differences:

- Speed - how much data can be sent or received in a certain amount of time, speed is usually referred to as the bit rate
- Line Coding – how the information is encoded and sent on the line. There are many different methods of encoding which will be discussed as is needed.
- Number of Lines – does it require one twisted pair of wires or two pairs
- Distance Limit (Reach) – how many feet/meters the signals can reliably travel

The next section of the paper will detail the most common forms of DSL and look at the differences between them in detail. See the DSL Quick Comparison for a more compact chart comparing each type.

## 2 – Types of xDSL

### 2.1) HDSL

#### **Definition and Primary Applications**

HDSL stands for High-bit-rate Digital Subscriber Line. HDSL is the most mature type of DSL today. It was first developed in the late 1980's as an alternative to T1 standards at the time. HDSL fulfills the role of traditional T1 lines and is currently implemented in business and corporate settings.

T1 lines (ITU Recommendation G.703) were developed and deployed for high speed data transmission. They are dedicated lines where there is always a connection between the end user and the service provider. A leased T1 line has customarily been quite expensive, HDSL offers an alternative which is just as effective and much cheaper.

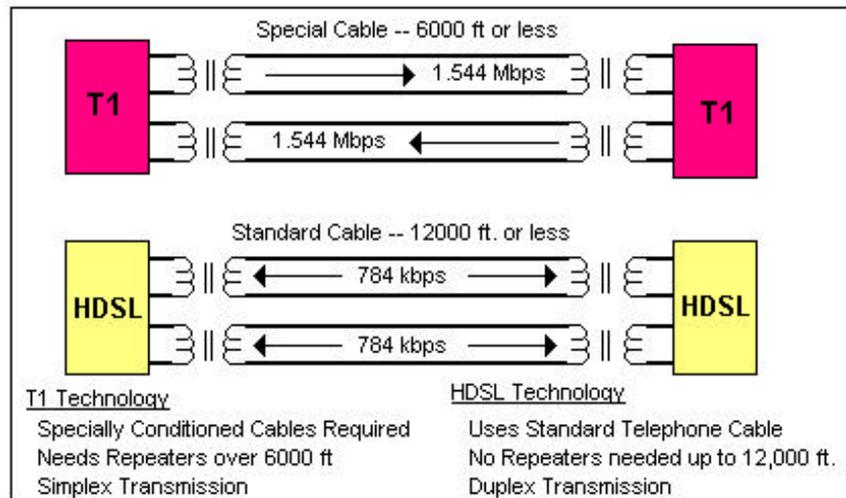
#### **Technical Information**

HDSL was designed to address many technical problems that traditional T1 faced. T1 technology required that the lines be preconditioned to match specific line requirements. To meet these line conditions, special cables had to be used. HDSL was designed to automatically compensate for line conditions. HDSL allows bridge taps and changes in the cable gauge where T1 technology would not.

Another drawback to T1 technology is that it uses simplex transmission. Simplex transmission is where information is sent exclusively in one direction on a line. Alternatively, HDSL uses Duplex transmission. Duplex transmission sends data bi-directionally. Using a technique called echo cancellation, HDSL allows data to be sent both

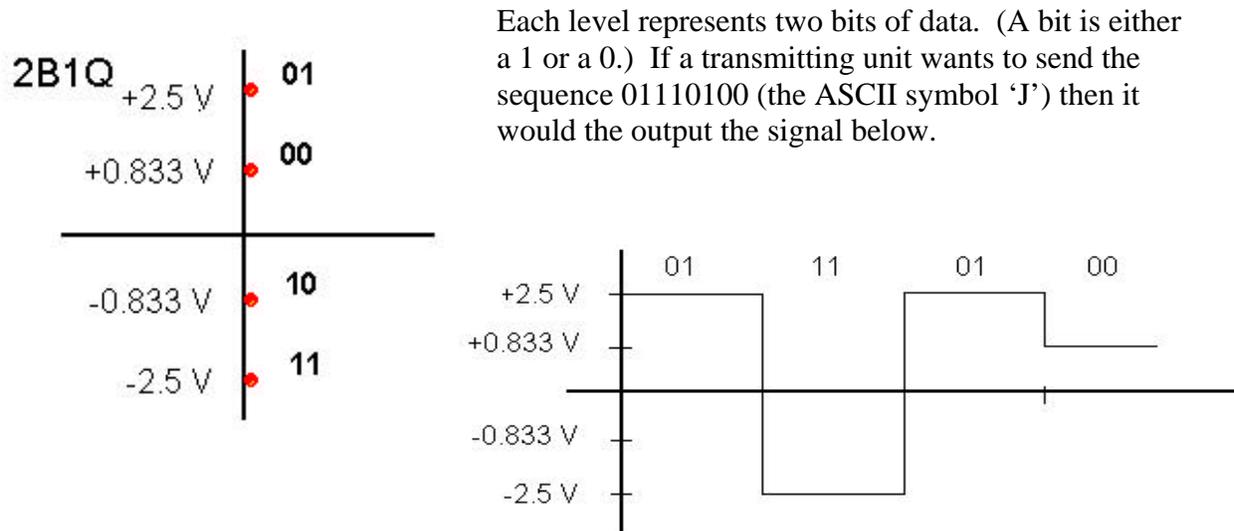
directions at the same frequency on the same line, which is desirable because it requires a smaller frequency band to send the same amount of data. The smaller frequency band means only the lower frequencies must be used, which helps reduce some losses on the line and reduces Near-End Cross Talk (NEXT).

As the picture shows below, HDSL is designed to run at the same bit rate as a T1 line (1.544 Mbps) and it uses the same number of lines, but it can achieve this same bit rate on less expensive lines over a greater distance. To do this, it sends a half rate signal (784 kpbs) on each line.



## Line Coding

Since symbols (like the ones you are reading right now) can't be sent over the copper line directly, they must somehow be encoded in a format that can be sent and received without confusion. The method of how symbols are sent across data lines is called **Line Coding**. The Line Code for HDSL is called 2B1Q, which stands for 2-binary 1-quaternary. 2B1Q is a 4-level code that encodes two bits at one time.



Each level represents two bits of data. (A bit is either a 1 or a 0.) If a transmitting unit wants to send the sequence 01110100 (the ASCII symbol 'J') then it would output the signal below.

One of the main advantages of using a 2B1Q scheme to encode data is that it is easy to understand and implement and does not suffer badly from NEXT (Near End Cross Talk). However, it does not make as efficient use of the available bandwidth as some other encoding techniques.

## HDSL Advantages and Disadvantages

The primary advantage of HDSL is that it is a mature and proven technology. It is also very easy and economical to install. Its other main advantage is that it has decent transfer rate in both directions at 1.544 Mbps (784 kbps x 2).

The primary disadvantage of HDSL is that it requires two twisted pairs of wires to operate, which increases the deployment cost for service providers. Also, HDSL does not support Plain Old Telephone Service (POTS) on the same lines as the data, so separate phone service is needed if the consumer wants to speak on the telephone. Another disadvantage is that HDSL is slightly slower than some other forms of DSL, but it is still far superior to analog transmission.

## Applicable Standards

**ITU Recommendation G.991.1 (10/98) High Bit-Rate Digital Subscriber Line (HDSL) Transceivers**

## 2.2) ADSL

### Definitions and Primary Applications

ADSL is the acronym for Asymmetric Digital Subscriber Line. ADSL derives its name from the fact that the data transfer rates downstream are much faster than the upstream data rates. (Downstream is the direction from the service provider to the consumer. Upstream is from the consumer toward the service provider.) The downstream rate is often up to 10 times faster than the upstream rate.

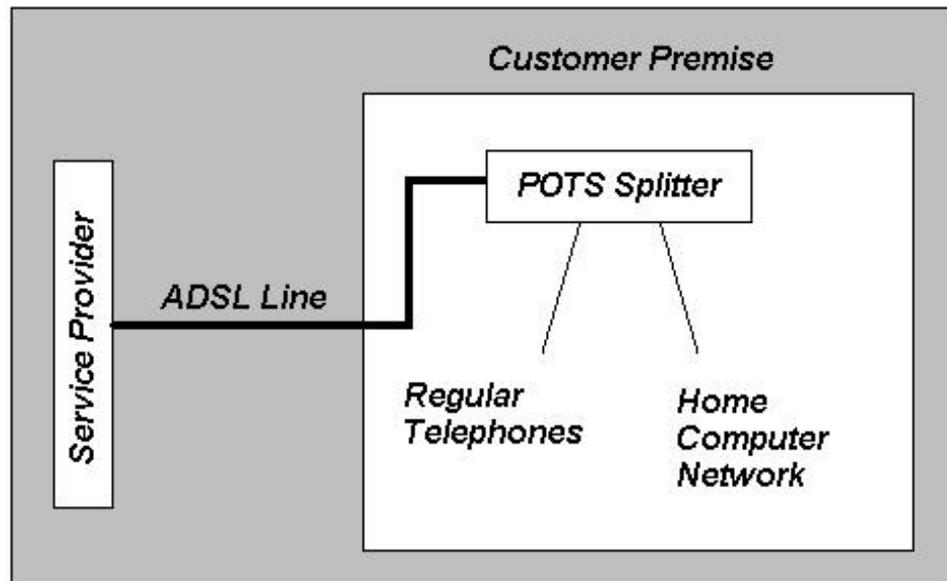
ADSL was originally developed for telephone companies that wanted to provide video-on-demand type applications. To do this, there would need to be a large amount of data sent from the company to the consumer, but very little data would need to be sent back. Since it's first development, the focus for ADSL has switched. ADSL is well suited for internet browsing where much more data is sent downstream than upstream. Currently, demand for high-speed internet access is fueling virtually all of the current ADSL market.

### Technical Information

The data rate of ADSL is highly dependent upon the distance from the Central Office (CO) to the Consumer Premises (CPE). At a distance of 9000 ft., 8 Mbps downstream can be achieved while at 18000 ft., only 1.544 Mbps downstream can be achieved. Upstream speeds max out at 640 kbps and scale down similarly to the downstream speeds.

ADSL was designed to coexist with a regular phone line, which operates at frequencies up to 4 kHz. In order not to interfere with POTS and to avoid interference from POTS, ADSL operates at frequencies above 4 kHz, typically from 30 kHz to 1.1 MHz. (Upstream is in the range from 30 kHz to 138 kHz, downstream ranges from 138kHz, to ~1.1 MHz).

Separate frequency bands for voice and data allow the signals to be individually obtained using filters. For ADSL these filters are combined into one central piece of equipment called a POTS splitter. The POTS splitter takes the signals received from the service provider and separates them into two home



networks. One is the regular telephone network that is installed in most homes and the

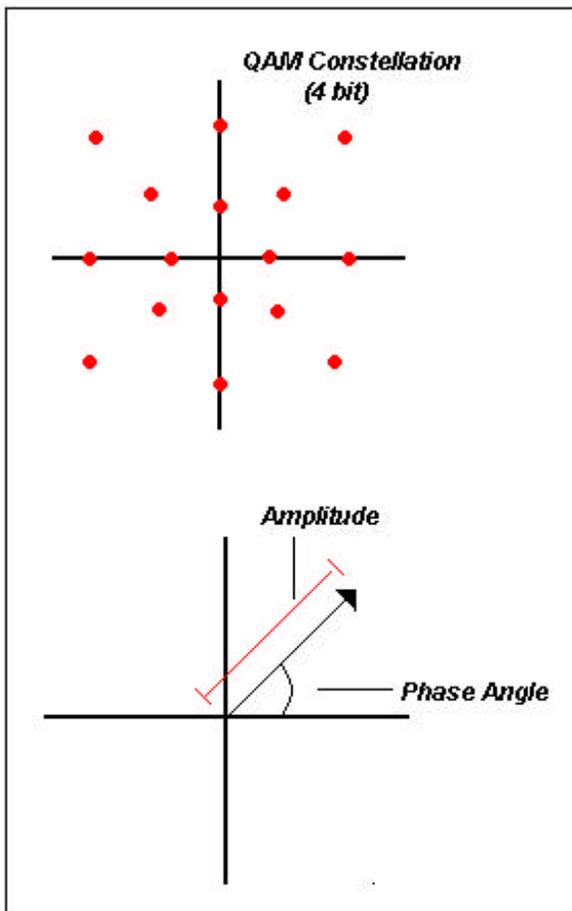
other network is the home computer network which may have one or many computers connected to it. POTS splitters do have a few pitfalls. The most prominent of these is the need for the service provider to send trained technicians to install the splitter. Since technicians are somewhat scarce, this adds cost and inconvenience to ADSL installation.

## Line Coding

Line coding for ADSL is a topic that has undergone considerable debate. There are primarily two different schemes that are under consideration, Discrete MultiTone Modulation (DMT) and Carrierless Amplitude Phase Modulation (CAP).

The coding scheme favored by the standards bodies is DMT modulation. DMT systems divide the frequency band into 256 subchannels that are about 4 kHz wide. 32 of these channels are reserved for upstream data. Each channel independently sends data using QAM encoding (Quadrature Amplitude Modulation). QAM is similar to 2B1Q encoding in the fact that multiple bits of data coded into each symbol that is sent over the line. However, that is where the similarities end. While 2B1Q modulates only the voltage level

of the signal, QAM modulates both the amplitude and phase angle of the signal. QAM encoding can be represented by the constellation of points shown here.



Each point represents a specific bit pattern (0000, 0001, 0011, etc). The amplitude and phase of the signal are used to create an "arrow" that determines the specific point. The amplitude tells how far the arrow point should be from the center and the phase angle tells how far the arrow should rotate around on the grid. In the constellation shown, there are 8 different phase angle possibilities and 2 amplitude levels. For a very clean line (a line with very little noise), a much denser constellation can be used with many more amplitude levels and smaller differences between phase angles.

In an ADSL system that implements DMT, each of the 256 different subchannels will have different amounts of noise that they see because different frequencies will have different responses to the line conditions. One of the strong points of DMT is that it allows each channel to use a different QAM constellation. At low frequencies, the line

usually has fewer problems than at high frequencies, so a denser constellation with more points can be used. Noisier channels will transmit fewer bits per symbol, or channels may not be used at all if there is too much interference. Since the condition of each channel

may change over time, the ADSL modem constantly must adapt its signal processing to accommodate these changes.

DMT is not perfect and does have a few downsides. The one of greatest importance is that the upstream DMT algorithm can produce significant NEXT (near-end cross-talk), which can interfere with the lower downstream bands. These bands could be turned off and not used to avoid the noise, but by doing that bandwidth for downstream data is decreased.

Other than DMT, the method called Carrierless Amplitude/Phase Modulation (CAP) is used in some ADSL systems. CAP has the advantage that it doesn't create as much cross talk and requires less digital signal processing. However, CAP does not make as efficient use of the available bandwidth as DMT does and most importantly, it is not part of the ADSL standard. Another negative is that CAP is more prone to noise from EMI (electromagnetic interference), specifically from AM radio stations. (The AM radio band overlaps the ADSL frequency bands.) Because it is not implemented in the ADSL standard, it is slowly fading away. (Think of it this way: CAP is to ADSL as Beta is to VCRs, DMT is forcing CAP out of the market as VHS tapes did to Beta.)

### **Advantages and Disadvantages of ADSL**

ADSL is well suited to residential applications. It uses lines that are already installed virtually everywhere and peacefully coexists with current phone service. ADSL is ideal for most home computing and small business applications because of the large downstream data capacity (up to 8 Mbps). Analog modem users will also appreciate that ADSL (like most other flavors of xDSL) is always connected.

There are disadvantages to ADSL also, such as low upstream data rates. For large businesses upstream data rates are often just as important as downstream, which would make ADSL a poor choice. ADSL data rates also suffer dramatically as line length increases. ADSL will extend out to 18,000 ft, but its ideal data rates only operate out to 9,000 ft.

### **Applicable Standards**

***T1.413 ADSL Standard.*** Approved by International Telecommunications Union (ITU) and the American National Standards Institute (ANSI).

**ITU Recommendation G.992.1** (06/99) Asymmetric Digital Subscriber Line (ADSL) Transceivers

## **2.3) G.Lite (DSL-Lite)**

### **History and Primary Applications**

G.Lite, known as the “Splitterless DSL”, is a derivative of ADSL technology. In fact, G.Lite is designed to address the problems ADSL faces, specifically the need for complicated hardware that must be installed by the service provider. G.Lite was born from desires to make DSL consumer installable and it is the home that is G.Lite’s target market.

Vendors of ADSL products quickly realized that many of the problems ADSL faced could be easily solved by simply reducing the speed that the service operated at. For most home users, the reduction in speed would hardly be noticeable. Generally there are speed bottlenecks on the internet which limit data transfer speeds. During rush hour in downtown Minneapolis, a sports car which has a huge speed advantage over a minivan, will probably still get from one point to the other in the about same amount of time. Similarly, on the internet a slower system often will retrieve the same information in about the same amount of time as a faster connection. Because of this fact, G.Lite’s top speed is 1.544 Mbps. Though much slower than full rate ADSL, this speed reduction helps to eliminate problems and is still faster than what the vast majority of users require.

Because of the lower bit rate, hardware design for G.Lite is much easier than for ADSL. Higher noise levels can be tolerated, which eliminates the need for a POTS splitter. Where ADSL used the POTS splitter to separate the signals onto a voice network and a data network in the home, G.Lite keeps everything on a single home network. In some cases the wiring in the home is old or done poorly, the voice and data signals can interfere with each other. In those cases, extra equipment is required to eliminate the noise. To solve the problem, small microfilters are placed on each phone line in the house. Microfilters are small, easy to connect and are relatively inexpensive.

### **Advantages and Disadvantage**

The primary advantage of G.Lite is that it is consumer installable. It provides speeds that will suit home users extremely well. The standards also make hardware manufacturers jobs easie. By eliminating the POTS splitter the number of components is reduced as so is the overall complexity of the system. Lower bit rate allows for more noise, and requires far less signal processing.

The disadvantages of G.Lite are that it does not offer the speed of full rate ADSL. For customers who require huge download rates and are connected to a very high-speed backbone (which will help to avoid internet bottlenecks) G.Lite may not offer a high enough bit rate.

### **Applicable Standards**

**ITU Recommendation G.992.2** (06/99) Splitterless Asymmetric Digital Subscriber Transceivers

## **2.4) HDSL2/G.SHDSL**

### **Definitions and Primary Applications**

HDSL2 and G.shdsl are two up-and-coming technologies that promise to offer many benefits to consumers. HDSL2 as the name implies, is an advanced form of HDSL. G.SHDSL is a generalized version of HDSL2 and is being developed by the ITU. Like the original HDSL2/G.SHDSL will be aimed at the business market and toward other applications where upstream data rates are as important as downstream.

### **Advantages of HDSL2/G.SHDSL**

One of the most prominent problems that the original HDSL faced was that it required two twisted pairs of wires to be implemented. In HDSL2 the 1.544 Mbps bit rate is preserved, but a single twisted pair of wires is used. This helps to drive the cost of a system down. Though only using one pair of wires is important, it is not HDSL2/G.SHDSL's only advantage.

To achieve the 1.544 Mbps bit rate that is required, HDSL2 drops the 2B1Q line code that was previously used and implements a much more efficient encoding scheme. This scheme is called Overlapped Pulse Amplitude Modulated (PAM) Transmission with Interlocked Spectra, or OPTIS. The details of OPTIS are somewhat confusing, so suffice it to say that OPTIS provides excellent use of the available bandwidth, does not suffer severely from cross talk and provides a small amount of error checking in the code itself. Luckily for design engineers, implementing this line code is straightforward, which reduces hardware complexity.

The other benefit of HDSL2/G.SHDSL is that it has excellent reach. Using 24 AWG (American Wire Gauge) wire, 1.544 Mbps can be achieved up to 13.2 kft from the central office and 384 kbps can be maintained all the way out to 22.5 kft. (That's over 4 miles!) Another advantage of this type of system is that the bit rate is symmetric, so upstream data rates are just as fast as downstream rates. The G.SHDSL standard goes even further by providing for even better data rates, up to 2.304 Mbps. G.shdsl also adds another benefit by implementing the G.hs protocol. G.hs (handshake) is a standard sequence that two machines go through to determine what line conditions are present and to optimize their performance for the line.

Where HDSL did not allow for telephone service on the same lines, HDSL2 provides for many voice channels in the data stream. By offering data and multiple voice lines on a single copper line, telephone companies can maximize their revenue from their capital investment in the copper lines.

Overall HDSL2/G.SHDSL's primary advantages are better noise immunity, less complexity in deployment, better use of available bandwidth, and less expense for service providers. However, HDSL2 and G.SHDSL do have drawbacks.

## **Disadvantages of HDSL2/G.SHDSL**

The most pressing problem facing HDSL2/G.SHDSL deployment is the harsh requirements it places on designers. While the line code in HDSL2 is not very complex to implement, it does require very stringent guidelines be followed. The systems must perform within 2 dB of the theoretical limits of the copper cable that it uses. Communication signal theory describes what the ideal performance is and HDSL2 requires that the system come very close to those limits.

## **Applicable Standards**

**ANSI T1E1.4** High Bit Rate Digital Subscriber Line 2<sup>nd</sup> Generation (HDSL2)

**ITU Recommendation G.991.2** G.shdsl

**ITU Recommendation G.994.1 (06/99)** Handshake Procedures for Digital Subscriber Line Transceivers

## 2.5) RADSL and VDSL

### Definitions and Primary Applications

RADSL stands for Rate Adaptive Digital Subscriber Line. Rate Adaptive simply means that the speed of the connection is adjusted to meet the line conditions that each transmit and receive unit sees. RADSL generally refers to rate adaptive ADSL services, but other types of DSL may also be rate adaptive. Rate adaptive services are generally used to extend reach of systems to areas that are far from the central office. By dynamically decreasing or increasing the bit-rate rate adaptive technology uses the optimal speed for the line.

VDSL stand for Very high bit-rate Digital Subscriber Line. Though the standards have not been completed yet, the speeds achievable by VDSL are absolutely astounding. Data rates of 13, 26, or up to 52 Mbps are possible with VDSL! VDSL is still in its infancy, but right now it appears that it will be offered in two varieties, one that is symmetric like HDSL and another that is asymmetric like ADSL.

Telephone companies would love to extend their fiber optic backbones closer to customers but it is quite expensive to do so. For the last 1000 ft of cabling serves only a few customers at best and is usually dedicated to a single customer. VDSL is poised to help a strategy of fiber-to-the-neighborhood (FTTN) or fiber-to-the-curb (FTTC). In these scenarios a fiber optic cable is run near a group of customers and VDSL provides final leg to each individual customer. And it is because it only will use a very short length of transmission cable that VDSL can offer such blazing speeds.

Though not complete at the time of this writing, the standard for VDSL is the **ITU Recommendation G.993.1 G.VDSL**.

## DSL Quick Comparison Guide

	Description	Wire Pairs	Data Rates	Reach	Application
<b>HDSL</b>	High bit-rate DSL	2	1.544 Mbps (784 kbps on each pair)	12 kft.	Businesses settings, server access, traditional T1 roles
<b>ADSL</b>	Asymmetric DSL	1	Downstream: 8.448 Mbps 6.312 Mbps 2.048 Mbps 1.544 Mbps Upstream: 16 to 640 bps	9 kft 12 kft 16 kft 18 kft	Residential Internet/Web access, limited Video on Demand service
<b>G.Lite</b>	Splitterless DSL	1	Downstream: 1.544 Mbps Upstream: 512 kbps	18 kft.	Residential Internet/Web access
<b>HDSL2</b>	High bit-rate DSL 2 <sup>nd</sup> Generation	1	1.544 Mbps 384 kbps	13.2 kft 22.5 kft	Business settings, server access, traditional T1 roles, high quality video conferencing, mutiple voice lines
<b>G.shdsl</b>	Generalized HSDL2	1	2.304 Mbps 384 Mbps	13.2 kft 22.5 kft	Same as HDSL2
<b>VDSL</b>	Very high bit-rate DSL	1	51.84 Mbps 12.96 Mbps	1000 ft 4500 ft.	Fiber to the Neighborhood

### A note on units for measuring data

The fundamental unit of data is the bit, which is either a one or a zero. A byte is 8 bits of data. In this paper two units of measure for data are used the kilobit and megabit (which are different from the kilobyte and megabyte). Usually these are given in a speed measure such as kilobits per second (kbps) or megabits per second (Mbps).

Because computers use a binary system for numbers the prefixes kilo and mega have slightly different meanings than the regular metric units. A kilobit is actually 1024 bits and a megabit is 1024 kilobits. 1024 is 2 raised to the 10<sup>th</sup> power, which is nice for computers to deal with and close to our normal unit.

## Glossary and Acronym List

<b>2B1Q</b>	2 bits, 1 Quaternary Line code for HDSL
<b>ANSI</b>	American National Standards Institute
<b>ASCII</b>	A standard for digitizing text. An 8 bit character set which contains the alphabet, numbers and all other printable characters
<b>ADSL</b>	Asymmetric Digital Subscriber Line Different upstream and downstream data rates, <i>ITU G.992.1</i>
<b>AWG</b>	American Wire Gauge. System for defining the diameter of a wire.
<b>Bit</b>	Either a 1 or 0, a small unit of data
<b>Byte</b>	8 bits
<b>Bridge Tap</b>	Accidental Connection of another local loop to the primary loop Becomes a transmission line stub and hurts DSL performance
<b>CAP</b>	Carrierless Amplitude Phase Modulation (CAP) Transmission method used by some ADSL systems. Not approved by standards bodies
<b>CODEC</b>	Coder / Decoder
<b>DMT</b>	Discrete MultiTone Modulation Transmission method used by ADSL systems. Approved by standard's bodies
<b>DSL</b>	Digital Subscriber Line
<b>Duplex</b>	Transmission method where data is sent bi-directionally
<b>Echo Cancellation</b>	Technique that allows data to be sent bi-directionally in the same frequency range by subtracting echoes of transmitted signals
<b>EMI</b>	Electromagnetic Interference
<b>FTTN</b>	Fiber to the Neighborhood
<b>Gauge</b>	Measure of the size of a wire

<b>HDSL</b>	High bit-rate Digital Subscriber Lines The most mature type of DSL, <i>ITU G.991.1</i>
<b>ISP</b>	Internet Service Provider
<b>ITU</b>	International Telecommunications Union Develops and maintains telecommunication standards
<b>Kbps</b>	Kilobits per second, 1000 bits per second
<b>LAN</b>	Local Area Network
<b>Line Code</b>	Refers to the way information is sent on a line
<b>Mbps</b>	Megabits per second, 1 million bits per second
<b>Microfilters</b>	Small inexpensive filters placed on phones Used by G.Lite systems to improve performance
<b>Modem</b>	Modulator/Demodulator Device that transmits and receives data over a line
<b>NEXT</b>	Near End Cross Talk Noise created at the point where a signal originates
<b>OPTIS</b>	Overlapped PAM Transmission with Interlocked Spectra Line code for HDSL2/G.shdsl systems
<b>PAM</b>	Pulse Amplitude Modulation
<b>POTS</b>	Plain Old Telephone Service. 'Normal' voice telephone service
<b>PSTN</b>	Public Switch Telephone Network
<b>QAM</b>	Quadrature Amplitude Modulation Line code for DMT ADSL systems.
<b>Simplex</b>	Transmission method where data is sent exclusively in one direction on a pair of wires.
<b>SOHO</b>	Small Office / Home Office
<b>T1</b>	A transmission line that transmits data at 1.544 Mbps

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