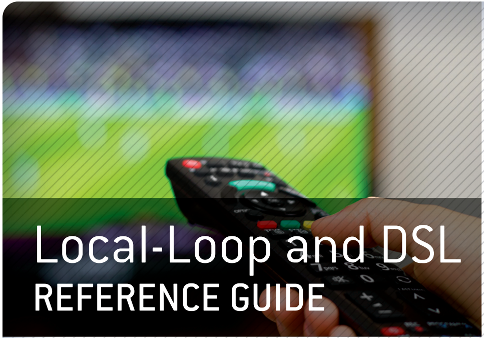
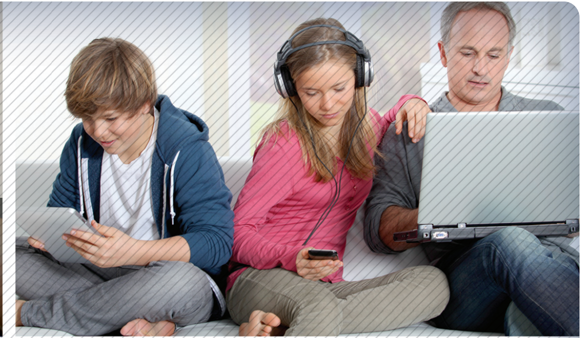
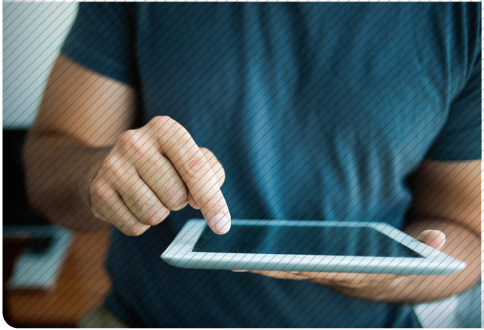
Local-Loop and DSL

REFERENCE GUIDE







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Prologue

Imagine if you will, for just a moment, where we'd be today if not for the hard work of great inventors such as Alexander Graham Bell, Antonio Meucci, and Samuel Morse. If you just went online on your tablet or smartphone to find out who these people are, I've proved my point. Without these gentlemen, I doubt you'd even be reading this Guide.

In 1840, Samuel Morse received a patent (USPTO #1,640) for "Improvement in the Mode of Communicating Information by Signals by the Application of Electro-Magnetism". In his patent, he talks about transmitting intelligence between distance points in the form of sounds and visible signs. He also mentions the recording of intelligence.

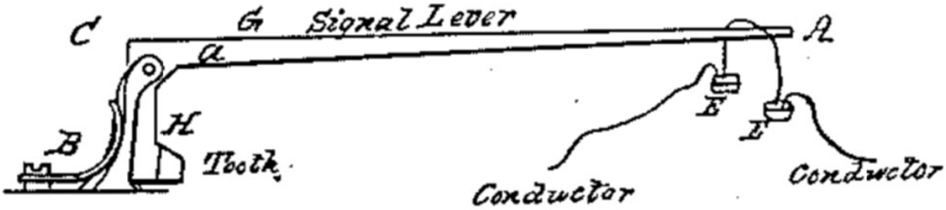


Figure 1. Excerpt Drawing from Samuel Morse's 1840 Patent for the Telegraph

In 1881, Alexander Graham Bell received a patent (USPTO #244,426) for the "Telephone Circuit". In this patent, he describes the improvements to the makeup of a wire pair and of a cable bundle. He also mentions that twisting of the two wires together is preferred.

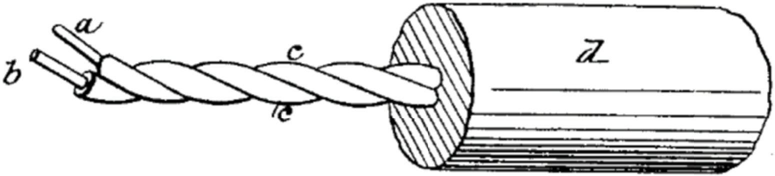


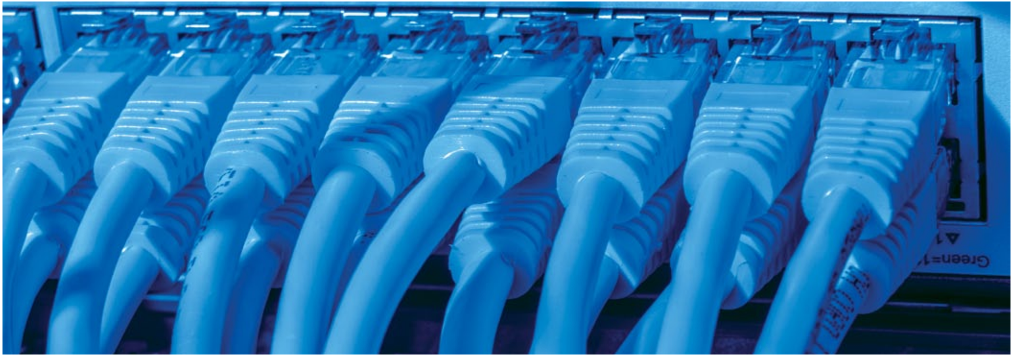
Figure 2. Excerpt Drawing from Alexander Graham Bell's 1881 Patent for the Telephone Circuit

What these gentlemen did over 130 years ago has helped shape what we often take for granted today. Broadband is a household term driven by IPTV, social media (Facebook™ is now 10 years old), "apps", and we can view our favorite television shows and movies on multiple different "smart" devices. The need for speed is all around us and the delivery of "intelligence" drives us. Sure, we don't use paraffin wax for insulation over the wire pair and our data speeds over copper are well above 30 to 70 words a minute, but what these two gentlemen helped shape is the life blood of today's local loop and DSL, including tomorrow's technologies such as G.Fast.

The benefit of this Local-Loop and DSL Testing Reference Guide, to you the reader, is that it quickly exposes you to the latest residential DSL technologies as well as the challenges seen by your peers as they deploy these new technologies. With each DSL technology introduced, or each "killer application" that was created, a new set of issues arose that the service provider technician had to contend with to ensure that the end subscriber was beyond satisfied, as satisfied implies "just good enough", which also meant that the end subscriber could take his business to a competitive carrier. The technician therefore needed to ensure that the end subscriber's perception of his quality of experience was surpassed. Exceeding subscriber expectations means a consistent revenue stream and new business, as that subscriber refers friends (and so on and so on) and often upgrades to the next even better package.

1. Introduction

This guide describes practical methods to detect faults and impairments found in the copper local-loop telephony cable plant for the successful delivery of DSL (digital subscriber line) technologies. Although most aspects of telephone cable fault detection are discussed, an emphasis is placed on preparing cables for the high-speed broadband signals of ADSL2+, VDSL2 and future technologies. It is also a useful reference for other deployment and testing issues regarding the services carried by DSL such as Internet services, e-mail, Internet-protocol television (IPTV), and Voice-over-Internet protocol (VoIP).



2. What Is DSL?

Before we get into a definition of DSL, let's first look at where we've come from with respect to communication technologies.

2.1 Pre-DSL Delivery of Data

The traditional telephone network, commonly known as the plain old telephone system (POTS) or public switched telephone network (PSTN), uses circuit-switched methods to route telephone signals from one destination to another. For the most part, each subscriber is connected to the network with a single pair of twisted wires. Typically, these local loops are less than 20,000 feet (6000 meters) in length; however, some can be as long as 90,000 feet (20 km) in rural areas. Currently in the U.S., there are 139 million telephone lines[1]. Worldwide, this figure is estimated to be upwards of 1.18 billion[2].

2.1.1 Dial-Up

Analog dial-up modems helped in the rapid expansion of the World Wide Web or Internet for the residential consumer. This method to carry data used the voice band (frequency range of 300 to 3400 Hz) and allowed PCs (personal computers) to "speak" with other PCs or servers. The upper limit of data transmission ranged from 300 baud up to approximately 38,400 kbit/s. The 56 kbit/s modems defined in the ITU-T V.90/V.92 standards then became available, but they were unable to offer true 56 kbit/s throughput.

[1, 2] *2010 World Fact Book, CIA*

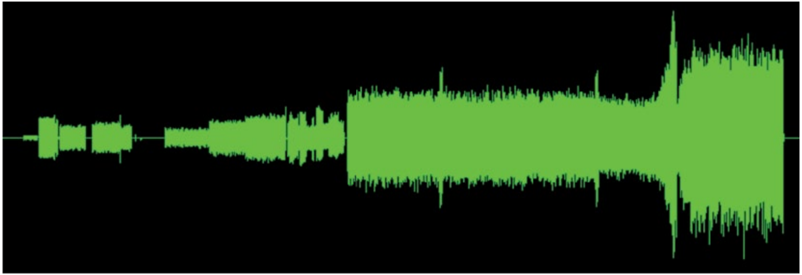


Figure 3. Spectrum of dial-up modem communication sequence

Different speeds of the dial-up modems were then made possible thanks to the compression and modulation techniques that were deployed at the time.

Dial-up modems are still in use today in many areas where DSL or Fiber-to-the-Home (FTTH) services are not yet available, perhaps due to loop-length issues or regulatory/government issues or restrictions.

2.1.2 ISDN

For many decades now, the industry has been pushing the boundaries of where the analog world ends and the digital world begins. The integrated-services digital network, better known as ISDN, which was ratified in 1984 by the International Telecommunication Union (ITU), a United

Nations (UN) organization, and considered one of the first DSL technologies, was developed to simultaneously carry digital voice, video and data over conventional copper cables. ISDN offered rates of 64 kbit/s per bearer channel and was deployed using several modulation schemes (2B1Q and 4B3T), ranging from 40 kHz to 80 kHz in bandwidth. Although ISDN didn't quite live up to the expectations of simultaneous delivery of voice, video and data, there are many areas throughout the world where ISDN still is in use today.

Over the past 10 years or so, digital subscriber line (DSL) technology has become extremely popular and is being rapidly deployed. DSL uses different compression and modulation schemes, and it bypasses the bandwidth-limited POTS and ISDN networks by using frequencies much higher than those of previous technologies. For example, VDSL2 can operate up to 30 MHz, whereas the future technology of G.Fast (ITU-T G.9700 and ITU-T G.9701) can operate up to 106 or 212 MHz.

2.2 xDSL Overview

Digital Subscriber Line (DSL) is a digital broadband technology that involves sending information over a subscriber's telephone line (which is also referred to as the local loop). Its primary application involves the transport of high-speed data to residential and business/enterprise customers, but DSL is also a solution for the mobile backhaul, where operators wish to replace their older time-division multiplexing (TDM) technologies (such as T1) operating over copper infrastructure with more bandwidth-capable and flexible VDSL2.

DSL in general describes the technology, while xDSL represents the family of DSL technologies. Depending upon the speed and application of the xDSL technology, the "x" is a placeholder. For example, HDSL (where the H stands for high speed) is best suited for the business/enterprise subscribers as a spectrally compatible replacement of T1, while VDSL2 (where the V stands for very high speed and the 2 represents second generation) is best suited for residential consumers and small-to-medium businesses (SMBs) alike.

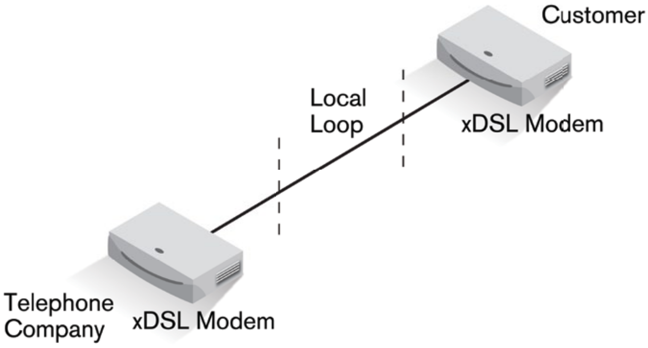


Figure 4. Basic DSL architecture

Compared to dial-up modems, DSL achieves its higher data transfer rates by utilizing more of the available bandwidth of a local loop. Ordinary telephone service only makes use of a limited amount of bandwidth, up to 3,400 Hz. Although a bandwidth of 3,400 Hz is more than enough for transmitting reasonable-quality analog voice or data transmissions up to 56 kbit/s, DSL can range up to 30 MHz, offering between 256 kbit/s and 100 Mbit/s or more of data-rate speed. This truly allows for the simultaneous transmission of high-quality digital voice, video and data.

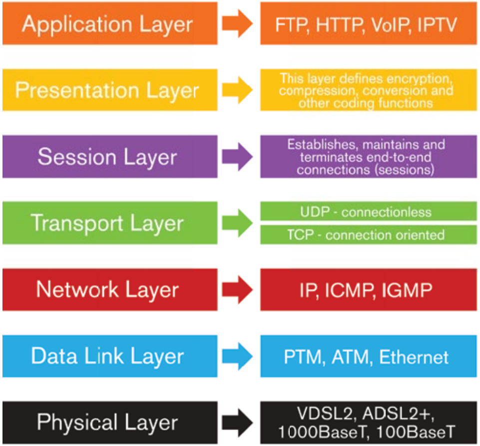


Figure 5. Open Systems Interconnection (OSI) Model

Service providers have been deploying HDSL (including HDSL2, HDSL4, and SHDSL/SHDSL.bis) technology for several years now. HDSL/SHDSL is primarily used as a more efficient and cost-effective method of delivering T1 or 2 Mbit/s (E1) services – the high-speed digital connections traditionally used to connect businesses to public and private networks. More recently, ADSL2+ and VDSL2 have been deployed in order to bring rich-content broadband services to residential consumers. The pioneers of ADSL2+/VDSL2 recognized that it would be a residential offering and designed it such that its signals could coexist with the subscriber's existing telephone (POTS) service.

Using the Open Systems Interconnection (OSI) Model as a consideration for DSL, we can put DSL at the lower physical layer of the OSI Model, alongside other technologies such as 10/100 BaseT Ethernet.

To be able to move application traffic, such as web pages or IPTV streams, over the physical-layer DSL links, this application traffic at the source needs to be encapsulated or encoded into other technology layers. Once the application traffic reaches its destination, the destination must then decode the different layers to extract the necessary data so it is meaningful for the end user.

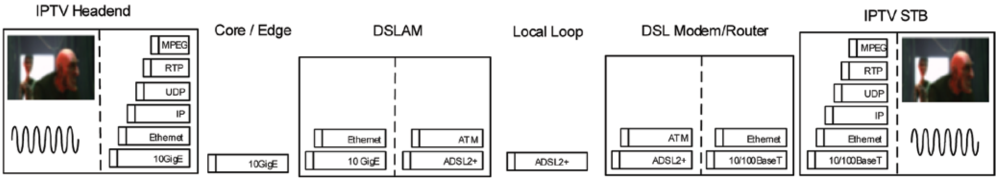


Figure 6. Linear view of traffic flow

2.3 DSL In-Depth

Today, there are a number of DSL technologies available, each offering different speeds for different needs and applications. Regardless of the technology, DSL offers fast speeds for both the residential and business customer. Various types of DSLs have been designed to either operate over one or two pair(s) of copper cable. For example, HDSL was originally designed as a two-pair technology, while ADSL was conceived as a single-pair technology from the start. ADSL was created to coexist on the same pair of copper cable as analog voice transmission (i.e., POTS), allowing users to use their existing phone lines. This gives an "always-on" connection that is ideal for Internet access applications while providing the ability to have uninterrupted analog voice service as well.

In addition, ADSL can also coexist on the same cable pair as basic-rate ISDN transmission so that users don't have to give up the dedicated digital voice, fax, data, and video link they already enjoy in order to subscribe to high-speed access to the Internet. Although ISDN is not commonly distributed to residential customers in the United States and Canada, it is quite important in many European countries and elsewhere in the world.

All the various DSL technologies are provisioned via pairs of DSL modem-chip sets, with one modem-chip set located inside the DSLAM either in the CO or in a remote cabinet, and the other at the customer premises inside the DSL modem/router. Some of the more popular xDSL technologies are described in the following sections.

2.3.1 ISDN

Integrated-services digital network – ISDN – can be considered one of the first DSL technologies and was developed to simultaneously carry digital voice, video and data over conventional copper cables. Basic-rate ISDN is comprised of three logical channels operating over a single copper pair. Two bearer channels (B channels) carry the voice, video and data, while the one signaling/control channel (D channel) is used for signaling. Commonly referred to as 2B+D, basic-rate ISDN offers speeds of up to 160 kbit/s symmetrically with typical deployments of 64 kbit/s. ISDN is also available in a primary-rate interface (PRI) configuration. The PRI offers data/voice/image transfers of up to 1.544 Mbit/s (North American T1 format) over 23 B channels with one D channel or up to 2.048 Mbit/s (European and international E1 format) over 30 B channels with one D channel. Each channel in the PRI configuration operates at 64 kbit/s.

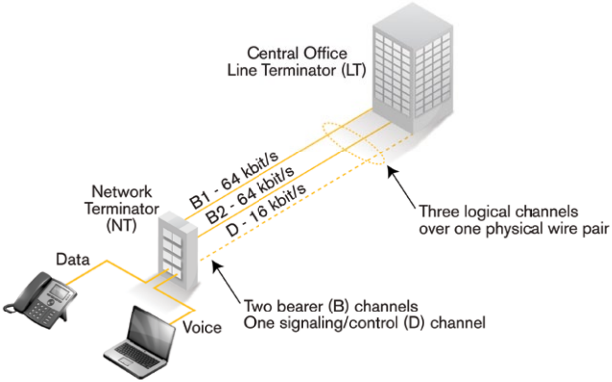


Figure 7. Basic-rate ISDN architecture

ISDN uses a 2B1Q line coding (two binary, one quaternary) to represent information. 2B1Q maps two bits of data into one quaternary symbol; i.e., onto four voltage levels that represent two bits of digital information at a regular clocking rate.

2.3.2 HDSL and HDSL2

High-bit-rate digital subscriber line – HDSL– is a symmetric DSL similar to T1 or 2 Mbit/s (E1) in that it delivers a bit rate of up to 1.544 or 2.048 Mbit/s, respectively. Most HDSL systems use one or two copper twisted pair(s), although some very early 2.048 Mbit/s systems required three copper twisted-pair cables. HDSL is comprised of an HDSL transceiver unit, located at the central office (HTU-CO), and a remote HDSL transceiver unit (HTU-R), located at the customer premises. Because HDSL's speeds and framing structures match those of T1 or 2 Mbit/s (E1) pipes, local telcos have been using the HDSL technology to provision local access to T1/E1 services whenever possible. It should also be noted that traditional T1 transmission uses two copper pairs, so the transition from traditional T1 to HDSL-based T1 is fairly easy. HDSL's operating range, in terms of distance, is more limited than that of SHDSL, ADSL and ADSL2+. Normally, an HDSL service can only serve customers within 12,000 feet of the serving office. Beyond such distances, signal repeaters are needed to extend the service.

As HDSL requires two twisted pairs, it is deployed primarily for businesses that require private branch exchange (PBX) network connections, virtual private networks (VPNs), frame-relay circuits, Internet access and private data networks. HDSL is also preferred over traditional T1 because it is more spectrally compatible with other technologies within a bundle of local loops, as compared to the AMI, B8ZS or HDB3 coded signals of legacy T1 and 2 Mbit/s (E1) solutions. HDSL uses 2B1Q or carrierless amplitude/phase modulation (CAP)-based line coding.

HDSL2 is similar to HDSL in operation, but is capable of achieving HDSL rates over a single pair of wires. This tends to limit transmission distances, but it is still a successful technology. Most HDSL2 systems are based on non-standard, proprietary, transmission signals and protocols. Little or no interoperability exists between vendors.

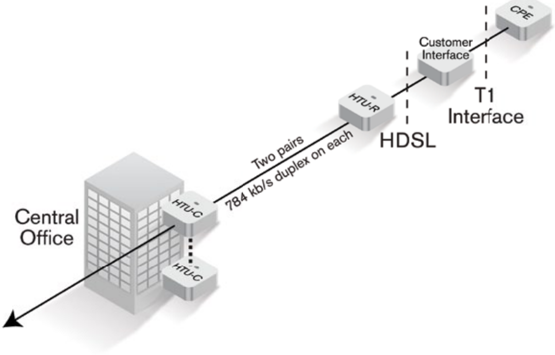


Figure 8. HDSL architecture

2.3.3 SHDSL

Symmetrical high-speed digital subscriber line – SHDSL – is a technology that is similar to HDSL and HDSL2. SHDSL operates over a single pair of wires but can be provisioned to use up to four pairs, depending upon the application. For single-pair operation, SHDSL offers data rates from 192 kbit/s to 2.3 Mbit/s in a symmetrical fashion, while two-pair operation offers data rates ranging from 384 kbit/s to 4.72 Mbit/s.

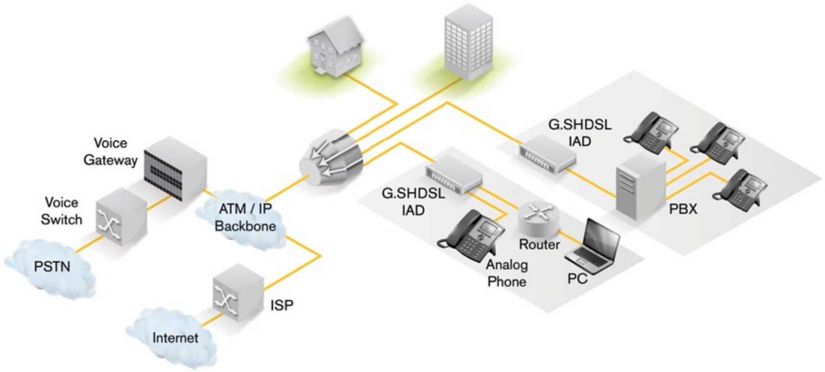


Figure 9. SHDSL architecture

SHDSL is designed to be more of a business solution than a residential service due to its symmetry. It can be used as a T1 and 2 Mbit/s (E1) replacement technology.

SHDSL is also known as an EFM (Ethernet in the First Mile) technology and may be referred to as EFM rather than SHDSL. EFM is often used in mobile/cell backhaul applications (as is VDSL2).

SHDSL has been developed to be spectrally compatible with other technologies within bundles of local loops. SHDSL owes this to the trellis-coded pulse amplitude modulation (TC-PAM) line coding. This coding technique maximizes the use of the lower frequencies of available loop bandwidth, thus avoiding higher frequencies where signals are more susceptible to crosstalk and attenuation (loss).

2.3.4 ADSL and ADSL2

Asymmetric digital subscriber line – ADSL – provides delivery of high-bit-rate digital technology for consumer-based Internet access. ADSL delivers more bandwidth downstream (from the service provider to the subscriber's premises) than upstream (from the subscriber premises towards the network). As most users view/read/watch far more information than they create (upload), ADSL is optimal for Internet and other IP-based services. Downstream rates range from 256 kbit/s to 8 Mbit/s, while upstream bandwidth ranges from 16 kbit/s to 1.5

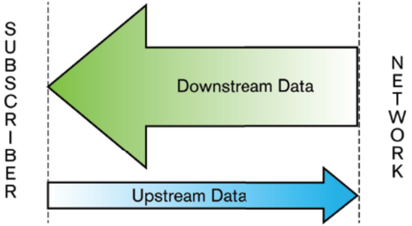


Figure 10. Asymmetric nature of ADSL

Mbit/s. ADSL transmissions may work at distances of more than 18,000 feet over a single twisted pair of copper wires, although it should be noted that only the lowest bit rates are available at these lengths.

For service providers and customers alike, ADSL allows subscribers to simultaneously use their existing phone line for high-speed Internet access as well as regular (including vital life-line) plain old telephone service (POTS). ADSL signals are able to coexist on the same loop as POTS service because they occupy a higher frequency band than POTS. Typically, ADSL uses the 25 kHz to 1.104 MHz range, while POTS uses the 300 Hz to 3400 Hz range. As a necessary precaution, a low-pass filter is placed on the line to separate ADSL signals from POTS signals. These small devices, called POTS splitters or microfilters depending on where they are installed, allow voice band frequencies to pass through to analog telephones while keeping the high-frequency signals of ADSL away from the phones. Likewise, the input filters in ADSL modems prevent telephone signals from entering. In a similar fashion to ADSL and POTS on the same line, ADSL can also coexist with ISDN. Since ISDN operates in the bandwidth up to 150 kHz, there are fewer ADSL subchannels that can be used for ADSL data transmission resulting in a lower achievable data rate. ADSL modems that are designed for use in conjunction with POTS services only are referred to as Annex A modems, whereas those designed to work on loops with ISDN are called Annex B. Both of these designations come from the annexes of ATIS/ANSI T1.413 and ITU-T G.992.1, 2 and 3 published standards.

Two types of line coding exist for ADSL. An early scheme used a non-standards-compliant carrierless amplitude/phase modulation (CAP) method. This modulation technique is very similar to that used for dial-up modems. These days, virtually all ADSL DSLAMs and modems use the discrete multitone (DMT) technique. This guide focuses on the DMT line coding as it is the DMT line code that is recommended by ADSL standards bodies and it is the one in popular use. ITU-T (G.992.1, G.992.2), ETSI, and ANSI/Committee T1 (North America) (T1.413 Issue 2) standards describe the technology.

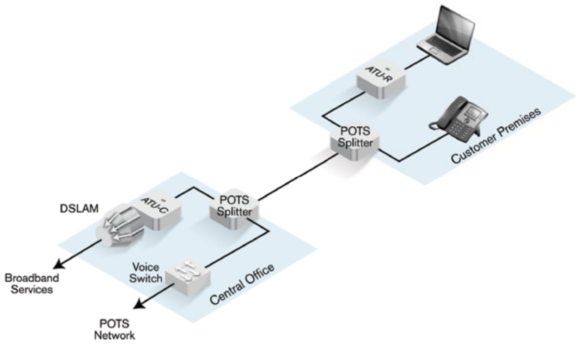


Figure 11. ADSL architecture

Below is a brief overview of the differences between the various types of ADSL:

Rate-adaptive digital subscriber line – R-ADSL – This was an early name for a specific type of ADSL modem that adjusted the transmission speed dynamically to the length and quality of the local loop. These days, most ADSL modems are rate-adaptive and most DSLAM network management systems allow the transmission speed to be set or limited to a maximum bit rate.

G.Lite – This is a lighter version of ADSL in which downstream rates are limited to approximately 1.5 Mbit/s. G.Lite uses 128 bins rather than 256 (still using 4.3125 kHz subchannel bandwidth) and only up to 8 bits/bin can be encoded per subchannel.

ADSL2 – This is an improved version of ADSL with slightly better data rates. Described in ITU-T standard G.992.3, ADSL2 can offer the same bit rate over longer loops and also offers improved rate adaptation. ADSL2 modems should generally be backward-compatible with ADSL modems.

Reach-extended ADSL2 – RE-ADSL2 – This variety of ADSL was approved by the ITU-T in October 2003 and is described in Annex L of the G.992.3 document. The RE-ADSL2 transmission scheme has carriers fit to a newly defined power spectral-density mask that reduces the crosstalk interference from pair to pair, thus increasing the ADSL2 reach.

2.3.4.1 Discrete Multi-Tone (DMT) Line Coding

The Discrete Multi-Tone (DMT) transmission scheme used by today's DSL uses frequency division duplexing (FDD), which divides the DSL frequency band into equally spaced subchannels, subcarriers, tones, or bins in addition to supporting unique upstream and downstream bands. For ADSL and ADSL2, this equates to a total of 256 bins. Each bin occupies 4.3125 kHz of bandwidth. Since ADSL is asymmetrical, the 1.104 MHz band is split once again into upstream and downstream bands. The upstream band carries information from the customer premises to the network, while the downstream band carries information from the network to the customer premises.

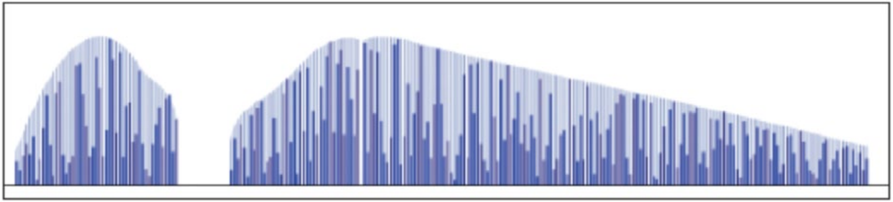


Figure 12. ADSL uses approximately 256 amplitude-modulated carriers. The dark bars represent a "snapshot" of the modulation at any one point in time. The light bars represent the maximum modulation state amplitude available for each carrier frequency. Notice how, at higher frequencies, there are fewer available positions due to a diminishing signal-to-noise ratio.

In systems that use echo cancellation – a method where the upstream and downstream tones coexist at the same frequencies – 32 bins are allocated for upstream transmission, and up to 250 bins are allocated for downstream transmission. For the most part, however, DMT implementations will use 218 bins for downstream signals. Guard bands that separate the upstream signals from the downstream signals use some of the possible carrier allocations. There is also a guard band between the POTS signals and the DMT carriers of ADSL signals.

The DMT standard suggests that equipment can use up to 15 analog levels per frequency bin to encode data per subchannel. DMT uses complex Quadrature Amplitude Modulation (QAM) constellation and Fast Fourier Transform (FFT) technologies. QAM is a technique using a complex hybrid of phase (or 'quadrature') as well as amplitude modulation. Each subchannel is 4.3125 kHz wide and is capable of carrying up to 15 bits. The size of the QAM constellation is 2^r ->. For example, with 14 bits/symbol, the QAM constellation is 2^14 = 16384 points represented in the complex plane with (Z(i) = x(i) + jy(i)). However, using the maximum 15 states per bin may result in the overall ADSL transmission power to be higher than would be practical or allowed by government regulators in a cable bundle. For the most part, ADSL makers have limited their designs to use 13 or 14 bits/bin. This lowers the power transmitted between modems and maximizes the reach of transmission without compromising potential data rates. To use a bigger constellation size, it is necessary to have a better signal-to-noise ratio (SNR) in order to hold a certain bit error rate. SNR is the key behind DMT technology.

For newer technologies (ADSL2+ and VDSL2), the DMT line coding is still used, but the frequency bandwidth has increased to accommodate the increased speeds that these technologies are capable of offering.

2.3.5 ADSL2+

Shortly after the release of ADSL2, the standard for ADSL2+ (ITU-T standard G.992.5) was published, and chip sets that supported the technology became available. ADSL2+ more than doubles the downstream data rate of ADSL by doubling the utilized bandwidth (from 1.1 MHz to 2.2 MHz) and doubling the number of DMT carriers (from 256 bins to 512 bins); the data rate can reach as high as 24 Mbit/s. This access technology is primarily designed to enable the delivery of streaming broadcast-quality video to subscribers. ADSL2+ modems also offer the full capabilities and interoperability of ADSL and ADSL2 modems.

With the release of ADSL2+, the industry started to see enhancements made to improve the stability of ADSL2+, such as impulse noise protection (INP) and physical-layer retransmission. Another enhancement included the use of ATM header compression, which allowed certain DSL chipsets to offer data rates as high as 30 Mbit/s.

2.3.6 VDSL2

The benefit of VDSL2 (ITU-T G.993.2) is to provide users with very-high-speed asymmetrical and symmetrical services by utilizing frequencies of up to 12 MHz and even as high as 30 MHz, and VDSL2 also supports bit rates up to 100 Mbit/s for single-pair deployments. The trade-off is that VDSL2 can only operate at higher bit rates on relatively short loops (less than 4000 ft./1200 m). To achieve the short distances and high rates, VDSL2 is typically deployed in an FTTx architecture, in which a fiber-optic backbone (1 GigE or 10 GigE) feeds a neighborhood and VDSL2 services the end subscriber.

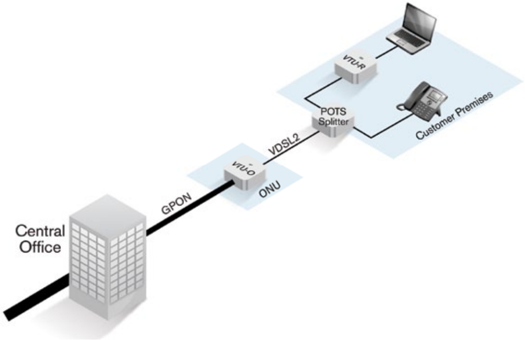


Figure 13. VDSL2 architecture

As in the case of ADSL2+, VDSL2 may coexist with POTS or ISDN on the same loop. One difference between them is that VDSL2 uses a slightly different approach to upstream and downstream band allocation. Instead of having just one upstream band and one downstream band, VDSL2 uses at least two downstream bands and usually two upstream bands for VDSL2 12a service deployments.

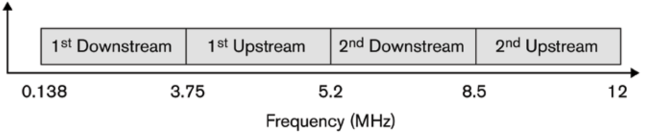


Figure 14. Plan 998 for North American VDSL implementation

VDSL2 can be provisioned up to 30 MHz, allowing for potential data rates of 100 Mbit/s. 100 Mbit/s is possible on very short loops (less than 1000 ft. or 300 m), which makes it ideal for deployment in MDU and MTU environments.

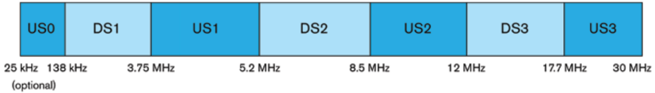


Figure 15. VDSL2 bandplan (based on Plan 998)

Profile	8a	8b	8c	8d	12a	12b	17a	30a
Bandwidth (MHz)	8.5	8.5	8.5	8.5	12	12	17.7	30
Data Rate Mbit/s	50	50	50	50	68	68	100	200

Figure 16. VDSL2 profiles

Figure 17 shows a comparison of downstream data rates for ADSL2, ADSL2+ and VDSL2.

2.3.7 Asynchronous Transfer Mode (ATM)

With the launch of DSL, Asynchronous Transfer Mode (ATM) was selected for use as the OSI Layer 2 (data-link layer) protocol, as it was already heavily deployed in the network at the time. ATM was designed to be an effective method for the transfer of data, video and voice signals between networks using asynchronous time-division multiplexing. Over a short period of time however, ATM was quickly replaced with Ethernet (IP) in the core/network side of the DSLAM, leaving ADSL, ADSL2, and ADSL2+ in the network between the DSLAM and the customer modem, which to this day

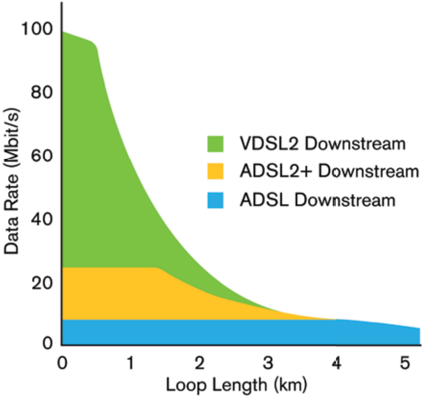


Figure 17. ADSL, ADSL2+ and VDSL2 rates and reach comparison

continue to be ATM-based. One key element of ATM is the idea of virtual vircuits (VCs). A VC is made of a virtual path identifier (VPI) and a virtual circuit identifier (VCI). The VPI and VCI were used to specify the destination for the ATM data payload. Typically, every operator, when considering the use of ATM between the DSLAM and the end subscriber's modem, uses the same VPI/VCI for all of their subscribers.

2.3.8 Packet Transfer Mode (PTM)

In recent years, the telecommunications network has transitioned from an ATM-dominated network to an Ethernet/IP-dominated network. VDSL2 adopted PTM quickly, although some older deployments of VDSL2 continue to use ATM even though the benefits of PTM vs. ATM are known. These benefits include lower cost of hardware and a lower data-transfer overhead, resulting in slightly higher data-rate potential.

PTM, although new to DSL, is not a new technology. The IEEE 802.3ah specification defines a specific Ethernet TPS-TC using the 64/65-octet encapsulation for Ethernet applications without an underlying ATM segment. In the ITU-T VDSL2 specification, TPS-TC is referred to as PTM-TC.

PTM uses virtual local-area network (VLAN) addressing to move data across the network. Similar to ATM, operators typically will use the same VLAN addressing for all subscribers. The majority of operators will provision services over different VCs. For example, high-speed Internet (HSI) may use VLAN = 35, whereas IPTV may use VLAN = 36. This separation in addressing for the different services allows for easier management as well as troubleshooting of the services.

2.3.9 Impulse Noise Protection

Electrical appliances often generate short bursts of high-amplitude noise called impulse noise. Impulse noise could cause errors in the transmitted stream, which could have a significant impact on IPTV and VoIP services since these services typically use User Datagram Protocol (UDP) rather than Transmission Control Protocol (TCP) in the transport layer of the OSI model. Unlike TCP, with UDP, there's no re-transmission of lost packets, so for IPTV and VoIP traffic, if an impulse noise spike knocks out the DSL frame carrying the UDP packet, which contains the program clock reference (PCR), the end customer is going to experience pixelization or freezing on their TV screen.

The industry has categorized impulse noise into different groups depending on their duration; we can now use terms such as REIN, SHINE, and PEIN to talk about impulse noise.

Table 1. Categorization of impulse noise

Impulse Noise Acronym	Full Name	Duration
REIN	Repetitive electrical impulse noise	< 1 ms
SHINE	Single high-impulse noise event	> 10 ms
PEIN	Prolonged electrical impulse noise	1 – 10 ms

2.3.9.1 Working of INP

Impulse noise protection (INP) works in conjunction with the DSL systems interleaver and forward error correction mechanisms to provide stability to the DSL link. INP attempts to limit bit errors from occurring by allowing the DSL system to adjust according to the number of consecutive DMT symbols that needs to be protected. As one DMT symbol occupies 250 μs, this is the minimum size INP needs to protect the DSL frame from being corrupted. However, since impulse noise is random, it is very unlikely that the impulse noise hit will occur at the very start of the DMT symbol, so INP always considers the protection of consecutive DMT symbols (i.e., two).

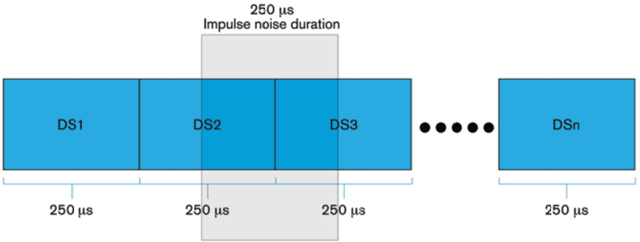


Figure 18. Minimum size INP needed to protect the DSL frame from being corrupted

INP is effective against the short impulse noise durations associated with REIN; however, the longer impulse noise events attributed to PEIN and SHINE may exceed the protection provided by the INP mechanism.

Table 2. INP value vs. duration

INP value	Maximum Impulse Noise Duration
2	250 µs
3	500 µs
4	750 µs
5	1 ms
6	1.25 ms
7	1.5 ms
8	1.75 ms
9	2 ms
10	2.25 ms
11	2.5 ms
12	2.75 ms
13	3 ms
14	3.25 ms
15	3.5 ms
16	3.75 ms

It must be noted that there is a correlation between INP values used and the data rate that can be deployed to a customer. Although it may make sense to use high INP values, the additional delay greatly reduces the data rates, as shown in the table below, which is an excerpt of Broadband Forum TR-176.

Table 3. INP values vs. delay – Excerpt of Broadband Forum TR-176

		INP_min						
		0	1/2	1	2	4	8	16
delay_max (ms)	1 (Note)	29556	0	0	0	0	0	0
	2	29556	25718	20928	7616	0	0	0
	4	29556	27612	25718	21092	7616	0	0
	8	29556	28394	27217	24703	19092	8112	0
	16	29556	28394	27217	24703	19092	10844	4024
	32	29556	28394	27217	24703	19092	10844	5393
	63	29556	28394	27217	24703	19092	10844	5393

Note: In ITU-T Rec. G.997.1, a 1 ms delay is reserved to mean that $S_p \leq 1$ and $D_p = 1$.

2.3.9.2 G.INP

Defined by ITU-T G.998.4, "Improved impulse noise protection for DSL transceivers", G.INP refers to physical-layer transmission of lost or out-of-sequence DSL frames. During the original transmission of DSL frames, the original frames are copied into a retransmission buffer. Should the receiving side detect lost or out-of-sequence DSL frames, a request is made to the transmitting side to resend the lost DSL frame.

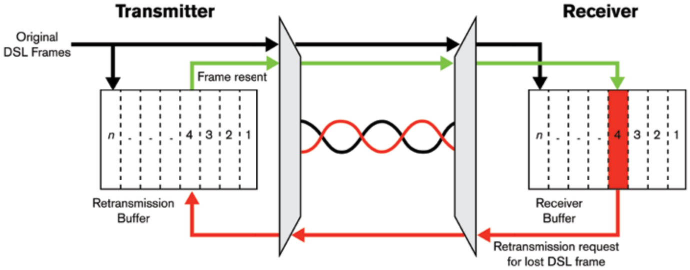


Figure 19. Minimum size INP needed to protect the DSL frame from being corrupted

Note that for ADSL2 (G.992.3) and ADSL2+ (G.992.5), G.INP is only available in the downstream direction (from DSLAM to CPE modem). For VDSL2 (G.993.2), G.INP is bidirectional.

2.3.9.3 REIN

REIN is defined within G.998.4 as “a type of electrical noise encountered on digital subscriber lines. It is evident as a continuous and periodic stream of short impulse noise events. Individual REIN impulses commonly have duration less than 1 millisecond. REIN is commonly coupled from electrical power cable appliances, drawing power from the AC electrical power network, having a repetition rate of twice the AC power frequency (100 or 120 Hz).”

2.3.9.4 SHINE

SHINE is defined within G.998.4 as “a type of electrical noise encountered on digital subscriber lines. SHINE generally arises as a periodic stream of impulses with effectively random inter-arrival time and impulse length both inversely related to intensity. Generally, the term SHINE is associated with large impulses with duration in the range milliseconds to seconds.”

2.3.9.5 PEIN

PEIN is defined as “all non-repetitive impulse noise events that have a duration between 1 ms and 10 ms.”

2.3.10 Bonding

Bonding is a method defined by ITU-T G.998.1 (ATM-based bonding) and G.998.2 (Ethernet-based bonding), whereby at least two copper pairs are used to increase the ADSL2+ or VDSL2 data rates to a customer and/or increase the overall distances covered by these technologies.

Bonding allows an operator to define, within the DSLAM, a set of available pairs, a “group” (which pairs to use) and the “group rate” (what speed). The bonded DSL system will assess each copper pair individually to see what each pair will be able to handle, allowing the system to determine how to provision the bonded group into the individual pairs. Ideally, each individual pair will support 50% of the load, but the ITU-T bonding standards realize that not every pair is deployed/maintained equally, so the bonding system can allow a 4:1 ratio in terms of data rate for the individual pairs.

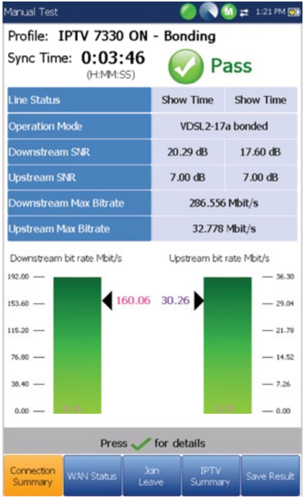


Figure 20. Example of manual bonding test

In terms of rate vs. reach, the graph below shows how ADSL2+ and VDSL2 technologies look when operating as a single-pair technology, as well as in their bonded forms.

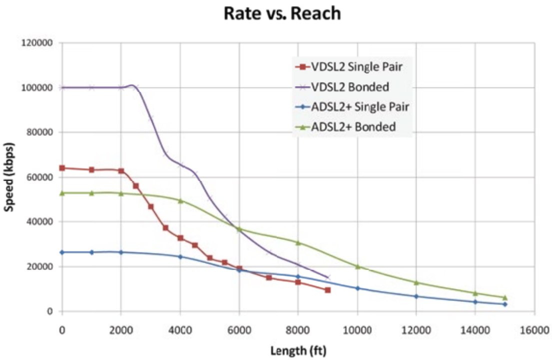


Figure 22. Difference between ADSL2+ and VDSL2 when operating as a single-pair technology

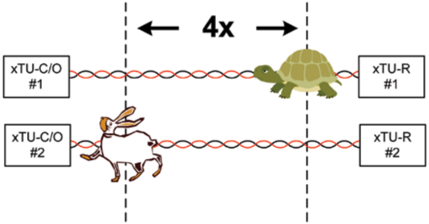


Figure 21. Illustration of 4:1 ratio data rate bonding system

2.3.11 Vectoring

Vectoring is defined in ITU-T G.993.5 as Self-FEXT cancellation (vectoring) for use with VDSL2 transceivers". The purpose of vectoring is to monitor and mitigate VDSL2 far-end crosstalk (FEXT) in near real time in order to ensure high data rates on the subscriber line. By mitigating the effect of crosstalk, the signal-to-noise ratio of the subscriber pair is improved, and the overall data rate possible on the subscriber pair can be significantly improved.

Vectoring applies only to VDSL2. Although FEXT exists on ADSL2+ circuits, the typical deployment scenario for ADSL2+ means that they have longer loop lengths than VDSL2. As such, the FEXT on ADSL2+ circuits, when received at the far end, is greatly attenuated, having little or no effect on the subscriber.

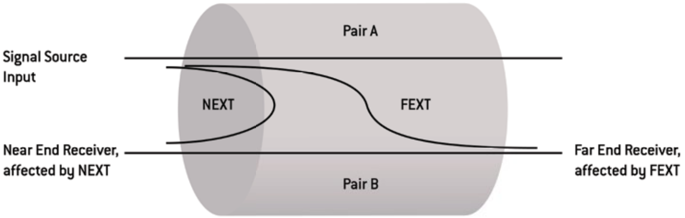


Figure 23. Crosstalk schematic

How vectoring works is that it measures the FEXT from all the other vectored lines and generates, toward the subscriber pair, a complex signal that encodes the original and inverse signals in order for the remote receiver to cancel out the FEXT noise. In this way, it acts like noise-cancelling head phones.

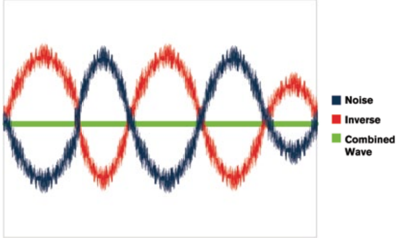


Figure 24. Noise cancellation schematic

One of the main issues with DSL vectoring is that it can only deliver the promised bandwidth if all the lines in a given cable bundle are vectored together. Assuming that they are, the remaining noise (e.g., radio frequency interference (RFI), impulse noise from electrical services in the home, alien crosstalk) will become the primary limitation. Use of other techniques such as bit swapping, INP and G.INP can help alleviate some of these issues.

2.3.12 G.Fast

Beyond vectoring and bonding, G.Fast is a future technology, defined by ITU-T G.9700 and G.9701, that makes it possible to deliver aggregate speeds up to 1 Gbit/s to copper-pair-based subscribers. G.Fast succeeds in achieving this speed thanks to two main factors: extra bandwidth and shorter loop lengths.

VDSL2 is able to operate up to 30 MHz bandwidth, offering subscribers located within 300 m of the DSLAM to aggregate rates up to 200 Mbit/s (100 Mbit/s upstream and 100 Mbit/s downstream). G.Fast pushes the available bandwidth to 106 MHz (however, initial offerings/deployments include plans to eventually reach up to 212 MHz) and, coupled with shorter loop lengths, can allow operators to offer bit rates from 150 Mbit/s on 250 m loops all the way up to 1 Gbit/s on 100 m loops at 106 MHz.

G.Fast can be provisioned to coexist with ADSL2+ and VDSL2. Similar to ADSL2+, notching out frequencies to support POTS or even ISDN, G.Fast can be deployed in cable bundles already in use with ADSL2+ and VDSL2 by offering the full spectrums of either ADSL2+ (2.2 MHz) or VDSL2 (30 MHz).

G.Fast also changes our understanding of upstream bands and downstream bands currently used by ADSL2+ and VDSL2. Still using DMT coding, G.Fast utilizes time-division duplexing (TDD) rather than FDD. While FDD allows for unidirectional bands (the frequency band and the DMT tones are always upstream or downstream; they cannot do both), TDD allows the tones to operate either upstream or downstream, as needed by the system. For example, if there is no reason to support an upstream bit rate, TDD allows all tones to be used to achieve a higher downstream bit rate (and vice versa).

3. DSL Deployment Issues

Despite all of its positive attributes, DSL, like most technologies, is not without flaws. For instance, in order to be eligible for DSL, end users must be located within a certain distance from the DSLAM located in the CO/exchange or the remote terminal; otherwise, the signal degradation (attenuation) may be too great such that DSL is either not feasible, the bit rate attainable is not attractive to the consumer, or an expensive repeater needs to be added.

DSL service performance varies due to the following factors:

- The distance between a customer premises and the DSLAM at the local telephone company's CO/exchange or remote terminal
- The type and brand of DSL equipment used at both ends of the connection
- The capacity of the digital backbone that is available to support each DSLAM
- The number of users that are aggregated to the available digital backbone
- The behavior of the served community (i.e., how often they use the service; how much data they consume; the type of services offered)
- The quality of the local loop between the customer premises and the service provider's CO
- The proximity and severity of noise sources to the DSL equipment and the local loop

- The state of the customer premises wiring
- The state and power of the user's PC and/or routers
- The condition of the public electrical power feed and grounding

With the growth in bandwidth-intensive applications, not to mention social media and multiscreen applications, the emphasis on providing stable, high-speed, broadband connections is the key to success. One way to guarantee stability and to ensure maximum bit rates is through an increased level of service and local-loop testing. Deploying top-speed, quality DSL service is dependent, in the most part, on the quality and makeup of the local loop. Most providers have adopted, or are turning to, pre-qualification of copper loops in order to determine if local loops are capable of supporting various DSL technologies. Defining a superior installation and maintenance plan is becoming critical in terms of service provider competitiveness. The more is known about the local loop, the greater the efficiency of repair crews and the lower the risk of customer disappointment through installation delays, intermittent failures, or under-performing services. The following chapters look at the testing elements recommended to support DSL through local-loop qualification and DSL service-confirmation testing.

3.1 Determining the Nature of the Problem

Before applying troubleshooting techniques, it is very helpful to know the reason that the loop was tagged as defective in the first place. It is quite easy to locate complete breaks in one or both of the conductors. Without conductivity, all services will not work. A simple TDR test will easily locate the break, allowing field technicians or construction crews to repair. Troubleshooting the local loop for DSL rates that are lower than the rates promised to a subscriber can be far more difficult. There are several factors that could affect service and, in fact, the local loop may simply be too long to ever support the service. In other words, it may be impossible to fix some loops, and customers will have to accept the limited service or no service at all.

Technicians should divide the complaints into three categories:

- No signals passing through the local loop
- Service functioning below acceptable levels
- Service functioning but experiencing occasional intermittent faults

Next, it is important to gather as much information as possible about the service(s) offered. Here is a list of helpful questions to answer:

- Should this loop be connected to a POTS?
- Should this loop provide a broadband service such as ADSL, ADSL2+, SHDSL, VDSL, etc.?
- Is the service on this loop being offered by the incumbent local-exchange carrier (ILEC) or a competitive local-exchange carrier (CLEC)?
- Should this be a dry pair (with no battery)?
- Should the pair have sealing current?

- Does this pair carry a home or business security alarm signal?
- Is this a two-wire service such as POTS, basic-rate ISDN, SDSL, HDSL2, HDSL4, ADSL or SHDSL, or is it a four-wire service such as T1, E1, primary-rate ISDN, DDS, HDSL, or EFM?

It is also important to gather as much information as possible about the make-up of the local loop. Some of these factors will be system-wide:

- According to loop plant records, what is the length of the loop?
- According to loop plant records, what are the lengths and wire sizes (gauges) of each section of loop?
- What type of cable is used (PIC, PULP, etc.)?
- What sections are buried? What sections are aerial?
- How many pairs exist in the F1 distribution bundle? In the F2 local distribution bundle? In the end sections (customer's side)?
- Does the loop enter the customer's premises through an NID?
- Does the loop pass through POTS splitters before it leaves the CO?
- Does the customer premises installation include a single POTS splitter or microfilters?
- What type of protectors (heat coils) are used in the CO?

- What kind of protectors are used at the customer premises?
- What is the age of the loop in that area?
- What cross boxes, junction boxes, and pedestals does the loop pass through?
- Are any of the bundles air-pressurized cable?
- Is the circuit deployed using subscriber loop-circuit (SLC) technology?
- Are there any repeaters or range extenders in the loop?
- Are there any load coils, or compensation capacitors used?
- Are there planned laterals, multiple appearances, multiple end sections or other forms of bridged taps?
- What is the general state of the local-loop plant?

It is also very helpful to note the following factors:

- Is the ground wet or very dry?
- Has it rained in the last few hours or days?
- Is it very hot or very cold?
- Does the environment have a high humidity level?

- Has there been recent seismic activity?
- Has there been a forest or grass fire in the area?
- Has there been heavy wind or storms with lightning activity?
- Have there been any mud slides recently?
- Is there any construction in the area that involves digging (including post holes for fences, etc.)?
- Has there been frost heaving (common in cold climates in springtime)?
- Have any pedestals, cross boxes or telephone poles suffered physical damage (run over by cars, snow ploughs, farm ploughs, construction vehicles, vandals, etc.)?
- Are there any AM radio transmitting towers in the area?
- Are there any industries known to produce high electrical noise in the area (arc welders, laser engravers, electroplating, power company switch yards, heavy industrial motors, electric trains, etc.)?

3.2 Performing a Visual Inspection

It is logical and efficient to do a drive-by visual inspection of the local loop first. A backhoe digging deeply through the direct path of buried loop bundles is an obvious area of concern. Beyond the very obvious, however, it is not very time-efficient to open and inspect each cross box and each pedestal. In fact, opening overstuffed pedestals can stress and break additional pairs, compounding the complexity of the troubleshooting effort.

3.3 Choosing a Test Point

The next logical step is to identify the type of fault that is causing the problem. If the trouble ticket indicates that service was suddenly lost and remains out of service, then checking the existence of an "open" or "short" should be the first test. If the customer has service but complains of noise on the line or lower DSL rates than promised, then the balance of the circuit and noise mitigation procedures should be used. If the circuit works well but once in a while has intermittent faults, then impulse noise, intermittent events (such as momentary continuity breaks when wind moves overhead cable), and splice cases should be investigated. In all of these cases, the troubleshooting technician must choose where to start testing. This choice is often dictated by the operating policy of the service provider. Some telecom companies prefer to start at the CO and work outwards towards the subscriber, as personnel are often collocated in work centers in or near the CO. Testing from this end can often identify the problem straight away, thus saving a truck roll. Other telephone companies prefer to start at the subscriber's premises. The visit often calms the subscriber, makes for good customer service, and allows the technician to gain as much information from the subscriber as possible. Tests can be performed from either end; however, each has its advantages and disadvantages.

3.4 Measuring the Service

Many service providers have made the mistake of rolling out new services without updating their troubleshooting procedures. Measuring loop loss at 1 kHz is helpful but not conclusive when it comes to DSL. In addition, it probably makes sense to repair a local loop to a level of quality suitable for DSL, even when the trouble ticket indicates a voice frequency (VF) problem only. A circuit with VF problems will almost certainly have problems with DSL. The corollary is not true and circuits with DSL problems may have no detectable POTS service problems. It is inefficient to deploy a construction crew to repair a POTS problem, and then send another one out again a few months later, when a DSL service is deployed.

3.5 Avoiding Cable Cuts

In a vacuum, without the use of proper test equipment or proper training, many of today's technicians cut the local loop at cross boxes and pedestals in order to isolate a cable fault. A single trouble ticket can result in three or four cable cuts and resplices. This not only runs up costs for time and splicing supplies, it also exposes the loop to more splices that can corrode or break down in the future. The proper application of a TDR is a far better choice for locating cable faults, as it eliminates the need for cutting the loop.

3.6 Testing the Service Level

If the troubleshooter's first stop is the customer premises, the first test should be aimed at determining if the problem is with the local loop and service or within the customer premises itself.

Normally, the technician should open the "jumpers" in the NID to remove the customer premises equipment and wiring from the local loop.

Next, the technician should perform a service confirmation test towards the CO. In the case of a POTS line, the technician should connect their butt set (hardened portable telephone used by telephone company personnel) to see if they can get a dial tone, place a call, receive a call, and listen to the quality on the line. If the only complaint from the subscriber was failed POTS service and everything seems fine to this point, the problem is likely with the customer's equipment or inside wiring. At this time, the technician would make arrangements to work inside the customer premises. Often, this is a service performed at an hourly rate.

In the case of ADSL2+/VDSL2, the technician will connect a specific test set to the loop, again connecting towards the telephone company's facilities. Once they complete a handshaking routine with the DSLAM, they report the connected rates and some other important parameters of that specific connection. If, at this point, the handshaking is successful and the proper rates are achieved, then the technician should once again anticipate further investigation inside the customer's premises.

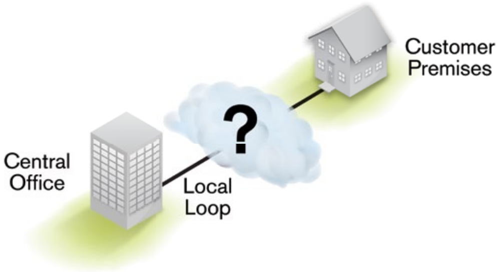


Figure 25. Testing the local loop answers many questions

4 Copper Loop Makeup and Testing

A few service providers use a “best guess” method to determine which subscribers within a given serving area are eligible for a particular version of DSL. Other still focus testing only on voice band analysis. Although voice band analysis wins hands down over the “best guess” method, to truly qualify a circuit for DSL, the service provider must widen the scope of their current methods and procedures or standard operating procedures. By widening the frequency bandwidth used on the pre-qualification testing, operators will have a much better of idea whether or not the circuit under test can handle the high frequencies associated with DSL. By adding wideband testing to the process, the number of false positives for DSL installations can be avoided.

4.1 Basic Electrical Characterization

Digital multimeter (DMM) measurements can reveal a lot about a local loop and the signals it carries. Although parameters such as DC and AC voltages can be performed with a simple DMM, it is recommended to use a more advanced test set; i.e., one that has been purpose-built for telephony applications and therefore automatically tests between all configurations between tip, ring and ground (earth). These test sets also measure loop capacitance, loop current and, if required, loop resistance. From these measurements, it calculates the capacitive balance and the equivalent capacitive length of the loop.

4.1.1 DC Voltage

DC Voltage is the heart of the telephone plant, that is, if analog phone services are being deployed. Within the CO/Exchange is a bank of batteries that provide a constant voltage of approximately 48 VDC. Due to the setup of the local loop with respect the battery connection to tip (T), ring (R), and ground (G), 48 VDC will be seen when measuring between T-R and R-G, but 0 VDC is common between T-G. When testing on a live circuit, you should be measuring 48 VDC (T-R); however, when the battery has been disconnected from the line under test, the voltage should be 0 VDC (T-R). If any voltages are seen when the battery is disconnected, it may be a battery cross situation whereby water has infiltrated the cable bundle and the voltage from another pair is now appearing on the line under test.

To locate the source of a battery cross, use a resistive fault location (RFL) measurement.

4.1.2 AC Voltage

AC voltage should only appear on the line under test if a subscriber ringing signal has been invoked (incoming call). Ringing voltage will be seen from 70 VAC to 110 VAC. Normally, there shouldn't be any AC voltage on any telephone cable pair. If there is more than about 5 VAC between T-R on a line when it is not in ringing mode, it can be an indication of grounding and/or bonding issues either in relation to the telephone plant or even the electric power company plant. In rare situations, the pair may be crossed with a line from the electric power company.

4.2 Length or Distance

Distance is an important factor in the delivery of DSL services; the longer the loop, the higher the attenuation, and the greater the amount of external noise that could be coupled onto the loop from various sources. This means that the longer the loop, the less likely the subscriber will get the DSL speeds they desire.

The “best guess” method is only a partially successful method of eliminating long-loop subscribers since telephone cables are not laid in a straight line. The cables follow streets, roads, tunnels, cable routes and rivers. If a telephone company has detailed cable-plant records, these can be used. Unfortunately, cable-plant records, in most cases, have not been kept up to date, or do not include repair information.

A typical method of determining loop length is by measuring the resistance of a circuit to determine loop resistance. To do so, the far end of the circuit is shorted so that a proper resistance measurement can be made. Once the loop resistance is determined, a calculation using the specific resistive constant for the cable gauge can be made to determine the length of the cable. The smaller the wire gauge, the higher the resistive

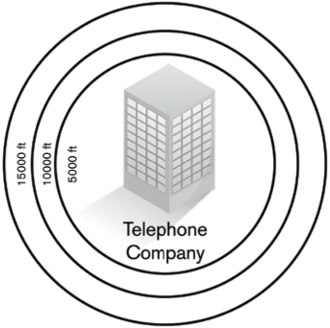


Figure 26. The “best guess” method of determining who gets DSL

Cable Gauge	Resistive Constant
22 AWG 0.6 mm	174 ohm/mile 108 ohm/km
24 AWG 0.5 mm	276 ohm/mile 172 ohm/km
26 AWG 0.4 mm	439 ohm/mile 273 ohm/km

Figure 27. Cable gauge vs. resistive constant

constant, which in turn means the shorter the distance to the end of the circuit (for a given loop resistance value).

Depending upon the plant makeup and where the technician conducts his loop resistance testing, he/she may be faced with a mixed cable gauge environment. In this case, loop resistance will be correct, but the calculation for determining loop length will be incorrect. Segmenting the network to ensure a single gauge of wire is always a good idea to ensure accurate results in this regard. Temperature also plays a factor in loop resistance. Since most cable specifications are referenced at 20°C or 68°F, lower temperatures yield lower resistance, and higher temperatures yield higher resistance. In turn, the calculation for loop length will yield shorter distances in cold weather and longer distances in hot weather.

Alternatively, the capacitance of the cable can be used to approximate its length. Typically, cable has a loop capacitance of approximately 83 nF per mile (52 nF per km) and is consistent for the common cable gauges. This is per the manufacturing process.

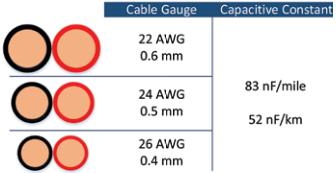


Figure 28. Cable gauge vs. capacitive constant

Using loop capacitance is good for mixed gauged environment. Unfortunately, measuring the capacitance of cable is not always an accurate method of determining cable length if faults or telco equipment exists on the circuit under test. Some local loops have extra capacitors in order to compensate for longer-length impedance-matching. Subscriber-side equipment such as POTS splitters and microfilters, which are added to enable DSL services, add large amounts of capacitance. The capacitance of bridged taps (also called laterals and multiple appearances) is added to the capacitance of the cable. Best practices would dictate to uncouple the telco and subscriber equipment; otherwise, the capacitance added by micro-filters, POTS splitters, telephones and modems would need to be taken into account, resulting in an inaccurate measurement. Additional capacitance makes the local loop appear to be much longer than it really is.

A more accurate approach to determining the correct loop length, but equally important, is to identify the location of faults is by using a time-domain reflectometer (TDR). Using a TDR, a short-duration pulse is sent into one end of the line (normally at the telephone-company service office or

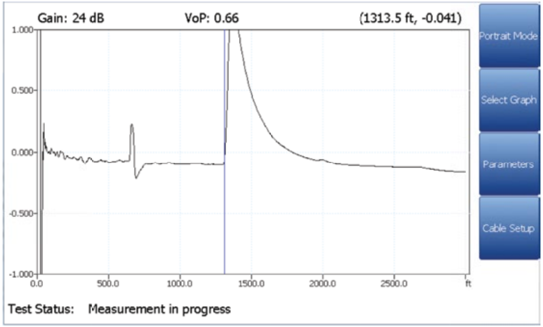


Figure 29. Example of a wideband attenuation test result as measured using EXFO's FTB-635

remote cabinet side). This pulse travels the length of the line and is reflected from the open-loop end of the cable, back towards the service office or remote cabinet to the test device. By knowing the speed at which electrical signals travel (propagate) on twisted-pair cable (typically around 66% of the speed of light), and by accurately determining the single direction travel time, the distance can be determined to the end of the cable as well as to any faults that may exist on the cable.

4.3 Attenuation

It is important to understand that the longer a twisted-copper telephone cable is, the greater the DC resistance. As discussed in Section 3.1, the capacitance also increases with the length of the cable. Like any conductors that are wound in a spiral fashion (i.e., twisted pair), telephone cable also has a certain amount of inductance per unit length. When all of these factors (L, R, C) are taken into account, it can be seen that twisted-pair cable has complex impedance that varies with length.

Figure 30. Illustration of impedance that varies with length

Twisted-pair cables have a non-linear attenuation, that is, higher frequencies are attenuated more than lower frequencies, and this effect is increased on longer circuits. The end result is that short cables have less attenuation overall, and the difference in attenuation between low frequencies and high frequencies is not as pronounced. On the whole, long cables have greater attenuation as compared to short cables. In addition, the higher frequencies on long cables are more greatly attenuated when compared to lower frequencies.

Measuring the attenuation or frequency response of a local loop involves inserting a test tone of a known power level at one end and measuring the power of the tone after it passes through the loop. The difference in power level between the transmitted test tone and received test tone is the attenuation at that frequency. By stepping through a number of different frequencies, the frequency response of the circuit can be determined. Telephone company personnel may also refer to this as insertion loss, attenuation, frequency run, level tracing or slope.

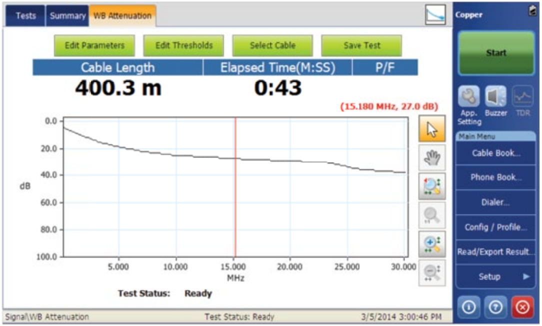


Figure 31. Example of a wideband attenuation test result as measured using EXFO's FTB-635

It is also possible to measure the insertion loss of a local loop from just one end of the local loop. This is achieved by creating an open circuit or short circuit at the far end of the loop. Test instruments use test tones that are inserted at one end of the line. Using advanced mathematics (Fast Fourier Transform or FFT), the transmit signal can be cancelled from the receive signals. That leaves only signals that have traveled the length of the circuit, that have been reflected back from the open or shorted end of the cable and once again traveled the length of the local loop. The one-way attenuation is one half of the overall attenuation measured.

With the results from this test, a technician can determine if various points of loss across the specific bandwidth of interest are too great to be able to transport DSL signals. To make the measured information more readable, frequency response tests are best displayed in a graphical form. Ideally, the frequency response results should be given in level (dB) with respect to frequency (kHz or MHz) for a selected frequency band.

From a frequency response plot, a technician can also view the roll off of the loop and observe notches that are caused by bridged taps and the ringing effects caused by loading coils.

4.3.1 Attenuation at a Specific Frequency

A single frequency measurement of attenuation or insertion loss is not effective for testing loops for their ability to carry the DMT signals of ADSL2+ or VDSL2 transmission. A single bridged tap can cause a reflection that effectively nulls the test tone at the test frequency. A bridged tap, depending upon the length, can knock out a few frequencies (long bridge taps) or a great many frequencies (short bridge taps). Therefore, it is possible to have a huge attenuation at a chosen test tone frequency but, in reality, have a good transmission path for ADSL2+ or VDSL2 (depending on your desired data rate, that is).

$$f=v/4d$$

Formula for determining the center frequency affected by a bridge tap

$$f'=f(2n+1)$$

Formula for determining subsequent nulls

On the other hand, technologies like ADSL/ADSL2+, HDSL, HDSL2, ISDN, and SHDSL use a signature frequency that can be tested using a single test tone. Inserting a tone at these specific frequencies can be used as a rough method to determine the suitability of the loop. This is a good way to approximate the response of the actual system. If the loss at the signature frequency is out of pre-set limits, technicians can isolate loop problems before attempting to install the transmission hardware. The adjacent table lists some of the signature frequencies commonly used to test different technologies.

Table 4. Frequency used by various DSL services

Technology	Signature Frequency
ISDN	40 kHz
HDSL	196 kHz
HDSL2	392 kHz
ADSL2+	300 kHz
VDSL2	12 MHz

4.4 Noise and Crosstalk

Noise is any unwanted signal that could adversely affect the desired signal as it passes through the transmission path. The end result might be a corrupt signal that can be misinterpreted by the receiver. This translates to errors in the digital bit stream. If the noise is corruptive enough, the far-end device may not be able to communicate at all, whereas at marginal noise levels, the data transmission rate may be slowed down.

The noise found on local loops is caused by many sources; light dimmers, radio signals (RFI), neon lights, electric trains and adjacent power lines are a few examples. A common type of noise found in the DSL arena is caused by the electromagnetic coupling of signals from one local loop to another within the same cable bundle—this effect is known as crosstalk. One of the reasons that telephone cable is twisted is in an effort to mitigate crosstalk. Another common type of noise is impulse noise.

4.4.1 Crosstalk

Unlike traditional leased lines and long-distance telephone circuits that use amplification, it is not necessary to measure noise in the presence of an active tone on DSL provisioned local loops. Continuous copper cable does not have inherent non-linear or harmonic distortion effects, as is the case where amplification is in place. A quiet terminated noise measurement is the best method for measuring noise. Again, it is desirable for the technician to be able to view a spectral display (spectrum analysis) of the measured noise. Because ADSL, ADSL2+ and VDSL2 use many carriers (up to 4096 subchannels thanks to the DMT line coding), so long as the total power of the noise is concentrated in a narrow band of frequencies, DSL transmission is still possible. For this reason, a numeric measurement of the total noise power in the transmission bandwidth is absolutely meaningless. Only a measurement that shows the noise distribution in each carrier's bandwidth has any significance. The industry has coined the term power spectral density (PSD) to indicate the graphical display of noise power at various frequencies.

Quiet noise, background noise, noise margin, or idle channel noise, as it is so often called, can be determined by a measurement taken with no test signal impressed on the line. Any background signals found on the cable are therefore measured and considered to be noise and/or crosstalk.

It should be noted that the signals used to carry DSL might be very low in terms of received level, especially those carriers in the upper frequencies where the attenuation presented by the local loop is the greatest. This is why the pass/fail limits established for testing voice circuits are not valid for DSL. Likewise, it is important that testing equipment used for the assessment of a local loop can measure noise power levels that are low enough. Normally, the test set should measure down to at least –140 dBm/Hz, which is roughly equivalent to –100 dBm.

The effects of crosstalk can only be determined in "live" bundles that already carry several DSL services. Consider, for example, an F2 facility with a pair count of 25. If no DSL or other higher-rate services have been deployed on that bundle, there is no useful crosstalk information to be measured. Once the first DSL circuit is deployed, the amount of crosstalk in the band of interest (for example, 2.2 MHz for ADSL2+) will drastically increase. Each subsequently added DSL service will continue to add to the crosstalk level. As far as an unused pair in that count is concerned, every additional service added to the bundle is a potential disturber to signals that will be added to the unused pair. The maximum number of disturbers in a 25-pair count is therefore 24. Many carriers have learned through experience that, on long lines, the first DSL deployed generally works very well until the second service is deployed (and so on).

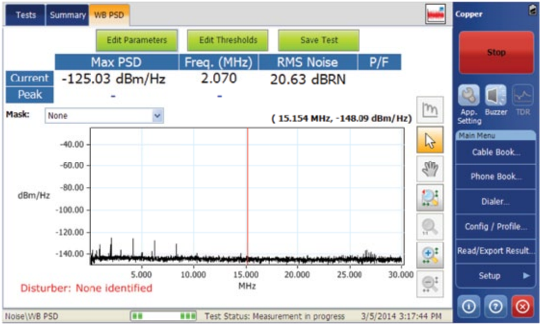


Figure 32. A power spectral density measurement of noise on a local loop, measured with EXFO's FTB-635

4.4.2 Impulse Noise

Spikes of transient voltages or noise can disturb a modem's ability to discern between coding levels or states. If these impulses happen often enough, they can take bandwidth away from the transmission path. Even a captured spectrum of noise across the DSL bandwidth may miss the fact that impulses are occurring frequently enough to cause problems.

Impulses may be complex in nature and may disturb several frequencies at once. Therefore, the common signal codings that carry DSL (DMT, CAP, 2B1Q and TC-PAM) signals can be equally affected. For this reason, measurements of impulse noise are important.

Impulse noise is also a measurement taken with no test signal impressed on the line under test. Instead of measuring the noise power at various frequencies, a threshold is set and a count of random pulses, whose amplitude exceeds the threshold, is taken for a chosen time period, as shown in Figure 33.

Whether or not an operator suspects impulse noise exists on the line, use of INP or G.INP is advantageous to offering quality of experience to users. Counting impulse noise hits that exceed the user-defined threshold is a good start, but it lacks the guidance on what values of INP to use or whether or not G.INP should also be used.

By conducting longer-term monitoring of a line and understanding the total duration of impulse noise spikes, an operator can quickly see what INP value is best, rather than relying on “best guess” methodology.

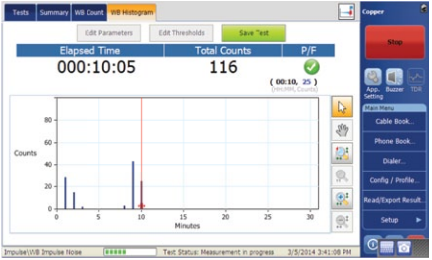


Figure 33. A measurement of counted impulsive noise hits vs. minutes

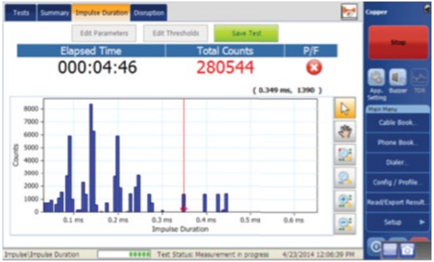


Figure 34. A measurement of counted impulsive noise hits vs. impulse duration.

4.5 Balance

Twisted-pair telephone cable should be both balanced and floating equally with respect to ground. The two conductors (tip and ring) are the same wire size and are twisted to give a consistent amount of electrical noise coupling. The two conductors are insulated with paper (older cables) or plastic (more recent cables) to isolate them from each other and from ground. Cable bundles are air-pressurized, filled with jelly or tightly sealed to keep water ingress to a minimum.

4.5.1 Resistive and Capacitive Balance

The most basic of health checks of the copper twisted pair must include checking the balance of the pairs from an electrical perspective. Utilizing capacitance against an open circuit and measuring T-G and R-G, the percentage balance between T-G and R-G can be determined, where 100% balance (i.e., T lead is the same length as R lead) is the ultimate goal; however, many operators aim for 95-97% balance. Performing a resistance test against a shorted circuit and looking at the balance ratio between T-G and R-G is also a well accepted practice.

In either case, a poor performing circuit can be quickly identified, and the necessary corrective actions can be implemented to solve the problem in a timely manner.

4.5.2 Longitudinal Balance

A more sophisticated balance measurement approach is to look at longitudinal balance. Measuring the longitudinal balance of a pair gives an indication of the differential voltages caused by imperfect balancing of tip and ring with respect to ground. The measurement is given as a level in dB; the higher the dB reading, the better the balance of the cable pair under test.

Longitudinal balance measurements are extremely useful for identifying loops that will suffer from crosstalk once a cable bundle is loaded with broadband signals. This is a good way to prevent future problems on bundles where DSL services have not yet been deployed. Note that loops that have improper longitudinal balance act as an efficient crosstalk receiver or transmitter. This is why a single, poorly balanced loop can bring down an entire bundle.

Longitudinal balance is affected by short circuits or partial short circuits, between either conductor and the cable sheaths and other ground sources. Water in the cable is one of the principal sources of partial conductivity to ground.

For DSL deployments and loop fault-finding, it is important to measure longitudinal balance at many frequencies across the utilized bandwidth. Although a DC fault (i.e., conductivity to ground) will cause problems with longitudinal balance across

Figure 35. A measurement of the longitudinal balance on a local loop

all frequencies, AC faults (i.e., capacitive conductivity to ground) may only present itself as high-frequency imbalances. Capacitive faults occur when cable bundles are squeezed or kinked during installation or with frost heaving, earthquakes, construction loading, etc.

Note: Longitudinal balance tests must be taken with a measurement reference connection to ground.

4.6 Load Coils

Load coils, which are electrically inductive by nature, were introduced into the local loop to lessen the effect of non-linear attenuation on voice circuits, usually on lines exceeding 18 kft or 6 km (including all bridged taps) due to a build-up of capacitance (effect of long lengths of two conductors separated by a dielectric). These series of inductors cause a flattening of the frequency response in the voice band that allows long-length loops to carry acceptable voice transmissions. The placement and spacing of load coils is important to maintain a good voice-frequency response. If a load coil cannot be spaced uniformly, a build-out capacitor is used to add capacitance to the local loop and to compensate for the increased inductance. This build-out capacitor makes the cable section appear longer in an electrical sense. This is why only a time-domain reflectometry (TDR) test will give accurate distance measurement for finding load coils. A conversion of measured capacitance to relative distance (i.e., simply using an ohms-to-distance calculator), can be misleading.

Load coils were optimized for voice band (< 4 kHz) and, as a result, do not allow high-frequency DSL or even TDR signals to pass through. Consequently, it is necessary to find and remove all load coils on a circuit intended for such DSL services.

Load-coil identification may be accomplished in a number of different ways, the easiest being accurate plant records. However, plant records are commonly out-of-date, inaccurate, or non-existent, so alternatives must be used.

A TDR may be used for a graphical interpretation of faults on a line and their respective location. In ideal conditions, a load coil produces a spike in the TDR plot. This is an effective test, but it leaves the user to determine which spike is, in fact, a load coil, and which is another type of cable fault. Plus, most coils are installed at set distances from COs (first coil at 3 kft from the CO, and the following coils installed every 6 kft – depending upon the value of inductance used), so a technician needs only to know if a load coil is present.

With this in mind, many test sets have a built-in load-coil detection feature that utilizes software to determine if load coils are present on a line and how many are installed. A text display is given, announcing the presence of one or more load coils.

A load coil can also be found by using an impedance vs. frequency plot. This test is performed using one test set from one end of the cable. A loop that does not have load coils will have a smooth, ascending impedance plot, whereas a loop with load coils will have wild swings in impedance.

4.7 Bridged Taps

Bridged taps are unterminated lengths of wire connected at some point along the utilized local loop. Various names exist for bridged taps, including laterals, multiple appearances, tail circuits, end taps, etc. As a common practice, most bridged taps were installed as a planning measure so that plenty of local loops would be available for subscribers without doubling the capacity of feeder cable (F1) bundles.

Bridged taps cause a reflection of the original signals that are delayed in time and attenuated to various degrees depending upon their length. These reflected signals can confuse DSL receivers and cause bit errors, which can result in poor DSL service. Field experience has demonstrated that depending on the length, location and overall loop configuration, bridged taps may have no effect on transmission rates or may prevent the service from working entirely.

As mentioned in a previous section, the fundamental frequency, as well as the harmonics caused by the bridge tap, can be determined using the following formulas.

$$f=v/4d$$

Formula for determining the center frequency affected by a bridge tap

$$f'=f(2n+1)$$

Formula for determining subsequent nulls

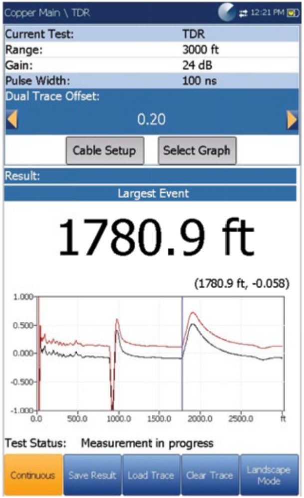


Figure 36. Bridged tap test

Other sources of bridged taps include subscribers, contractors or poorly trained technicians who perform wire repair or circuit rerouting. One example is the practice of running a parallel “gray wire” to externally build around a defective pair. If the left-over bundled section between the new run has any length of wire pair attached at either end, a bridged tap is created. Technicians often leave an unused section of wire pair connected to the newly installed pair, thus producing an unwanted bridged tap.

The taps that create the most problems would be those that are located near the CO or the remote terminal. In practical terms, this generally means the taps within the customer premises or multiple appearances in the local distribution cable (F2). These taps need to be found and removed. Finding a bridged tap is more difficult than finding a load coil. If a bridged tap is long enough, a TDR may be used. Bridged taps produce a TDR trace dip or valley followed by a transition to a positive trace spike or peak. In ideal situations, the distance between the start of the negative TDR trace (dip) and the start of the very next peak is the length of the bridged tap.

One special case to note is when the lateral path (bridged tap) is longer than the primary path to the subscriber. Automatic CO-based loop-qualification test systems that use reflectometry technology to determine the end of a cable will be fooled into thinking that the end of the lateral is the end of the cable and that the end of the bridged tap is the end of the loop.

Test systems that measure loop capacitance to determine loop length will give false distance readings any time a bridged tap exists. The extra capacitance of the bridged tap(s) is added to the overall capacitance. This makes the loop appear longer than its actual length.

It should be noted that all test sets have limitations in locating bridged taps. If the bridged taps are too far away, too short in length or have little of the original local loop beyond them, they may be undetectable.

4.8 Split Pairs

The pairs of wires within cable bundles are twisted for a number of reasons; namely, to reduce the amount of crosstalk coupled to/from adjacent pairs. Telephone-company personnel utilize pairs as needed for customer services. In neighborhoods or business parks, where spare pairs have become scarce, telephone technicians have often turned to “split” pairs to deliver service. A split pair is created from two semi-defective loops, each of which contains a single broken conductor. By using the remaining good conductor from each pair, an additional pair is gained.

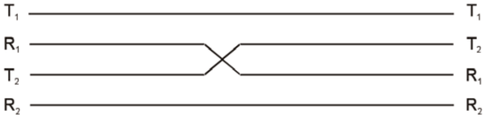


Figure 37. Example of a split pair

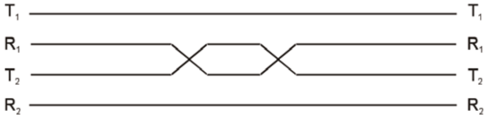


Figure 38. Example of a re-split pair

Split pairs can be acceptable for short-to-medium distance voice frequency applications. For DSL applications, however, the increased amount of crosstalk as compared to normal pairs is unacceptable. In the case of DMT-based DSL, it may cause the upstream and downstream connection rates to be unnecessarily low or it may prevent the establishment of a connection altogether.

Identifying split pairs within cable bundles that already have other DSL circuits within the same binder group is quite simple. Since a split pair does not have a consistent twisting between its two conductors, it will pick up more crosstalk than normal pairs. Therefore, comparing multiple PSD noise measurements taken from several pairs will expose the split pair. Pairs that exhibit abnormally high crosstalk are most likely split or have one of their conductors partially or fully grounded.

In cases where DSL does not exist or the loop has been disconnected from the exchange (or remote) and the subscriber site, placing a signal on one pair and measuring the influence on a second pair will be able to help locate the split pair. This type of test is known as a crosstalk test (i.e., NEXT).

Using a TDR test can pinpoint the location of the split once the split pair has been identified.

4.9 High-Resistance Faults

The copper-loop plant is generally a blend between old and new facilities. A typical loop plant is made up of several different types of cable of various gauges. Typically, 19, 22, 24 and 26 gauge cable is used in the USA and Canada with 0.4, 0.5, 0.6, and 0.8 being used in Europe and the rest of the world.

The earliest cable used was PULP cable. It used copper conductors wound with paper insulation to keep the conductors electrically isolated. Later, plastic-insulated cable (PIC) was introduced; PICs were initially tightly wound into a bundle and later sealed with a jelly designed to prevent water ingress. Some have named this type of cable “icky-pic” as it oozes jelly when cut open.

Some cable bundles are pressurized with compressed air. The positive pressure prevents water from entering should the cable be damaged. In addition, a positive change in monitored out-going airflow can indicate a new nick in the integrity of the cable bundle’s sheath.

The installation process of new cables can create small cuts in the outer sheath or, for that matter, cuts in the insulation that surrounds each conductor. When cable is produced at the factory, the process can create pinholes in the insulation. The aging process, test leads with beds of nails, lightning strikes, and other factors can create faults that can materialize over time.

Cable bundles are normally exposed to ground water. The armored and water-sealed sheath is designed to keep water out. When water does get into the cable bundle, it starts causing problems. In PULP bundles, the effect is immediate. The water soaks into the paper and promotes conductivity between the conductors. This type of fault is easy to observe as several dozen (perhaps hundreds) of customers are immediately affected.

With PIC and especially jelly-filled PIC, faults develop slowly over time. Typically, the insulation around a single conductor can be nicked. The differential voltage between the conductor (tip or ring) and the cable bundle’s shield will cause the ions in the water to bond to the conductor as electrolysis takes place. The end effect is that a relatively high resistance builds between the cable sheath and the conductor.

This type of fault can be tricky to identify/locate and difficult to eliminate. The first symptom of the fault manifests itself as a change in the longitudinal balance (capacitive balance). This causes the differential noise and crosstalk to rise on the affected pair. This results in an increased audible noise, slower DSL rates or a loss of DSL service.

4.10 Resistance Fault Location

To locate high-resistance faults, a resistance fault location (RFL) test should be performed. The first task is to determine if the fault is between tip and ground, ring and ground, or tip and ring. A good test unit will determine this by automatically measuring the resistance between all three conductors. In a cable bundle, the shield or a cabinet-grounding braid that connects to the bundle is used for the ground connection.

Once the fault is identified, the tester automatically instructs the technician to create certain “straps” at the other end of the loop. Normally, a technician will isolate one section of cable bundle that contains the fault before the final location is performed. This not only improves the accuracy of the determined location, but, in most cases, makes it a shorter walking distance to install strapping. Typically, straps (i.e., a short circuit) will be required between both conductors of a spare pair in the bundle, tip or ring of the faulty pair, and ground.

RFL measurements utilize one conductor of the additional (spare) pair to feed voltage to the other end of the defective loop. The other conductor of the spare pair is used to establish a common link and take a voltage measurement.

The result of an RFL measurement is the distance from the measuring unit to the fault, the distance to the strap, and the distance from the strap to the fault.

It should be noted that an RFL measurement consists of determining resistance. Distances are calculated by the measuring instrument through resistance-to-distance calculations. Since the resistance of cable changes with temperature, accurate distance measurements require cable temperature measurements.

For buried cable, it is best to have a temperature probe buried at normal cable depths. If this is not available, the technician could either estimate the temperature knowing the depth, the local climate, and the time of year. Normally, water pipes are buried at depths similar to those of telephone cables, so a measurement of tap-water temperature can be a good indicator.

For overhead wires, the temperature will vary dramatically with ambient temperature and will be dependent on how much of the cable is in the sun. On hot days, they can easily reach an internal temperature of more than 50°C.

4.11 Faulty Splices

Local-loop facilities are rarely straight runs of manufactured cable bundles. Typically, a local loop is comprised of several sections that have been spliced together. Over time, splices tend to oxidize (corrode), become damaged through electrolysis or suffer physical separation.

Usually, a splice becomes a partially open circuit before it becomes a fully open circuit. Any break or degradation in the path of the two conductors of a pair will cause DSL circuits to fail. Finding a bad splice is easily done using a TDR.

4.12 Insulation (or Isolation) Resistance

Before the advent of RFL test sets, it was common to use high voltage (breakdown voltage) to convert high-impedance faults to severe faults that could be more easily located using a TDR or another methodology.

These test sets were mostly effective in PULP cables, where a high-resistance fault was identified between tip and ring. A battery-driven, 100 – 10k VDC supply was briefly applied between tip and ring. The high current of the battery would either cause the pair to weld together at that point or would cause the fault to vaporize.

Unfortunately, high voltage breakdown sets have been known to cause personal injury, damage perfectly good sections of cable, or be ineffective for finding conductor-to-shield faults. In addition, they would

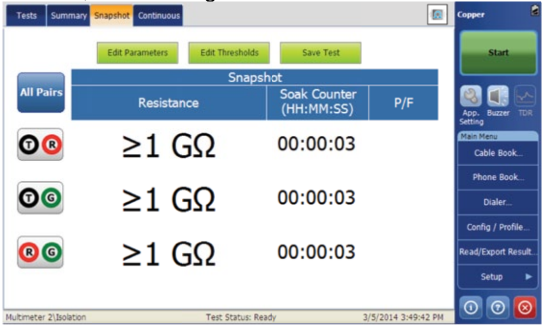


Figure 39. Isolation test

often temporarily complete the electrolysis process, creating the appearance of clearing the fault. However, after some time, the fault would reappear, as water or moisture recurs.

Many telephone companies have banned the use of breakdown test sets. In the worst cases, fires were started, at times inside the customer premises.

4.13 Spectrum Management

A bundle of local loops may carry all of the signals for an entire neighborhood or business park. It is a given that cable bundles will have POTS signals on the majority of the utilized loops. They may also contain traditional signals such as those used for security-system alarm monitoring, T1/E1 transmissions, digital data service (DDS), basic-rate ISDN and HDSL. When adding ADSL2+ or VDSL2, it is important to take into account the signals that already exist in the bundle. In most cases, a B8ZS-coded T1 or HDB3 code E1 signals are not spectrally compatible with ADSL2+ or VDSL2 in the same bundle. The level and frequencies of crosstalk produced by these signals kill the DMT-coded signals in the downstream direction.

In addition to the type of signals in the bundle, the transmitted power levels are also important. In the United States, the Federal Communications Commission (FCC) has set limits on the power that can be transmitted over a loop. The European Community and many other countries have also set similar limits. Since cable bundles are shared between incumbent telephone companies and the competitive telcos (CLECs), under line-sharing and loop-unbundling regulations, some level of spectrum policing is needed. Appropriate testers for this application offer the ability to bridge onto in-service lines in order to determine the transmitted levels on the local loop. It should be noted that signals should be measured at or very near the modem or DSLAM in order to measure the correct levels. Signals measured at mid-points in the circuit will have already been attenuated by an amount dictated by the quantity of cable to that point.

The power spectral density (PSD) signature of a T1 or E1 signal varies based on the type of line coding, the type of framing, and the actual data carried. If it is assumed that live traffic is relatively similar to random data, then the above spectrum, based on a quasi-random signal, will be similar to what might be seen with live traffic.

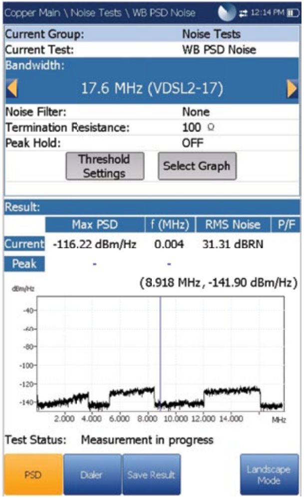


Figure 40. PSD noise test

4.14 Interoperability of DSL Equipment

DSL is a technology that allows subscribers to buy customer premises equipment (CPE) from a number of different manufacturers and feel confident that this equipment will be compatible with the network. However, despite favorable press about interoperability, the best approach for true DSL interoperability is still to use the same brand of DSL chipset in the DSLAM and in the modem equipment at the customer premises. This ensures maximum interoperability and maximizes data rates. Using different vendors may give lower data rates or may cause intermittent problems.

Portable, handheld test sets that determine the upstream and downstream connection rates for ADSL2+ and VDSL2 single-pair, as well as ADSL2+ and VDSL2 bonded-pair deployments are currently available. This “golden modem” approach is widely held as the accepted practice for telecom service providers. All of the major incumbent local-exchange telephone companies (ILECs) and many of the competitive local-exchange carriers (CLECs) rely heavily on this approach. Test sets are also used to troubleshoot the Internet connection through the ATM layer and IP layers; test VoIP; and test MPEG2 or H.264 (MPEG4) video-over-IP on ADSL2+ and VDSL2 (IPTV testing).

Depending upon the data rates and services that the consumer requires, many telephone companies have a pricing scale – the higher the speed requested, the more money this service will cost the user. Performing a single-ended pre-qualification test from the telephone company’s CO can determine the quality of the local loop. Only through actual measurements can it be determined if the loop is too long or if there are any loop impairments that may restrict the DSL speeds being offered by the operator and ordered by the consumer.

Many telephone companies use service-confirmation testing to gather information in order to up-sell their services to the subscriber. If a customer orders a low-cost, low-bit-rate service, but qualifies for a higher-cost service, they could be targeted for up-selling by the service provider’s sales and marketing departments.

More and more service providers are now offering video services to their subscribers. These services could be video-on-demand or broadcast television services. Most companies have chosen

Internet protocol-based television, commonly known as IPTV. Typically, these services require a fairly high-bit-rate DSL service that must be very stable and error-free. For one channel of standard-definition television, around 2 Mbit/s to 4 Mbit/s is required in the downstream direction. For HDTV using H.264 MPEG-4, 6 Mbit/s to 8 Mbit/s is required. Delivery of multiple simultaneous IPTV channels increases the required bandwidth substantially, not to mention the addition of Internet and VoIP bandwidth requirements. As service providers migrate from best-effort delivery of Internet and e-mail services to the triple-play delivery of HDTV, VoIP and Internet services, the demand for circuit-by-circuit testing becomes more crucial.

4.15 Shielding, Bonding and Grounding

Cable bundles have a metallic shield to keep outside electromagnetic interferences from disturbing signals. It is important to identify the frequency and level of the interference to determine the source. It should be noted that DSL modems may work in the presence of noise but can easily provide higher data rates with proper shielding, grounding and bonding.

Theoretically, the local-loop plant should be comprised of cable bundles that are installed and maintained with excellent quality. Cable splices should be very solid and tightly sealed against water ingress. The shields should be well connected electrically to ground at the serving office and should also be properly grounded at the customer premises (to the same earth ground as the electrical service). The shield should be thoroughly connected using copper-braided grounding for very low resistance through pedestals and remote cabinets, both in and out of the pedestal.

The shields should be properly bonded to ground throughout the loop plant. Pairs within pedestals, cabinets and within the customer premises should be cut to the proper length and should remain twisted all the way to their terminations. In some cases, DSL services have failed to operate simply because the consumer had 20 ft. of untwisted wire to connect a normal telephone set or their DSL modem.

Test equipment can be used to measure the resistance of the ground path through a cabinet, to locate a break in the shield (typically a knocked-over pedestal that has had its ground braid come loose), or to locate buried underground shield breaks (using TDR from T and R to shield).

DSL services are much more sensitive than voice services. For this reason, far more care should now be applied in the loop plant.

4.16 Water in the Bundle

Water in the bundle may or may not affect a voice service. In fact, subscribers often tolerate marginal noise and hum on a voice telephone circuit. This same level of noise may adversely affect DSL or even prevent its deployment. Exposing, drying and resealing splice cases is now more necessary than ever. In many cases, wet cable sections need to be replaced. Locating these sections is possible with an RFL test (as explained in previous sections of this guide).

4.17 Powerline Maintenance

Often, telephone cables and powerline cables share poles or underground routes. When power companies perform load-balancing switching, huge bursts of electromagnetic interference can be caused. Capturing a spectrum analysis of the effect these events have on telecommunications is powerful ammunition in the fight to incite corrective/prevention measures.

One of the greatest sources of powerline interference comes from pole-mounted powerline taps. In many cases, powerline customers are served using wrapped powerline taps. A drop wire is simply wrapped around a small exposed portion of copper in the main feeder. When the wind blows these taps, it often produces micro-arcing. Like the first spark-gap radios, plenty of RF noise is produced during electrical arcing. Most DSL modems use only the DMT carriers that are deemed to provide clean and undisturbed DMT signals. Each time the powerline arcs, some DMT carrier signals are lost. Over the period of a windy day, a DSL service can go from acceptable to poor to lost. Until very recently, the only recovery method was to turn the modem off and on (resetting the carriers). Modems are now being made that perform this function routinely.

Some telephone companies monitor the broadband noise spectrum on a single loop within the bundle on a wind-free day. They then send a repair crew from pole to pole, which are shaken one by one. When the pole with the loose electrical tap is shaken, the noise spectrum jumps to a much higher level. At that point, the electrical company can be called to repair the loose electrical tap.

Other sources of electrical noise are conducted between the power grid and the DSL service. In many cases, this is a direct coupling through the AC adapter that powers the DSL modem within the customer premises. Electrical machinery, photocopy machines, laser-engraving machines, neon signs, and arc welders are some of the worst offenders.

Test equipment can be used to prove the correlation between the event (for example arc welding) and a noise burst on the local loop. Often, this interference does not only disturb that one subscriber, but every subscriber in the bundle.

5 ADSL2+ and VDSL2 Service Testing

The most common method to test the data rates for an ADSL2+ or VDSL2 single pair or bonded circuit is to use a test set with a built-in modem chipset whereby the chipset manufacturer could be Broadcom©. The test will establish a connection to the DSLAM and give a maximum upstream and downstream data rate for the pair under test. The modem incorporated in the test set offers a quick and easy test to determine the maximum data rates for a pair.

There are some limitations to this method, as it cannot be performed unless the DSLAM is installed, provisioned, and correctly set up.

In addition, this type of test set uses a number of frequencies to communicate with the xTU-C during training and negotiation. If a circuit is very noisy, especially in the high-frequency range, the modem and test set may not be able to establish a connection. If in doubt in this situation, run copper test measurements to determine where the noise is coming from.

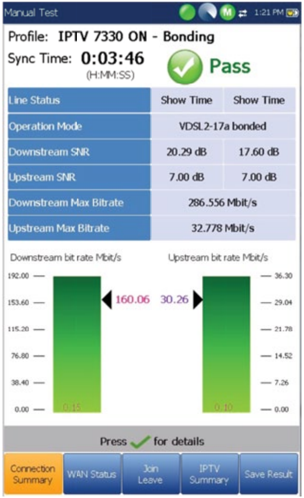


Figure 41. Service test

In the following sections, it is assumed that the line under test is relatively noise-free and a properly provisioned DSLAM is connected to the end of the line.

5.1 DSL Performance Verification

When service installation or troubleshooting is conducted, the first point to test is at the demarcation point between the telephone company and the residential customer. This demarcation point is at the network interface device (NID). Depending on the service the customer is getting, such as IPTV plus high-speed Internet or just high-speed Internet, the base starting point is verification of the DSL layer in terms of performance.

In this situation, the technician would conduct testing at the NID and test towards the DSLAM (per Point 1 in Figure 42).

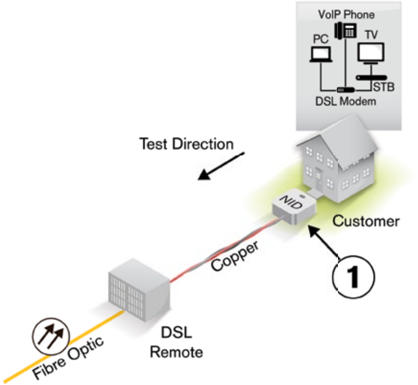


Figure 42. Verification of DSL layer starts at the NID (Point 1)

The first thing the technician would do is ensure that the test setup is correct. He would then start verifying several things such as the actual achieved upstream and downstream data rates, the signal-to-noise ratio margin, CRC count and FEC count.

If the DSL verification proves to be less than desirable, it is highly recommended to redo the test closer to the DSLAM or at the DSLAM, as perhaps the DSLAM port was misconfigured or faulty (per Point 2 in Figure 43). Before going to the DSLAM, the technician can leave the NID as an open circuit so that copper testing can commence after the DSL upstream/downstream analysis.

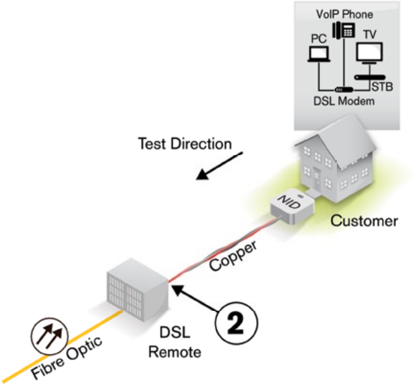


Figure 43. DSLAM port testing (Point 2)

Table 5. DSL testing – Recommended values

Measurement	Threshold	Description
Actual Bit Rate	> target set in DSLAM or what the customer is paying for (i.e. 25 Mbit/s)	**Actual Bit Rate** The actual bit rate is the current negotiated value between the DSL modem (or test set) and the DSLAM port. This value must be greater than the target set in the DSLAM or within the range of the speed package the customer is paying for. If the actual bit rate is less than the target, it's possible that the loop length is too long (high attenuation), there's high noise, there is a cable fault (i.e., short, ground, bridge tap, improper cable balance, etc.) or there is a fault DSLAM, port/modem.
SNR Margin	> 6 dB for Internet > 8 dB for IPTV	**Signal-to-Noise Ratio Margin** The SNR margin is a good way to determine if the circuit will be susceptible to noise causing bit errors. Typically, the target SNR margin (set in the DSLAM) is 6 dB for Internet and > 8 dB for IPTV. With the SNR margin target, the system attempts to maintain a 10^{-7} bit error rate. If the SNR margin falls below the target, the error rate will increase potentially causing DSL frame loss or loss of sync to occur.
CRC	< 5 CRC	**Cyclical Redundancy Check** The CRC counter looks at uncorrectable errors. These are usually caused by cable faults, crosstalk, or impulse noise events. If greater than 5 CRC counts occur over a 15-minute period, the customer may start experiencing issues.
FEC	< 200	**Forward Error Correction** The FEC counter provides analysis on correctable errors. If greater than 200 FEC counts occur in a 15-minute period, the system (DSLAM and CPE) may be spending more time transmitting/receiving FEC than actual data. Typically, reducing the target bit rate in the DSLAM can reduce the FEC count.

Depending on the outcome of the DSL testing, if the DSL performance is suspect, conducting copper testing is required. Even if the DSL performance seems to be acceptable, perhaps the copper loop is being afflicted by an intermittent fault. In both cases, conducting copper testing is highly recommended to ensure that the quality of the copper is good (free of faults, minimal noise, etc.).

5.2 Basic Services Verification

As services vary in complexity, it is advantageous to start with basic tests that verify network connectivity. A ping test (ICMP ping test) is the simplest method to determine if the customer is connected to the Internet after a DSL link to the DSLAM has been established. This ensures the DSLAM port is active, the provider can authenticate the user, and there is an active gateway passing traffic onwards into the Internet.

A ping test can give evidence not only of connectivity, but also if the network seems to be behaving slowly. If it is suspected that the network may be slow, running a traceroute test will allow a technician to visualize the faulty part of the network (which router or switch) or locate heavy network traffic.

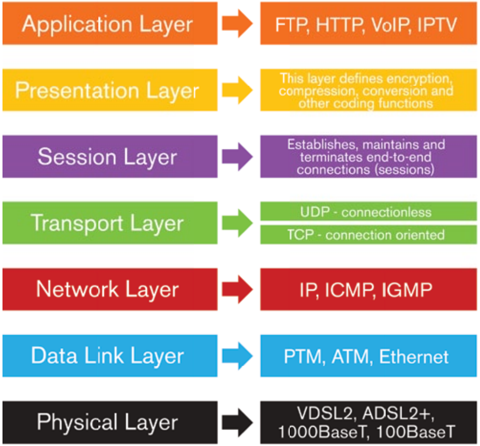


Figure 44. OSI Model

Typically, a DSL installer will not be able to solve an issue that is beyond the DSLAM, but at least it gives the installer confidence that the problem is beyond his control. Depending on where the issue is, a few subscribers or a large number of subscribers will be complaining of slow Internet speeds.

5.3 IPTV/VoIP Services Verification

IPTV and VoIP services require the greatest amount of testing of all. Because applications such as e-mail and Internet browsers automatically request the retransmission of packets (using TCP) that contain errors, Internet data-only lines can tolerate a certain level of impairment. IPTV and VoIP use User Datagram Protocol (UDP), which does not offer retransmission of lost or out-of-sequence packets.

It is also fair to say that users generally consider any speeds above 1 Mbit/s to be a good web-surfing experience (excluding online gamers). In most cases, the DSL circuit is able to provide much more than that. However, delivering an IPTV service, especially multiple-channel HDTV, often utilizes nearly all of the available downstream capacity of the DSL link. Therefore, a relatively small degradation in the DSL connection rate may greatly affect the performance of the IPTV service.

What's more, video requires a relatively constant communications channel. Subscribers will not tolerate video that stops and starts or "freezes", so it is important to ensure that there is enough overhead of downstream channel to accommodate the planned maximum use of the DSL connection. For example, the minimum requirement for an offered ADSL2+ service might be 15 Mbit/s downstream that will support one MPEG4-encoded HDTV channel plus two standard-definition channels. Each MPEG4 channel might be set up in a way that it requires 8 Mbit/s, and each standard-definition channel requires 3 Mbit/s. In total, that is 8 + 3 + 3, plus some provision for Internet data and some provision for VoIP. With such provisioning, the total requirement is close to the DSL connection rate (14 Mbit/s vs. 15 Mbit/s). Test equipment should be used to ensure that the actual DSL connection rate is achieved and that the whole circuit runs error-free with all three channels simultaneously.

The quality of both IP networks and DSL connections can change over time. Technicians should monitor an installation of an IPTV service for 15 minutes in order to check the stability of the overall customer experience, particularly packet loss. Loss of IP packets (ultimately those carrying MPEG information) may occur for multiple reasons – bandwidth limitations, network congestion, failed links and transmission errors. Depending on the type of transport protocol used for the video streaming, a packet loss will affect the quality of the perceived video differently. When UDP is used, the lost packets will directly affect the image since the information cannot be recovered and the image will be corrupt or unavailable, and when transmission control protocol (TCP) is used, a packet loss will generate a retransmission, which can produce a buffer underflow that may result in a frozen image.

6 Summary

Based on what has been discussed thus far, below is a summary of what can be done to perfect local-loop testing techniques. The weakest link in the DSL chain is the copper local loop. Each local loop is slightly different from the next. They vary in length, quality and noise levels. When DSL services don't work, or connect rates need to be improved, it is time to bring out proper copper cable troubleshooting tools.

Table 6. Local-loop testing techniques

Auto-tests can be used as close-out tests, whereby the results from these tests can be uploaded into cloud-based servers for data-mining by operators.

Customer has no connection	Customer has bad rates	Customer has intermittent problems
Copper auto-tests provide quick pass/fail indication of loop quality. TDR, loop resistance and/or loop capacitance can be compared against loop plant records to see if major physical faults exist. TDR or smart fault location measurements such as EXFO's FaultMapper is the best solution as users can "visualize" faults that resistance and capacitance tests are not able to show.	Copper and DSL auto-tests provide quick indication of loop and DSL quality. TDR, loop resistance and/or loop capacitance can be compared against loop plant records to see if major or minor physical faults exist. TDR or smart fault location measurements such as EXFO's FaultMapper is the best solution as users can "visualize" faults that resistance and capacitance tests are not able to show. Spectrum analysis (PSD) and impulse noise testing help isolate noise problems. Crosstalk, REIN and SHINE could be attributing factors to the poor data rates.	Copper and DSL auto-tests provide quick indication of loop and DSL quality. TDR, loop resistance and/or loop capacitance can be compared against loop plant records to see if major or minor physical faults exist. TDR or smart fault location measurements such as EXFO's FaultMapper is the best solution as users can "visualize" faults that resistance and capacitance tests are not able to show. Spectrum analysis (PSD) and impulse noise testing help isolate noise problems. Crosstalk, REIN and SHINE could be attributing factors to the poor data rates.

7 Author Information

7.1 About the Author

Chris Dunford is a Product Line Manager for EXFO's Access business unit and has been focusing on copper and DSL test and measurement solutions for over 17 years. Mr. Dunford has written several articles on technologies such as IPTV, VDSL2, and Vectoring that have appeared in publications such as OSP Magazine and EXFO Blog and has been a speaker at events held by OSP EXPO and Light Reading.

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8 Bibliography

8.1 ITU-T Recommendations

8.1.1 DSL Recommendations

Number	Title
G.991.1 (10/98)	High-bit-rate digital subscriber line (HDSL) transceivers
G.991.2 (12/03)	Single-pair high-speed digital subscriber line (SHDSL) transceivers
G.992.1 (07/99)	Asymmetric digital subscriber line (ADSL) transceivers
G.992.2 (07/99)	Splitterless asymmetric digital subscriber line (ADSL) transceivers
G.992.3 (04/09)	Asymmetric digital subscriber line transceivers 2 (ADSL2)
G.992.5 (01/09)	Asymmetric digital subscriber line 2 transceivers (ADSL2) – Extended bandwidth DSL2 (ADSL2+)
G.993.2 (12/11)	Very-high-speed digital subscriber line transceivers 2 (VDSL2)
G.993.5 (04/10)	Self-FEXT cancellation (vectoring) for use with VDSL2 transceivers
G.994.1 (06/12)	Handshake procedures for digital subscriber line transceivers
G.996.1 (02/01)	Test procedures for digital subscriber line (DSL) transceivers

G.996.2 (05/09)	Single-ended line testing for digital subscriber lines (DSL)
G.997.1 (06/12)	Physical-layer management for digital subscriber line transceivers
G.998.1 (01/05)	ATM-based multi-pair bonding
G.998.2 (01/05)	Ethernet-based multi-pair bonding
G.998.4 (06/10)	Improved impulse noise protection for DSL transceivers

8.1.2 Copper Testing Recommendations

Number	Title
O.9 (03/99)	Measuring arrangements to assess the degree of unbalance about earth
O.41 (10/94)	Psophometer for use on telephone-type circuits
O.71 (11/88)	Impulsive noise measuring equipment for telephone-type circuits

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Should you need more information, please do not hesitate to contact me (see Chapter 8 for contact details).

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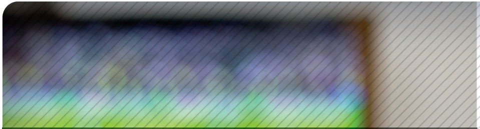

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