About EXFO

EXFO is a recognized test and measurement expert in the global telecommunications industry through the design and manufacture of advanced and innovative solutions as well as best-in-class customer support. The Telecom Division, which represents the company’s main business activity, offers fully integrated and complete test solutions to network service providers, system vendors and component manufacturers in approximately 70 countries. One of EXFO’s strongest competitive advantages is its PC/Windows-based modular platforms that host a wide range of tests across optical, physical, data and network layers, while maximizing technology reuse across several market segments. The Life Sciences and Industrial Division mainly leverages core telecom technologies to offer value-added solutions in the life sciences and high-precision assembly sectors. For more information about EXFO, visit www.EXFO.com.

About the Authors

Robert Fitts attended the University of Guelph and is an Electronics Engineering (Telecommunications) Technology graduate of Fleming College near Toronto, Canada. As EXFO’s Vice-President, Product Management, Copper Access business unit, Mr. Fitts has been an active participant in the field of local-loop testing, DSL, IPTV and VoIP. Mr. Fitts has nearly 25 years of direct experience in the telecommunications testing industry.

Chris Dunford is an Electronics Engineering Technology graduate of Fleming College near Toronto, Canada. He is currently Product Manager for EXFO’s Copper Access business unit. Mr. Dunford is active in the field of testing local loops that carry voice, HDSL, G.shdsl, ADSL, ADSL2, ADSL2+, SHDSL, VDSL, and VDSL2.
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1. Introduction

This book describes practical methods to detect and repair faults and impairments found in the local-loop telephony cable plant. Although all aspects of telephone cable are discussed, an emphasis is made on preparing cables for the broadband signals of DSL. This book is also a useful guide for other deployment and testing issues regarding the services carried by DSL such as Internet services, e-mail, IPTV, and VoIP.

1.1 Background

The traditional telephone network, commonly known as the plain old telephone system (POTS), 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 in length; however, some can be as long as 90,000 feet in rural areas. Once a subscriber's telephony signals arrive at telephone company central offices, the analog speech signals are digitized and carried from city to city and country to country over digital transmission facilities. These days, this is done primarily over fiber-optic cables, although plenty of microwave radio systems are also in use. Currently in the U.S., there are 194 million telephone lines that are routed through circuit switches, of which 100.2 million are residential. Worldwide, this figure is estimated to be upwards of 900,000,000. It took over a hundred years and hundreds of billions of dollars to build the current telephone network. A large part of the investment has been made in the local-loop plant; in other words, the copper wire between the central office (CO) exchange and the subscriber.

A limitation of the traditional telephone network is its relative inability to efficiently carry data. Since the system was only designed to carry voice signals (300 to 3400 Hz), the switched circuits used in these systems are bandwidth-limited such that the upper limit of data transmission is approximately 38,400 kb/s. This stems from how the POTS network was developed. An input device such as a telephone takes the human voice and converts it into an electrical equivalent in terms of volume (signal amplitude) and pitch (frequency of wave change) – basically, an analog signal. These analog signals are transmitted over the copper wires. The analog signal is digitized at the central office and then transmitted over the digital long-distance network. Once delivered to the switch that serves the subscriber at the final destination, the signal is converted back to sound (spoken) for the end user to hear. Due to this architecture, early data transmission technologies relied on this process as well. As an example, a V.34 modem takes the digital information from one personal computer (PC) and converts it to analog signals (modulation) to be transported over the dial-up network. At the destination, another V.34 modem converts the incoming analog signal back to a digital data stream (demodulation) so that a second PC can use the information.
Within the past few years, digital subscriber line (DSL) technology has become popular and is being rapidly deployed. DSL bypasses the bandwidth-limited, circuit-switching infrastructure of the POTS network. In the case of DSL, the copper local loops that carry DSL signals from the subscriber to the central office are terminated into a parallel device called a digital-subscriber loop-access multiplexer (DSLAM). From the DSLAM, the data moves directly to high-speed digital backbone networks that connect to application servers such as those found at Internet service providers. In addition, DSLAMs may serve virtual private networks (VPN) to corporate users, or may enable other services such as streaming video services. The prime advantage of DSL is that it permits the reuse of the current investment in existing copper, but without dependency on, and limitations of, the central office switch.

Eventually, higher-bandwidth media such as fiber-optic cable will reach each and every business and residence. In the meantime, DSL provides a cost-effective way to roll out desirable broadband services such as video-on-demand (VoD), Internet protocol-based television (IPTV) services, Internet access, voice over Internet protocol (VoIP) and virtual private network (VPN) services to a vast majority of residential and business telecom subscribers.
2. What’s Behind DSL?

DSL is a digital broadband technology that involves sending digital information over a subscriber’s line, which is also referred to as the local loop. The acronym DSL stands for digital subscriber line. The applications of DSL involve the transport of high-speed data to residential and business customers. 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 subscriber, while ADSL (where the A stands for asymmetrical) is best suited for the residential consumer. Each of these technologies will be explained in later chapters of this book.

Compared to regular analog modems (for example, a dial-up, 56 kb/s V.34 modem), 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, DSL provides between 256 kb/s and 100 Mb/s. This allows for the simultaneous transmission of high-quality digital voice, data and perhaps video.

Service providers have been deploying HDSL technology for several years now. HDSL is primarily used as a more efficient and cost-effective method of delivering T1 or E1 services — the high-speed digital connections traditionally used to connect businesses to public and private networks. More recently, ADSL has been deployed in order to bring rich-content broadband services to residential consumers. The pioneers of ADSL 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.
Telephone companies are not the only ones delivering broadband services to the residential consumer. Cable companies are leveraging installed coaxial cables with cable modems to deliver broadband service. Coaxial cable has a higher bandwidth potential as compared to bundled twisted-pair telephony cables. Cable modems, however, utilize a broadcast architecture. This means that the link between the user and the Internet (through the cable company) is shared amongst other cable modem users in a neighborhood arrangement. This results in inconsistent data rates based on the amount of traffic. DSL, unlike cable modems, is not shared, resulting in relatively consistent data rates for each user, based on the length and condition of the local loop.
In addition to DSL and cable modems, wireless service providers offer broadband services, as do satellite service providers, powerline carrier providers, and laser line of site providers. These services are far less common than DSL and cable modems at the moment. They could, however, pose a competitive threat in the future. It should also be noted that DSL is an interim solution, as it is generally agreed that fiber-optic cable will eventually reach each subscriber. Most experts agree that it will take another 15 to 20 years for fiber to reach the majority of subscribers due to the massive investments required to achieve this ideal.
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 central telephone office; 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 local telephone company's central office 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 providers' central office
- The proximity 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 power feed and grounding
4. Pre-Qualifying for DSL

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 coupled onto the loop from various sources. This means that the longer the loop, the less likely the user will get DSL. Many service providers use only a “best guess” method to determine which subscribers are within the serving area for a particular version of DSL. Businesses are less likely to be denied DSL as there is a higher concentration of businesses in urban areas. Telephone companies have generally designed their networks in such a way that these areas are well served. On the other hand, DSL is relatively new to the residential user. Longer loops are a more common limiting factor in residential DSL delivery.

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. They 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 more accurate approach to determining the correct distance from the telephone company’s serving office is through the method of pre-qualification. Generally, an automatic test system is used to measure some parameters of each loop in order to determine its length and perhaps its quality. One method that is in common use is time-domain reflectometry (TDR). Using this method, a short-duration pulse is sent into one end of the line (normally at the telephone-company service office or 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 (usually around 66% of the speed of light), and by accurately measuring the round-trip travel time, the distance can be determined.

Figure 4.1 – The “best guess” method of determining who gets DSL.
If a local loop is properly terminated (i.e., connected to a telephone and DSL modem at the subscriber site), the energy of a TDR pulse may be totally absorbed and not reflected. Telephone companies that rely solely on TDR therefore need to install an automatic loop-disconnect device within the network interface device (NID), a small box attached to the outside of a customer's premises. Alternatively, the telephone company can dispatch personnel to the subscriber's location to run the test (i.e., roll a truck). The latter is time-consuming and expensive, but it may be a good interim solution while waiting for automated test systems to be fully deployed.

Alternatively, the capacitance of the cable can be measured to approximate its length—the longer the cable, the greater the capacitance. Typically, cable has a capacitance of approximately 83 nF per mile (51 nF per km). Unfortunately, measuring the capacitance of cable is not always an accurate method of determining cable length. The distance between the conductors has an effect on its capacitance. Each type and brand of cable bundle has a unique value of capacitance per mile. Some local loops have extra capacitors in order to compensate for longer-length impedance-matching. Subscriber-side equipment such as POTS splitters and micro-filters, which are added to enable DSL services, add large amounts of capacitance. The capacitance of bridge taps (also called laterals and multiple appearances) is added to the capacitance of the cable. As is the case for TDR measurements, the local loop needs to be uncoupled from the subscriber's premises; otherwise, the capacitance added by micro-filters, POTS splitters, telephones and modems would need to be taken into account for an accurate measurement. Additional capacitance makes the local loop appear to be much longer than it really is.
Interoperability of ADSL Equipment
5. Interoperability of ADSL Equipment

DSL is slowly becoming 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. Despite favorable press about interoperability, the best approach for true DSL interoperability is still to use the same brand of equipment in the central office DSLAM and in the equipment at the customer premises. This ensures maximum interoperability and maximizes data rates. Using different vendors may give lower data rates, cause intermittent problems, or prevent technical people within the service provider from having network management visibility of the customer premises equipment.

Portable, handheld test sets that determine the upstream and downstream connection rates for actual ADSL and ADSL2+ deployments are currently available. This “golden modem” approach is widely held as the accepted practice for telecom service providers in North America and around the world. All of the major incumbent local-exchange telephone companies (ILECs) and many of the competitive local-exchange carriers (CLECs) use this approach.

Installers and maintenance staff use such portable test sets to confirm the connection rates of both asymmetrical (ADSL, ADSL2+) and symmetrical (SHDSL) services. They are also used to troubleshoot the Internet connection through the ATM layer and IP layers; test VoIP; and test MPEG video over IP on ADSL, ADSL2 and ADSL2+ (IPTV testing).

Depending upon the data rates and services that the user wishes to get, 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 central office can estimate the quality of the local loop. Only through actual measurement can it be determined if long lengths or loop impairments actually restrict the DSL level.
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.

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 is very stable and error-free. For three channels of standard-definition television, around 6 Mb/s is required in the downstream direction. For HDTV, 12 Mb/s or more is required. As service providers migrate from “best effort” delivery of Internet and e-mail services to the triple-play delivery of HDTV television, VoIP and Internet services, the demand for circuit-by-circuit testing becomes more crucial.
Today, there are a number of different 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 day one. 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 this is not common 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 central office (CO) or in a remote cabinet, and the other at the customer premises inside the DSL modem/router. Although rarely labeled DSL, integrated-services digital network (ISDN) service is a unique example of a type of DSL because although it is a digital technology, it uses analog signals over the existing telephony local-loop cabling infrastructure. However, ISDN differs from pure DSL technologies in that it is a public switched-network service, as opposed to DSL that is point-to-point over the local loop and generally ATM- and/or IP-concentric.

Some of the more popular xDSL technologies are described as follows:

**Integrated-services digital network - ISDN** - Can be considered one of the first DSL technologies. ISDN was developed to simultaneously carry digital voice, data, and images 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, data, and images, 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 kbps symmetrically. ISDN is also available in a primary-rate interface (PRI) configuration. The PRI offers data/voice/image transfers of up to 1.544 Mbps (North American T1 format) over 23 B channels with one D channel or up to 2.048 Mbps (European and international E1 format) over 30 B channels with one D channel. Each channel in the PRI configuration operates at 64 kbps.
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.

**ISDN digital subscriber line** - IDSL – is similar to ISDN except a packet router replaces the CLASS 5-style switch at the central office. With this technology, there is generally only one logical channel containing all the information. IDSL is always connected to the server and therefore “calls” don’t need to be set up. This type of service is now considered obsolete technology that has mostly been replaced by ADSL, ADSL2+ or SHDSL.

**High-bit-rate digital subscriber line** – HDSL – is a symmetric DSL similar to T1 or E1 in that it delivers a bit rate of up to 1.544 or 2.048 Mb/s. Most HDSL systems use one or two copper cables, twisted pairs, although some very early 2.048 Mb/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 E1 pipes, local telcos have been using the 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 E1. HDSL uses 2B1Q or carrier-less amplitude/phase modulation (CAP)-based line coding.

HDSL2 and SDSL are similar technologies to HDSL in operation, but they are 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.

**Symmetrical high-speed digital subscriber line** — SHDSL — is a...
technology that is similar to HDSL and HDSL2. SHDSL operates over a single pair or two pairs of wire, depending upon the application. For single-pair operation, SHDSL offers data rates from 192 kb/s to 2.3 Mb/s in a symmetrical fashion, while two-pair operation offers data rates ranging from 384 kb/s to 4.72 Mb/s.

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/E1 replacement technology and is also well-suited for VoDSL solutions.

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.

**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 far more information than they create, ADSL is optimal for Internet and other IP-based services. Downstream rates range from 256 kb/s to 9 Mb/s, while upstream bandwidth ranges from 16 kb/s to 640 kb/s. ADSL transmissions may work at distances of more than 18,000 feet over a single copper twisted pair of 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 4 kHz range.
As a necessary precaution, a low pass filter is placed on the line to separate ADSL signals from POTS signals. These small devices 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 ANSI T1E1.4 published standards.

Two types of line coding exist for ADSL. An early scheme used a non-standards-compliant carrier-less 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 book 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.

A DMT transmission scheme divides the frequency band from 0 Hz to 1.104 MHz into equally spaced subchannels or “bins.” 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.
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.

DMT standards suggest that equipment can use up to 15 analog levels per frequency bin to encode data per subchannel. However, using the maximum 15 states per bin would be practical or allowed by government regulators in a cable bundle. For the most part, ADSL modems 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.

- **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 Mb/s. G.Lite uses 128 bins rather than 256 (still using 4.3125 kHz subchannel bandwidth) and only up to 8 states/bin can be encoded per subchannel.

- **ADSL2**: This is an improved version of ADSL with slightly improved data rates. Described in ITU-T standards G.992.3 and G.992, ADSL2 can offer the same bit rate over longer loops and also includes on-the-fly rate adaptation as well as certain diagnostics of the local loop. ADSL2 modems should generally be backward-compatible with ADSL modems.
ADSL2+ — Shortly after the release of ADSL2, the standards for ADSL2+ (ITU-T standard G.992.5) were published, and chip sets that supported the technology became available. This scheme more than doubles the downstream data rate of ADSL to 25 Mb/s by doubling the utilized bandwidth (from 1.1 MHz to 2.2 MHz) and doubling the number of DMT carriers (from approximately 256 to approximately 512). 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. Not all of the world’s carriers have launched services using ADSL2+ modems yet, but most plan to use this technology very soon. In addition, the bit rates and the mature feature set offered by ADSL2+ may replace plans that some carriers have to upgrade their networks to very-high-speed DSL (VDSL) and VDSL2. Other carriers will embrace VDSL2 or fiber all the way to the subscriber.

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 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.

Very-high-speed digital subscriber line – VDSL — The intent of VDSL is to provide users with very-high-speed asymmetrical and symmetrical services by placing carriers at frequencies up to 30 MHz and supporting bit rates as high as 52 Mb/s. The trade-off of VDSL is that it can only operate at higher bit rates on relatively short loops (less than 4500 feet). To achieve the short distances and high rates, VDSL is typically deployed in a fiber-to-the-curb (FTTC) architecture, in which a fiber-optic backbone (OC-3, OC-12, OC-48, GigE, or 10GigE) network feeds a neighborhood. Because of the loop’s distance limitations and the cost of deploying fiber-optic cable to each serving area, VDSL has been mostly successful in multitenant units (MTU) or multifamily units (MDU) although some carriers have announced plans to deploy large-scale VDSL2.

Figure 6.7 – VDSL architecture
The standards bodies such as ITU-T and ANSI Committee T1 have preliminarily defined VDSL to use frequencies up to 12 MHz; maximum asymmetrical data rates of 22 Mb/s (downstream) and 3 Mb/s (upstream); and maximum symmetrical data rates of 13 Mb/s.

The typical makeup of a VDSL deployment will consist of an optical network unit (ONU), a VDSL transceiver unit ONU (VTU-O), and a remote VDSL transceiver unit (VTU-R).

As in the case of ADSL, VDSL may coexist with POTS on the same loop. One difference between ADSL and VDSL is that VDSL uses a slightly different approach to upstream and downstream band allocation. Instead of having just one upstream band and one downstream band, VDSL uses two downstream bands and two upstream bands, with the first downstream band at the lowest VDSL frequencies.

VDSL can operate in two modes depending upon the manufacturer and service provider. The VDSL standard proposes two line-coding techniques - single-carrier modulation (i.e., CAP), and multicarrier modulation (i.e., DMT).

VDSL2 - This technology promises to combine the benefits of ADSL and ADSL2+ with the advantages of VDSL. Again, DMT carriers are used to transport data over the local loop. On very short local loops, VDSL2 can transmit up to 100 Mb/s in both directions simultaneously. In practical applications on loops of up to 4,000 feet, downstream data rates of 25 Mb/s can be achieved. This makes VDSL2 very compelling for the delivery of HDTV and other broadcast-quality video services.

### Table 1 - Data rates for asymmetrical and symmetrical service

<table>
<thead>
<tr>
<th>Service Type</th>
<th>Downstream Data Rate (Mb/s)</th>
<th>Upstream Data Rate (Mb/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asymmetrical</td>
<td>22</td>
<td>3</td>
</tr>
<tr>
<td>Symmetrical</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>13</td>
</tr>
</tbody>
</table>

### Figure 6.8 - Plan 998 for North American VDSL implementation
7. DSL Testing and Loop Qualification

With the growth in Internet, video on demand (VoD), broadcast/multicast video services (IPTV) and small office/home office (SOHO) applications has come an increased emphasis on providing stable, high-speed, broadband connections. 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, or are turning to pre-qualification of copper loops in order to determine if local loops are capable of supporting various DSL transmission rates. Defining a superior installation and maintenance plan is becoming critical in terms of service provider competitiveness. The more that 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 service. With many CLEC’s struggling to compete, consumers are flocking to the incumbent local-exchange carriers (ILECs) and other name-brand DSL suppliers for quality. This chapter looks at the testing elements recommended to support DSL through local-loop qualification and DSL service-confirmation testing.

7.1. Frequency Response

It is very intuitive that the longer a twisted-copper telephone cable is, the greater the DC resistance. As discussed in Chapter 4, 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.

Twisted-pair cable therefore has a non-linear attenuation. Higher frequencies are attenuated more than lower frequencies, and this effect is enhanced 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 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, level tracing or slope. 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. After some isolation, the transmit signal is canceled 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) 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 bridge taps and the “ringing” effects caused by loading coils.
7.2 Insertion Loss at a Specific Frequency
A single frequency measurement of insertion loss is not effective for testing loops for their ability to carry the DMT signals of ADSL transmission. A single bridge tap can cause a reflection that effectively nulls the test tone at the test frequency. A bridge tap will only knock out very few frequencies. Therefore, it is possible to have a huge attenuation at a chosen test tone frequency but, in reality, have an excellent transmission path for ADSL. On the other hand, technologies like HDSL, HDSL2, ISDN, IDSL, SDSL, 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 the “signature” frequencies commonly used to test each technology. Notice that IDSL and ISDN use the same test frequency. HDSL2 and SDSL also use the same frequency.

<table>
<thead>
<tr>
<th>Technology</th>
<th>“Signature” Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISDN/IDSL</td>
<td>40 kHz</td>
</tr>
<tr>
<td>HDSL</td>
<td>196 kHz</td>
</tr>
<tr>
<td>HDSL2/SDSL</td>
<td>392 kHz</td>
</tr>
</tbody>
</table>

Table 2 – Frequency used by various DSL services

7.3 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 is slowed down.

The noise found on local loops is caused by many sources; light dimmers, radio signals, neon lights, electric trains, and adjacent power lines are a few examples. The most common and problematic types of noise are caused by the electromagnetic coupling of signals from one local loop to another within the same cable bundle. This effect is known as crosstalk. In fact, the reason that telephone cable is twisted is to reduce crosstalk. The reason that the twisting of the wires in a pair works is that, every few inches (or centimeters), the signal coupling from adjacent pairs is reversed. This reversal helps to cancel the previously-coupled signal.

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 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), 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 meaning. The telecom 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 –110 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.
7.4 Impulse Noise

Spikes of transient voltages or noise can also 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. In addition, 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.

In order to measure only the impulses that affect the DSL of interest, the American National Standards Institute (ANSI), the European Telecommunications Standards Institute (ETSI) and the International Telecommunications Union, Telecom (ITU-T), all of which are standards bodies, have defined various noise filters. The table below lists those filters, along with their bandwidths and their application:

<table>
<thead>
<tr>
<th>Filter</th>
<th>Related Technology</th>
<th>Frequency Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>D Filter</td>
<td>DDS</td>
<td>0 kHz to 32 kHz</td>
</tr>
<tr>
<td>E Filter</td>
<td>ISDN</td>
<td>1.0 kHz to 50 kHz</td>
</tr>
<tr>
<td>F Filter</td>
<td>HDSL</td>
<td>4.9 kHz to 292 kHz</td>
</tr>
<tr>
<td>G Filter</td>
<td>ADSL</td>
<td>20 kHz to 1.1 MHz</td>
</tr>
</tbody>
</table>

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 7.4, above.

![Figure 7.4 - A measurement of counted impulsive noise hits.](image-url)
7.5 Longitudinal Balance

A proper pair of local-loop wires consists of two conductors, both of which are floating and balanced with respect to ground. In other words, neither is connected, even partially, to ground. 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 lower the dB reading, the better the balance of the cable pair under test. A poorly balanced pair invites greater near-end crosstalk (NEXT) or far-end crosstalk (FEXT) that may disturb the carried signals.

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 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.

Figure 7.5 - A measurement of the longitudinal balance on a local loop

Note: Longitudinal balance tests must be taken with a measurement reference connection to ground.
7.6 Load-Coil Detection

Load coils were introduced in the local loop to lessen the effect of non-linear attenuation on voice circuits, usually on lines exceeding 18 kft (including all bridge taps). 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) or frequency-domain reflectometry (FDR) test will give accurate distance measurement for finding load coils. A conversion of measured capacitance to relative distance can be misleading.

Load coils result in large attenuations of signals at higher frequencies, making the transport of DSL signals impossible. As a result, it is necessary to find and remove all load coils on a circuit intended for such services. It should be noted that a new breed of load coils that do not need to be removed has been introduced recently by an American company. 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 ft from the CO, and the following coils installed every 6 ft – 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 test 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 similar to the impedance plot shown in Figure 7.7.

Figure 7.7 – Example of load-coil detection and count, produced with EXFO’s CableSHARK.
Bridge taps are unterminated lengths of wire connected at some point along the utilized local loop. Various names exist for bridge taps, including laterals, multiple appearances, tail circuits, etc. As a common practice, most bridge taps were installed as a planning measure so that plenty of local loops would be available for subscribers without doubling the capacity of distribution-cable (F1) bundles. Most homes are wired with multiple telephone jacks. If these appearances are not treated with micro-filters or some other method of termination, they act as short-distance bridge taps. If left unterminated, bridge taps cause reflections of the original signals that are delayed in time and somewhat attenuated. These signals can confuse receivers and cause bit errors. In addition, the extra attenuation caused by bridge taps may reduce DSL signal power and therefore DSL transmission rates. Field experience has demonstrated that depending on the length, location and overall loop configuration, bridge taps may have no effect on transmission rates or may prevent the service from working at all. A degradation of 300 kb/s is common.

Other sources of bridge 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 leftover bundled section between the new run has any length of wire pair attached at either end, a bridge tap is created. Technicians often leave an unused section of wire pair connected to the newly installed pair, thus producing an unwanted bridge tap.

Many negative effects caused by bridge taps can be reduced or eliminated by the digital signal processing algorithms found in most DSL systems. 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 bridge tap is more difficult than finding a load coil. If a bridge tap is long enough, a TDR may be used. Bridge taps produce a TDR trace dip followed by a transition to a positive trace (a hump 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 bridge tap. New ANSI standard TR68 makes ADSL2+ modems more resilient to bridge taps.
One special case to note is when the lateral (bridge tap) is longer than the primary path to the subscriber. Automatic central-office-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 bridge tap is the end of the loop. Automated centralized test systems that measure loop capacitance to determine loop length will give false distance readings any time a bridge tap exists. The extra capacitance of the bridge tap(s) is added to the overall capacitance. This makes the loop appear longer than its actual length.

Frequency-domain reflectometry (FDR) is the best method to locate bridge taps. From one end of the line, a sweep of signals is sent, and the signals are then reflected back (from the end of the cable, and from the beginning and end of bridge taps). The reflected signals interfere with the transmitted signals. By observing where, in the frequency range of the transmitted signals, peaks and valleys occur, an FDR measurement can determine the distance to the start and finish of a bridge tap (and any other fault for that matter).

It should be noted that all test sets have limitations in locating bridge taps. If the bridge taps are too far away, too short in length or have little of the original local loop beyond them, they will be undetectable. Luckily, very short bridge taps near the end of the cable have less effect on DSL than long bridge taps.

78 Split Pairs

The pairs of wires within cable bundles are twisted in order 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 "splitting" 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.

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 ADSL, 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, a comparative measurement of crosstalk between several pairs will expose the split pair. Some TDR units allow installers or repair crews to store the spectrum analysis stored from a measurement of crosstalk (PSD) from a good pair for on screen comparison to all subsequently tested pairs. Pairs that exhibit abnormally high crosstalk are most likely split or have one of their conductors partially or fully grounded. If the abnormal pair has a normal longitudinal balance, then the pair is split.

It is more difficult to identify split pairs in bundles that contain no DSL services as of yet. In these cases, a new practice is to place an artificial signal on one loop within the bundle and to then make another comparison to the crosstalk measured on several or all other pairs. This test is called a stressed noise test by some and four-wire crosstalk test by others. Some optimized testers have two connection ports in order to perform this test. A test tone is transmitted on one port, and the amount of crosstalk is measured on the other.

It is also possible for a split pair to act as an efficient transmitter (as opposed to receptor) of crosstalk. Locating and eliminating this scenario is not an easy task. One split pair may degrade the performance of all surrounding loops. A binder group that has remarkably low connection rates as compared to other binder groups in the same bundle probably has a split pair that carries DSL or T1/E1 signals.
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, DSL, DLC and HDSL. When adding ADSL, SHDSL, VDSL, VDSL2 and other modern DSL signals, 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 ADSL 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 local exchange carriers (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.
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 knick 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, lightning strikes, and other factors can create faults.

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 dirty 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 will 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 and difficult to locate and 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.
7.11 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 or FDR technique.

7.12 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 locate 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.

The measurement of RFL utilizes one conductor of the additional (spare) pair to feed voltage to the other end of the defective loop, and the other conductor of the spare pair to establish a common link to make 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 a measurement of the temperature of the cable.

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 60°C. A test cable with a temperature probe inside could be established.

7.13 Ground Resistance Testing

Ground resistance (also known as station ground) measurements allow telephone technicians to verify that correct grounding rules are being followed at the location under test. An adequate station ground and ground distribution system provide a common electrical reference point for all telecommunications equipment in the installation and minimizes the problems of electrical potential between various equipment and between the equipment and the earth.

Testers that perform ground-resistance measurements provide results based on three possibilities focused around the central office (CO) line card:

- Constant voltage source (old style)
- Constant current source (new style)
- Ground balanced source (such as the Lucent/AT&T 5ESS switch)

To test ground resistance, the tester is connected as shown below, and the measurement is executed in the following fashion:

1. Measure the open-loop (on hook) tip-ring voltage (station voltage). The voltage must be negative. If not, an error message reporting “Tip and ring polarity reversed” will be displayed.
2. The unit will detect the balanced/unbalanced source (on hook) by measuring the ring/ground voltage. For a grounded system, it must be 5 V. If the ring/ground voltage is ≥ 5 V, the line is balanced.
3. The tester then measures the loop current (off hook) by seizing the line with a 435-ohm internal load.
4. For the constant voltage sources, the unit measures the tip/ring voltage (off hook) with the 435-ohm load.
5. For the grounded system, the unit switches the loop current path with the 435-ohm load (currently off hook), from tip/ring to tip/ground. Then, both the ring/ground voltage and the loop current are measured.

**A ground-resistance measurement sequence is based on the following assumptions:**

- The ground lead of the test instrument is connected reliably to the ground of the CO.
- The standard CO voltage is nominally –48 VDC. The twisted pair is connected to the CO with tip as positive and ring as negative.
- The grounded constant current source limits the current on the –48 V side only.

### 7.14 Breakdown Test Sets

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, 600 V D.C. 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, 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 often temporarily complete the electrolysis process, creating the appearance of clearing the fault. However, after some time, the fault would magically reappear.

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

Identifying the nature of a fault in the local loop plant is only the first step in the process. Pinpointing the location of the fault and taking corrective action is also necessary. Although most telephone companies already have corrective-action plans, this section may provide some ideas for improvement to practices, especially when the added criteria of DSL are taken into account.

8.1 Spectral Management

Many of the world’s DSL equipment suppliers have published a lot of data about reach testing. In fact, the attenuation alone of a cable, due to its length, is not the critical factor. The limiting factor for DSL, as far as reach is concerned, is either noise or more often crosstalk. The DSL modems operate at full speed with no errors unless the attenuation of the local loop causes the DSL signals to become mixed with the noise and crosstalk on the line.

In the local loop bundle, a single source of interference can cause all ADSL modems in the same bundle to run at lower upstream and downstream rates. Eliminating the disturber is therefore an easy way to improve the service for many customers. This is especially important if rates must be higher than a specific target. For example, some video-on-demand services may require a minimum of 6 to 25 Mb/s.

Traditional T1 and E1 services that use AMI, B8ZS or HDB3 line codes are the worst offenders. Replacing these services with the more bundle-friendly G.SHDSL-based T1 and E1 can clear a lot of trouble tickets.

In addition to eliminating the source of the crosstalk, it is also important to identify and avoid using split pairs and to ensure that high-resistance faults are cleared.

8.2 Shielding, Bonding, 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 be made to 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 both the serving office side and be properly grounded at the customer premises side (to the same earth ground of 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 TIP and RING to shield). DSL services are much more sensitive than voice services. For this reason, far more care should now be applied to the loop plant.

8.3 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 book).

8.4 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.

Powerline influence is commonly measured on telephone pairs. Unlike the above impairment, powerline influence normally does not affect DSL performance. Typically, the main cross-coupled interferences caused by powerline noise is in the over 60 Hz harmonic range. Even the 9th harmonic of 60 Hz is still only 540 Hz. This frequency falls well below those used by ADSL and other DSL technologies.

It should be noted, however, that a problem with the longitudinal balance of a local loop will generally cause measurements of powerline influence (PI) to be high so long as powerlines are in the vicinity. If the loop has poor longitudinal balance, it will also suffer from abnormally high crosstalk. This is why some technicians have been fooled into thinking that a high PI reading is the cause of DSL problems, when in fact the true problem is a high-resistance fault that increases PI, NEXT, FEXT and possibly other noise influence.
9. ADSL and ADSL2+ Service Testing

It is recommended that each of the previously mentioned tests be used to qualify a pair for service or to troubleshoot a problematic line. Additionally, it is possible to know what data rate can be achieved for a particular line. To calculate this rate for an ADSL or ADSL2+ DMT-based service, a signal-to-noise ratio calculation at each frequency of the DMT tones can be used. A data rate can be determined for both upstream and downstream directions using this method. Approximating how many amplitude states can be coded onto each of these tones and summing the total bits that can be transferred per second can be used.

This type of testing is also useful for troubleshooting. If the technician were to move to the network interface device (NID) from the inside connection jack and find that, at that particular location, data rates were more acceptable, then a “home-run” (or dedicated pair from the NID to the inside of the house) may need to be installed. If the test at the NID did not show any improvement, tests at the pedestal, cross-connects, and so on, would prove that the problem lies in the cable plant or network devices. There are two methods of testing these data rates.

The most common method to test the data rates for an ADSL circuit is to use a test set with a built-in modem chipset. The unit will establish a connection and give a maximum upstream and downstream data rate for the pair under test. The connection is made with the DSLAM at the CO or network terminating point. 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. It is therefore not useful for pre-qualification.

Figure 9.1 — The results of a golden-modem test conducted with EXFO’s CoT250+ Ethernet.
In addition, this type of test set uses a number of frequencies to communicate with the ATU-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. The frequencies used for handshaking are between 189 kHz and 258 kHz downstream and 34 kHz to 60 kHz upstream. This implies that on non-working lines, modem-dependent tests cannot give useful information.

A second method of testing is by using a physical-layer test set. During a modemless test, tones similar to those used during the “modem-dependent” test are evaluated. The advantage of this type of test set is that it will identify and locate major faults early in the process.

Figure 9.2 – DMT result of test performed with EXFO’s CableSHARK; the unit determines the expected data rate of the circuit.
10. Troubleshooting the Local Loop

As discussed in previous chapters, there are several factors that cause local loops to become defective or to degrade to the point of affecting performance. This section examines the sequences used to identify, locate and repair loop faults.

10.1 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 the 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 about the service(s) offered as possible. 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 E&M?

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? How many pairs in the F2 local distribution bundle? How many pairs 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 bridge 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? This includes 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.)

10.2 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.

10.3 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 or intermittent events such as momentary continuity breaks when wind moves overhead cable, then 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. This will be discussed in later sections of this document.
10.4 Measuring the Service
Many service providers have made the mistake of rolling out new services without updating their troubleshooting procedures. A measurement of 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.

10.5 Avoiding Cable Cuts
In a vacuum 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 or FDR is a far better choice for locating cable faults, as it eliminates the need for cutting the loop.

10.6 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 DSL, T1, E1, HDSL, SHDSL, SDSL, DDS, basic-rate ISDN, etc., the technician will connect a specific test set to the loop, again connecting towards the telephone company’s facilities. These test sets contain an actual ADSL, ADSL2+ or SHDSL modem. 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.

For T1, FT1 and E1 services carried by HDSL, HDSL2, HDSL4 and SDSL, the technician would connect another type of test set to the T1 or 2 Mb/s (E1) port of the subscriber’s equipment (at the DEMARC point) and perform a bit-error-rate test. Typically, a temporary loopback of the equipment within the digital serving office is made to conduct this test.

10.7 Troubleshooting Copper Loops

10.7.1 DC and AC Voltage or Capacitance

Digital multimeter (DMM) measurements can reveal a lot about a local loop and the signals carried upon them. 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.

If the loop should be carrying POTS but the tip/ring DC voltage is less than 20 volts, then the loop either has an open or a partial-open circuit, or maybe it is not properly connected to the line card of the central office switch. If the AC voltage from tip to ring is high (greater than 5 V), then the circuit has a lot of noise, most likely from powerline interference.

10.7.2 Loop Isolation

If indeed testing up to this point indicates that the problem lies in the local loop or the central office exchange, DSLAM or digital equipment, it may be necessary to isolate the local loop for further testing. Normally, this is done by removing the protectors (sometimes called coils or heat coils) from the CO or from the subscriber line circuit (SLC) equipment. Nonetheless, a test towards a subscriber usually requires no action so long as the customer has all telephones “on-hook” and their DSL modem temporarily disconnected.
Disconnecting the local loop from the CO or SLC allows the loop to be more thoroughly tested from one end. The active signals of the line card, T1, DSL, etc. equipment will no longer be present on the loop and any capacitance and resistance that is added by this equipment will be removed. In addition, TDR and FDR tests require an open or short in order to obtain the best reflection of the energy from the end of the pair.

10.7.3 Balance

Theoretically, 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.

If the capacitance measured between tip and ground is different from that measured between ring and ground, it is likely that the conductor with the lower capacitance is cut at some point along the route or that either tip or ring (or both) are partially or completely grounded at some point.

Most telephone companies like to measure longitudinal balance of the pair to see what effect noise or crosstalk would have on the pair. An equal-level signal is placed between ground to tip and ground to ring. To measure the balance, the amount of tip/ring signal is measured in dBs with respect to the originally added signal. A good circuit will have a balance of at least 40 dB with most being above 50 dB at 1.1 MHz for ADSL and 2.2 MHz for ADSL2+. Longitudinal balance for voice band (1 kHz) should be better than 60 dB.

If the cable is cut (open) or has a short, the best way to locate the fault is with a time-domain reflectometer (TDR). A TDR works by sending an electrical pulse into one end of a telephone line. The pulse travels down the line at roughly two thirds of the speed of light. When it gets to the point where the line has gone open or when it gets to the end of the loop, the energy will reflect back towards its origin. By measuring the time it takes for the signal to travel down and back and then dividing by two, a calculation of the distance to the fault can be made. Most modern TDRs plot the received voltage versus time (divided by two) so that each reflection may be viewed.

If the tip, ring or both conductors are cut or shorted for some reason, it is obvious that they will need to be repaired to restore service.

On the other hand, it is not so obvious that a balance problem could be caused by a partial short to ground. Locating this type of fault is best achieved using RFL.
10.7.4 Load Coils
Traditional load coils prevent all digital services such as basic-rate ISDN, HDSL, HDSL2, HDSL4, ADSL, SDSL, SHDSL. It is important to scan the line for load coils and remove or replace them with next-generation devices. A load coil test looks at the impedance of the loop at different frequencies. Load coils present higher impedance at certain frequencies as compared to straight telephone cable.

10.7.5 DSL Reach
There are a number of ways of determining the overall length and makeup of a local loop. A measurement of tip-to-ring capacitance can be converted to length using a standard capacitance to length conversion. A typical figure is 83 nF per mile (58 nF per km). Likewise, a TDR measurement that finds the end of a loop can be used. Typically, the velocity of propagation (VOP) of cable is around 0.666 of the speed of light, although this will vary by wire gauge, by wire type, and by manufacturer.

In both cases, the measured length should be compared to loop plant records (if they exist). If a loop measures much shorter than expected, it may be an indication that it has been cut. If it measures much longer, then it probably has a planned or unplanned bridge tap.

Also, load coils should be removed before the loop is measured for length. In addition, POTS splitters, micro-filters, and the front end of electronics of DSL modems add capacitance. This is yet another reason to open the circuit at the NID or remove the protectors at the SLC or CO to perform an accurate test.

Many technicians place too much emphasis on loop length to determine the ability of DSL. For example, 18,000 ft (5.5 km) of 24 AWG (0.5 mm) will successfully carry a decent level of ADSL, whereas only up to 12,000 ft (3.6 km) of 26 AWG (0.4 mm) will do the same. A badly balanced circuit that is 1000 ft (300 m) long is more likely to have problems than one that is well-balanced and 10,000 ft (3 km) long.

At this point, however, it is important to make sure that the service has not been promised on a loop length and loop make-up that outstrips the reach of the DSL equipment in question.
10.7.6 Crosstalk and Noise

A long loop alone does not make a DSL circuit fail. In fact, the crosstalk from other pairs in the same bundle, combined with the attenuation due to the length, predict the connection rates that are possible. A bundle that has only ADSL will perform better than a bundle that has a mixture of B8ZS-encoded T1 or 2B1Q-based HDSL.

A spectrum analyzer that can measure up to at least 2.2 MHz for ADSL2+ (even more for VDSL2) should be used for this application. Particular attention should be paid to the pair that is disconnected from the CO (or SLC). Some test sets will automatically recognize the type of disturbances and will indicate them to the technician.

It should be noted that a single numeric measurement of circuit noise is not useful for testing loops that carry adaptive-coding technologies such as the DMT used by ADSL. It is quite possible to have a large amount of noise power at one frequency and very little at another. Therefore, a single value for the "noise on the line" is useless. Noise must be evaluated for each carrier frequency of DMT.

A wideband yet high-resolution test set provides a power spectral density (PSD) test that can assist in this regard. The PSD will indicate the levels of noise for the carrier frequencies and will allow users to visualize any noise or crosstalk that may be on the line. To view intermittent noise problems, a PEAK HOLD function is useful, as it will record, over time, any noise events that occur. An impulse-noise histogram test can also be useful.

10.7.7 Noise Mitigation

If a service is disturbed by noise, the first thing to repair is the balance. If the balance is fine, then it is necessary to ensure that grounds and shield integrity is maintained. A good solid ground must be established at the customer premises, within the CO, and as per practice for overhead bundles.

In addition, it is important to ensure that, through each pedestal and each splice case, the shield bonding braids are maintained.
**10.7.8 Bridge Taps**

The best method for identifying and locating bridge taps is through an FDR measurement. As most bridge taps occur closer to the subscriber than to the CO, it makes sense to locate them from the subscriber side. An FDR will show one reflection for the end of the loop, one reflection for the beginning of the bridge tap (lower impedance), one reflection from the end of the bridge tap (higher impedance) and one reflection from the end of the loop (higher impedance).

Some test sets automatically translate the complex traces of an FDR test into a local-loop map. There aren't any hard and fast rules about bridge taps; however, the following guidelines can be used:

- ADSL and other DSL services can work in the presence of some bridge taps.
- Some bridge taps can degrade or kill service, especially on longer loops.
- If the addition of the bridge tap and the loop itself are longer than the reach of the modem service is not likely.
- Removing bridge taps will improve marginal ADSL service.
- Applying microfilters on every POTS line appearance within the customer premises helps terminate them.

**10.7.9 Impulsive Noise**

Often, intermittent service interruptions are caused by impulsive noise. For customers with this complaint, an impulse noise test can be performed. The best way to achieve this is with a graphic power-spectral-density peak-and-hold test set. The test set is connected to the loop for as long as required to catch at least two events in consideration of the periodicity of the typical customer reported outage.

The technician will have to correlate the occurrence of impulse noise hits with external events; this is why it is important to make a note of the environmental conditions. Impulse noise can be caused by many different things such as the passage of a train, opening/closing of an electric gate, wind moving the overhead cables, electrical interferences (mechanical relays, crossbars), use of heavy work machinery, induction motors, lasers, etc.
10.7.10 Central Office Tests

Testing very long lines from the CO is often very convenient. In fact, there are many automated test systems that perform this function. As far as pure POTS lines are concerned, so long as the subscriber has all telephones on-hook, the loop is not terminated, and measurements of balance, TDR, etc. are possible. It can be difficult however to locate small bridge taps (such as multiple customer telephone jacks) through a very long loop.

10.7.11 Evaluation

The proper testing equipment will have ability to predict the DSL rates and services that a local loop can support. From one end, it should probe the line for a number of measured parameters and then apply that knowledge against the algorithms used by typical modems, in order to predict the rates (for example, ADSL or ADSL2+ downstream and upstream connection rates).

Of course, a number of conditions must be analyzed before the data rate can be accepted as absolutely correct. For example, a loop has an open circuit caused by a severed cable. If a TDR test was not first performed and compared against existing loop plant records, the data rate would be accepted since the prediction was made to the open rather than to the end of the cable. As outlined throughout this document, multiple tests must be run to qualify a cable. Each step must be evaluated to ensure that going to the next step is prudent. If not, customers will keep calling in about repeat problems and the local loop will steadily become less useful.
11. Summary

Based on what’s been discussed thus far, below is a summary of what can be done to perfect local-loop testing techniques.

1. Use a butt set to determine if there is signal present on the line (voice or other to determine if circuit is free).
2. Use the PSD analyzer to determine if any of the circuit has live DSL, T1 or 2 Mb/s (E1). The PSD analyzer should be able to tell you the underlying technology.
3. Do not continue to test or interrupt service if the circuit is live based on points 1 and 2 above (i.e. greater than –40 dBm RMS of signal).
4. If this is a dry pair or if the customer has acknowledged that service will be interrupted, move on to the next cable.

As an example, the tests indicated below are performed by EXFO’s CableSHARK.
The weakest link in the DSL chain is the local loop. Each one 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 cable troubleshooting tools.

Table 4 – Tests that can be performed by EXFO’s CableSHARK to troubleshoot common network problems.

<table>
<thead>
<tr>
<th>Customer has no connection</th>
<th>Customer has bad rates</th>
<th>Customer has intermittent problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADSL Auto-test provides quick pass/fail indication. Loop capacitance (OPENS meter) or loop resistance-based distances can be compared against loop plant records.</td>
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</tr>
<tr>
<td>Manual TDR to locate OPENS or SHORTS. Distances provided can be compared against loop plant records.</td>
<td>ADSL or SHDSL data-rate prediction test</td>
<td>Impulse noise histogram set to 24 hours.</td>
</tr>
<tr>
<td>Manual TDR can also locate and display bridge taps or bad splices. Compare distance with loop plant records.</td>
<td>PSD test to look for crosstalk</td>
<td>Longitudinal balance</td>
</tr>
<tr>
<td>Ground fault (RFL) testing to determine distance to potential water or corrosion damage.</td>
<td>Longitudinal balance</td>
<td></td>
</tr>
<tr>
<td>Loop must be repaired</td>
<td>Loop must be repaired</td>
<td>Loop must be repaired</td>
</tr>
</tbody>
</table>

The weakest link in the DSL chain is the local loop. Each one 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 cable troubleshooting tools.
12. Glossary and Acronyms

10BaseT - 10 Mb/s Ethernet
This specification uses two pairs of twisted-pair cabling (Category 3, 4, or 5): one pair for transmitting data and the other for receiving data. 10BaseT, which is part of the IEEE 802.3 specification, has a distance limit of approximately 328 feet (100 meters) per segment. 10BaseT is a LAN transmission technology.

100BaseT - 100 Mb/s Ethernet
Same principle as 10BaseT Ethernet, but with a higher data rate.

A

American National Standards Institute (ANSI)
An official body within the United States delegated with the responsibility of defining standards – ANSI T1E1.4 is the standards body group that develops the American specifications for T1, DSL, etc., and ANSI T1.413 is the standard that has been defined for American ADSL.

American Standard Code for Information Interchange (ASCII)
Code that assigns specific letters, numbers, and control codes to the 256 different combinations of 0s and 1s in a byte.

American Wire Gauge (AWG)
Measurement of wire diameter; the lower the AWG number, the larger the wire diameter – For copper phone-line wiring, common sizes in use are 22, 24 or 26 AWG.

Asymmetric Digital Subscriber Line (ADSL)
Transmission technology that consists of modems attached to twisted-pair copper wiring that transmit from 1.5 Mbit/s to 8 Mbit/s downstream (to the subscriber) and up to 1.5 Mbit/s upstream, depending on line distance – Several standards exist for ADSL; namely T1.413 Issue 2, ITU-T G.992.1 (G.DMT), and ITU-T G.992.1 (G.Lite).
Asymmetric Digital Subscriber Line (ADSL) Transceiver Unit — Central or Remote (ATU-C and ATU-R)
The device at the end of an ADSL line that stands between the line and the first item of equipment in the subscriber premises or telephone switch — An ATU may be integrated within an access node.

Asynchronous Transfer Mode (ATM)
A method of data transportation whereby fixed-length packets are sent over a switched network — The ability to ensure reliable delivery of packets at a high rate makes ATM suitable for carrying voice, video, and data.

Access Network
That portion of a public switched network that connects access nodes to individual subscribers — The access network today is predominantly passive, twisted-pair copper wiring.

Access Nodes
Points on the edge of the access network that concentrate individual access lines into a smaller number of feeder lines — Access nodes may also perform various forms of protocol conversion. Typical access nodes are digital loop carrier systems concentrating individual voice lines to T1 lines, cellular antenna sites, private branch exchanges, and optical network units (ONUs).

Algorithm
A specific procedure used to modify a signal — For example, the key to a digital compression system is the algorithm that eliminates redundancy.

Analog
A continuously varying signal or wave — As with all waves, analog waves are susceptible to interference that can change the character of the wave. Analog is the alternative to digital.
Backbone
A high-speed line or series of connections that handles the major traffic using the highest-speed, and often longest paths, for network-to-network connections.

Bandwidth
A measure of capacity of communications media – Greater bandwidth enables the communication of more information in a given period of time. Bandwidth is generally described either in terms of analog signals in units of Hertz (Hz), which describes the maximum number of cycles per second, or in terms of digital signals in units of bits per second.

Basic-Rate Integrated-Services Digital Network (BRI-ISDN)
The basic-rate ISDN interface provides two 56/64 kbps channels (called B channels) to carry voice or data and one 16 kbps signaling channel (the D channel) for signaling/call information.

Baud Rate
The actual symbol frequency being used to transmit data – The term baud rate is often used incorrectly as an equivalent to bits per second (bps or b/s). For example, both ITU-T V.22bis (2400 b/s) and V.22 (1200 b/s) modems transmit data at 600 bauds, but V.22bis modems use four bits per symbol and V.22 modems use two.

Binary 8 Zero Substitution (B8ZS)
A coding technique used to carry the digital bit stream of a T1 signal over a local loop.

Bit
A single unit of data, either a one or a zero, used in digital data communications – When discussing digital data, a lowercase “b” refers to bits, and an uppercase “B” refers to bytes. Eight bits are needed to create one byte or character.
Bits per Second (Bps or b/s)
The speed at which bits (electronic signals) are transmitted and a measure of the actual data transmission rate. The b/s rate may be equal to or greater than the baud rate, depending on the modulation technique used to encode bits into each baud interval. This is the correct term to use when describing modem data transfer speeds.

Broadband
A transmission channel with bandwidth exceeding the normal 4 kHz or 64 kbps telephone channel. The term broadband is typically used to describe large-capacity networks that are able to carry several services (such as data, voice, and video) at the same time.

Broadband Integrated-Services Digital Network (B-ISDN)
A digital network with ATM switching operating at data rates in excess of 1.544 or 2.048 Mbps. ATM enables transport and switching of voice, data, image and video over the same infrastructure.

Byte
A group of bits, normally eight, which represent one data character.

C
Carrier
An electromagnetic wave or alternating current that is modulated to carry signals in radio, telephonic, or telegraphic transmission.

Carrier Serving Area (CSA)
The area served by a local-exchange carrier, regional Bell operating company or telephone company. CSAs often use digital-loop carrier (DLC) technology.

Carrierless Amplitude Phase (CAP)
A type of quadrature amplitude modulation. Used for some types of DSL, CAP stores pieces of a modulated message signal in memory and then reassembles the parts in the modulated wave.
Central Office (CO)
A telephone company facility within which all local telephone lines terminate and which contains the equipment required for switching voice communications across the telephone network. For DSL service, special equipment is set up at the CO to support DSL service for customer lines terminating at the CO. COs are not necessarily offices; often, they are more like centrals contained in large cabinets.

Channel Service Unit (CSU)
A network device that receives and transmits signals to and from the wide-area-network (WAN) line. The CSU performs loopback testing of signals from the phone company and provides a barrier for electrical interference from either side of the unit (customer premises or phone company).

Circuit-Switched Network
A type of network in which a continuous link is established between a source and a receiver. Circuit-switching is used for voice and video to ensure that individual parts of a signal are received in the correct order by the destination site.

Community Access Television (CATV)
Also known as Cable TV.

Competitive Local-Exchange Carrier (CLEC)
Mainly consist of telephone companies founded after the Telecommunications Reform Act of 1996 to compete with incumbent local-exchange carriers (ILECs). CLECs usually pioneer new technologies for delivering voice and data communications services.

Crosstalk
Interference from an adjacent channel and/or technology.

Customer Premises Equipment (CPE)
Any piece of equipment in a communication system that resides within the home or office. Examples of CPEs include analog and digital telephones, fax machines, analog and DSL modems and routers.
Data Service Unit (DSU)
A network device that converts digital data frames from the communications technology used on a local-area network (LAN) into frames appropriate to the communications technology used on the wide-area network (WAN) and vice versa.

Dedicated Connection
A communication link that operates constantly and is not shared between users.

Dial-Up Connection
A link that is created using the public switched telephone network (PSTN) to connect computers over modems with remote LAN access modems/routers and/or terminal servers.

Digital Loop Carrier (DLC)
Proprietary schemes for transporting multiplexed digitized voice channels over a local loop – DLCs are similar in concept to DSL and may utilize a specific DSL coding technique.

Digital Signal
A signal that takes on only two values, off or on, typically represented by 0 or 1 – Digital signals require less power but (typically) more bandwidth than analog signals, and copies of digital signals can be made exactly like the original.

Digital Subscriber Line (DSL)
The generic term that refers to the entire family of DSL technologies, such as SDSL, ADSL, and VDSL – DSL refers to digital modems placed at either end of a local loop. DSL bypasses the circuit-switched lines that make up that network and yields much faster data transmission rates than analog modem technologies.

Digital Subscriber Line Access Multiplexer (DSLAM)
A network device typically installed at the local telephone company’s central office – The DSLAM aggregates multiple DSL connections terminated by DSL users and transmits the traffic over an high-speed backbone connection to the Internet service provider network and to the Internet.
Discrete Multitone Modulation (DMT)
A method of transmitting data on copper phone wires that divides the available frequency range into subchannels or tones – ADSL uses the DMT line coding, which divides the frequency from 0 to 1.104 MHz in 256 subchannels.

Domain Name Service (DNS)
A TCP/IP protocol for discovering and maintaining network resource information distributed among different servers.

Downstream
Direction of data traveling from the central office or local-exchange company to the customer premises – In ADSL, the downstream link provides much greater data rates than the upstream link (from customer premises to central office).

Dynamic Host Configuration Protocol (DHCP)
A service that lets subscribers on a LAN request configuration information, such as IP host addresses, from a server.

E

E1
A dedicated digital communication link provided by a European telephone company that offers 2.048 Mb/s multiplexed signals over 30 channels – E1 is commonly used for carrying traffic to and from private business networks and Internet service providers.

E-business or e-commerce
The buying and selling of goods and services, providing services to customers and collaborating with business partners over the Internet.

Echo Cancellation
The elimination of reflected signals (i.e., echoes) in a two-way transmission created by some types of telephone equipment – Echo cancellation is used in data transmission to improve the bandwidth of the line.
Ethernet
A physical medium for transmitting local-area-network (LAN) traffic at speeds of up to 100 Mb/s.

European Telecommunications Standards Institute (ETSI)
A standards body that has developed DSL standards, as well as other telecom standards.

Extranet
Network that can be viewed as an extension of a company's intranet, as it can be extended to users outside the company - An extranet allows a company to communicate and do business with customers and other companies.

Far-End Crosstalk (FEXT)
The interference occurring between two signals at the far end of the local loop, usually at the customer premises.

Feeder Network
That part of a public switched network that connects access nodes to the core network.

Fiber-to-the-Cabinet (FTTCab)
A network in which the deployment of fiber runs from a central-office telephone switch to a street-side cabinet serving numerous subscribers - The remaining link between the subscriber and the cabinet is made of twisted-pair copper wire.

Fiber-to-the-Curb (FTTC)
A network in which the deployment of fiber runs from a central-office telephone switch to a curb-side distribution point close to the subscriber - The remaining link between the subscriber and the curb-side distribution point is made of twisted-pair copper wire.

Fiber-to-the-Home or Fiber-to-the-Premises (FTTH or FTTP)
A network in which the deployment of fiber runs all the way from the central-office telephone switch to the subscriber's premises or home.
Frequency-Division Multiplexing (FDM)
The transmission of multiple signals simultaneously over a single transmission path by dividing the available bandwidth into multiple channels that each cover a different range of frequencies.

Frame Relay
A high-speed packet-switching protocol used in wide-area networks (WANs) – Frame relay is often used to connect local-area networks (LANs) to each other, with a maximum bandwidth of 44.725 Mb/s.

Frequency
The number of oscillations in an alternating current that occur within one second, measured in Hertz (Hz).

G

G.992.1 or G.DMT ADSL
A kind of asymmetric DSL technology, based on DMT modulation, that offers a downstream bandwidth of up to 8 Mb/s, and an upstream bandwidth of up to 1.544 Mb/s – G.DMT is another name for the standard officially known as ITU-T Recommendation G.992.1.

G.992.2 or G.Lite ADSL
A kind of asymmetric DSL technology, based on DMT modulation, that offers maximum Internet connectivity rates up to 1.5 Mb/s downstream and 384 k/s upstream – G.Lite is another name for the standard officially known as ITU-T Recommendation G.992.2.

Gateway
A physical or logical point of entrance to another network – A router, computer, server or an integrated access device can serve as a gateway to a network.

Gigabyte (GB)
1,000,000,000 bytes, or 1,000 megabytes (see Byte).
H

HDB3
A digital-line coding technique used internationally to carry E1 signals over the local loop.

Hertz (Hz) - See Frequency.

High-Data-Rate Digital Subscribe Line (HDSL)
The earliest variation of DSL to be widely used – HDSL is applied for wideband digital transmission within corporate sites and between telephone companies and customers. The main characteristic of HDSL is that it is symmetrical; i.e., an equal amount of bandwidth is available in both directions. For this reason, the maximum data rate for HDSL is lower than for ADSL. HDSL can carry as much on a single wire of twisted-pair wire as can be carried on a T1 line in North America or an E1 line in Europe (2,320 kbps).

High-Definition Television (HDTV)
Any television system that provides a significant improvement in picture quality over existing television systems – Most HDTV systems offer more than 1,000 scan lines, in a wider aspect ratio, with superior color and sound fidelity.

Host
A single, addressable device on a network – Examples of hosts include computers, networked printers, and routers.

Hub
A local-area-network (LAN) device that serves as a central "meeting place" for cables from computers, servers, and peripherals – Hubs typically repeat signals from one computer to the others on the LAN.

Hybrid Fiber Coax (HFC)
System (usually CATV) in which fiber deployment runs to a distribution point close to the subscriber – The remaining link between the subscriber and the distribution point is made of coaxial cable.
Incumbent Local-Exchange Carrier (ILEC)
A large telephone company that has been providing local telephone service in the United States since the divestiture of the AT&T telephone monopoly in 1982 – all regional Bell operating companies (RBOCs) are considered ILECs.

Institute of Electrical and Electronics Engineers (IEEE)
A professional organization whose activities include the development of communications and network standards – IEEE LAN standards are the predominant LAN standards today.

Integrated Access Device (IAD)
A one-box DSL voice and data solution equipment typically installed at the customer's site.

Integrated-Services Digital Network (ISDN)
An early dial-up predecessor of the DSL family that can support up to 128 kb/s symmetrical service – ISDN is a usage-based service offered by telephone companies that is being rapidly eclipsed by DSL. ISDN is a circuit-switched technology.

Integrated-Services Digital Network Digital Subscriber Line (IDSL)
The always-on cousin of dial-up ISDN – IDSL delivers a symmetrical service of 144 kb/s without the usage charges inherent to ISDN service.

Inter-Exchange Carrier (IXC)
A telephone company that provides connections between local exchanges in different geographic areas – IXCs are commonly referred to as long-distance carriers. AT&T, Sprint and MCI Worldcom are examples of IXCs.

International Organization of Standardization (ISO)
Organization that develops, coordinates, and promulgates international standards that facilitate world trade.

International Telecommunications Union (ITU)
A United Nations organization that coordinates use of the electromagnetic spectrum and creation of technical standards for telecommunication and radio communication equipment – The ITU-T looks after telephony standards.
Internet
The worldwide network of networks connected to each other, through internetworking protocols – The Internet provides file transfer, remote login, e-mail, news, and other services. To be on the Internet, you must have Internet protocol (IP) connectivity, so that the computer can “telenetwork” or “ping” other systems.

Internet Engineering Task Force (IETF)
The standards organization that standardizes most Internet communication protocols, including Internet protocol (IP) and hypertext transfer protocol (HTTP).

Internet Protocol (IP) Address
A number assigned to any computing device that uses the Internet protocol (IP) – Part of the address is the network number (IP network address), and part is the host address. All machines on a given IP network use the same IP network number, and each machine has a unique IP host address. The system administrator sets a subnet mask to specify how much of the address is network number and how much is host address.

Internet Protocol Security (IPSec)
Security measures that involve using encryption technology to provide data confidentiality, integrity, and authenticity between participating peers in a private network – IPSec provides two choices of security services: authentication header (AH), which essentially allows authentication of the sender of data; and encapsulating security payload (ESP), which supports both authentication of the sender and encryption of data. The specific information associated with each of these services is inserted into the packet in a header that follows the IP packet header.

Internet Service Provider (ISP)
An organization offering and providing Internet access to the public using computer servers connected directly to the Internet.

Intranet
A network serving a single organization or site that is modeled after the Internet, allowing users to access almost any information available on the network – Unlike the Internet, intranets are typically limited to one organization or one site, with little or no access to outside users.

Inverse Multiplexing (Imux)
A technology that allows physical links to be aggregated to form a higher-bandwidth logical link whose rate is approximately the sum of the individual link rates.
**J**

**Joint Photographic Experts Group (JPEG)**

A committee formed by the International Organization of Standardization to set standards for digital compression of still images – JPEG also refers to the digital compression standard for still images created by this group.

**K**

**Key**

A sequence of random or pseudo-random binary digits used to set up (and periodically change) the operations performed in crypto-equipment for the purpose of encryption and decryption – The length of the key determines how difficult it will be to decrypt the text in a given message.

**Kilobit (kb)**

One thousand bits.

**Kilobits per Second (kb/s)**

Measurement unit to specify the speed of an Internet connection; i.e., the number of bits that can be transmitted over a wire in a single second – Most analog modem connections operate at speeds between 9.6 kb/s (9600 bits per second) and 33.6 kb/s (33,600 bits per second). ADSL can operate up to 8 Mb/s (8,000,000 bits per second).

**Kilobyte (KB)**

One thousand bytes.
**L**

**Laser**
Term that was originally an acronym for light amplification by stimulated emission of radiation – A laser usually consists of a light-amplifying medium placed between two mirrors. Light not perfectly aligned with the mirrors escapes from the sides, but light perfectly aligned will be amplified. As one mirror is made partially transparent, the result is an amplified beam of light that emerges through the partially transparent mirror.

**Last Mile** (see Local Loop)

**Leased Line**
A dedicated circuit (private telephone line) between two locations – A leased line is available full time for transmission of data or voice.

**Local-Area Network (LAN)**
A network connecting a number of computers to each other or to a central server so that the computers can share programs and files.

**Local Loop**
The copper lines between a customer's premises and a telephone company's central office (see Central Office).

**Loop Qualification**
The process of determining if a line (or loop) will support a specific type of DSL transmission at a given rate.
Media Access Control (MAC) Address
A data-link layer address that is required for every port or device that connects to a LAN – Other devices in the network use MAC addresses to locate specific ports in the network and to create and update routing tables. MAC addresses are controlled by the IEEE and are also referred to as MAC-layer addresses or hardware addresses.

Megabit (Mb)
One million bits.

Megabits per Second (Mb/s)
Measurement unit to specify the speed of a local or wide-area network connection; i.e., the number of bits that can be transmitted over a wire in a single second – Ethernet LANs operate at speeds of 10 Mb/s. A T1 WAN connection operates at 1.544 Mb/s.

Megabyte (MB)
1,000,000 bytes or 1,000 kilobytes (see Byte).

Millions of Instructions per Second (MIPS)
This is a common measure of the speed of a computer processor.

Modem
Short for modulator/demodulator – A modem is a data communications device that connects a computer to the telephone network. Technically, a modem converts a computer’s digital signals to analog signals that can be transmitted over standard telephone lines. Digital or ISDN modems, also called terminal adapters, are used to connect computers to digital ISDN lines.

Moving Pictures Experts Group (MPEG)
A committee formed by the International Organization of Standardization to set standards for digital compression of full-motion video – MPEG also refers to the digital compression standard for full-motion video created by this group. Three levels of quality have been defined: MPEG-1 for VHS-quality, MPEG-2 for broadcast-quality video; and MPEG-3 for broadcast-quality audio.
Multilink Point-to-Point Protocol (ML-PPP or MP)
Enables the aggregation of multiple independent circuits or links, providing a virtual link that offers greater bandwidth than any of the links independently.

Multinetwork Address Translation (MultiNAT)
An enhancement of Network Address Translation (NAT) – Instead of using only one public IP address and translating it to many private IP addresses, MultiNAT can get a block of public IP addresses and each of these public IP addresses in the pool can be translated into many private addresses.

Multiplexing
Transmitting multiple signals over a single communications line or computer channel – The two common multiplexing techniques are frequency-division multiplexing, which separates signals by modulating the data onto different carrier frequencies, and time-division multiplexing, which separates signals by interleaving bits one after the other.

N

Narrowband
A designation of bandwidth less than 56 kilobits per second.

Near-End Crosstalk (NEXT)
The interference between pairs of lines at the telephone switch end (central office).

Network Termination Equipment (NTE)
The equipment at the ends of the communication path.
**Optical Carrier, Level 3 (OC-3)**  
A fiber-optic line carrying 155 Mbps - OC-3 is a U.S. designation generally recognized throughout the telecommunications community worldwide.

**Optical Network Unit (ONU)**  
A form of access node that converts optical signals transmitted via fiber to electrical signals that can be transmitted via coaxial cable or twisted-pair copper wiring to individual subscribers (see Hybrid Fiber Coax).

**Packet**  
A formatted unit of data transmitted on a network.

**Packet-Switched Network**  
A network that allows a message to be broken into small "packets" of data that are sent separately from a source to a destination - The packets may travel different paths and arrive at different times, with the destination sites reassembling them into the original message. Packet-switching is used in most computer networks because it allows a very large amount of information to be transmitted through a limited bandwidth.

**Passive Optical Network (PON)**  
A fiber-based transmission network containing no active electronics.

**Plain Old Telephone Service (POTS)**  
The traditional function of telephone networks for voice communications - In most contexts, POTS is synonymous with the public switched telephone network (PSTN). POTS takes the lowest 4 kHz of bandwidth on twisted-pair wiring. Any service sharing a line with POTS must either use frequencies above POTS or convert POTS to digital and interleave with other data signals.
Plain Old Telephone Service Splitter (POTS Splitter)
A device that uses filters to separate voice from data signals when they are to be carried on the same phone line – A POTS splitter is required for several types of DSL service.

Point of Presence (PoP)
The physical point of connection between a data network and a telephone network.

Point-to-Point Protocol (PPP)
A protocol that can be used on various physical media, including twisted-pair or fiber-optic lines, or even satellite transmission – A PPP link can transport traffic for protocol suites that include TCP/IP, AppleTalk, OSI, IPX, and transparent Ethernet bridging. PPP can handle both synchronous and asynchronous communication.

Point-to-Point Protocol over Ethernet (PPPoE)
Combines the point-to-point protocol commonly used in dial-up connections with the Ethernet protocol, which supports multiple users in a local-area network – PPPoE is commonly used as a way to assign IP addresses to users behind cable and DSL modems. It also provides a method of accounting for the Internet service provider while giving the user a virtually configuration-free environment.

Point-to-Point Tunneling Protocol (PPTP)
Allows corporations to extend their corporate network through private “tunnels” over the public Internet – This type of interconnectivity is what creates a virtual private network (VPN). With PPTP, which is an extension of the point-to-point protocol (PPP), any PC user with PPP client support can connect securely over the Internet to a server at the corporate network.

Port
A location for passing data in and out of a device and, in some cases, also for attaching other devices or cables.

Postal, Telegraph and Telephone (PTT)
The generic European name usually used to refer to state-owned telephone companies.
Primary-Rate Integrated-Services Digital Network (PRI-IDSN)
Interface carrying voice or data – In North America, PRI-IDSN provides 23 B channels operating at 64 kb/s for 1.544 Mb/s transmission and one D channel operating at 16 kb/s for signaling/call information. In Europe, PRI-IDSN provides 30 channels operating at 64 kb/s for 2.048 Mb/s transmission.

Protocol
A formal description of message formats and the rules that two or more systems must follow to exchange those messages – Protocol definitions range from how bits are placed on a wire to the format of an e-mail message. Standard protocols allow different manufacturers’ computers to communicate.

Packet Internet or Inter-Network Groper (PING)
A basic Internet program that verifies if a particular IP address exists and that it can accept requests – Using the word PING as a verb means the act of using the PING utility or command. As a diagnostic utility, PING is used to ensure that a host computer you are trying to reach is actually operating.

Public Switched Telephone Network (PSTN)
The worldwide communications network that carries phone calls and data – PSTN is also known as POTS.

Quality of Service (QoS)
A premium class of data communication service in which the provider guarantees a level of service for mission-critical business data traffic.
Radio Frequency (RF)
Electromagnetic carrier waves upon which audio, video, or data signals can be superimposed for transmission.

Rate-Adaptive Digital Subscriber Line (RADSL)
A version of ADSL in which the modems test the line at start-up and adapt their operating speed to the fastest the line can handle.

Regional Bell Operating Company (RBOC)
One of the seven local telephone companies formed upon the divestiture of AT&T. The seven are: NYNEX, Bell Atlantic, BellSouth, Southwestern Bell, US WEST, Ameritech, and Pacific Telesis.

Remote Access
Access to a computer or a network from a remote location – Workers at branch offices, telecommuters, and mobile workers access the corporate network by a number of remote access methods. Remote access methods include analog and ISDN dial-up connectivity, private leased lines and, more recently, xDSL, cable modem and wireless. Remote access may be over the Internet or a private network. Typical remote access equipment includes modems and routers.

Resistance Fault Location (RFL)
A measurement technique that uses measured resistances to identify and locate tip-to-ring, tip-to-ground or ring-to-ground faults on the local loop.

RJ-11
A telephone-industry standard connector type, usually containing four pins.

RJ-45
A telephone-industry standard connector type, usually containing eight pins.

Router
A device that routes data between networks through IP addressing information contained in the IP packet – A DSL router routes data between the network and the Internet via the DSL connection.
S

Splitter
A filter to separate ADSL signals from POTS signals and thus prevent mutual interference.

Subnet
A network address created by using a subnet mask to specify that a number of bits in an address will be used as a subnet number rather than a host address.

Subnet Mask
A 32-bit number to specify which part of an address is the network number, and which part is the host address. When written in binary notation, each bit written as 1 corresponds to 1 bit of network address information. One subnet mask applies to all IP devices on an individual IP network.

Symmetrical Digital Subscriber Line (SDSL)
Similar to HDSL with a single twisted-pair line, carrying 1.544 Mb/s (U.S. and Canada) or 2.048 Mb/s (Europe) in each direction on a duplex line. This is considered symmetric because the data rate is the same in both directions.

Symmetrical High-Speed Digital Subscriber Line (SHDSL)
Similar to HDSL, SHDSL can operate over a single pair of wires for data rates of 2.3 Mb/s. Optionally, SHDSL can operate over two pairs and can provide data rates up to 4.7 Mb/s.

Synchronous
Data communications in which transmissions are sent at a fixed rate, with the sending and receiving devices synchronized.
T1.413

T1
A dedicated digital communication link provided by a telephone company that offers a bandwidth of 1.544 Mb/s, commonly used for carrying traffic to and from private business networks and Internet service providers.

T3
A dedicated digital communication link provided by a telephone company that offers bandwidth of 44.75 Mb/s, commonly used for carrying traffic to and from private business networks and Internet service providers.

Telco
The generic name for telephone companies throughout the world – The term telco encompasses RBOCs, ILECs, CLECs, and PTTs.

Telecommuting
The practice of using telecommunication technologies to facilitate work at a site away from the traditional office location and environment – Telecommuting usually involves teleconferencing, and interactive, electronic communication among three or more people at two or more sites. It also includes audio only, audio and graphics, and video-conferencing.

Terminal Adapter (TA)
Used on an ISDN line, device that serves the same function as a modem on a normal analog telephone line – A terminal adapter is an external device that connects a PC or Mac to an ISDN circuit, allowing non-ISDN equipment to use ISDN.

Time-Division Multiplexing (TDM)
A digital data transmission method that takes signals from multiple sources, divides them, and then reassembles them– Once divided, the signals are periodically placed into time slots and transmitted down a single path. The time slots are then reassembled back into multiple signals on the remote end of the transmission.
Trace Route
A utility that records the route between one computer and another specified destination computer on the Internet – The utility also calculates and displays the amount of time each hop takes. Trace Route can identify where problems are in the Internet network. The utility (PING, Packet Internet or Inter-Network Groper) is often used to first check whether a host is present on the network before trace route is used.

Transmission Control Protocol/Internet Protocol (TCP/IP)
A method of packet-switched data transmission used on the Internet – The protocol specifies the manner in which a signal is divided into parts, as well as the manner in which address information is added to each packet to ensure that it reaches its destination and can be reassembled into the original message. Basically, TCP/IP is the "language" of the Internet.

Tunneling
Refers to the use of the Internet as part of a private network – The "tunnel" refers to the path on the Internet that packets will be able to securely travel through. These tunnels are created by protocols such as point-to-point tunneling protocol or Layer 2 tunneling protocol for the establishment of a virtual private network (VPN).

Twisted Pair
The set of two copper wires used to connect a telephone customer with a switching office – A twisted pair is loosely wrapped around each other to minimize interference from other twisted pairs in the same bundle.

U
Uniform Resource Locator (URL)
A text-based address used to identify specific resources on the Internet, such as web pages – URLs are arranged in a hierarchical form that specifies the name of the server on which a resource is located and the name of the file on that server.

Universal Serial Bus (USB)
A computer interface with a maximum bandwidth of 1.5 MB/s used for connecting computer peripherals such as printers, keyboards and scanners.
Very-High-Data-Rate Digital Subscriber Line (VDSL)
A developing technology that promises much higher data rates over relatively short distances (up to 52 Mb/s over lines up to 1,000 ft or 300 m in length) – it is envisioned that VDSL may emerge somewhat after ADSL is widely deployed and coexist with it. The transmission technology (CAP, DMT, or other) and its effectiveness in some environments have not yet been determined; however, a number of standards organizations are currently working on it.

Video-on-Demand (VoD)
A pay-per-view television service in which a viewer can order a program from a menu and have it delivered instantly to the television set, typically with the ability to pause, rewind, etc.

Voice-over-Digital Subscriber Line (VoDSL)
The technology and service that enable voice services to be delivered over high-bandwidth DSL lines.

Virtual Private Network (VPN)
A way to deliver private data safely over a public network, such as the Internet – the data traveling between two hosts is encrypted for privacy using both hardware and software solutions.
**W**

**Wall jack**
A small hardware component used to tap into telephone wall cable. An RJ-11 wall jack usually has four pins; an RJ-45 wall jack usually has eight pins.

**Wide-Area Network (WAN)**
A WAN is typically constructed to span a number of locations within a single city, across a country, or even across the world.

**X**

**X.25 Data Protocol**
A packet-switching standard developed in the mid-1970s for transmission of data over twisted-pair copper wire.

**xDSL**
Generic name for digital-subscriber-line technology – The x is a variable that, in context, is replaced according to the appropriate variety of DSL (such as SDSL, IDSL, and ADSL). Also see DSL.
Contact the Authors

EXFO and the authors of this book welcome suggestions and feedback. Please forward any comments of questions you may have to:

EXFO, Copper Access Testing
160 Drumlin Circle
Concord (Ontario) L4K 3E5
CANADA

Tel.: 1 905 738-3741
E-mail: Robert.Filts@EXFO.com or Chris.Dunford@EXFO.com
Fax 1 905 738-3712
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