ADSL Basics (DMT)

Introduction

Asymmetrical digital subscriber line (ADSL) is emerging as the optimal solution to high-speed Internet access technology. ADSL matches the asymmetric pattern of Internet traffic with speeds of up to 8 Mb/s downstream from the network to the end user, and up to 640 kb/s upstream from the end user to the network. Because ADSL can transmit both voice and data simultaneously over an existing, single copper pair up to 18,000 feet long, it is the perfect solution for service providers to meet the increasing customer demand for faster Internet access. With its amazing speed and economical use of the installed base of copper cable, ADSL keeps the service cost low for both service providers and end users.

This ***Technical Note*** provides an overview of ADSL technology, a detailed discussion of how ADSL works, and recommended physical layer test procedures that can guarantee consistent performance. This ***Technical Note*** focuses on the discrete multi-tone (DMT) version of ADSL.

ADSL Overview

An ADSL system consists of the following components:

- ADSL transceiver unit-central office (ATU-C)
- ADSL transceiver unit-remote (ATU-R), also referred to as an ADSL modem
- Splitter – low pass filter for separating POTS from ADSL
- Digital subscriber line access multiplexer (DSLAM) – Multiplexes many ADSL copper lines into one asynchronous transfer mode (ATM) fiber and may include the splitter and ATU-C in the same frame

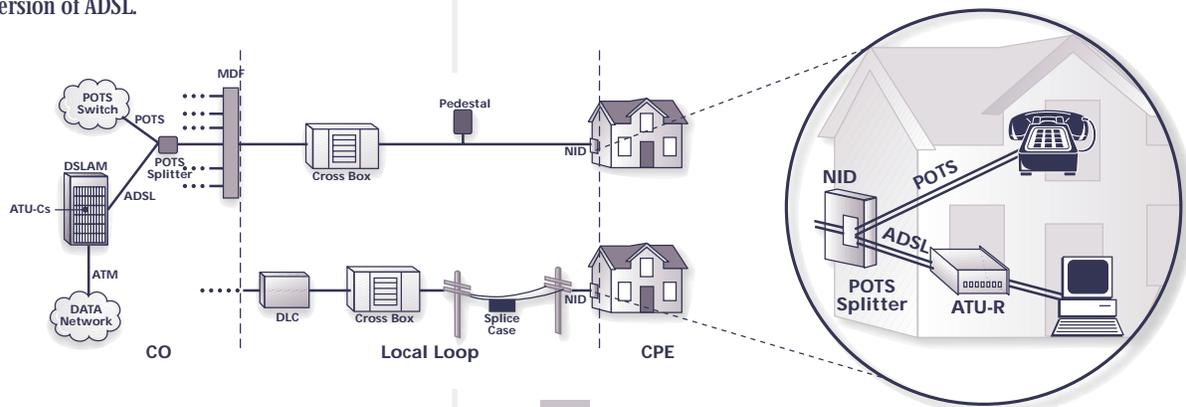Standard ADSL loop architecture is illustrated in ***Figure 1***.

Figure 1
ADSL loop architecture.

From the Loop
to the Customer Premise

The combined POTS and ADSL signal travels downstream from the loop to the network interface device (NID) at the customer premise. A splitter in, or adjacent to, the NID splits the signal and sends two distinct signals to the customer premise. The splitter is a passive, low-pass filter that always allows POTS to go through, guaranteeing uninterrupted voice service even if ADSL fails. The splitter also protects the ADSL signal from POTS transients originating from hand sets going on-hook and off-hook. The first output sends a POTS-only signal to the standard telephone sets in the house. The second output sends the combined ADSL and POTS signal to the ATU-R, which contains a high-pass filter that screens out the POTS signal. This resulting data-only signal is then converted to a standard 10BaseT or ATM.25 output for connection to a PC network interface card. This process is illustrated in *Figure 2*.

Depending on the application, existing house wiring is often used to carry the ADSL signal. This is typically referred to as the pair of wires used for line 2 —the yellow and black wires. However, some applications may require the installation of a dedicated pair, sometimes called a homerun, to carry the ADSL signal. For example, faulty wiring that will not carry the ADSL signal or two existing POTS lines would require a dedicated pair.
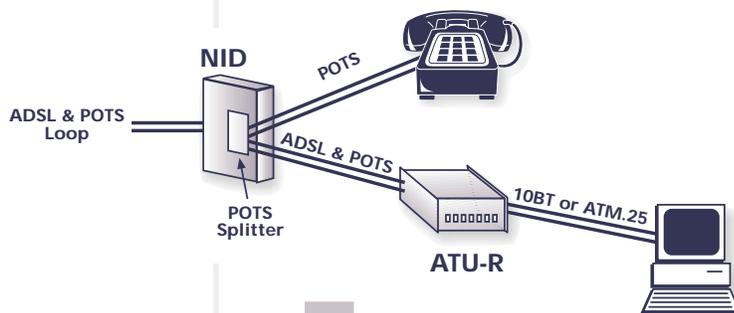

Figure 2
Signal at the customer premise.

From the Customer Premise
to the Central Office

The combined POTS and ADSL signal travels upstream from the customer premise to the main distribution frame at the central office. The signal then proceeds to the splitter where the POTS signal is routed to the voice switch to be handled via the public telephone network. The ADSL signal continues to the ATU-C, which, along with the splitter, is usually located in the DSLAM. The DSLAM contains many ATU-Cs where the ADSL signals are multiplexed onto an ATM fiber network. This ATM fiber network connects to Internet service providers, which provide data connections to the Internet and other services such as video-on-demand. The Internet service provider is chosen by the end user.

Customers who are located many miles from a central office usually obtain voice service from a digital loop carrier and can also obtain ADSL service via this carrier. The same DSLAM principle applies for a digital loop carrier as for a central office-based DSLAM; however, ADSL is multiplexed onto a fiber many miles away from the central office. An environmentally-hardened DSLAM, which includes the ATU-C and the splitter, is installed at the digital loop carrier. The POTS signal is split off to the voice route fiber and the ADSL signal is multiplexed onto an ATM fiber, which carries the ADSL signal back to the ATM network for access to the Internet. In some applications, ADSL is multiplexed using inverse multiplexing ATM over several T1 lines and is carried back to the central office.

ADSL Signal Encoding

Traditional plain old telephone service (POTS) uses a narrow 4-kHz baseband frequency to transmit analog voice signals. This means that even with sophisticated modulation techniques, current modem technology can only achieve throughput of up to 56 kb/s. To attain a much higher throughput of up to 8 Mb/s, ADSL increases the usable frequency range from 4 kHz to 1.1 MHz. Frequency division multiplexing (FDM) then allows ADSL to create multiple frequency bands to carry

upstream and downstream data simultaneously with the POTS signal over the same copper pair. The lower 4-kHz frequency range is reserved for POTS, the middle frequency band is used to transmit upstream data, and the larger, higher frequency band is used for downstream data. (See *Figure 3*.)

Discrete multi-tone (DMT) modulation has been chosen by the American National Standards Institute (ANSI) as the standard T1.413 line code. DMT, as its name implies, divides the data bandwidth into 256 sub-channels, or tones, ranging from 20 kHz to 1.1 MHz. Upstream data transfer frequencies range from 20 kHz to 160 kHz, and downstream data transfer frequencies range from 240 kHz to 1.1 MHz. (See *Figure 4*.) The remaining tones are used as guardbands for dividing the three frequency bands, and one pilot tone is used in each data stream, both upstream and downstream, for

timing purposes. Each tone has a spacing of 4.3 kHz and supports a maximum number of 15 bits, as limited by its signal-to-noise ratio. Since the tones in higher frequencies are subject to higher attenuation and noise, the number of bits per tone is usually fewer than that in lower frequencies.

In addition to the normal data bits, an embed-ded operations channel (EOC) is provided as a part of the ADSL protocol for communication between the ATU-C and ATU-R to provide in-service and out-of-service maintenance, to retrieve a limited amount of ATU-R status information, and to monitor ADSL per-formance. The EOC may also be used in the future to extend maintenance and performance monitoring.
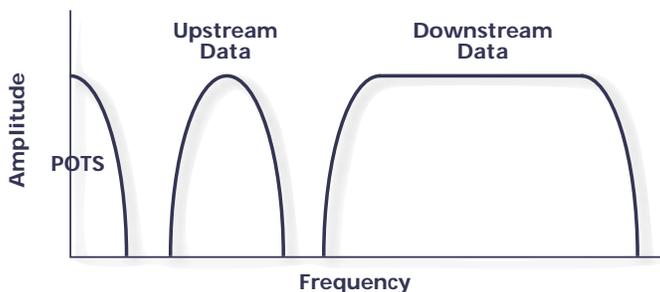
Frequency Division Multiplexing

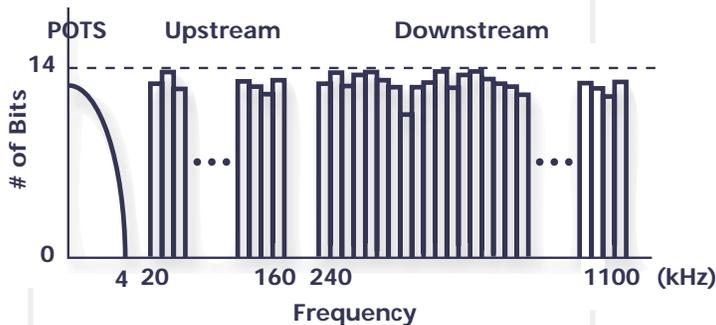*Figure 3*
Frequency bands.

Figure 4
Data bandwidth tones.

Quadrature Amplitude Modulation

ADSL uses quadrature amplitude modulation (QAM) to achieve the 15-bit maximum that any single tone can carry. QAM is a technique that employs a combination of amplitude modulation and phase shift keying.

For example, a signal that transmits at three bits per baud requires eight binary combinations to represent the signal. This example assumes two possible measures of amplitude and four possible phase shifts, which allow for eight possible waves. **Table 1** corresponds each binary combination to amplitude and phase shift.

Using the above technique, a large bit stream can be broken down into three-bit words, as shown in the following example:

001-010-100-011-101-000-011-110

Figure 5 illustrates QAM-encoded signals of the above bit stream with each wave shifted in relation to the wave that immediately precedes it.
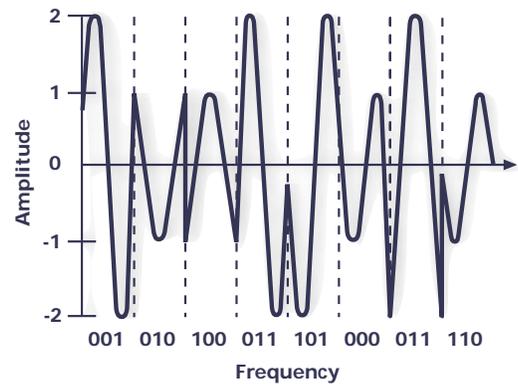

Figure 5
Example of QAM encoding.

In order to assign 15 bits of data to a single tone, 32,768 combinations of amplitude and phase shift combinations are required.

Bit Value	Amplitude	Phase Shift
000	1	None
001	2	None
010	1	1/4
011	2	1/4
100	1	1/2
101	2	1/2
110	1	3/4
111	2	3/4

Table 1
Quadrature amplitude modulation.

Rate Adaptation

Because ADSL is implemented over a normal copper twisted pair, it must adapt to various conditions associated with the traditional phone line. The quality of the local loop varies dramatically depending on gauge, installation practice, proximity to influences and other factors. A rate-adaptive ADSL (RADSL) system attempts to deliver the best throughput by adjusting the connection to compensate for these problems. There are three possible modes in a rate-adaptive ADSL system, which is provisioned by the Network Management System (NMS). Each mode deals with startup and operations, or showtime, in a different manner, as described below.

Mode 1: Manual – Rate Set Manually

In manual rate adaptation, the NMS specifies at startup the desired bit rate that the ATUs must support. If conditions are not satisfactory to achieve this rate, the synchronization between the ATUs will fail and re-synchronization will be attempted. During showtime, no rate adaptation will occur. The ATUs will maintain the NMS-specified bit rate.

Mode 2: Initialization – Rate Automatically Selected at Startup and Does Not Change during Showtime

In rate adaptation at initialization, the NMS specifies at startup the desired minimum and maximum bit rate range that the ATUs must support. The ATUs will attempt to maximize throughput up to the maximum bit rate setting. If conditions are not satisfactory to achieve the minimum bit rate, synchronization between the ATUs will fail and re-synchronization will be attempted. Once the bit rate has been established, the showtime operating conditions are the same as Mode 1.

The Network Management System

The Network Management System (NMS) is the control center for the ADSL system. The NMS is used to analyze the network for quality and performance and contains system parameters such as minimum and maximum bit rates. When a new line is commissioned, the NMS is used to set end user configurations, which include bit rate settings that limit throughput. For example, if the end user has an option to pay $20.00 per month for 1 Mb/s service, the NMS is set to a maximum bit rate of 1 Mb/s. Likewise, if another end user is paying $50.00 per month for 3 Mb/s, the NMS bit rate is set accordingly. The NMS is also used to control system settings such as interleaved bit rates, noise margins and power settings.

Mode 3: Dynamic – Rate Automatically Selected at Startup and Continuously Adapted during Showtime

In dynamic rate adaptation, the operating conditions are the same at startup as in Mode 2. During showtime, the system will monitor the line condition to continuously attempt to achieve the maximum bit rate possible based on the NMS settings.

Bit Swapping

Bit swapping occurs during showtime of all three rate-adaptive modes. The ADSL system adjusts itself to compensate for network problems such as crosstalk or noise. As the system operates, the quality of each 4-kHz sub-channel is monitored constantly, and adjustments are made to the bits-per-tone distribution to maintain performance. If the noise margin for a particular tone degrades below the minimum noise margin and the system performance is compromised, one or more bits on that tone are automatically moved to another tone that can support additional bits. This constant monitoring allows for high performance and robust communications by allowing the ADSL system to continuously adapt to changing channel and noise characteristics. See *Figure 6* on the next page for an illustration of bit swapping.
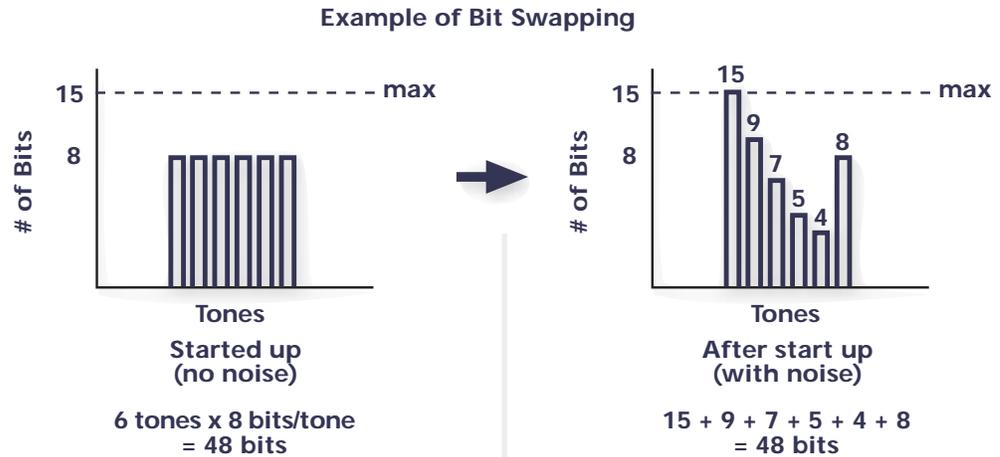
Example of Bit Swapping

# of Bits

15 ---------------------------- max

8

Tones

**Started up
(no noise)**

**6 tones x 8 bits/tone
= 48 bits**

# of Bits

15 — 15

9

8 — 7

5

4

8

---------------------------- max

Tones

**After start up
(with noise)**

**15 + 9 + 7 + 5 + 4 + 8
= 48 bits**

Figure 6
Bit swapping

ATM over ADSL

According to the Open Systems Interconnect (OSI) reference model, ADSL is a physical layer technology. Functionally, the next layer up is the link layer, which in most cases, is implemented using ATM. ATM is the preferred method because it is an inherently broadband technology that is characterized by universality, high throughput and low delay.

During the initial synchronization between the ATU-C and ATU-R, the ADSL signal is transmitted with empty ATM cells. The transfer rate of these and subsequent ATM cells can be configured for two modes: fast data and interleaved. As the name implies, fast data is the transport method with lower latency. Interleaved mode is more robust because of additional error correction bits embedded in the signal. As a result of the different implementation, fast data mode has lower delay when compared to the interleaved mode.

Permanent Virtual Connection

Note that the ADSL connection from the customer premise equipment to the Internet service provider is always on. There is no dial-up required as with analog or ISDN modems. When an end user turns on the ATU-R, synchronization is established with the ATU-C. The ATM cells riding on top of the ADSL physical layer contain addressing information that specifies which Internet service provider to connect to. When the connection is made, a permanent virtual connection (PVC) is established between the ATU-R and the Internet service provider. As a result, the end user has a direct link to the Internet as long as the ATU-R remains powered on.

ADSL Loop Requirements

Length

An ADSL loop typically extends 12,000 to 18,000 feet, including all bridged taps. The exact length depends on wire gauge, gauge changes and overall line condition.

Bridged Taps

The length of all bridged taps on the span should total less than 2,500 feet with no single tap exceeding 2,000 feet. For instance, eight 60-foot bridged taps are acceptable, but one 2,400-foot tap is unacceptable. Special attention should be paid to bridged taps that are extremely close to the ATU. The closer the bridged tap is to the ATU, the more likely it is to return reflections that contain more energy than incoming data pulses from the other ATU. If this occurs, the circuitry is unable to distinguish between data and unwanted reflections. For example, a bridged tap within 100 feet of an ATU-R can dramatically impair the ADSL signal. For these reasons, it is recommended that no bridged taps are placed within 1,000 feet of the ATUs.

Load Coils

ADSL, which operates over a high-frequency range, does not work with load coils in the loop. Load coils are used to extend POTS and do not allow high-frequency signals to be transmitted.
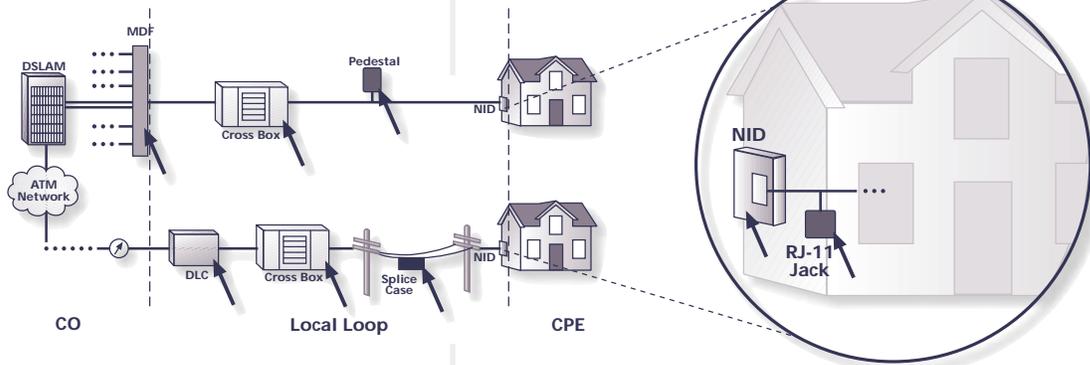
Testing ADSL (DMT)

When testing ADSL, it is important to understand the service layers of the system according to the OSI Reference Model. In most cases, ATM is used as the transport method that rides on top of the ADSL physical layer. Furthermore, the ATM layer may be used to transport TCP/IP or bridged Ethernet packets. Although each of these layers could cause performance problems, a reliable network requires trouble isolation first at the physical layer where environmental conditions can have the most effect.

This **Technical Note** focuses on testing at the physical layer. Accessing the copper loop is the only way to diagnose the actual ADSL signal; consequently, a physical layer test is critical. In addition, physical layer testing is the most effective approach for performing service qualification and troubleshooting, because if physical layer conditions prevent synchronization of the ATUs, testing at the ATM or TCP/IP layer would be impossible.

Figure 7 illustrates physical layer test access points.

Figure 7
Physical layer test access points.

The main applications for testing ADSL consist of service qualification, trouble isolation and loop qualification.

Service Qualification

Service qualification is used to close out repairs, verify new installations, ensure that the service meets customers' expectations, and avoid return visits or kickbacks. Recommended service qualification measurements are as follows:

- Throughput – ensures that the line rate meets requirements at both ADSL and ATM layers
- Line capacity – verifies that there is ample capacity for increasing or maintaining throughput via bit swapping in case trouble arises on the span
- Noise margin – verifies that noise margins are acceptable and that a marginal increase in line noise will not impact performance
- Power – verifies that the signal power lies within defined specifications
- Bit error rate test (BERT) – verifies that the bit error rate meets the ANSI T1.413 specification
- Dial tone – verifies that POTS service was not inadvertently affected

Trouble Isolation

If the service qualification fails or the system does not synchronize, the following systematic, trouble isolation procedures are recommended:

1. Test synchronization at the ATU-R. Replace the ATU-R with the test set to perform emulation and attempt to synchronize with the installed ATU-C.

   - If you are able to synchronize with the test set but not able to do so with the ATU-R, a check of the minimum bit rate setting at the NMS is recommended. If the minimum rate is set too high, the ATU-R will not synchronize.

   - If the NMS settings are correct, the ATU-R should be replaced.

2. If the test set cannot synchronize in the house, go to the NID and try to synchronize.

   - If you cannot synchronize at the NID, check for dial tone. This determines if the network is connected back to the central office.
     - If dial tone is available, check for load coils on the span and remove any that are present. If no load coil is found, go to step #5.
     - If dial tone is not present, check for an open using a loop troubleshooting tool with a time domain reflectometer (TDR).
   - If synchronization is successful at the NID, there is most likely an inside house wiring problem, which can typically be isolated with a simple digital volt ohm meter. An alternate solution is to install a homerun line.

3. If synchronization is possible in the house but the performance is poor, move the test set to the NID to check for improved performance. If performance is improved, there is faulty in-house wiring.

4. If synchronization is possible at the NID but performance is poor, there is most likely trouble on the span. Perform a wide-band frequency sweep and look at the bits carried per DMT tone. Compare the bits per DMT tone to the noise power per DMT tone.

   - If a major dip in bits per tone is seen, there is AC trouble on the loop. See *Figure 8*.
     - Transmission influence – To verify the type of AC trouble present, compare the bits per tone to noise power per tone. If there is noise influence at the same frequency that the bits-per-tone dip occurred, the degraded performance is most likely due to a transmission influence. (See *Figure 8*) The frequency

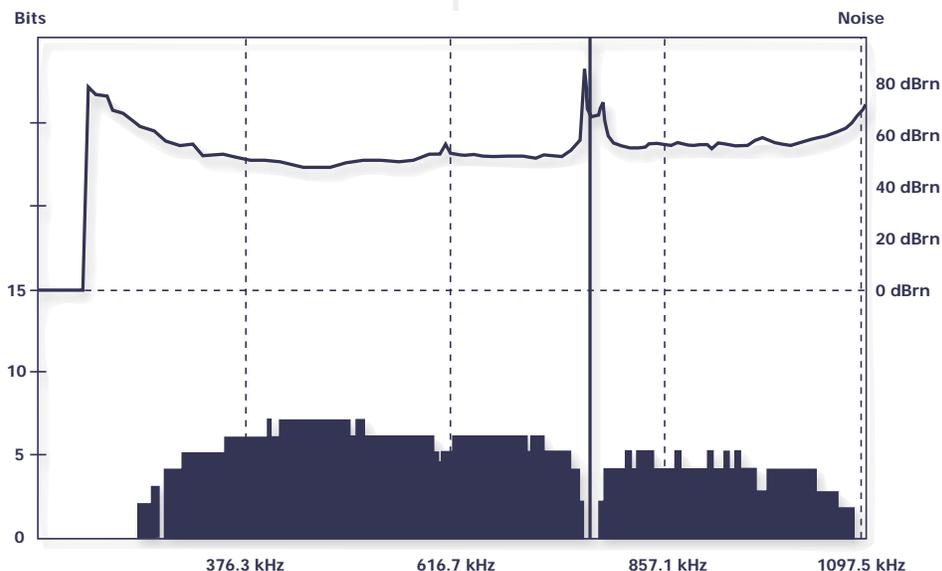**Bits** **Noise**

80 dBrn
60 dBrn
40 dBrn
20 dBrn
0 dBrn

15

10

5

0

376.3 kHz   616.7 kHz   857.1 kHz   1097.5 kHz

Figure 8
Bits-per-tone vs. noise graph
with possible T1 influence.

at which this occurs will help identify the source of influence or crosstalk. An example of possible shared frequency zones would be T1 centered at 770 kHz or HDSL at 196 kHz.

– Bridged taps/wet sections – If there is a major dip in the bits-per-tone graph but the noise power-per-tone graph does not show any abnormalities, the most likely troubles are bridged taps or wet sections on the span. Use a loop troubleshooting tool with a TDR to quickly find and fix these problems.

• DC troubles – If the bits per tone are low across the whole bandwidth, the cause is most likely DC troubles on the loop, such as shorts or grounds.

5. If synchronization is not successful at the NID, move up the loop to the next access point, which is typically the pedestal. Disconnect the connection from the pedestal to the customer premise equipment and connect the test set to the loop facing the central office or digital loop carrier. If synchronization is successful, isolate the problem on the loop between the pedestal and the NID. Continue this process, as needed, along the complete copper span, checking the splice case(s), crossbox, and main distribution frame.

6. Once the problem is isolated and/or identified, report to the appropriate group for resolution. A good loop troubleshooting tool can be used to locate and fix the problem.

Loop Qualification

In addition to service qualification and trouble isolation, an ADSL physical layer test set, such as the T-BERD 1000, can also perform loop qualification. This application is best used when a loop is questionable or

RJ-11 Pin In/Out

At the customer premise, the ADSL and POTS signals are divided at the splitter. This means that access to the ADSL signal at the NID is different than access to the signal inside the customer premise. In the United States, the line input usually enters at pins #3 and #4 in the RJ-11 jack in the NID. After the signal proceeds through the splitter, the ADSL data signal is accessible on pins #2 and #5 of the indoor RJ-11 jack.
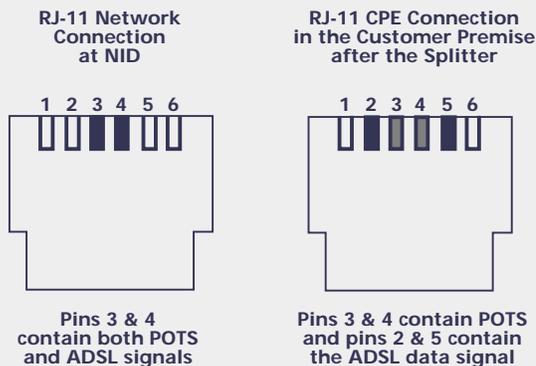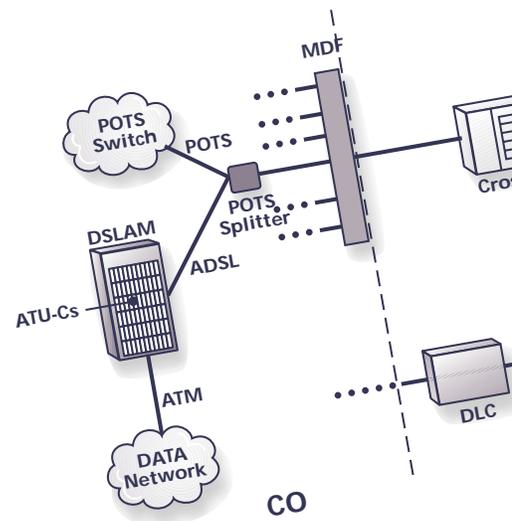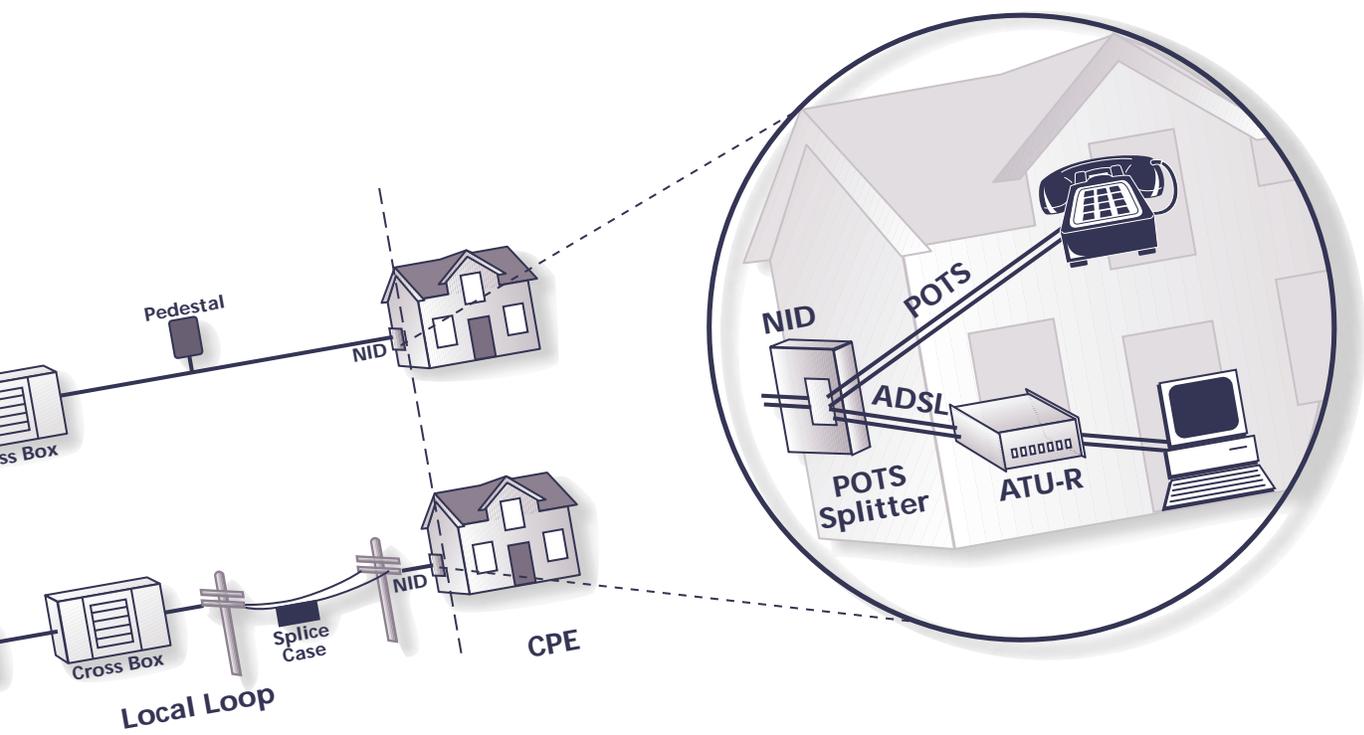
RJ-11 Network Connection at NID

1 2 3 4 5 6

RJ-11 CPE Connection in the Customer Premise after the Splitter

1 2 3 4 5 6

Pins 3 & 4 contain both POTS and ADSL signals

Pins 3 & 4 contain POTS and pins 2 & 5 contain the ADSL data signal

Figure 9
Diagram of RJ-11 pin in/out.

barely qualifies according to the standard qualification method in place. To qualify a loop, perform a service qualification test at the customer's NID. (See the Service Qualification section on page 8.) This can be accomplished by a single technician in conjunction with an installed ATU-C in the central office or digital loop carrier.

Conclusion

ADSL promises to be the technology for the new millennium, enjoying enormous popularity from both service providers and their customers. Offering overwhelming advantages over other broadband technologies such as cable and satellite, ADSL:

- Matches the asymmetric pattern of Internet applications with high download volume
- Provides the high bandwidth required by small office/home office (SOHO) applications
- Uses existing copper twisted pair, lowering the capital investment of service providers as well as the cost to end users
- Adapts to various line conditions and influences
- Manages end user throughput for multiple performance offerings
- Maintains consistently high bandwidth
- Co-exists with lifeline POTS

As service providers deploy more and more ADSL lines, it becomes ever more vital to have a solid installation and maintenance plan in place to stay competitive. Testing ADSL at the physical layer and targeting the root cause of problems before exploring more complex and time-consuming issues is an integral part of that plan.

NOTE: Specifications, terms, and conditions are subject to change without notice.

Notes

POTS
Switch

POTS

MDF

Cro

POTS
Splitter

DSLAM

ADSL

ATU-Cs

DLC

ATM

DATA
Network

CO

Pedestal

NID

ss Box

Cross Box

Splice
Case

NID

CPE

Local Loop

NID

POTS

ADSL

POTS
Splitter

ATU-R

TTC™