

INTRODUCTION

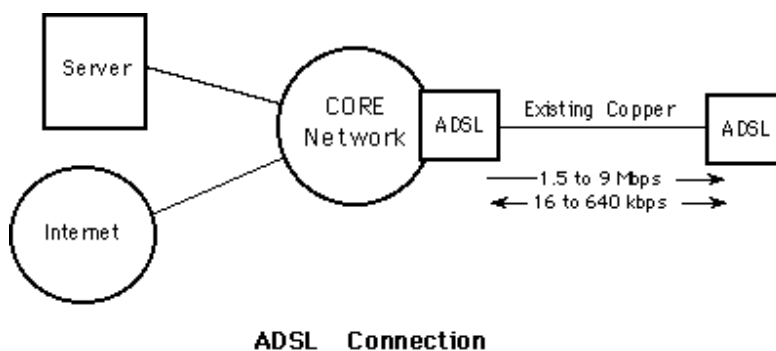
ADSL technology is asymmetric. It allows more bandwidth downstream – from an NSP’s central office to customer site – than upstream from the subscriber to the central office. This asymmetry, companied with always-on access (which eliminates call setup), makes ADSL ideal for Internet/intranet surfing, video- on –demand, and remote LAN access. Uses of this application typically download much more information than they send.

ADSL transmits more than 6 Mbps to a subscriber, and as much as 640Kbps more in both directions. Such rate expands existing access capacity by a factor of 50 or more with out new cabling. ADSL can literally transform the existing public information network from one limited to voice, text, and low-resolution graphics to a powerful, ubiquitous system capable of bringing multimedia, including full motion video, to every home this century.

ADSL will play a crucial role over the next decade or more as telephone companies enter new markets for delivery information in video and multimedia formats. New broadband cabling will take decades to reach all prospective subscribers. Success of these new services will depend on reaching as many subscribers as possible during the first few years. By bringing movies, television, video catalogs, remote CD-ROMs, corporate LANs and the internet into homes and small businesses, ADSL will makes these markets viable and profitable for telephone company and application suppliers.

DEFINITION

ADSL- (Asymmetric Digital Subscriber Line) -- A method for moving data over regular phone lines. An ADSL circuit is much faster than a regular phone connection, and the wires coming into the subscriber's premises are the same (copper) wires used for regular phone service. An ADSL circuit must be configured to connect two specific locations, similar to a leased line. A commonly discussed configuration of ADSL would allow a subscriber to receive data (download) at speeds of up to 1.544 Megabits per second, and to send (upload) data at speeds of 128 kilobits per second. Thus the 'Asymmetric' part of the acronym. Another commonly discussed configuration would be symmetrical: 384 kilobits per second in both directions. In theory ADSL allows download speeds of up to 9 megabits per second and upload speeds of up to 640 kilobits per second. ADSL is often discussed as an alternative to ISDN, allowing higher speeds in cases where the connection is always to the same place.



ADSL

ADSL is a newly standardized transmission technology facilitating simultaneous use of normal telephone services, data transmission of 6 Mbit/s in the downstream and Basic-rate Access (BRA).

ADSL can be seen as a FDM system in which the available bandwidth of a single copper-loop is divided into three parts. See figure. The base band occupied by POTS(Plain Old Telephone Service) is split from the data channels by using a method which guarantees POTS services in the case of ADSL-system failure (eg. passive filters).

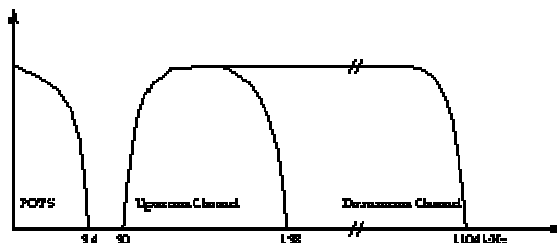


Figure: Frequency Spectrum of ADSL

ADSL MODULATION METHODS

ANSI standard describes a basic ADSL system which uses DMT (Discrete Multitone) modulation. There is also at least one other ADSL system available. This system facilitates Carrier less AM/PM (CAP). In this chapter the DMT modulation method is described.

- Discrete Multitone (DMT)
- ADSL DMT Modulation
- Pilot
- Nyquist frequency
- Modulation by the inverse discrete Fourier transform (IDFT)
- Synchronization symbol
- Cyclic prefix
- ATU-R

ADSL DMT MODULATION

In ADSL DMT-systems the downstream channels are divided into 256 4-kHz-wide tones. The upstream channels are divided into 32 sub channels. See also the frequency spectrum of the ADSL-channels in figure.

Discrete Multitone (DMT)

The basic idea of DMT is to split the available bandwidth into a large number of subchannels. DMT is able to allocate data so that the throughput of every single subchannel is maximized. If some subchannel can not carry any data, it can be turned off and the use of available bandwidth is optimized. The examples in figure give an idea about of the functionality of DMT.

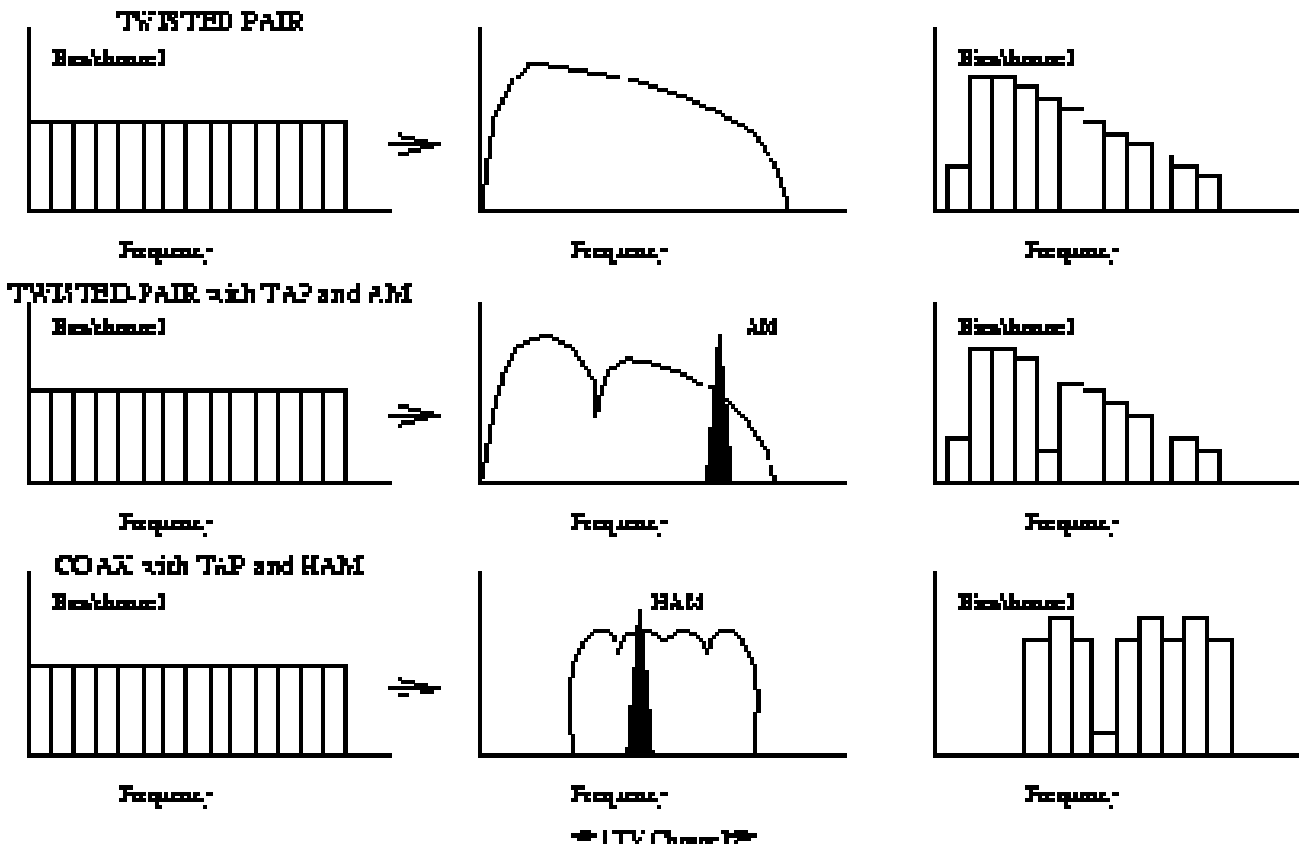


Figure: Examples of DMT

First an equal number per tone is transmitted to measure the characteristics of the line. The processing of the signal takes place in ATU-R, and the optimized bit distribution information will be delivered for ATU-C by using the same phone-line at a secure low speed.

The first example describes a segment of 24-gauge twisted pair phone-line. Low frequencies are eliminated by the transformer coupling. The attenuation at the higher frequencies depends on the length of the phone-line.

The second example includes the notch in spectrum that is illustrative of bridge taps and also the interference of an AM radio station.

A third example shows that DMT is also an interesting possibility for other transmission channels, such as coaxial cable-TV networks, as well.

Pilot

Carrier 64 ($f = 276$ kHz) is reserved for a pilot. The data modulated onto the pilot subcarrier shall be constant 0,0. Use of this pilot allows resolution of sample timing in a receiver modulo-8 samples.

Nyquist frequency

The carrier at the Nyquist frequency (256) may not be used for data. The frequency of the carrier must be greater than twice the maximum modulating frequency.

Modulation by the inverse discrete Fourier transform (IDFT)

The modulating transform defines the relationship between 512 real values x_k and the Z_i

$$x_k = \sum_{i=0}^{511} \exp\left(\frac{j\pi ki}{256}\right) Z_i$$

for $k = 0$ to 511.

The encoder and scaler, see figure, generate only 255 complex values of Z_i (plus zero at dc, and one real value if the Nyquist frequency is used). In order to generate real values of x_k these values shall be augmented so that the vector Z_i has Hermitian symmetry.

Synchronization symbol

The synchronization symbol permits recovery of the frame boundary after micro-interruptions that might otherwise force retraining.

Cyclic prefix

The last 32 samples of the output of the IDFT (x_k for $k = 480$ to 511) are prepended to the block of 512 samples and read out to the D/A converter in sequence. The cyclic prefix is used for data and synchronization symbols.

ATU-R

For ATU-R the maximum number of subcarriers is 31 and carrier 16 is reserved for a pilot. The modulating transform defines the relationship between 64 real values x_k and the Z_i

$$x_k = \sum_{i=0}^{63} \exp\left(\frac{j\pi ki}{32}\right) Z_i$$

for $k = 0$ to 63.

For the cyclic prefix the 4 last samples are used.

HOW DOES ADSL WORK?

The service makes use of your existing telephone line and splits the signal into voice communications and high speed data connection. ADSL makes use of a frequency range not used by voice communications.

ADSL CAPABILITIES

An ADSL circuit connects an ADSL modem on each end of a telephone line, creating three information channels -- a high speed download, a medium speed duplex channel, depending on the implementation architecture, and a POTS (Plain Old Telephone Service) or an ISDN channel. POTS/ISDN channel is split off from the digital modem by filters

maintaining uninterrupted POTS/ISDN, even if ADSL fails. The high speed channel can range from 1.5 to 6.1 Mbps, while duplex rates range from 16 to 832 kbps. The high speed channel can be sub multiplexed to form multiple, lower rate channels, depending on the system.

ADSL modems provide data rates consistent with North American digital hierarchies and can be purchased with various speed range capabilities. The minimum configuration provides 1.5 or 2.0 Mbps downstream and 1.5 or 2.0 Mbps duplex channel; others provide rates of 6.1 Mbps and 64 kbps downstream and 1.5 or 2.0 Mbps duplex with downstream rates up to 8 Mbps and duplex rates up to 640 kbps. ADSL modems will accommodate ATM transport with variable compensation for ATM overhead, as well as IP protocols.

Downstream data rates depend on a number of factors, including the length of the copper line, its wire gauge, presence of bridged taps, and cross-talk. Line attenuation increases with line length and frequency, and decreases as the wire diameter increases. Ignoring bridged taps, ADSL will perform as follows:

| Data Rate | Wire Gauge | Distance | Wire Size | Distance |
|------------------|-------------------|-----------------|------------------|-----------------|
| 1.5 or 2 Mbps | 24 AWG | 18,000 ft | 0.5 mm | 5.5 km |
| 1.5 or 2 Mbps | 26 AWG | 15,000 ft | 0.4 mm | 4.6 km |
| 6.1 Mbps | 24 AWG | 12,000 ft | 0.5 mm | 3.7 km |

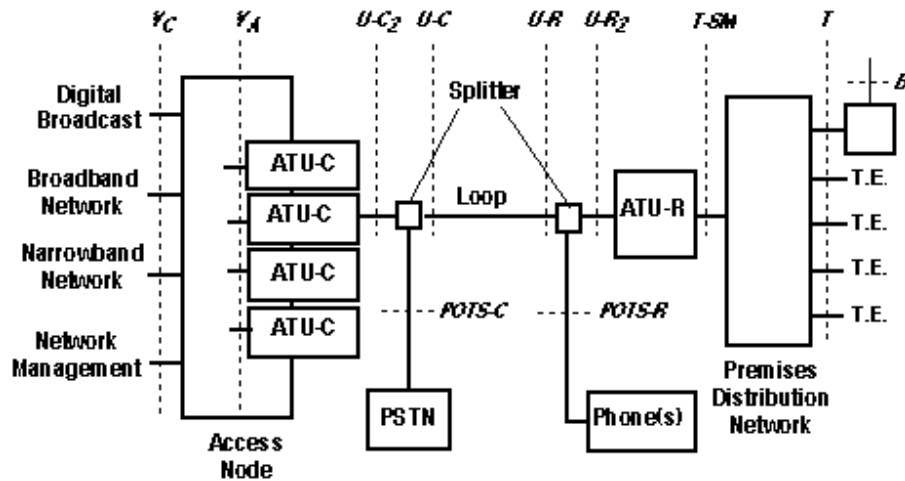
While the measure varies from provider to provider, these capabilities cover up to 95% of a loop plant depending on the desired data rate. Customers at these distances can be reached with fiber-based digital loop carrier systems. As these DLC systems become commercially available, telephone companies will provide virtually ubiquitous access in a relatively short time.

Many applications enabled by ADSL involve digital compressed real time signal, digital video cannot use link or network level error correction procedures commonly found in data communications systems. ADSL modems incorporate forward error correction that dramatically reduces errors caused by pulse noise. Error correction on a symbol-by-symbol basis also reduces errors caused by continuous noise coupled into a line.

TECHNOLOGY

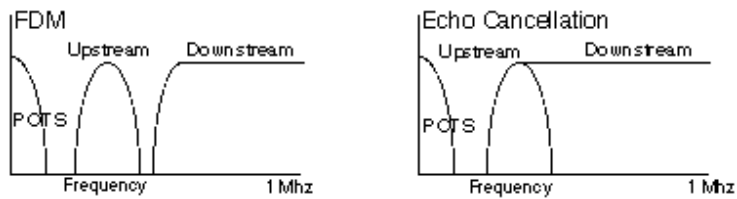
ADSL depends upon advanced digital signal processing and algorithms to squeeze so much information through twisted-pair telephone lines. In addition, many advances have been required in transformers, analog filters, and amplifiers. Long telephone lines may attenuate signals at one megahertz (the upper edge of the band used by ADSL) by as much as 90 dB, forcing analog section modems to work very hard to realize large dynamic ranges, separate channels, and maintain low noise figures. On the outside, ADSL looks simple -- transparent continuous data pipes at various data rates over ordinary telephone lines. (

, where all the transistors work, there is a miracle of modern technology.



To create multiple channels, ADSL modems divide the available bandwidth of a telephone line in one of two ways -- Frequency Division Multiplexing (FDM) or Echo Cancellation. FDM assigns one band for

downstream data and another band for upstream data. The downstream path is divided by time division multiplexing into one or more high speed channels and one or more low speed channels. The upstream path is also multiplexed by time division multiplexing low speed channels. Echo Cancellation assigns the upstream band to be used for the downstream, and separates the two by means of local echo cancellation. This technique well know in V.32 and V.34 modems. With either technique, a 4 kHz region for POTS at the DC end of the band.



An ADSL modem organizes the aggregate data stream created by multiplexed channels, duplex channels, and maintenance channels together, and attaches an error correction code to each block.

The receiver then corrects errors that occur during transmission up to the limit defined by the code and the block length. The unit may, at the user's option, divide data into subblocks by interleaving data within subblocks; this allows the receiver to correct any combination of errors within a specific span of bits. This allows the simultaneous transmission of both data and video signals alike.

ADSL STANDARDS AND ASSOCIATIONS

The American National Standards Institute (ANSI), working with the International Telecommunications Union (ITU-T), approved the first ADSL in 1995. It supported data rates up to 6.1 Mbps (ANSI Standard T1.413). The European Technical Standards Institute (ETSI) adopted an Annex to T1.413 to reflect European requirements. T1.413 (Issue I) was limited to a single terminal interface at the premise end. Issue II (T1.413-2) was adopted in 2001, expanded the standard to include a multiplexed interface at the premise.

end, protocols for configuration and network management, and
vements.

Work towards an Issue III was ultimately submitted to the interna
rds body, the ITU-T, to develop the international standards for ADSL
' standards for ADSL are most commonly referred to as G.lite (G.992.
(G.992.1)—both of which are approved in June of 1999. Havi
ational standard has aided in moving towards vendor interoperabilit
e provider acceptance, further increasing deployment, and ultia
ility to the consumer.

The ATM Forum has recognized ADSL as a physical
ission protocol for unshielded twisted pair media.

The DSL Forum was formed in December of 1994 to promote th
ot and facilitate development of DSL system architectures, protocol
ces for major DSL applications. The DSL Forum has expanded its eff
s marketing issues surrounding awareness, and enabling high
ations via DSL. The DSL Forum has approximately 340 members repres
e providers, equipment manufacturers, and content developers from thro
rld.

ADSL MARKET STATUS

ADSL is available in various speeds and pricing throughout the l

, Canada, Europe and Asia. There are emerging markets in the Caribbean, South America, and Latin America. North America has just hit its 1 (M) millionth customer. Worldwide the number is rapidly approaching 3 million in third quarter 2000.

There has been extensive work on interoperability, and the DSL market has demonstrated any-to-any interoperability with 42 vendors at SUPERCOMM. Interoperability is broadening rapidly due to emerging solutions to reaching customers. DSL is Digital Loop Carrier (DLC).

ADSL TRANSPORT CAPACITY

The different ADSL transport classes for $\times 2.048$ Mbps bearers are 2M-1, 2M-2 and 2M-3. In which 2M-1 corresponds the highest rate and shortest range.

ADSL downstream transport capacity is basically from 2.048 Mbps to 6.144 Mbps. At 6.144 Mbps it is possible to achieve the range of about 3 kilometers. The lower the transmission rate is the longer the range will be. Upper limit is according to tests about 9 kilometers. It is possible to achieve higher data rates of 52 Mbps and 155 Mbps, corresponding range of one mile and a quarter mile, if the used transmission media is fiber. By using DMT ADSL it is also possible to use other data rates, the exact rate depends only on interface circuits. So the system is flexible enough to support, eg., T1. The downstream bit rates are summarized in table.

| Default bearer channels n × 2.048 Mbit/s | | | |
|--|--|-------------------------------------|-------------------------------------|
| | Transport Class 2M-1 | Transport Class 2M-2 | Transport Class 2M-3 |
| Total downstream simplex bearer capacity | 6.144 Mbit/s | 4.096 Mbit/s | 2.048 Mbit/s |
| Duplex C channel | 64 kbit/s | 64 kbit/s | (see note 1) |
| Total for optional duplex bearers | 0, 160, 384, 544, or 576 kbit/s (see note 2) | 0, 160, or 384 kbit/s | 0 or 160 kbit/s |
| Total bearer channel capacity | 6.208 - 6.784 Mbit/s | 4.160 - 4.544 Mbit/s | 2.048 - 2.208 Mbit/s (see note 3) |
| Overhead range | 128 - 192 kbit/s | 128 - 192 kbit/s | 128 - 160 kbit/s |
| Aggregate rate range (typical) | 6.336 - 6.976 Mbit/s (6.912 Mbit/s) | 4.288 - 4.736 Mbit/s (4.704 Mbit/s) | 2.176 - 2.368 Mbit/s (2.336 Mbit/s) |
| NOTES | | | |
| 1. The 16 kbit/s duplex C channel is transported entirely within the overhead dedicated to synchronization capacity. | | | |
| 2. 544 kbit/s is required when a 160 kbit/s and a 384 kbit/s optional duplex bearer are both included. | | | |
| 3. The duplex C channel is not included in total bearer channel rates for transport class 2M-3; it's included in the overhead. | | | |
| 4. The overhead required for FEC is not shown in this table. | | | |

Table: Downstream bit rates

ADSL upstream transport capacity is 0 -- 640 kbit/s depending on transport class.

The aggregate upstream bit rates are summarized in table.

| | Transport Class 2M-1 | Transport Class 2M-2 (see note 1) | Transport Class 2M-3 |
|---|--|--------------------------------------|---------------------------------|
| Duplex C channel | 64 kbit/s | 64 kbit/s | (see note 2) |
| Total for optional duplex bearers | 0, 160, 384, 544, or 576 kbit/s (see note 3) | 0, 160, or 384 kbit/s | 0 or 160 kbit/s |
| Total bearer channel capacity | 64 - 640 kbit/s | 64 - 448 kbit/s | 0 - 160 kbit/s |
| Overhead range | 96 - 128 kbit/s | 96 - 128 kbit/s | 96 - 128 kbit/s |
| Aggregate rate range (typical) | 160 - 768 kbit/s (768 kbit/s) | 160 - 576 kbit/s (576 kbit/s) | 96 - 288 kbit/s (288 kbit/s) |
| <p>NOTES</p> <ol style="list-style-type: none"> 1. If it is determined that transport class 2M-2 can support the 576 kbit/s optional duplex bearer, then the maximum total bearer channel capacity and maximum aggregate rate will increase by 32 kbit/s. 2. For transport class 2M-3, the duplex C channel is 16 kbit/s; this is not included in the total bearer channel rates because it is transported entirely within the overhead dedicated to synchronization capacity. 3. 544 kbit/s obtained when both optional duplex bearers are included. 4. The overhead required for FEC is not shown in this table. | | | |

Table: Upstream bit rates

ATM can be transported over ADSL and the components of the aggregate bit rates are summarized in table.

| | Transport Class 2M-1 | Transport Class 2M-3 | Transport Class 2M-3 |
|--|-------------------------|-------------------------|-------------------------|
| Total assigned downstream simplex bearer capacity | 6.944 Mbit/s | 4.640 Mbit/s | 2.336 Mbit/s |
| Duplex C channel | 64 kbit/s | 64 kbit/s | (see note 1) |
| Total for optional duplex bearers | 0 kbit/s | 0 kbit/s | 0 kbit/s |
| Total bearer channel capacity | 7.008 Mbit/s | 4.704 Mbit/s | 2.400 Mbit/s |
| Overhead range | 128 - 160 kbit/s | 128 - 160 kbit/s | 128 - 160 kbit/s |
| Aggregate rate range | 7.136 - 7.168 Mbit/s | 4.832 - 4.864 Mbit/s | 2.528 - 2.560 Mbit/s |
| <p>NOTES</p> <p>1. The duplex C channel is not included in total bearer channel rate for transport class 2M-3; it is included in the overhead.</p> <p>2. Maximum overhead is 160 kbit/s for all transport classes because only one downstream simplex channel is allowed.</p> <p>3. These values have been calculated by $\frac{63}{47} \times n \times 2.048$ Mbit/s and rounded up to the nearest 32 kbit/s multiple</p> | | | |

Table: ATM bit rates

ADSL's RELATIONSHIP WITH VDSL

Simply put, VDSL is a very fast version of ADSL. With VDSL, the maximum downstream rate for short lengths of cable can reach almost 55Mbps (see Table 14.4). Upstream rates can reach speeds of up to 2.3Mbps (future projections reach 19.2Mbps or higher). Both the upstream and

downstream data channels can be separated (by frequency) and overlaid on existing POTS or ISDN services, making VDSL a very appetizing solution to high-speed, cheap networking. Later upgrades may need to switch to echo cancellation or some other method to manage the pipeline. Like ADSL, VDSL will be used mainly for real-time video transmissions and high-speed data access.

Table: VDSL speed/distance (estimates).

| <i>Speed</i> | <i>Dist</i> |
|--------------|-------------|
| >100 00 | 51.8 |
| >100 00 | 25.8 |
| >300 00 | 12.9 |

CONCLUSION

ADSL will play a crucial role over the next ten or more years as telephone companies enter new markets for delivering information in video and multimedia formats. New broadband cabling will take decades to reach all prospective subscribers. But success of these new services will depend upon reaching as many subscribers as possible during the first few years. By bringing movies, television, video catalogs, remote CD-ROMs, corporate LANs, and the Internet into homes and small businesses, ADSL will make these markets viable, and profitable, for telephone companies and application suppliers alike.

Semiconductor companies have introduced transceiver chipsets that are already being used in market trials. These chipsets combine off the shelf components, programmable digital signal processors and custom ASICs. Continued investment by these semiconductor companies have increased functionality and reduce chip count, power consumption, and cost, enabling mass deployment of ADSL-based services.

FUTURE SCOPE

ADSL2 is inching closing to being a working reality. Clearly, the new standard offers some nice improvements to the design and development of ADSL equipment. But will it challenge VDSL services?

ADSL2 is a new standard that will eventually supersede existing ADSL standards. G.dmt.bis and G.lite.bis are designations for G.992.3 full-rate ADSL and G.992.4 for splitter less ADSL. The beauty of ADSL2 is that it is interoperable with existing ADSL deployments—it will perform both ADSL and ADSL2 modes of operation. This is essential to current ADSL providers—providers need to be able to continue to use the equipment they have invested in.

ADSL2+ is an extension of the new ADSL2 standard that should be approved by the ITU early in 2003. ADSL2+ is a hot topic because it is capable of doubling the transmission speed of typical ADSL connections from 1.1 MHz to 2.2 MHz. This doubles downstream data rates to over 20 Mbps, but these data speed rates will only be attainable on loops shorter than 8,000 feet. Here's where things get a bit jumbled—ADSL2 is often called ADSL+, but most experts expect that ADSL2+ will be the term used within technical circles, as this name highlights that it is in fact an extension of ADSL2.