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# ASYMMETRIC DIGITAL SUBSCRIBER LINE (ADSL)

***SUMMARY***

*ADSL (Asymmetric Digital Subscriber Line) is a technology that allows transmission at 8.488 Mbps over the existing telephone copper line (speed range depending on the distance).*

*ADSL circuit connects the ADSL modems by twisted-pair telephone lines creating three information channels: high speed simplex (maximum 9 Mbps), medium speed duplex channel (maximum 2 Mbps) and plain old telephone service channel.*

*ADSL technology supports up to seven synchronous channels that can be configured to meet the needs of the end user. One could simultaneously view four movies stored in MPEG1 format on separate television sets (MPEG1 transmitted at 1.5 Mbps), hold a video-conference (transmitted at 348 kbps), download data files from a server at 128 kbps via ISDN and even receive a telephone call.*

## 1. INTRODUCTION

Today's telephone network delivers standard telephone or voice service with 4 kHz of bandwidth to and from the home or office.

As the need emerged in the second half of the 80's to transfer electronic data back and forth between home and business sites, analogue modems became popular. Utilising the same 4 kHz of bandwidth, analogue modems deliver data rates as high as 28 kbps (V.34 modems) over today's telephone lines. This technology, however is believed to be reaching its limits.

Customers desire faster faxes, faster credit card acceptance, and faster data transfers of all types. Advances in digital signal processing enabling advanced coding and error correction techniques, combined with advances in silicon design and manufacturing techniques, enable much higher data rates over a larger 80 kHz spectrum. ISDN (Integrated Services Digital Network) employs these methods to provide significant improvement required by customers.

ISDN delivers data at 144 kbps, a significant improvement over V.34 modems. The 144 kbps is apportioned to support voice and data services. In addition, new applications such as video conferencing are now possible.

Many of the newly proposed interactive multimedia services require full motion video. Full motion video requires a minimum of 1.5 Mbps for VHS quality using MPEG 1 (Motion Pictures Expert Group) compression and 3-6 Mbps for broadcast quality using MPEG 2 compression. Clearly, the rates required to deliver video are beyond ISDN data rates, and even transmission of large graphics files is slow. Thus, as more video, more graphics, and larger data files become the norm, higher data rates are required.

At the same time, telephone companies are facing competition from cable TV companies, long distance companies and others for the first time. Thus, the telephone companies are motivated to search for new revenue streams.

Services such as movies on demand, remote LAN access for telecommuters, remote CD ROM access, and faster Internet access have emerged as potential revenue generators. However, very little data is available on whether customers will purchase, and how often they will purchase, the new services. Some areas that have clearly come to the forefront are Internet access, LAN access, and access to on-line services.

As telephone companies around the world plan to enter this new market full of risk and uncertainties, huge capital investments in new cabling and lengthy deployment periods loom in front of them.

What is needed is a technology that can deliver video today - over the 560 million telephone lines installed around the world.

Such a technology is here. It is called ADSL.

## 2. ADSL (ASYMMETRIC DIGITAL SUBSCRIBER LINE)

As its name implies, ADSL transmits an asymmetric data stream, with much more going downstream to the subscriber and much less coming back. The reason for this has less to do with transmission technology than with the cable plant itself. Twisted pair telephone wires are bundled together in large cables. Fifty pair to a cable is a typical configuration towards the subscriber, but cables coming out of the central office may have hundreds or even thousands of pairs bundled together. An individual line from a corporation to a subscriber is spliced together from many cable sections as they fan out from the central office. Alexander Bell invented twisted pair wiring to minimise the interference of signals from one cable to another caused by radiation of capacitive coupling, but the process is not perfect. Signals do couple, and they couple more so as frequencies and the length of line increase. It turns out that if you try to send symmetric signals in many pairs within a cable, you significantly limit the data rate and length of line your can attain.

The majority of target applications for digital subscriber services are asymmetric. Video on demand, home shopping, Internet access, remote LAN access, multimedia access, specialised PC services, all feature high data rate demands downstream, to the subscriber, but relatively low data rate demands upstream. MPEG movies with simulated VCR controls, for example, require 1.5 or 3.0 Mbps downstream, but can work just fine with no more than 64 kbps (or 16 kbps) upstream. The IP protocols for Internet or LAN access push upstream rates higher, but a ten to one ratio of down to upstream does not compromise performance in most cases.

An ADSL circuit connects an ADSL modem on each end of a twisted-pair telephone line, creating three information channels:

- a high speed downstream channel
- a medium speed duplex channel and
- a plain old telephone service (POTS) channel.

The POTS channel is split off from the digital modems by filters, thus guaranteeing uninterrupted POTS, no matter what other services are being utilised via the line. The high speed channel ranges from 1.5 to 6.1 Mbps, while duplex rates range from 16 to 640 Kbps. Each channel can be sub-multiplexed to form multiple, lower rate channels.

An example of an ADSL connection is shown in Figure 1.

So, ADSL has a range of downstream speed depending on the distance:

| | |
|---|---|
| Up to 18,000 feet | 1.544 Mbps (T1) |
| 16,000 feet | 2.048 Mbps (E1) |
| 12,000 feet | 6.312 Mbps (DS2) |
| 9,000 feet | 8.448 Mbps |

Upstream speeds range from 16 kbps to 640 kbps. Individual products today incorporate a variety of speed arrangements, from a minimum set of 1.544/2.048 Mbps down and 16 kbps up, to a maximum set of 9 Mbps down and 640 kbps up. All of these arrangements operate in a frequency band above POTS, leaving POTS service independent and undisturbed, even if a premises ADSL modem fails.

As ADSL transmits digitally compressed video, among other things, it includes error correction capabilities intended to reduce the effect of impulse noise on video signals. Error correction introduces about 20 msec of delay, which is far too much for LAN and IP-based data communications applications. Therefore, ADSL must know what kind of signals it is handling, to know whether to apply error control or not (this problem is present for any wire-line transmission technology, over twisted pair or coaxial cable). Furthermore, ADSL will be used for circuit switched (available today), packet switched (such as an IP router) and, eventually, ATM switched data. ADSL must at the same time connect to personal computers and television set top boxes. Taken together, these application conditions create a complicated protocol and installation environment for ADSL modems, moving these modems well beyond the functions of simple data transmission and reception.

ADSL technology supports up to seven synchronous channels that can be configured to meet the applications of the end user. The scalability of ADSL maximises the network capacity and utilises channels more effectively by dividing available bandwidth to create multiple channels of various data rates.

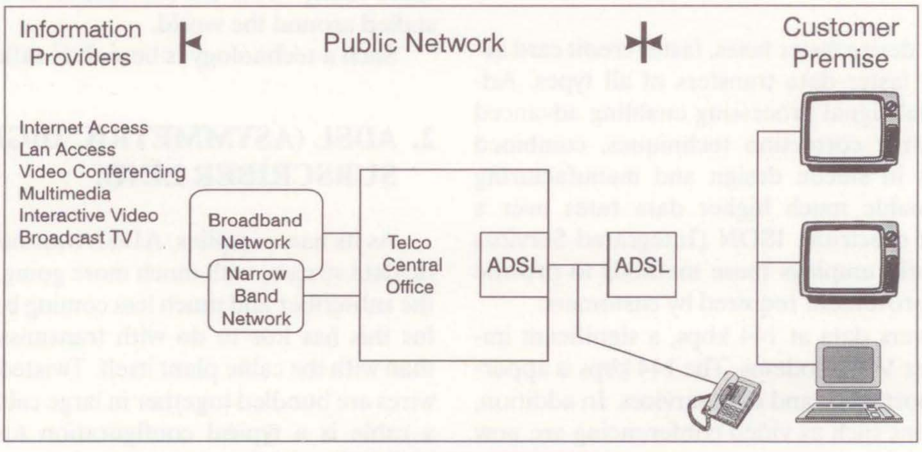


Figure 1 - ADSL connection

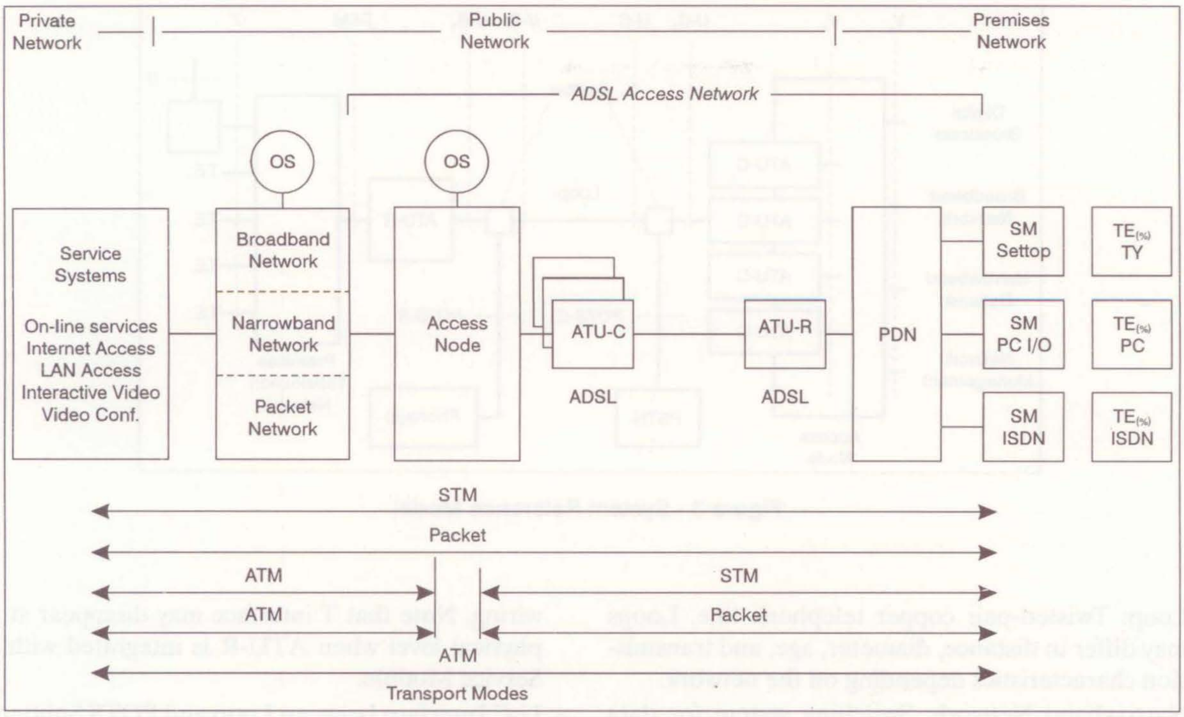


**Figure 2 - Overall Network and ADSL**

For illustration, a home or office receiving ADSL-based services could simultaneously view up to four movies stored in MPEG 1 format and transmitted at 1.5 Mbps on separate television sets, while holding a video conference utilising 384 Kbps, and downloading data files from a server at work utilising 128 Kbps via ISDN. And if that's not enough, it could also receive a telephone call from a customer or neighbour without disturbing the other activities.

## 3. SYSTEM REFERENCE MODEL OF ADSL

This technical report presents an ADSL-based System Reference Model and defines all the relevant interfaces present in an ADSL Access Network.

### 3.1. Overall Network and ADSL

The ADSL Forum develops technical guidelines for architectures, interfaces, and protocols for telecommunications networks incorporating ADSL transceivers. The overall network diagram above describes the network elements incorporated in multimedia communications, and suggests a group of transport configurations ADSL will encounter as networks migrate from Synchronous Transfer Mode (STM) to Asynchronous Transfer Mode (ATM).

The overall network diagram and ADSL are shown in Figure 2.

| | |
|---|---|
| ADSL | Asymmetric Digital Subscriber Line |
| STM | Synchronous Transfer Mode |
| ATM | Asynchronous Transfer Mode |
| TE | Terminal Equipment |
| OS | Operations System |
| PDN | Premises Distribution Network point definitions |
| SM | Service Module |

### 3.2. System Reference Model

System Reference Model is shown in Figure 3.

Definitions

- ATU-C: ADSL Transmission Unit at the network end. The ATU-C may be integrated within an Access Node.
- ATU-R: ADSL transmission Unit at the customer premises end. The ATU-R may be integrated within an SM.
- Access Node: Concentration point for Broadband and Narrowband data. The Access Node may be located at a Central Office or a remote site. Also, a remote Access Node may subtend from a central access node.
- B: Auxiliary data input (such as a satellite feed) to Service Module (such as a Set Top Box).
- Broadcast: Broadband data input in simplex mode (typically broadcast video).
- Broadband Network: Switching system for data rates above 1.5/2.0 Mbps.

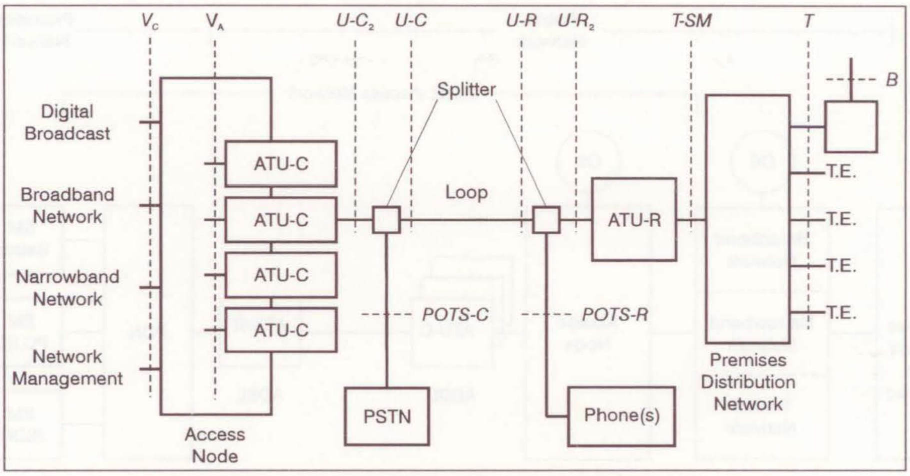


**Figure 3 - System Reference Model**

- Loop: Twisted-pair copper telephone line. Loops may differ in distance, diameter, age, and transmission characteristics depending on the network.
- Narrowband Network: Switching system for data rates at or below 1.5/2.0 Mbps.
- POTS: Plain Old Telephone Service.
- POTS-C: Interface between PSTN and POTS splitter at network end.
- POTS-R: Interface between phones and POTS splitter at premises end.
- PDN: Premises Distribution Network: System for connecting ATU-R to Service Modules. May be point-to-point or multi-point; may be passive wiring or an active network. Multi-point may be a bus or a star.
- PSTN: Public Switched Telephone Network.
- SM: Service Module: Performs terminal adaptation functions. Examples are set top boxes, PC interfaces, or LAN router.
- Splitter: Filters which separate high frequency (ADSL) and low frequency (POTS) signals at network end and premises end. The splitter may be integrated into the ATU, physically separated from the ATU, or divided between high pass and low pass, with the low pass function physically separated from the ATU. The provision of POTS splitters and POTS-related functions is optional.
- T-SM: Interface between ATU-R and Premises Distribution Network. May be the same as T when network is point-to-point passive wiring. An ATU-R may have more than one type of T-SM interface implemented (e.g., a T1/E1 connection and an Ethernet connection). The T-SM interface may be integrated within a Service Module.
- T: Interface between Premises distribution Network and Service Modules. May be the same as T-SM when network is point-to-point passive wiring. Note that T interface may disappear at the physical level when ATU-R is integrated within a Service Module.
- U-C Interface between Loop and POTS Splitter on the network side. Defining both ends of the Loop interface separately arises because of the asymmetry of the signals on the line.
- U-C2: Interface between POTS splitter and ATU-C. Note that at present ANSI T1.413 does not define such an interface and separating the pots splitter from the ATU-C presents some technical difficulties in standardising the interface.
- U-R: Interface between Loop and POTS Splitter on the premises side.
- U-R2: Interface between POTS splitter and ATU-R. Note that at present ANSI T1-413 does not define such an interface and separating the POTS splitter from the ATU-R presents some technical difficulties in standardising the interface.
- VA: Logical interface between ATU-C and Access Node. As this interface will often be within circuits on a common board, the ADSL Forum does not consider physical VA interfaces. The V interface may contain STM, ATM, or both transfer modes. In the primitive case of point-to-point connection between a switch port and an ATU-C (that is, a case without concentration or multiplexing), then the VA and VC interfaces become identical (alternatively, the VA interface disappears).
- VC: Interface between Access Node and network. May have multiple physical connections (as shown) although may also carry all signals across a single physical connection. A digital carrier facility (e.g., a SONET or SDH extension) may be interposed at the VC interface when the access node and ATU-Cs are located at a remote site. Interface to the PSTN may be a universal tip-ring interface or a

multiplexed telephony interface such as specified in Bellcore TR-08 or TR-303. The broadband segment of the VC interface may be STM switching, ATM switching, or private line type connections.

## 4. ADSL TECHNOLOGY

ADSL depends upon advanced digital signal processing and creative algorithms to squeeze so much information through twisted-pair telephone lines. In addition, many advances have been required in transformers, analogue filters, and A/D converters. Long telephone lines may attenuate signals at one megahertz (the outer edge of the band used by ADSL) by as much as 90 dB, forcing analogue sections of ADSL modems to work very hard to realise large dynamic ranges, separate channels, and maintain low noise figures.

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 upstream data and another band for downstream data. The downstream path is then 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 into corresponding low speed channels. Echo Cancellation assigns the upstream band to over-lap the downstream, and separates the two by means of local echo cancellation, a technique well known in V.32 and V.34 modems. Echo cancellation uses bandwidth more efficiently, but at the expense of complexity and cost. With either technique, ADSL splits off a 4 kHz region for POTS at the DC end of the band.

An ADSL modem organises the aggregate data stream created by multiplexing downstream channels, duplex channels, and maintenance channels together into blocks, and attaches an error correction code to each block. The receiver then corrects errors that occur during transmission up to the limits implied by the code and the block length. The unit may, at the users option, also create superblocks by interleaving data within subblocks; this allows the receiver to correct any combination of errors within a specific span of bits. The typical ADSL modem interleaves 20 ms of data, and can thereby correct error bursts as long as 500 μsec. ADSL modems can therefore tolerate impulses of arbitrary magnitude whose effect on the data stream lasts no longer than 500 μsec. Initial trials indicate that this level of correction will create effective error rates suitable for MPEG2 and other digital video compression schemes.

## 5. STANDARDS/DMT

Discrete Multitone (DMT) line code developed by Amati Communications is the internationally-recognised line code standard for ADSL technology. The American National Standards Institute (ANSI) working group T1E1.4 recently approved the DMT-based ADSL standard at rates up to 6.1 Mbps (ANSI Standard T1.413). The European Technical Standard Institute (ETSI) contributed an Annex to T1.413 to reflect European requirements. T1.413 currently embodies a single terminal interface at the premise end. Issue II, now under study by T1E1.4, will expand the standard to include higher data rates up to 8 Mbps, ATM over ADSL and other improvements.

DMT was chosen as the standard line code for ADSL by the ANSI T1.413 because of its ability to obtain the highest throughput on any given line while dynamically adapting to changing line conditions. Rate adaptive capability was built into the DMT standard originally and is now recognised as a key to the business case for ADSL deployment for Internet access and on-line services. In this mode of operation, the modem analyses the line conditions and determines the maximum throughput that the line is capable of supporting. The phone company can utilise their operations and maintenance system to add a margin of 3-6 db to the maximum rate. A standard DMT-based adaptive rate modem can adjust the data rate to within 32 Kbps of the maximum throughput the line is capable of supporting. Thus, telephone companies can assure customers of the greatest throughput possible while eliminating the need for qualifying the line.

DMT has also proven to have greater noise immunity and flexibility than its proprietary competitor, Carrierless Amplitude/Phase Modulation (CAP). In addition, DMT is more robust over long distances. Another key factor for the acceptance of DMT as the standard was the belief by Motorola and other semiconductor companies that a DMT-based solution can be implemented cost effectively.

The ADSL standards have been established to create interoperable system components that can be used to design networks suited to the distinct needs of individual service providers.

Interoperability will become a key factor in successful commercial deployment of ADSL. Consumers purchasing a modem for home use expect it to work wherever they choose to obtain the service. If they move between two cities, they expect the modem to be usable once ADSL service has been installed. DMT and CAP modems are not and cannot be made interoperable.

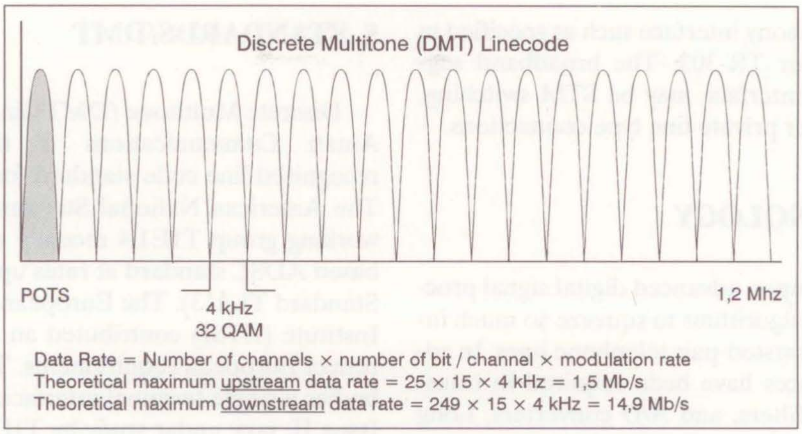


Figure 4 - DMT

# 6. LINE CODING

At the core of ADSL is the Discrete Multitone (DMT) line coding. The US standards body, ANSI (American National Standards Institute) T1 Committee, chose DMT over CAP (Carrierless Amplitude/Phase Modulation) and QAM (Quadrature Amplitude/Phase Modulation) because of the technology's robustness over long distances. In tests performed at Bellcore, DMT has also proven to have better noise immunity and greater flexibility in the date rates than its two challengers.

DMT utilises the spectrum between 26 kHz and 1.1 Mhz for broadband data and the spectrum from 0 to 4 kHz for POTS.

The spectrum above 26 kHz is further divided into 249 discrete channels, ref. Figure 4.

DMT's most significant advantage is its ability to dynamically adapt to the line conditions to attain the maximum throughput per channel, ref. Figure 5. A DMT transceiver is sometimes called "The Optimized Transceiver" for this reason.

Figure 5 gives a graphical representation of how DMT adapts to line conditions. The first of the three graphs represents a theoretical maximum transmission, fully loaded with 15 bits per channel prior to transmission. The second graph depicts the signal-to-noise results that the DMT transceiver computes based on an analysis of the line condition during initialisation. The transceiver then maps the actual bits

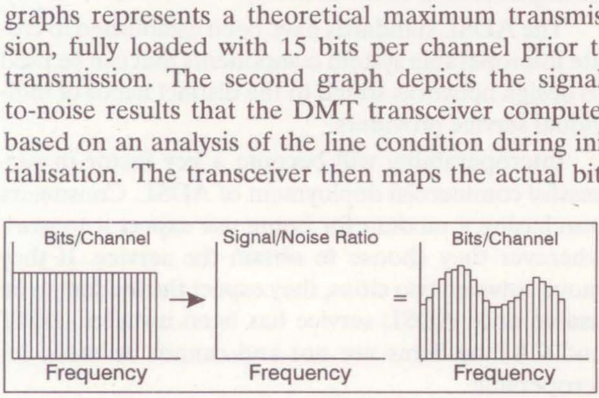


Figure 5 - graphical representation of how DTM adapts to line conditions

per channel to be transmitted based on the results shown in graph 2. The outcome is shown in the third graph.

The dip in the middle of graph 2, represents a noise source such as HDSL interference and/or an AM radio station. In the most severe case, DMT-based ADSL transceiver has the ability to completely block out a sub-channel if it becomes too noisy. The DMT transceiver continues to adapt to the line conditions during all subsequent transmissions. Therefore, a DMT transceiver will achieve the highest throughput possible on any given telephone line.

## 6.1. Embedded digital signal processing

ADSL employs embedded digital signal processing techniques to implement the DMT coding technique, and various communications functions. In addition, forward error correction allows the receiver to identify and correct errors that occur during transmission.

The combination of Reed Solomon forward error correction, trellis encoding, echo cancellation, and MPEG compression results in rates that enable high quality, full motion video transmission over the standard telephone line.

Today, early versions of ADSL chips, equipment and systems are on the market with lower cost and higher performance systems under development. Today's solutions are composed of discrete components including analogue ICs, multiple DSPs, and Gate Arrays.

ADSL is a proven technology but the future success of this powerful technology is highly dependent upon the ability of equipment providers to provide cost effective solutions. Integration of all these functions into a single Integrated Circuit such as the ADSL transceiver chip currently being designed at Motorola will make this possible.

## 7. ADSL "BENEFITS"

Telephone companies around the world have recognised that ADSL is providing them with a means of generating additional revenues from their existing copper plant with less financial risk and faster deployment.

They also realise that, by allowing them to provide the advanced services required by their customers at fair prices and in a timely manner, ADSL provides them with a competitive advantage in an increasingly competitive market.

ADSL reduces the financial risk, because it provides the telecom-operators with a very selective method of delivering new services. Funds are expended to provide service to a customer only when the customer requests the service. With other technologies such as hybrid fibre coax, a large and dostly infrastructure must be installed before a single customer can receive a service. Thus, ADSL eliminates the need to estimate the take rate of a neighbourhood and lay cables in anticipation of a need.

Telephone companies are also excited by the enhanced benefits of DMT-based ADSL transceivers. Rate adaptive capability was built into the DMT standard originally and is now recognised as the key to the business case for ADSL deployment. First, the modem analyses the line conditions and determines the maximum throughput that the line is capable of supporting. The phone company can utilise their operations and maintenance systems to add a margin of 3-6 db to the maximum rate. A standard DMT-based adaptive rate modem can adjust the data rate to within 32 kbps of the maximum throughput the line is capable of supporting. This technology can optimise throughput while eliminating the need for qualifying the line.

In addition ADSL can be deployed more rapidly than a new cable laid, enabling telephone companies to reach their customers with interactive services more quickly.

End users benefit from the fact that ADSL allows phone companies to get the most out of their phone lines. By fitting the data rate to the phone line's capacity, an ADSL adaptive rate modem can provide the best performance possible from every residential or business telephone line. This is especially important for Internet access and work-at-home applications, as it enhances worker productivity.

Small businesses and remote branch offices require access to high speed data services today and interactive video in the future. New cabling is only planned for residential areas.

For network managers, ADSL provides a cost-effective way to meet the high bandwidth needs to telecommuters. This is a growing area of concern - two-thirds of Fortune 1000 companies now have a telecommuting program; 60% of companies which do not currently employ the program say they will institute one within the next three years; and, it is estimated that 40% of today's workers could telecommute, and more and more are taking advantage of this option each day.

For telecommuters to remain productive, they will need to have quick, two-way access to data and other types of information. As illustrated above, a home office receiving ADSL-based services could simultaneously tap into their corporate server, hold a meeting via video phone, and field a hot call from a prospect. This is in marked contrast with the telecommuter who throws a load of laundry in while waiting for the weekly report from his supervisor to download onto his home system.

## 8. CONCLUSION

ADSL has been successfully tested at over 30 telephone companies throughout the US, Europe, Asia and Australia. One standard covering the key markets of North America and Europe has been approved.

Trial deployment of ADSL throughout the world is providing key insights into the capabilities of the technology, and the type of services on which customers are willing to spend money.

Commercial deployment has begun, with InterAccess deployment of ADSL technology in Chicago. In addition, four telcos recently announced that they will deploy ADSL commercially in 1997. This deployment will move ADSL even further from the trial stage to the commercial realm and will enable customer access to advanced communication services such as high-speed Internet access, teleconferencing, and video on demand.

Higher performance versions of ADSL technology, known as VDSL, are under study by ANSI and ETSI with bit rates as high as 12 Mbps, 26 Mbps, and/or 52 Mbps believed to be achievable over a standard twisted pair telephone line.

The desire to have broadband services delivered home and to small offices is expressed by customers and business people alike. Telephone companies world-wide are gearing up to meet this growing need.

One of the significant challenges of providing these services through the telephone network is the bottleneck in the "Last Mile". The capital investment required to install fibre or coax would be extensive and the time necessary for deployment unnecessarily prohibitive.

The promise of ADSL is to allow telephone companies to spend their capital on enhanced service and not on the "Last Mile".

Semiconductor companies are committed to make this promise a reality with cost-effective, flexible solutions to address future services as they emerge.

*SAŽETAK*


*ASIMETRIČNA PRETPLATNIČKA DIGITALNA LINIJA*

*ADSL (Asimetrična pretplatnička digitalna linija) je tehnologija koja omogućuje prijenos od 8.448 Mbps preko postojećih bakrenih vodova (brzina prijenosa ovisi o udaljenosti). Uspostavljanjem ADSL veze pomoću krajnih ADSL modema, preko telefonskih parica, oblikuju se tri kanala: brzi simpleks kanal (maksimum 9 Mbps), srednje brzi dupleks kanal (maksimum 2 Mbps) i stari govorni telefonski kanal. ADSL tehnologija omogućuje vezu preko sedam sinkronih kanala prema krajnjem korisniku. Korisnik može istovremeno gledati četiri televizijska kanala na odvojenim televizorima (MPEG1 se prenosi brzinom od 1.5 Mbps), održavati videokonferencijsku vezu (prenosi se brzinom od 348 kbps), prenositi podatke sa servera brzinom od 128 kbps preko ISDN i istovremeno razgovarati telefonom.*


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