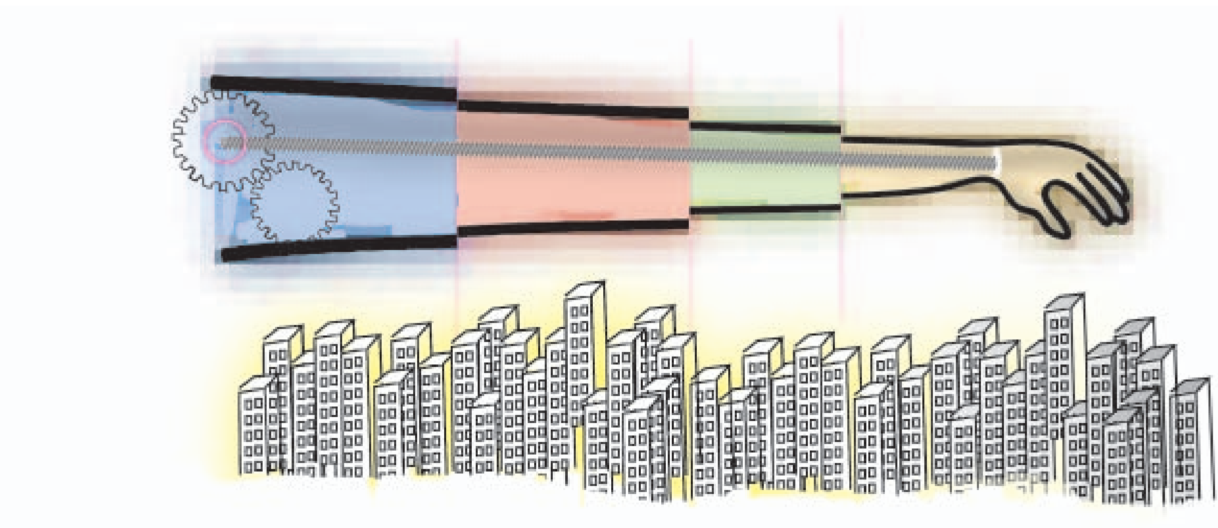
 By David Marsh, Contributing Technical Editor



STANDARDS EXTEND BROADBAND'S speed and REACH

INITIALLY SLOW OFF THE BLOCKS, BROADBAND'S UPTAKE CONTINUES TO GROW APACE THROUGHOUT THE INDUSTRIALISED WORLD AT RATES THAT SURPRISE EVEN TELECOMMUNICATIONS COMPANIES. AS A RESULT, NEW STANDARDS ARE NECESSARY TO INCREASE BANDWIDTH AND LENGTHEN SERVICE REACH.

As every IT professional and network manager knows, you simply can't have enough bandwidth: Whatever you provision for, users will eventually outrun capacity. If you're a data-communications engineer designing new telecommunications infrastructures, you'll similarly acknowledge that the challenge of providing for tomorrow's needs is intense. Back at the desktop, end-user frustration arises when Moore's Law fails to keep up with Parkinson's Rule—that is, when available computing resources can't satisfy data-intensive applications. But with midlevel machines packing more-than-1-GHz processors and massive local storage, most of today's PC users feel constraints only when they log into an Internet connection. This situation is especially true for the multitude of residential and home-office users who must still employ dial-up connections that at best return less than 50 kbps over V92 modulation.

Unsurprisingly, the telecommunications companies anticipated this bottleneck several years ago and embarked on developing broadband technology to pump data along standard copper phone lines at multimegabaud rates. According to June 2003 estimates, consumer uptake now accounts for some 77 million broadband lines worldwide, 60% of which employ ADSL (asymmetrical-digital-subscriber-line) technology to make the critical "last-mile" connection between the telecommunication company's central office and subscriber premises. Crucially for the service providers, that's almost 25% growth over the previous six-month period—and the United Kingdom is the fastest growing Western country to benefit, with China and Japan not far behind.

Today, most European subscribers who lie within broadband reach enjoy download speeds of around 500 kbps for a monthly subscription fee of €50 or less. Put into perspective, broadband offers much more than three times the best speed that previous-generation ISDN (integrated-services digital-network) technology delivers and does so at a much lower cost. But if you consider this performance good, look toward the Far East, where intense competition between incoming service providers, such as Yahoo Japan, and incumbent telecommunications companies, such as Japan's NTT (Nippon Telegraph and Telephone), currently provide consumers with 12 to 26 Mbps for around €30/month. That speed is as much as 10 times faster than a 2.048-Mbps E1 leased line that costs thousands of euros per year, albeit without the service reach or quality-of-service guarantees that data-intensive business users demand.

One reason why the Far East has such services is technical: Its infrastructure is new and has little legacy technology to accommodate. Also, high population densities allow short copper lines that permit high-speed operation within urban areas. Lastly, the respective telecommunications companies service a different business model. European subscribers who are used to dial-up connections favourably perceive 10-times faster services. By contrast, a new generation of Far Eastern subscribers with no such experience possesses an innate desire for the latest and best-available services, such as high-bandwidth Internet connections for streaming video content.

AT A GLANCE

- ▷ ADSL is today's dominant last-mile broadband carrier.
- ▷ The G.dmt implementation has ousted the much-heralded G.lite.
- ▷ Telecom companies want more bandwidth and reach but demand backward compatibility.
- ▷ ADSL2 delivers a raft of improvements that reflect operators' experience.
- ▷ Reach-enhanced ADSL2 improves data rates and service reach.
- ▷ ADSL2+ doubles bandwidth to challenge VDSL technologies.

Regardless of region, these points serve to illustrate one of the ADSL features that telecommunications companies find most attractive—the flexibility to divide bandwidth allocations and to accordingly adjust their tariffs. Following a telecom company's massive investment in infrastructure, providing subscribers with variable amounts of bandwidth is relatively inexpensive and basically requires dividing end-user channels across a number of DSLAMs (digital-subscriber loop-access multiplexers). These multiplexers connect the customer-premises-equipment device—that is, an ADSL modem/router—to the core network, which most often comprises multiple ATM (asynchronous-transfer-mode) links that run at 34 to 155 Mbps (**Figure 1**). Clearly, the greater the available bandwidth, the more profit service providers can expect. But there are limits to both bandwidth and reach (the maximum distance from a telecom company's central office to a subscriber's premises). These limits depend upon the flavour of ADSL that's available within your region, which in turn largely depends on the underlying telecommunications infrastructure.

For example, almost all broadband connections within the United Kingdom depend on British Telecom's core network. Here, the system employs the popular PPPoA (point-to-point protocol over ATM). First-generation ADSL routers invariably employ simple RFC-1483 bridging, in which the router bridges Ethernet frames from the subscriber's local-area network, out across the ATM virtual circuit, and onto the Internet-service provider (**Reference 1**). PPPoA builds upon this architecture to introduce per-session authentication and accounting, together with NAT (network-address translation) to conserve IP (Internet Protocol) addresses. The service provider can also to some degree troubleshoot individual connections and optionally oversubscribe the network by enforcing maximum session lengths and balancing idle session time-outs. Effectively a model of a dial-up connection, these features make PPPoA appealing to service providers, because their hardware impact is minimal and billing arrangements can remain unchanged. These factors serve to illustrate the importance to the telecom companies of maintaining backward compatibility within legacy environments, such as exist in much of Europe and the United States.

Another key network feature is the modulation technique that pumps data packets between DSLAMs and customer premises. The ITU (International Telecommunication Union) ratified the principal standards as recently as July 1999. They include G.dmt, a version of discrete-multitone encoding that the ITU-G.992.1 specification describes, and the lower rate G.lite, or ITU-G.992.2 (**Reference 2**). Note that you can now download as many as three ITU specifications every year for free. G.dmt accommodates a theoretical maximum throughput of 8 Mbps downstream to the customer premises, with a potential 1-Mbps upstream return path; realistic maxima are more like 6.1 Mbps and 640 kbps, respectively. With a potential downstream rate of around 1.5 Mbps, ITU conceived G.lite as a slimmed-

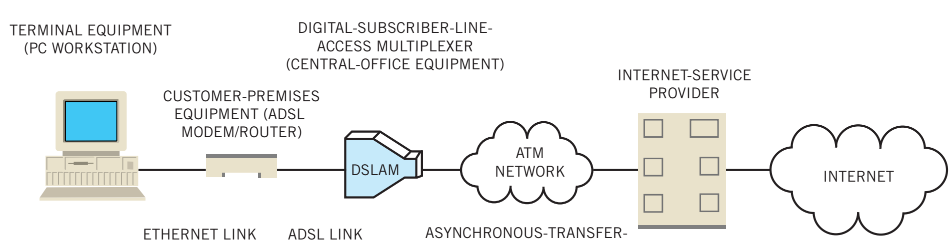


Figure 1 The PPPoA (point-to-point protocol over ATM) service mirrors a dial-up connection to bond USB/Ethernet traffic to an ATM environment via an ADSL link.

down derivative at a time when ADSL uptake was far lower than network operators' expectations (**Reference 3**).

A key advantage that the ITU intended G.lite to enjoy over its full-rate sibling is splitterless operation. That is, G.lite includes no requirement for filters to separate voice and ADSL frequencies at customer premises, which network operators fear would mandate installation-engineer visits; rather, G.lite locates the splitters at the central office. (Also, lower demands on processing power promise cheap modems.) But, given that the traditional POTS (plain-old-telephone-service) system occupies the voice band between 300 and 3400 Hz, you may wonder why microfilters are essential for correct operation. The answer is that, although industry regulations state that phones shall not transmit any frequencies greater than 4 kHz, there's no mention of impedance effects beyond this frequency. In practice, most phones exhibit substantial loading on the tip-and-ring interface that can extend far beyond 100 kHz. As a result, circuit-impedance changes from a virtual open circuit in the on-hook state to approximately 600Ω off-hook at traditional telephony frequencies. But, because the ADSL band stretches out beyond 1 MHz, some equipment can present a frequency-dependent impedance as low as 10Ω at the highest extremity; microfilters are essential to decouple the ADSL line from such loads.

VERSATILE CHIP SETS TACKLE MULTIPLE STANDARDS

In a continuously evolving environment, you may wonder how the semiconductor companies fulfil equipment makers' needs without introducing radically different silicon. Just as in every other area of electronics, designers want to maximise their investments in development environments and hard-won experience. Almost invariably, it's also essential for their products to integrate within legacy infrastructures while fulfilling the promise of current and future specifications.

To assist designers in refining products for launch, the DSL Forum holds regular "plugfests" that offer the opportunity to test new chip sets for interoperability under nondisclosure conditions. Attendees evaluating ADSL2 chip sets at the University of New Hampshire's Interoperability Laboratory event last July included Analog Devices, Aware, Broadcom, Catena Networks, Centillium Communications, GlobespanVirata, Infineon Technologies, Realtek Semiconductor, Samsung Electronics, and Texas Instruments. Note that this list by no means encompasses all vendors with ADSL interests; examples of other big European names include Ericsson, which has just used ADSL2 to supply Russia's first DSL network; Siemens; and STMicroelectronics. A raft of less familiar vendors, such as ADC, ECI Telecom, and Metalink, hails from Israel alone.

Representative examples of today's chip sets include products from Analog Devices, Motorola, and Texas Instruments. Each of these vendors has lengthy experience in the DSP techniques that lie at the heart of DSL communications and offer chip sets that suit central-office and subscriber-premises equipment. (Because these products are so new, some details remain under nondisclosure agreements and are available only to qualified customers.) Suiting central-office applications, the OptiCOm chip set from Analog Devices employs one AD6670 data pump and two AD6498 transceivers to bridge a Utopia-level 2 ATM network and 16 subscriber ports (**Figure A**). Standards support includes regular ADSL, ADSL2, and ADSL2+, as well as the reach-extended variant. Consuming less than 900 mW/port, the devices run from 12, 3.3, and 1.8V supplies. A single 512-kbyte SRAM serves four chip sets. The AD6770 is a multichip module and comes in a 37.5-mm-sq PBGA package, and the AD6498 occupies a 5-mm-sq leadless device; the combination packs each port into less than 1 sq in. of pc-board area. The complementary AD6488 AFE (analogue-front-end) mates with Eagle or Pathfinder family processors to provide an ADSL2/2+ option for consumers' modems.

Motorola's PowerQuicc family offers a line of upwardly capable communications processors that similarly targets consumer to deep-infrastructure needs. Andy Hixon, marketing manager for the company's networking group, stresses customer requirements for defined upgrade paths within a uniform development environment. He says that the scalable capability of the PowerQuicc family to support any DSL application, together with the Metrowerks CodeWarrior development platform, are key factors in winning new business. Three major PowerQuicc derivatives span performance levels of 200 to 2000 MIPS at about $10 to $125 (10,000). The latest products in the low-end PowerQuicc-I family are the MPC875/885 Duet devices, which suit residential gateways, with features such as USB 1.1 and dual 10/100-Mbps Ethernet ports. Crucially, these devices add hardware-encryption engines to permit full on-the-fly security. Hixon notes that previous software-encryption techniques can't keep pace with network traffic, compelling designers to select a subset for processing and thus compromising network security at the point that needs it most—the entry to the WAN (wide-area network).

New 0.13-micron versions of the PowerQuicc-II series, such as the MPC8280, offer some 50% greater performance than their immediate predecessor and maintain backward compatibility. In a DSLAM application, one MPC8280 can serve as many as 62 users. Microcode offloads tasks, such as ATM Layer 2 processing, from the main PowerPC core to allow autonomous port switching that furnishes router functions. Other functions include

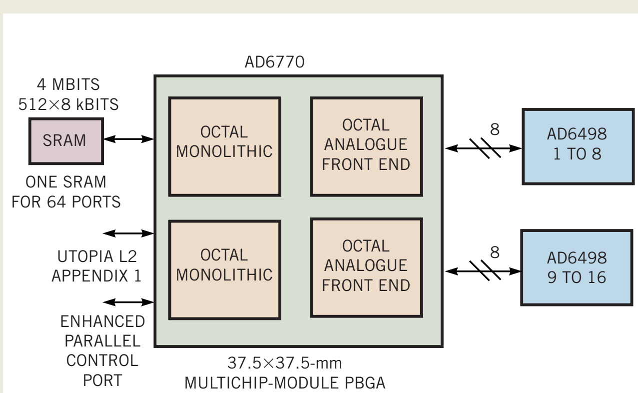


Figure A **The 16-port OptiCOm chip set from Analog Devices combines a multichip module and two transceivers to consume less than 900 mW and 1 sq in. per port.**

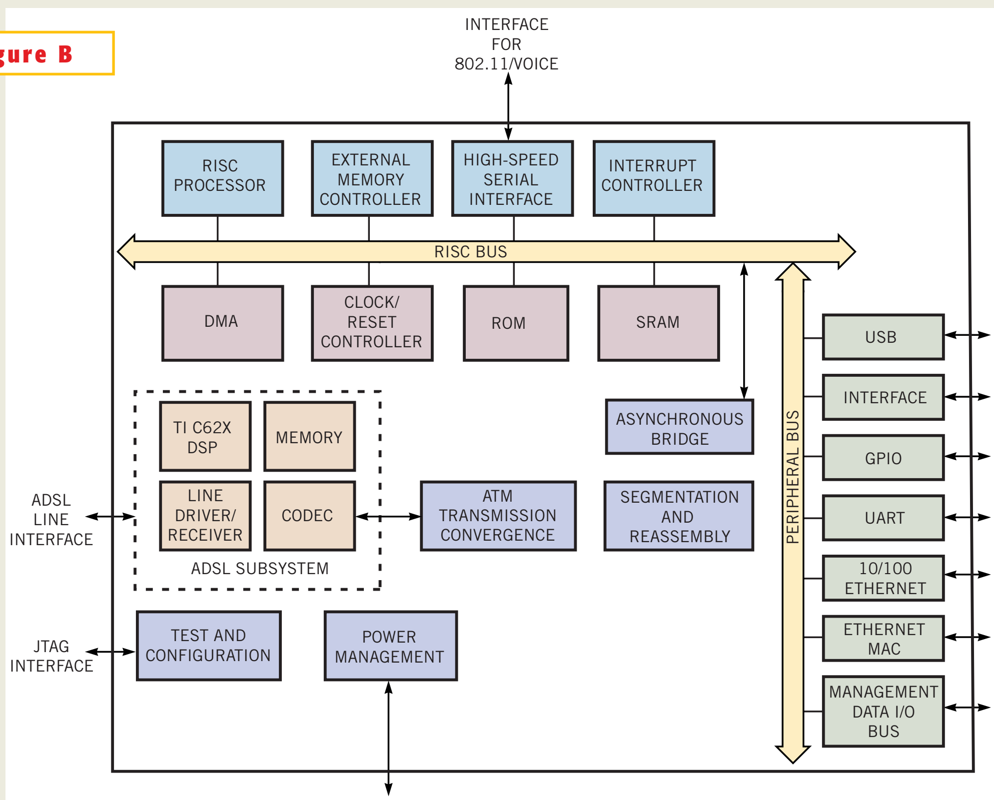
However, improvements in semiconductor and passive-filter design promoted G.dmt to its status as today's dominant deployment. David Greggains, vice president of the DSL Forum, confirms that he knows of no operators who have deployed G.lite, stating that telecommunications companies find it unnecessary. He does concede that these companies did evaluate and take some ideas from G.lite's development, such as using microfilters in residential and small-office environments. Greggains further explains that the three annexes to G.dmt tailor ADSL to worldwide infrastructures. Annex A describes ADSL transmissions on the same wiring as POTS, which is the system that the United Kingdom and most other countries use. For countries with a high level of ISDN presence, such as Germany and Norway, Annex B modifies the ADSL-transmission spectrum to avoid potential interference with ISDN traffic on the same wiring. Both annexes refer to systems that use frequency division and support simultaneous full-duplex operation for the services that they carry. Uniquely for Japan, Annex C describes performance improvements to Annex A in an environment in which ADSL must coexist with TCM (time-compression-multiplex) ISDN. In this mode, ADSL upstream and downstream transmissions are separate in a system that's popularly known as "pingpong" ISDN.

a multicast capability that can route as many as 256 media sources to 31 endpoints to suit applications such as video on demand. At the top end of the range, the MPC8560 PowerQuicc-III embeds an e500 PowerPC core with a RISC-based communications processor that's capable of more-than-1-Gbps aggregate bandwidth. With two ATM Utopia Level 2 interfaces and eight T1/E1 ports, this chip suits core-infrastructure applications. It can also support Gigabit Ethernet for infrastructures that choose Internet Protocol in place of ATM for network back-haul traffic.

The AC7 and AR7 families from Texas Instruments tackle central-office and customer- premises applications, respectively. The AC7 is a two-device chip set that comprises the TNETD7160 16-port transceiver and the dual-channel TNETD7122/7123 AFEs. The transceiver contains all the communications logic—the codec, DSP block, framer and management subsystems, memory, and filters—necessary to support traffic up to ADSL2+ speeds, including reach-extended deployments. Data interfaces include Utopia level-2 and packet-over-SONET for back-haul transport, together with an optional LVDS (low-voltage differential-signalling) serial link that minimises trace routing to channel-aggregation logic on dense pc boards. The embedded ARM7 processor manages all real-time modem maintenance and can dispense with a local microcontroller for supervisory control. The chip interfaces directly with TNETD7122 (POTS) and TNETD7123 (ISDN) analogue-front-end chips either of which serves two ports; overall, power consumption is just 750 mW/port.

For end-user modems, the single-chip AR7 couples a 32-bit MIPS RISC processor with a c62x DSP core, a codec, a transceiver, and integrated line driver/receivers (**Figure B**). This chip also suits all ADSL standards, including digital-loop variants, in which the power spectrum includes dc. Bill Timm, ADSL consumer-premises-equipment program manager at Texas Instruments, notes that the key to chip-set flexibility lies within programmable filter architectures. Specifically, the AR7 has on-chip line drivers with all-digital filters that facilitate integration within the multiple frequency profiles that the various ADSL flavours demand. Timm also points toward more integrated features, such as IEEE-802.11g wireless-LAN interfaces, which he believes will become significant with the growth of mobile data. In this scenario, he foresees that local wireless "hot spots" in urban conurbations will increasingly connect mobiles with the global WAN structure.

Figure B



The single-chip AR7 from Texas Instruments integrates all the communications elements that any flavour of ADSL consumer modem requires.

The discrete-multitone encoding principle relies on dividing spectrum into a number of discrete frequency tones (or bins) that carry parallel digital information. G.dmt Annex A divides 1104 kHz of bandwidth into 255 individual carriers at 4.3125-kHz spacing, reserving the lowest 4-kHz area for normal telephony services (**Figure 2**). The modulation method is inverse fast-Fourier transform with optional trellis coding. The lower stopband for the ADSL data spectrum is the POTS area, so to allow microfilter splitters sufficient separation, it does not use the frequency band greater than POTS to 25 kHz, which corresponds to bins 1 through 5. Bins 6 through 31 carry upstream data, and the remainder carry data and some management information, such as the pilot tone at 276 kHz (bin 64). The lower frequencies are intrinsically quieter and thus can carry more information than higher order tones.

The specification allows for as many as 16 bits per bin and excludes bins that can't carry at least 2 bits. The asymmetrical division between upstream and downstream channels is a balance between data rate and reach, because transmitters create echoes and reflections that limit reliable reception. In this sense, ADSL takes advantage of reduced far-end crosstalk to lengthen the useful transmission line. In practice, this division also reflects the fact that most subscribers consume far more data than they produce. To serve as many subscribers as possible, rate-adaptive ADSL systems, such as in the United Kingdom, actively measure line conditions and vary their transmission characteristics to suit. Methods include adaptively assigning data bits for transport to individual bins, which avoids any changes to the transmission spectrum. Experience shows that rate-adaptive technology permitted British Telecom to increase its first-generation system's reach from about 3.5 km to some 5.5 km today.

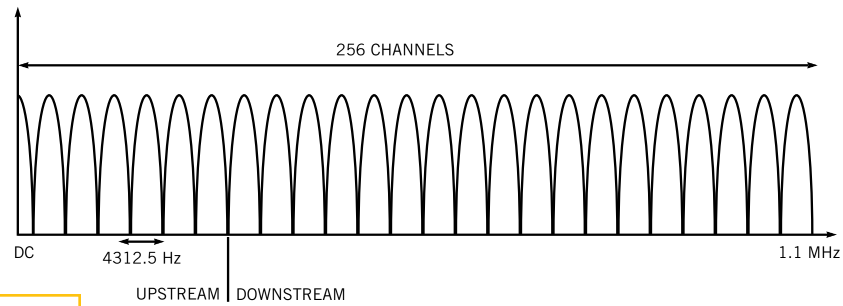


Figure 2 Standard ADSL's discrete-multitone carrier divides some 1.1 MHz of raw copper-loop bandwidth into 256 bins at 4.3125-kHz spacing.

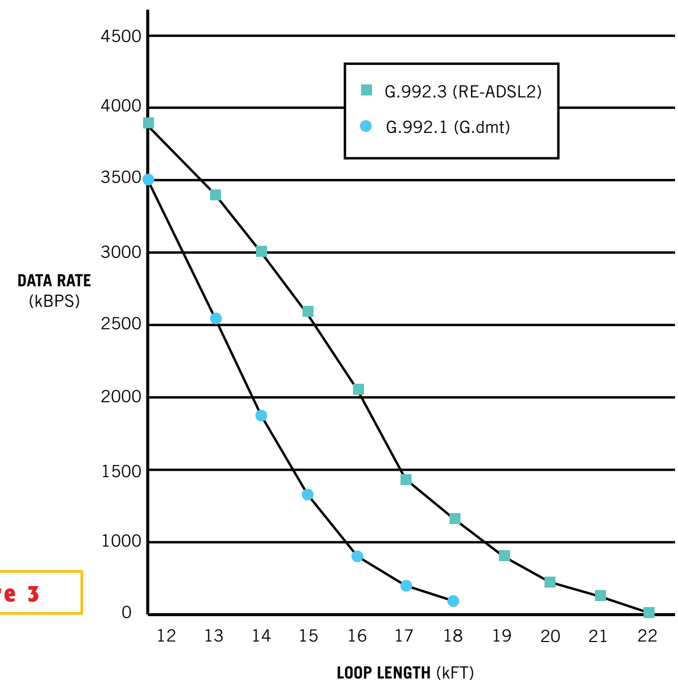


Figure 3 Reach-extended ADSL2 promises to improve data rates while increasing coverage by 35% or more.

TWEAKS BOOST REACH AND BANDWIDTH

Now, with the benefit of several years' operational experience, network operators are focussing on increasing last-mile bandwidth, either to divide resources among a larger subscriber pool or to charge premium rates for high-bandwidth data pipes. Network operators also naturally wish to position more customers within their embrace, so it's desirable to increase ADSL's reach from its current approximately 5-km limit. Because on average, capture area grows geo-

TABLE 1—ADSL FAMILY SPECIFICATIONS

Annex	Environment	Use of tones: 1 to 5	6 to 31	32 to 64	65 to 255	256 to 512	Applicable to: ADSLG.992.1	ADSL2G.992.3	ADSL2+G.992.5
A	POTS	POTS	Up	Down	Down	Down*	Yes	Yes	Yes
B	IDSN	ISDN	ISDN	Up	Down	Down*	Yes	Yes	Yes
C	TCM-ISDN	TCM-ISDN	Up	Down	Down	N/A	Yes	Yes**	Yes**
I (ADSL)	TCM-ISDN	TCM-ISDN	Up	Down	Down	Down	Yes	No	No
I (ADSL2)	POTS	Up	Up	Down	Down	Down*	No	Yes	Yes
J	ISDN	Up	Up	Up	Down	Down*	No	Yes	Yes**
L (READSL2)	POTS	POTS	Up***	Down***	Down***	N/A	No	Yes**	No
L (ADSL2+)	POTS	Up	Up	Up	Down	Down*	No	No	Yes**

Notes: Use of tones applies only to the nonoverlapped PDS masks.*ADSL2+ only.**Approval expected October 2003.***Not all tones are used.

metrically with the increasing radius of a circle, relatively modest reach increases bring area gains equal to πr^2. But without quality-of-service guarantees, bandwidth alone is useless to organisations that rely on data transmission for their survival. It is therefore important for any new business-oriented ADSL services to demonstrate equivalent quality to the established leased-line resources. Further, any new technology must maintain backward compatibility with the technical and commercial infrastructure.

Enter ADSL2 and its extensions to the G.dmt and G.lite specifications, respectively known as G.dmt.bis and G.lite.bis (**Reference 4**). Ratified over the summer of 2002, these specifications improve modulation efficiency by mandating 4-D, 16-state trellis coding and single-bit QAM (quadrature-amplitude modulation) to construct transmission-symbol constellations. In particular, this combination provides better performance on long lines, where the signal-to-noise ratio is weak. Other tweaks include swapping the original standards' fixed 32 kbps of overhead bits per frame for a programmable overhead of 4 to 32 kbps, providing a potential 28 kbps of additional data traffic. Also, ADSL2 permits a minimum of 1 bit per bin before excluding a tone from the carrier group. Improvements to the framers that construct ADSL2's Reed-Solomon code words now achieve higher coding gain over long lines, where data rates are lower. A tone-reordering system at the receiver spreads nonstationary noise, such as from AM radio stations, to improve gain within the Viterbi convolutional-code decoder that deciphers incoming symbols. Together, these and other measures achieve the unlikely result of simultaneously increasing data rate and reach by around 50 kbps and 200m. In reach terms, that's an average of about 6%, or 4 km^2.

Other important measures include power-cutback capabilities at both ends of the transmission line. This step reduces near-end echoes, crosstalk within the binder that carries multiple signal pairs, and power consumption. Maury Wood, marketing director for xDSL products at Analog Devices, observes that the bipolar amplifiers that drive the transmission side from a central office account for 60 to 80% of a channel's power consumption. With each of a typical DSLAM's 48 ports consuming 800 mW to 1W, ADSL2's L2 (low-power) and L3 (sleep) power-saving modes directly translate into lower electricity bills for service providers. Wood contends that energy charges now comprise a large percentage of a telecom company's operational costs, and power dissipation can be a factor in small cabinets. The new L2 capability introduces a statistical power-saving mode, in which central-office transceivers rapidly switch between L0 (full-power) and low-power modes, depending on traffic levels. For large file downloads, the transceiver operates in L0 mode to maximise connection speed, seamlessly switching into and out of L2 mode without incurring even a single bit error. Therefore, users see no service interruptions, and the channel retains its always-on character. But when subscribers leave a connection unused for some time, such as overnight, the L3 capability places both ends of the channel in sleep mode, and the channel is offline until the user starts a new session. On detecting user activity, it takes 3 to 6 seconds to re-establish normal communications, but tests indicate that this delay is transparent to the user.

Wood also points toward ADSL2's SRA (seamless rate adaptation) and online-reconfiguration features, which enhance reach and bolster transmission robustness. ADSL2-compliant devices evaluate spectral disturbances from both ends of the line, seamlessly remapping bits to tones to prevent subscribers from experiencing service disturbances. Much of this activity occurs within the modified initialisation-state machine. For example, the receiver and transmitter can now control key initialisation-state lengths to optimise training between their signal-processing blocks. The receiver can also determine pilot-tone location and evaluate which carriers successfully deliver initialisation messages, remapping accordingly to avoid the channel nulls due to impedance discontinuities or interference.

By decoupling the framing layer from the modulation layer, ADSL2 makes it possible to alter transmission rates without affecting the framing layer, which would cause receivers to lose synchronisation, freeze, or both. In operation, receivers monitor the channel's signal-to-noise ratio; if it exceeds a threshold value, the receiver requests that the transmitter adjust the channel's data rate. The message that the receiver sends

FOR MORE INFORMATION...

For more information on products such as those discussed in this article, contact any of the following manufacturers directly, and please let them know you read about their products in *EDN Europe*.

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Infineon Technologies
www.infineon.com

ITU (International Telecommunication Union)
www.itu.int

Metalink
www.metalinkdsl.com

Metrowerks
www.metrowerks.com

Motorola Semiconductors
www.mot-sps.com

NTT Communications
www.ntt.com

Realtek Semiconductor
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www.st.com

Texas Instruments
www.ti.com

University of New Hampshire
www.iol.unh.edu

Video Networks
www.videonetworks.com

Yahoo Japan
www.yahoo.co.jp

embodies information, such as the number of modulated bits and the transmission power on each carrier, enabling the transmitter to adjust intelligently. The transmitter then responds with a synchronisation flag that tells the receiver when to switch and which new parameters to use, enabling a seamless rate transition. Such refinements tackle common operational problems, such as AM-radio interference—levels of which change throughout the day—and more tangible issues, such as water ingress into the binder that often distributes 24 or more twisted pairs between junction boxes. Similar to early rollout problems due to line bridge-taps and transitions between copper and aluminium conductors, water ingress leads to line-impedance discontinuities that generate reflections and compromise transmission reliability. Other effects that you may not expect include varying levels of RF interference that principally couple into overhead conductors. These levels also continuously vary throughout the day, due to the same changes in the ionosphere that affect radio transmission.

There's also a breadth of measures that improve interoperability between equipment and refine line-diagnostic capabilities. Although only about 3% of end users ever call telecom companies to help resolve ADSL-connection problems, the original specification was fuzzy regarding exactly what should be exchanged at initialisation time, leading to operational problems between different manufacturers' equipment. Partially as a result of this experience, telecom companies are keen not only to evaluate local-loop conditions, but also to determine which equipment lies at customer premises; ADSL2 provides the framework to deliver these capabilities. But industry insiders universally acknowledge that one of the biggest attractions of ADSL2 appears in the specification's Annex L, which describes reach-extended operation (READSL2). Now in the late stages of achieving ITU-standard status, this annex provides a loop-reach extension of 150 to 900m, an area gain of as much as 35% over the Annex A implementation (**Figure 3**). This feature is crucially important for telecom companies in Western Europe and the United States, where more affluent subscribers tend to live away from dense urban conurbations. The development is so significant that—

"MARKET FORCES WILL SOON COMPEL TELECOM COMPANIES TO DELIVER SUCH GUARANTEES OR RISK LOSING CUSTOMERS TO THOSE WHO DO."

even before reach-extended ADSL becomes a formal standard—semiconductor vendors have been working on silicon in anticipation of operators' needs (see **sidebar** "Versatile chip sets tackle multiple standards").

Reach-extended ADSL works by altering its transmission PSD (power-spectral-density) in response to the observation that you can improve reach by transmitting at higher power levels but over less bandwidth than Annex A systems. As a result, Annex L mandates one downstream PSD mask and two upstream masks, and allows a further optional downstream mask. The bandwidth trade-off means that downstream frequency usage terminates at 522 kHz—half of regular ADSL—and similarly, upstream bandwidth has to fit within either 35 or 78 kHz. Largely because channel attenuation makes higher frequencies unusable over long lines, these changes deliver higher data rates over such lines and under a variety of crosstalk conditions. But because lower frequencies are less susceptible to attenuation, crosstalk, and other interference, it also means that READSL2 systems can deliver better performance than can Annex A implementations over short, low-bandwidth service lines. However, improved reach is what it's all about. Tests demonstrate that under similar conditions of injected white noise to simulate crosstalk, a READSL2 system extends a 768-kbps downstream service by almost 1 km over its Annex A equivalent.

BANDWIDTH GAINS PROMISE EXTRA SERVICES

For customers such as SMEs (small to midsized enterprises) that don't want to share telephone and data services on the same line, ADSL2 optionally enables data transmission within the POTS bandwidth, adding 256 kbps more of upstream capacity. This capability is known as the "all-digital loop" that annexes I and J describe, for POTS and ISDN environments, respectively. ADSL2 also has a packet-mode transmission-convergence layer that makes it possible to assimilate packet-based services—notably Ethernet—for transmission over ADSL2. This ability is important in the context of deployments that specify Ethernet technologies in place of ATM for long-haul transport. And, for the first time, ADSL2 adopts the ATM Forum's IMA (inverse-multiplexing-for-ATM) standard, which allows service providers to bond multiple phone lines to increase bandwidth to data-hungry subscribers.

The DSL Forum's Greggains says that bonding lines is important for telecom companies looking to deliver greater bandwidth to SMEs that can't afford optical fibre. Originally conceived for SHDSL (symmetric high-bit-rate digital-subscriber-loop) services, ADSL2 modems that work in bonded mode aggregate as many as four pipes side by side and treat the result as a single connection. The issue for SMEs then becomes one of quality of service: "The technical issues surrounding quality of service aren't difficult. I believe that market forces will soon compel telecom companies to deliver such guarantees or risk losing customers to those who do," says Greggains. He cites anecdotal evidence of regular ADSL's robustness, when researchers who were unable to explain a link's sudden performance drop discovered that one line of the connection pair had failed; nevertheless, communications continued, and the return occurred via the laboratory equipment's safety-ground connection.

Greggains also believes that ADSL2's new channelisation capabilities will prove popular. In this way, you can assign bandwidth to different channels with alternative link characteristics to suit applications such as voice over ADSL. Although voice channels have low latency but high error-rate tolerances, data channels are quite the opposite. ADSL2 makes a provision for a CVoDSL (channelised-voice-over-DSL) function that transports time-domain-multiplexed voice traffic simultaneously with, and transparently to, regular POTS and data traffic. This provision is part of an evolutionary strategy that Greggains foresees will ultimately enable a single set-top box to serve all a residential subscriber's needs: "To stem the tide of mobile telephony, telecom companies need new service offerings in their battle to retain residential lines," he says.

One of these services isn't exactly new but has struggled to gain widespread consumer acceptance in the West—VoD (video on demand). As long ago as the mid-1990s, British Telecom pioneered VoD in a 2000-consumer test based around the UK towns of Ipswich and Chelmsford. In this trial, 1800 homes received an ADSL connection, and 200 homes received fibre to evaluate the competing technologies' comparative strengths. The experiment foundered but, at press time, Video Networks, a spin-off result of those early trials, announced a €15 million order with Alcatel to supply enough DSLAMs to service 1 million subscribers. Observers perceive that this news implies that the company has gained regulatory approval to make its own connections to British Telecom exchanges (switches), thus taking advantage of European Union directives that compel incumbent telecom companies to "unbundled local loops"—that is, to open their doors to competition. From a technical perspective, VoD requires about 2.3 Mbps to deliver TV-quality movies and around 4.3 Mbps for DVD-equivalent definition. Interestingly for an area in which digital-rights management is a burning issue, some production companies don't permit service providers to transmit their movies over links that can't deliver DVD quality. In ideal transmission conditions, this demand limits residential reach to about 1 km on standard ADSL or ADSL2.

Other issues that face telecom companies include the nature of connections that many subscribers make. In particular, peer-to-peer connections that stream audio and video files account for as much as 60% of the bandwidth that today's broadband infrastructure provides and threaten the typically 50-to-1 contention ratios that telecom companies offer to residential subscribers. To tackle these and sundry other high-bandwidth applications, the ITU ratified specification G.992.5 in May 2003 (**Reference 5**). Building on the ADSL2 foundation, ADSL2+ doubles the downstream data bandwidth to 2.2 MHz to deliver 20 Mbps and more on lines shorter than about 1.5 km (**Table 1**). This data rate challenges the VDSL (very-high-bit-rate digital-subscriber-line) deployments that some Far Eastern operators are using to deliver VoD and high-bandwidth Internet connections to apartment blocks. In this scenario, fibre connects the central office to street cabinets that service in-building DSLAMs. The resulting copper cable runs are short, thus allowing subscribers access to connection speeds as high as 26 Mbps over 300m. The downside is that VDSL is incompatible with any ADSL services; hence, little opportunity exists for scalable service provision.

By contrast, ADSL2+ fits gracefully within the technology family to provide a uniform architecture that accommodates multiple service scenarios. As a result, ADSL2+ may ultimately remove the need for VDSL. In the meantime, alternative uses for ADSL2+ include crosstalk reduction by masking downstream frequencies below 1.1 MHz to leave only the higher bins to deliver data. This facility allows telecom companies to optimise difficult connections, such as when dense central-office and remote-terminal traffic compete within the same binder. In this example, the central-office connection might use the normal band out to 1.1 MHz, and the remote terminal minimises interference susceptibility by using the 1.1- to 2.2-MHz area.□

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