Physical Signaling in 100VG-AnyLAN

A physical layer has been developed for demand priority local area networks that accommodates different cable types by means of different physical medium dependent (PMD) sublayers. The major goal was to provide 100-Mbit/s transmission on existing cables, including Category 3, 4, and 5 UTP, STP, and multimode optical fiber.

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The physical layer (PHY) of a 100VG-AnyLAN demand priority local area network (LAN) acts as an interface between the MAC (media access control) and the link (the cable), adding control signaling and data formatting to the MAC frame when necessary (see Fig. 1).

Several goals were identified in the early stages of the demand priority PHY development. First, the PHY should be as simple as possible, easy to implement, and above all, low in cost. Second, the PHY should provide robust data transfer. LAN performance deteriorates if multiple retransmissions of packets are necessary because of errors. Errors can occur if a PHY does not provide sufficient immunity against noise on the transmission medium (such as impulse noise on unshielded cable running close to switching gear). Typically a LAN is required to operate with less than one error in 10^8 bits.

Third, the PHY should support a range of existing media types. 10Base-T LANs operate over voice-grade, or Category 3, unshielded twisted-pair (UTP) wire. More recently, higher-quality UTP (Categories 4 and 5) has been specified and is now being used in new installations. Shielded twisted-pair (STP) has been used extensively in token ring LANs, although recently these too have been connected with UTP. Multimode optical fiber is also being used increasingly.

Fourth, the PHY should be capable of data transfer at 100 Mbits/s. Finally, when not transmitting data, the PHY should be capable of signaling five independent control states from one end of a link to another. These control signals are required for the operation of the demand priority protocol.

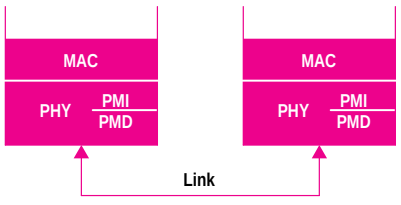

Fig. 1. Network layer model, showing the media access control (MAC) and the physical layer (PHY) with its physical medium dependent (PMD) and physical medium independent (PMI) sublayers.

The following constraints were also placed on the design of the demand priority PHY:

- EMC. The transmission techniques used for the PHY must not cause radiated emissions from the LAN equipment or cabling that would violate electromagnetic compatibility (EMC) regulations as shown in Fig. 2 (for example, FCC Class A in the U.S.A., EN 55022 in Europe). This constraint becomes most significant with Category 3 UTP.
- Cable cross talk. 25-pair bundles are often used for connections from a wiring closet to multiple wall outlets. As a result, several end nodes may be connected to a hub through a single 25-pair bundle. Simultaneous transmissions between the hub and more than one such end node may then cause cross talk within the cable (see "Cross Talk in Unshielded Twisted-Pair Cables" on page 19). The PHY must not be detrimentally affected by this cross talk.
- Transformer Coupling. Connections to twisted-pair (UTP and STP) are made through transformers so that dc currents cannot flow between devices with nonequipotential grounds. However, the transformers cause distortion of data signals with dc content, so the PHY must process the data to reduce the dc content of the signal. This often requires that some form of block coding be performed on the data before transmission.[1]

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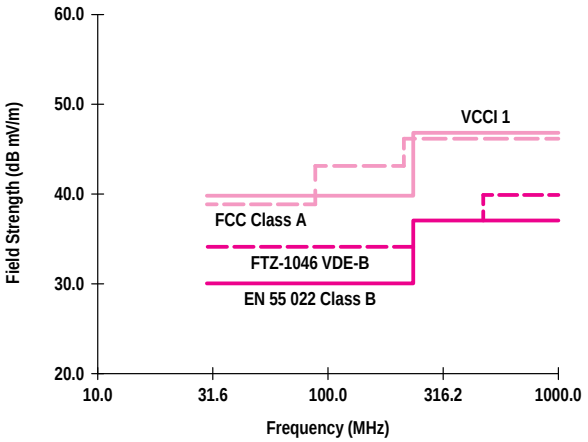

Fig. 2. CISPR and FCC radiated emissions regulations. Radiated emissions must fall below the lines shown for each regulatory body.

Cross Talk in Unshielded Twisted-Pair Cables

Cross talk in UTP cables is caused by capacitive coupling between pairs. Signals on pair A cause noise signals on pair B, and often the cross talk noise proves to be the limiting factor in the link performance. Cross talk occurs in two ways. Near-end cross talk (NEXT) happens when a signal from a transmitter at one end of a cable interferes with a receiver at the same end of the cable. Far-end cross talk (FEXT) occurs when a signal interferes with a receiver at the opposite end of the cable from the transmitter.

Near-End Cross Talk (NEXT)

Near-end cross talk loss is defined as:

$$\text{NEXT} = -20\log\left(V_n/V_i\right),$$

where V_n and V_i are shown in Fig. 1a. The minimum NEXT loss between pairs in a cable tends to follow a smooth curve, as shown in Fig. 1b, decreasing at a rate of 15 dB per decade. However, the actual NEXT between two particular pairs deviates significantly from this curve because of resonances in the twisted-pair. Typical measurements of the NEXT loss between some pairs in a 25-pair cable are also shown in Fig. 1b.

Far-End Cross Talk (FEXT)

Far-end cross talk loss is defined as:

$$\text{FEXT} = -20\log\left(V_f/V_i\right),$$

where V_f and V_i are shown in Fig. 2a. The minimum FEXT loss also decreases with frequency following a smooth curve, but at a rate of 20 dB per decade. As with NEXT loss, the actual FEXT loss between two particular pairs deviates from this curve. Typical measurements of the FEXT loss between some pairs in a 25-pair cable are shown in Fig. 2b.

Cross Talk Measurements

Our analysis of cross talk required a database of accurate and detailed measurements of cross talk between pairs in 25-pair cables. A measurement system was constructed to measure NEXT and FEXT losses of all pair combinations in 25-pair cables (see Fig. 3, next page).

Individual pairs were routed to the stimulus and response ports of a network analyzer via a computer-controlled switch. This allowed the automatic selection of 300 different pair combinations for NEXT measurements and 600 pair combinations for FEXT measurements. Any pair not being measured was terminated in 100 ohms via a balun and a 50-ohm termination internal to the switch. The network analyzer measured the cross talk loss (phase and magnitude) to 40 MHz, and this was downloaded to a computer database. Using this system, the NEXT and FEXT losses were measured for many thousands of pair combinations in a selection of 25-pair cables of varying manufacturer and age. The database was used to input NEXT and FEXT loss characteristics to the computation of cross talk noise described in "Cross Talk Analysis" on page 22.

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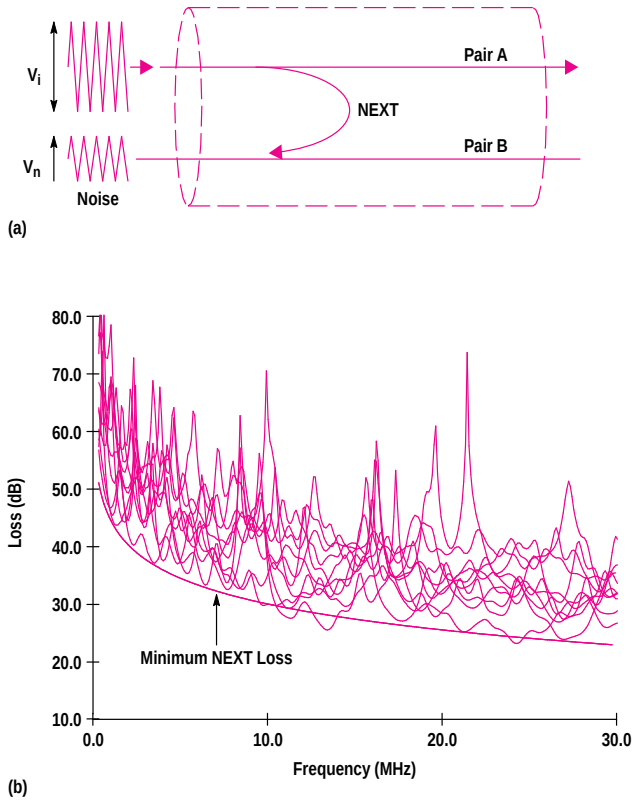

Fig. 1. (a) Near-end cross talk (NEXT). (b) Minimum theoretical NEXT loss and actual measurements.

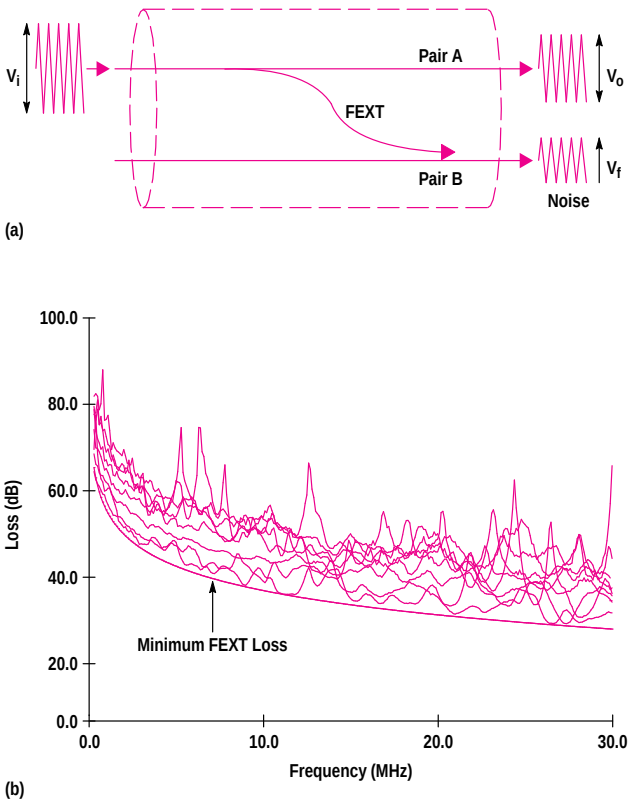

Fig. 2. (a) Far-end cross talk (FEXT). (b) Minimum theoretical FEXT loss and actual measurements.

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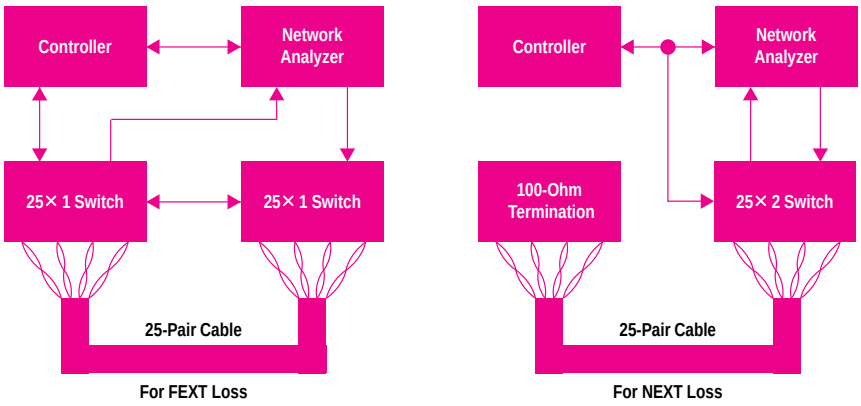

Fig. 3. Measurement system for NEXT and FEXT loss.

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Given these constraints, the design goals for the PHY were-met by developing a physical medium dependent (PMD) sublayer for each media type (UTP, STP, and multimode optical fiber) and a physical medium independent (PMI) sublayer that contains all the functions common to all media types. These two sublayers together form the demand priority PHY.

In the remainder of this article we will discuss the design choices made for each of the three demand priority PMDs.

The Four-Pair UTP PMD

The first PMD to be developed was to support UTP cabling, since this addresses the large 10Base-T upgrade market.

10Base-T uses full-duplex signaling at 10 Mbit/s on UTP cabling.[2] One twisted pair is used to transmit and one to receive data. The dc content of the signal is minimized by Manchester coding the data before transmission on the twisted-pair channel. Manchester coding is a very simple form of block coding:

Bit	Code
0	10
1	01

This is a 1B/2B block code, and results in a 100% bandwidth expansion. Manchester coding is spectrally inefficient relative to other block codes, but does provide a guaranteed transition for every two symbols, has very low dc content, and is very simple to implement.

The transmission rate in 10Base-T is 20 megabaud, giving a data rate of 10 Mbits/s (1 baud is one symbol per second). This means that the transmitted signal can be low-pass filtered with a cutoff frequency somewhat less than 20 MHz. This helps minimize radiated emissions above 30 MHz, the lower bound of stringent EMC regulations.

From 10Base-T to 100VG-AnyLAN

The progression from 10Base-T to 100VG-AnyLAN was made in three simple steps.

First, it was recognized that since full-duplex transmission was not absolutely necessary in a hub-based network, both twisted pairs used for 10Base-T could be used simultaneously for transmission in one direction or reception in the other. This immediately doubles the bit rate achieved on existing 10Base-T networks.

Second, the spectrally inefficient Manchester code was replaced with a more efficient 5B/6B block code (5 bits of data are coded to 6 transmitted binary symbols). This reduced the bandwidth overhead from 100% with Manchester coding to 20%. As a result, the data rate on each pair could be increased to 25 Mbits/s (that is, a symbol rate of 30 megabaud after 5B/6B coding) while the main lobe of the data spectrum remained below 30 MHz, the lower limit of EMC regulations. As with 10Base-T, low-pass filtering with a cutoff below 30 MHz can then be applied to minimize the risk of excessive radiated emissions. The 5B/6B code chosen also has very low dc content, which avoids distortion from the coupling transformers. See the article on page 27 for more details.

Third, the UTP PHY takes advantage of the two unused pairs available in every four-pair cable. Surveys of customer cable plants revealed that a large proportion of these customers adhered to structured cabling recommendations[3] when installing cable, and connected four-pair cable to each wall outlet. Two of these four pairs currently lie unused. By transmitting 5B/6B coded data at 30 megabaud on all four pairs, it is possible to provide a total signaling rate of 120 megabaud (100 Mbits/s) over UTP cable.

Quartet Signaling

The four-pair transmission scheme, called quartet signaling, uses binary transmission, that is, only two voltage levels are used as symbols. Other approaches to the UTP PMD were examined. One was multilevel (m-ary) signaling (see "Multilevel Signaling" on page 21). In a multilevel scheme, n data bits are mapped to one of $m = 2^n$ symbols, and each symbol is a unique voltage level. For example, in a quaternary scheme, two data bits may be mapped to one of four voltage levels. In this way the number of symbols transmitted, and hence the transmission rate required, is reduced by a factor of n. However, for a fixed power supply voltage, the voltage separation between symbols is reduced by a factor of $1/(m-1)$ from the binary case. The binary quartet signaling scheme maximizes the voltage separation between symbols, which provides greater immunity to noise at the receiver.

Multilevel Signaling

Multilevel signaling is often used as a means of compressing the bandwidth required to transmit data at a given bit rate. In a simple binary scheme, two single symbols, usually two voltage levels, are used to represent a 1 and a 0. The symbol rate is therefore equal to the bit rate. The principle of multilevel signaling is to use a larger alphabet of m symbols to represent data, so that each symbol can represent more than one bit of data. As a result, the number of symbols that needs to be transmitted is less than the number of bits (that is, the symbol rate is less than the bit rate), and hence the bandwidth is compressed. The alphabet of symbols may be constructed from a number of different voltage levels. Fig. 1 shows an example for a four-level scheme.

In the four-level scheme, groups of two data bits are mapped to one of four symbols. Only one symbol need be transmitted for each pair of data bits, so the symbol rate is half the bit rate. The drawback of the multilevel scheme is that symbols are separated by a smaller voltage than in the binary scheme. This means that when noise is added to the data signal (cross talk or impulse), the probability of the noise changing one symbol to another is increased. The symbol separation could be increased to that of the binary scheme by increasing the peak-to-peak transmitted voltage by a factor of (m – 1) for an m-level scheme, but this is generally not possible given fixed power supply voltages, and in any case it increases the power required for a transmitter.

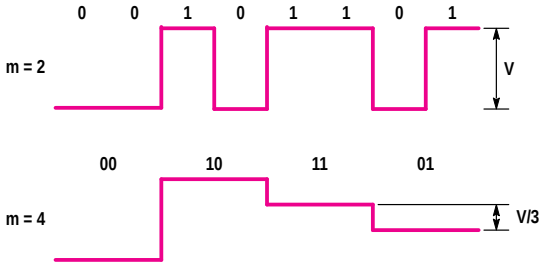

Fig. 1. Two-level and four-level signaling.

The susceptibility of a scheme to errors caused by noise is measured by the ratio of signal separation to noise. Fig. 2 shows the signal-to-NEXT-noise ratio plotted against the transmission bandwidth for several multilevel schemes and for multipair schemes for a bit rate of 100 Mbits/s. A 16-level scheme reduces the bandwidth to 25% of the bit rate, but the S/NEXT ratio is 13 dB (a factor of 4.5) worse than for a four-pair scheme with 25 Mbits/s per pair, which is the scheme used in the 100VG-AnyLAN standard.

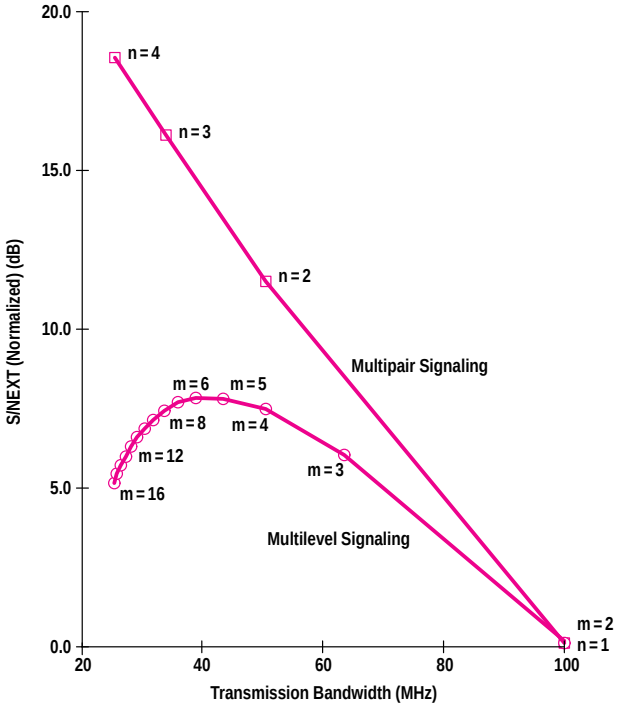

Fig. 2. Susceptibility to errors from noise.

Two noise sources are significant in UTP cabling: external noise and cross talk noise. External noise may be caused by electromagnetic radiation from radio stations (often referred to as continuous wave or CW noise) or impulses from switching equipment (impulse noise). Cross talk noise arises from capacitive coupling between twisted pairs within a cable. Cross talk affects links most significantly when the links use 25-pair bundles.

Impulse Noise

Little data is available to describe the characteristics of impulse noise occurring on UTP cable plant. It was decided that the safest approach to impulse noise was to maintain the margin of 10Base-T, since the success of 10Base-T proves that its level of robustness is appropriate. The choice of binary signaling meant that the UTP PHY could provide the same immunity to impulse noise as 10Base-T.

Cross Talk

The 100VG-AnyLAN cross talk environment is very different from that of 10Base-T. Since a four-pair UTP cable only carries a single network link in a network and the traffic on all four pairs is in the same direction, only far-end cross talk (FEXT, see "Cross Talk in Unshielded Twisted-Pair Cables" on page 19) is a problem. FEXT is less severe than near-end cross talk (NEXT) in UTP cables, and can be disregarded in four-pair links.

However, when 25-pair cables are used to connect end nodes to hubs, up to six network links (each occupying four pairs) can populate one cable. In addition to FEXT, NEXT is also a problem at the hub end of a cable. When a packet is being received on one port, retransmission of that packet at other ports will result in NEXT at the receiving point. It is essential that the level of this NEXT be minimized to prevent errors at the receiving port. The protocol minimizes this NEXT in the following way.

When a packet is received that has a single destination address, the hub forwards the packet to that destination immediately. If the source and destination are attached to the hub by the same 25-pair cable, NEXT will occur from the retransmitted packet to the received packet. An extensive analysis of the cross talk noise generated in such a scenario verified that the received signal is robust to this level of cross talk (see "Cross Talk Analysis" on page 22).

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Cross Talk Analysis

Many previous analyses of twisted-pair transmission systems have assumed that the distribution of cross talk noise is Gaussian. These have yielded reasonably accurate predictions of system bit error rates. However, in applying the error rate analysis, there is an implicit assumption that the cross talk noise is independent of the data on the disturbed system. This is often the case in telecommunication systems, but is not always the case in LANs, where the disturbing links are those on which the disturbed data is being retransmitted. For example, the NEXT interfering with data received at one port of a hub is a result of the retransmission of earlier bits of the same data on other ports. If the cross talk noise is of sufficient amplitude to cause an error in the received data, this error is extremely likely to be repeated every time the same data is transmitted. If a packet is errored by cross talk, that particular packet is likely always to be errored.

To guarantee the error-free transmission of any packet, the worst-case peak cross talk voltage must be found. The peak cross talk noise from multiple disturbers can be calculated directly from a knowledge of the cross talk channels and the disturbing data source. The NEXT and FEXT cross talk channel frequency responses can be calculated for any pair combination using measurements of the pair-to-pair NEXT or FEXT loss. Once the cross talk channel frequency response is known, it is possible to find the impulse response of this channel by inverse Fourier transform. We define the impulse response of the NEXT channel as:

$$g_n(t) = F^{-1}\left(H_n(f)\right)$$

and the impulse response of the FEXT channel as:

$$g_f(t) = F^{-1}\left(H_f(f)\right)$$

To find the cross talk noise voltage at the receiver decision point, n(t), caused by any data pattern f(t), the impulse response is convolved with f(t):

$$n(t) = f(t) \star g(t), \qquad (1)$$

where g(t) represents either $g_f(t)$ or $g_n(t)$ as appropriate. Our goal is to find the worst-case cross talk for any data pattern, so n(t) must be calculated for all values of f(t). It is therefore useful to apply some limit to the duration of f(t) to shorten the computation time, and this can be done by taking into consideration the finite duration of the cross talk channel impulse response. A typical impulse response of a NEXT channel is shown in Fig. 1. The duration of the cross talk impulse response is typically less than 1400 ns, which is equivalent to 42 symbol periods for the 30-megabaud transmission rate used in quartet signaling. Therefore, the cross talk waveform during the last six symbols of a pattern f(t) can be predicted accurately if the duration of f(t) is restricted to 1600 ns.

The cross talk for any f(t) is calculated as follows. The disturbing data source is assumed to be the output of a 5B/6B block coding function and consists of eight sequential six-bit codewords, each chosen from an alphabet of 32 codewords. The total number of permutations that f(t) can take is therefore 32^8. For each permutation, n(t) is computed according to equation 1. The peak cross talk noise voltage generated by any value of f(t) can then be found by searching each resultant n(t).

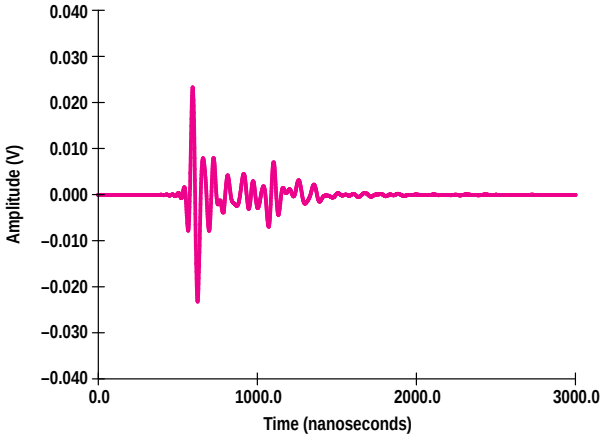

Fig. 1. Typical impulse response of a NEXT channel.

The peak cross talk noise voltage, which represents the maximum noise generated by a worst-case data pattern, can be calculated in this way for each pair combination in a 25-pair cable by repeating the search described above using the NEXT or FEXT loss particular to that pair combination. For each pair combination, the maximum cross talk noise voltage is recorded. The distribution for a typical cable is shown in Fig. 2 for NEXT and FEXT. (The cross talk noise voltage is normalized to the signal amplitude at the receiver decision point.) We denote the maximum NEXT noise voltage for pair i disturbing pair k as $v^{i,k}_{pk,NEXT}$, and the maximum FEXTnoise voltage due to pair i disturbing pair k as $v^{i,k}_{pk,FEXT}$.

Multiple-Disturber Cross Talk

The worst-case cross talk environment for UTP PMDs operating over 25-pair bundles consists of three far-end disturbers and four near-end disturbers. Modeling this environment is relatively straightforward given the distributions of $v^{i,k}_{pk,NEXT}$ and $v^{i,k}_{pk,FEXT}$. For each choice of disturbed pair (k), four NEXT disturbers (a,b,c,d) and three FEXT disturbers (p,q,r), the total noise voltage for multiple disturbers is:

$$v_{pk,total} = \sum_{i=a,b,c,d} v^{i,k}_{pk,NEXT} + \sum_{j=p,q,r} v^{j,k}_{pk,FEXT}.$$

By calculating the multiple disturber noise voltage in this way we assume, pessimistically, that the maximum noise voltages for the worst-case disturbing patterns from each disturbing source occur at the same time and with the same polarity on the disturbed pair k. This is obviously a worst-case scenario.

A Monte-Carlo approach has been used to choose combinations (k,a,b,c,d,p,q,r) randomly from the 25 pairs of a cable. For each choice, $v_{pk,total}$ was calculated. The resulting distribution of $v_{pk,total}$ is shown in Fig. 2. The maximum multiple-disturber cross talk noise expected on any pair of the cable for any choice of disturbing pairs can be estimated from the higher extreme of this distribution (such as the first percentile). This number represents the noise voltage for the worst-case choice of disturbing and disturbed pairs, with the maximum noise contributions from all disturbing pairs occurring simultaneously on the disturbed pair. For the example shown, the first percentile of the total peak noise distribution is 47% of the signal. This allows a substantial margin for error-free signal detection.

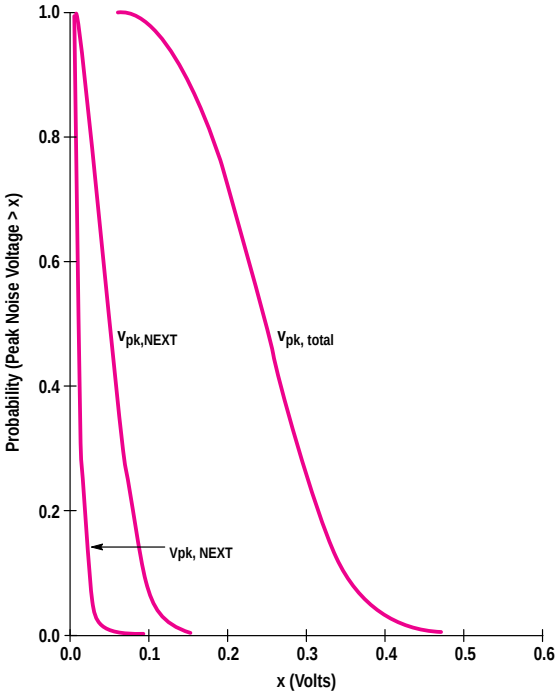

Fig. 2. Distribution of $v^{i,k}_{pk,FEXT}$, $v^{i,k}_{pk,NEXT}$, and $v_{pk,total}$ for a typical 25-pair cable.

When a broadcast or multicast packet is received, the hub does not immediately forward this packet. The NEXT caused by retransmitting the packet to several destinations sharing the same 25-pair cable as the source would result in erroneous reception. Rather, the packet is stored until reception is complete and is then forwarded to all destinations simultaneously. In this way, no NEXT occurs during reception. This store-and-forward technique is only implemented when 25-pair cables are attached to a hub. If only four-pair cables are used, all packets (single and multiple addresses) are forwarded immediately, since there is no NEXT between the individual four-pair cables.

Implementation of Quartet Signaling

Fig. 3 shows a block diagram of the 100VG-AnyLAN implementation of quartet signaling. The PMI and PMD sublayer functions are considered separately when transmitting or receiving data.

PMI Transmitting. The PMI splits the data into four streams, each of which is scrambled. This removes patterns that would result in a repetition of the same codeword in the output of the 5B/6B coder. This helps avoid spectral peaks that might violate EMC regulations when the coded data is transmitted.

Typically, LAN traffic contains data patterns that are simply repetitive 1s or 0s. If left unscrambled, when split into quintets (five bits) at the PMI, the distribution of quintets is heavily biased towards all 0s (quintet value of 0) or all 1s (quintet value of 31). This is confirmed by Fig. 4 which shows the distribution of quintets obtained from real LAN traffic. Scrambling removes this bias, providing a more random distribution of quintets at the input to the 5B/6B coder.

After scrambling, the PMI performs the 5B/6B coding. It then adds start and end delimiters to the four streams, and a preamble sequence (a 0101… pattern) to the start of each stream. The four parallel streams of coded data (30 Mbits/s per stream) are then passed to the PMD.

PMD Transmitting. The PMD converts the four parallel data streams to the binary signaling levels (±2.5V) on each of the four twisted pairs. The data is nonreturn-to-zero (NRZ) coded and low-pass filtered. The low-pass filter has a cutoff at 20 MHz, and is used to attenuate spectral components that would cause undesirable emissions above 30 MHz. A typical eye diagram at the output of the PMD is shown in Fig. 5.

PMD Receiving. When receiving data, the low-pass filter in the PMD rejects out-of-band noise on the twisted pair. The signals on the four channels are then equalized. This compensates for the attenuation of the cable and minimizes the intersymbol interference at the sampling point of the data. To perform this function for any cable length between 0 and 100 m the equalizer must be adaptive. The protocol provides a training sequence, during which the PMD equalizer trains its response to compensate for the length of cable present in the link. A typical eye diagram at the output of the receiver

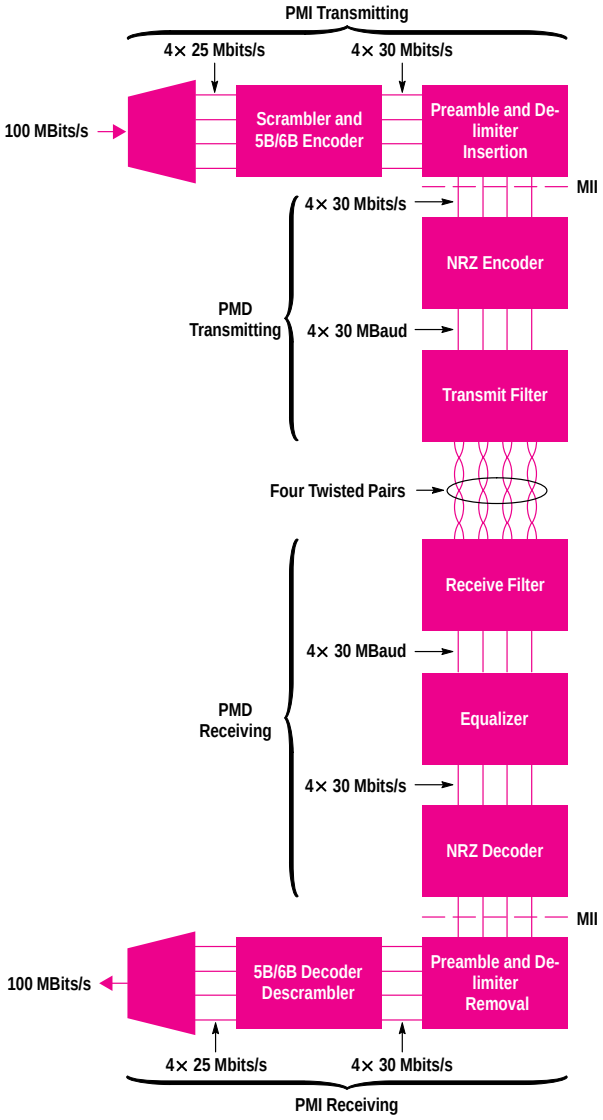

Fig. 3. Implementation block diagram. The MII is the medium independent interface.

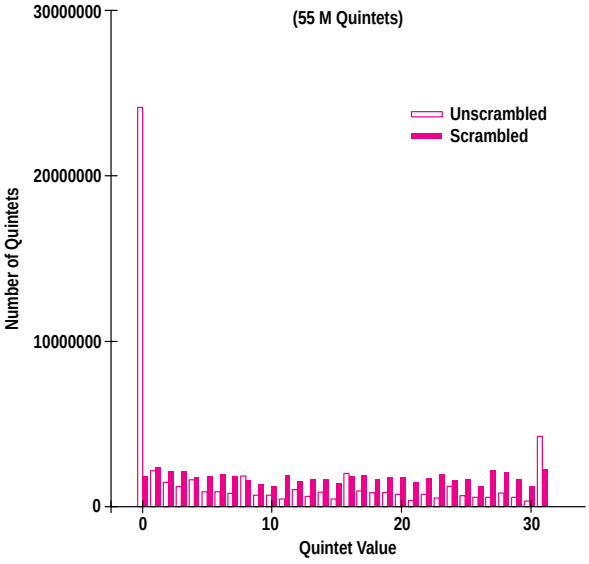

Fig. 4. Distribution of quintets obtained from real LAN traffic.

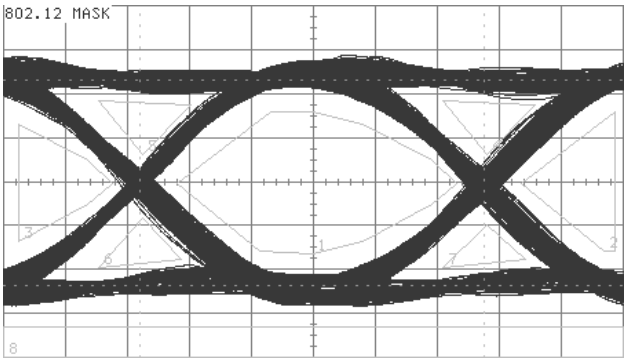

Fig. 5. Transmission eye diagram.

equalizer is shown in Fig. 6. In this case the cable length was 121 m, which approximates a worst-case 100-m cable.

After equalization the received signals are sampled. The PMD recovers a clock from the received signals by using the preamble pattern generated by the transmitting PMI. This clock is used to sample the received data. The four channels are often misaligned in time by up to two bit periods with respect to each other after traveling over a length of UTP cable. This is because the twist rate, and hence the propagation delay, varies from one twisted pair to another. The PMD realigns the received signals to a common clocking point before passing the four parallel streams of data to the PMI.

PMI Receiving. The PMI further realigns the received data to remove any skew between the start delimiters on each stream. The data on each stream is then decoded, unscrambled, and reformatted into a single data stream, which is passed to the receiving MAC. The PMI also performs a number of error-checking functions. These provide extra protection against errored packets being accepted as valid by the MAC, above the protection offered by the frame check sequence. The PMI first checks that the start delimiters on each stream are all valid and occur with the correct time relationship to each other. Then, while decoding, it checks that only valid 6-bit codewords are received. It signals to the MAC if an error is detected in the received data.

Quartet signaling meets all the design goals identified for the PHY apart from control signaling (described next). By retaining a binary signaling scheme the simplicity and robustness of 10Base-T was maintained. Keeping the baud rate low makes it easy to implement in a standard CMOS process, thereby meeting the low-cost requirement. The increased data rate is mainly attributable to more efficient block coding and better use of the available twisted-pair channels.

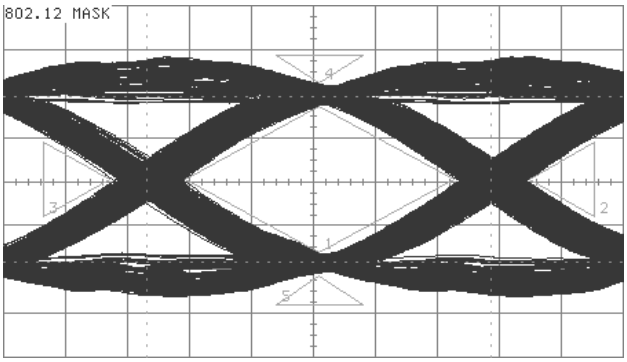

Fig. 6. Reception eye diagram.

Control Signaling

The protocol uses control signals to transfer requests, acknowledgments, and training signals between the hub and the end nodes. These control signals must be continuously available on all network links whenever data is not being transferred. They must be full-duplex and distinct from any data pattern.

Since the control signals are required to operate continuously, signaling at the data rate of 30 megabaud was rejected because of the large levels of cross talk that might be generated when 25-pair cables were used. Instead, a low-frequency signaling scheme has been developed that allows all five control states to be transmitted using only signals with fundamental frequencies less than 2 MHz. No valid data pattern contains components with such low frequencies, providing distinct identity for the control signals. Full-duplex operation is achieved by using two pairs in each direction to carry control signals.

Two control signals are defined: CS1 is a 0.9375-MHz square wave formed by repeating a pattern of sixteen 0s followed by sixteen 1s, and CS2 is a 1.875-MHz square wave formed by repeating eight 0s followed by eight 1s. Four of the five control states are represented by combinations of CS1 and CS2 on two pairs as shown in Table I.†

The fifth control state is represented by silence (no energy) on the two pairs. Silence is used by a hub to indicate that a request to transmit data has been granted. On receiving silence, an end node can cease control signaling and begin transmission immediately, since the cable is already silent. This allows rapid turnaround of the half-duplex link.

The two square waves have been chosen to have a large separation in frequency so that the receiver is able to distinguish them without having a clock that is precisely phase-locked. The control signals are generated and recovered within the UTP PMD.

The STP and Optical-Fiber PMDs

The STP PMD was developed to support existing token-ring network cabling. These consist of cables up to 100 m in length with two shielded twisted pairs. The optical-fiber PMD was developed to provide a means of connecting hubs and end nodes over longer distances than the 100 m provided by the STP and UTP PMDs. This extra distance is particularly important when cascaded networks are built and hubs are distributed over a campus area. The optical-fiber PMD allows LANs to have up to 4-km diameter.

† The control signals shown in Table I are for the 100VG-AnyLAN implementation of the IEEE 802.12 standard. The control signal definitions in the standard have different names.

Table I
Control Signaling in 100VG-AnyLAN

Tone Wires		Transmitted from			Received by		
1	2	End Node	Root Hub	Another Hub	End Node	Root Hub	Another Hub
CS1	CS1	IDLE	IDLE	IDLE	IDLE	IDLE	IDLE
CS1	CS2	REQ_N	INCOMING	REQ_N	INCOMING	REQ_N	INCOMING
CS2	CS1	REQ_H	ENABLE_HIGH_ONLY	REQ_H	Reserved	REQ_H	ENABLE_HIGH_ONLY
CS2	CS2	REQ_T	REQ_T	REQ_T	REQ_T	REQ_T	REQ_T

REQ_N = Normal-priority request
REQ_H = High-priority request
REQ_T = Link training request
INCOMING = A packet is about to be transmitted
ENABLE_HIGH_ONLY = Put normal round-robin sequence on hold while a high-priority request is serviced

STP has less attenuation and greater NEXT loss than even Category 5, data-grade UTP, and is already used for data transmission at 100 Mbits/s. For example, the SDDI specification[4] provides for transmission of FDDI traffic at 100Mbits/s over STP.

The STP physical layer uses the same modulation and coding techniques as SDDI, that is, binary signaling at a rate of 100 Mbits/s (before coding). The low attenuation of the cable makes it possible to transmit 100Mbits/s on a single pair, so one pair is dedicated to transmitting and one pair to receiving at each end of a link. The cable shield reduces radiated emissions to satisfactory levels.

Multimode optical-fiber links have also been in use for many years at data rates of over 100 Mbits/s (such as FDDI).[5] The optical-fiber PMD uses components that have recently been developed for low-cost FDDI implementations. Examples are the HFBR 5106 and HFBR 5107 developed by HP's Optical Communications Division. These use LED transmitters with wavelengths of either 850 nm (for 500-m links) or 1300 nm (for 2-km links). The transmitter forms part of a small module that also includes an optical receiver. This module forms a simple interface between the optical fiber and a transceiver chip, which can be identical to the STP transceiver (see "Optical-Fiber Links for 100VG-AnyLAN" on page 26).

For the demand priority STP and optical-fiber PHYs, the block code and NRZI coding specified for SDDI have been replaced with an alternative scheme based on the same 5B/6B block code that is used for the UTP PHY. This approach allows the 5B/6B block coder to be placed in the PMI sublayer. The amount of logic that is common to all physical layers is thereby increased, resulting in a lower-cost PHY device.

The PMI provides four 30-Mbit/s channels of scrambled and 5B/6B block coded data at the MII. These four channels are multiplexed, codeword by codeword, by the STP and fiber PMDs (see article, page 27). Even after codeword multiplexing, the 5B/6B code retains its advantageous properties. The serialized data stream is NRZ coded and transmitted at 120 megabaud on one pair using symbol levels of ±0.25V for STP media or passed to the optical module mentioned above for optical-fiber cables.

Control Signaling on STP and Optical Fiber

The two-pair, two-tone control signaling developed for the UTP PMD is not suitable for the STP and optical-fiber PMD because only one pair per direction is available for control signaling. Because cross talk is not an issue with STP or optical-fiber links, we were able to explore the use of higher-frequency signals. Square waves were again attractive because they can easily be chosen to be distinct from valid data patterns.

One concern was that the control signals not produce harmonics that, when transmitted on STP, might cause radiated emissions that violate regulations. It was decided that the control signal spectra should always fall below the random data spectrum, since it was known that the data transmission met EMC regulations. Calculations showed that square waves with frequencies less than 4 MHz met this requirement. A lower bound on the control signal frequency was set by the need to avoid distortion of the square wave resulting from transmission through the transformers used to couple to twisted-pair.

The final choice of control signals is five square waves with frequencies between 1.875 and 3 MHz. Again, the control signals are separated in frequency sufficiently to allow detection without a phase-locked clock at the receiver.

Summary

The physical layer developed for 100VG-AnyLAN local area networks accommodates different cable types by means of three different physical medium dependent (PMD) sublayers.

The major goal was to provide 100-Mbit/s transmission on the existing cable plant. The three PMDs allow LANs to operate across the vast majority of LAN media installed today: UTP (categories 3, 4, and 5), STP, and multimode fiber. As a result, customer investment in structured cabling is protected while at the same time an upgrade path to high-speed LANs is created. All three PMDs are designed to be simple and cost-effective. Customers can now benefit from a factor of up to eight improvement in the cost/performance ratio of their LANs without the significant cost penalty of replacing their cable plant.

Optical-Fiber Links for 100VG-AnyLAN

As data rates increase, low-cost optical-fiber links play an increasingly significant role in LANs for extending the length of links beyond what can be achieved with copper media, while meeting the full range of electromagnetic emission and susceptibility requirements for networks.

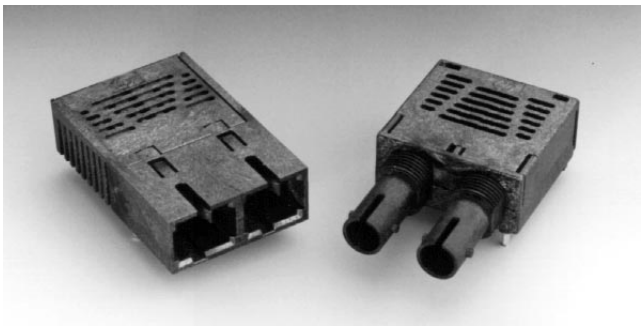

Fig. 1. HP optical transceiver.

The 100VG-AnyLAN standard defines a serialized interface with a 120-megabaud signaling rate for STP and multimode optical-fiber links. The standard defines two optical-fiber link length specifications, which allow the use of low-cost 850-nm technology for 500-m building backbones (this is the same technology used in the existing IEEE 802 standard CSMA/CD 10Base-F and 802.5J token-ring links) and 1300-nm technology for 2-km campus backbone links.

Fig. 1 shows the new Hewlett-Packard low-cost industry-standard optical transceiver package. This small package is 1 inch wide and 1.5 inches long and has a duplex SC optical connector on the front and a 1-by-9 row of electrical pins at the rear. HP transceivers HFBR 5106/5107 meet the two 100VG-AnyLAN link length standards and allow interchanging link technology in the same printed circuit board footprint. The transceivers are also available with AT&T ST optical connectors to address the large installed base having ST connectors for building and campus backbones.

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