The ATM Forum
Technical Committee

155.52 Mb/s Physical Layer Specification for Category-3 Unshielded Twisted Pair

af-phy-0047.000

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1. Introduction

This specification describes an extension to the current ATM Forum specification af-phy-0018, “Mid-range Physical Layer Specification for Category-3 Unshielded Twisted-Pair,” for a private UNI over Category-3 unshielded twisted-pair (UTP) cabling to support a higher bit rate of 155.52 Mb/s. This is considered an extension because this specification uses a similar technique to the one described for the mid-range bit rate. Devices built to this 155.52-Mb/s specification can optionally be made interoperable with those built according to the mid-range specification. The precise operating characteristics (e.g. start-up, bit-rate negotiation) of interoperable devices is for future study.

1.1 Overview

This section specifies the physical layer electrical interface for a 155.52-Mb/s private UNI. The functions of the Physical Layer are grouped into the Physical Media Dependent (PMD) sublayer and the Transmission Convergence (TC) sublayer as shown in Figure 2-1. The PMD Sublayer addresses bit rates and symmetry, bit error rate, bit timing, line coding and modulation characteristics, medium characteristics, and connectors. Also included in an Annex are discussions on impulse noise and electromagnetic susceptibility. The TC Sublayer addresses frame format, transfer capability, Header Error Control (HEC), etc.

Transmission Convergence Sublayer	*HEC generation/verification* *Cell scrambling/descrambling* *Cell delineation (HEC)* *Path signal identification (C2)* *Frequency justification/Pointer processing (optional for transmit)* *Scrambling/descrambling (SONET)* *Transmission frame generation/recovery*
Physical Media Dependent Sublayer	*Bit timing* *Line coding* *Physical medium* *Scrambling/descrambling*

FIGURE 2-1 PHYSICAL LAYER FUNCTIONS (U-PLANE)

1.2 Acronyms

ACR	Attenuation to Crosstalk Ratio
AIS	Alarm Indication Signal
AII	Active Input Interface
AOI	Active Output Interface
ATE	ATM Terminating Equipment
ATM	Asynchronous Transfer Mode
BER	Bit Error Rate
BIP	Bit Interleaved Parity
64-CAP	Carrierless Amplitude/Phase Modulation with 64 constellation points
EMC	Electromagnetic Compatibility
FEBE	Far End Block Error
HEC	Header Error Check
ITU-T	International Telecommunication Union - Telecommunication Standardization Sector
LOC	Loss of Cell Delineation
LOF	Loss of Frame
LOP	Loss of Pointer
LOS	Loss of Signal
LTE	SONET Line Terminating Equipment
NEXT	Near End Crosstalk
OAM	Operation, Administration and Maintenance
OCD	Out-of-Cell Delineation
OOF	Out Of Frame
POH	Path Overhead
PMD	Physical Media Dependent
PTE	SONET Path Terminating Equipment
RDI	Remote Defect Indicator
SDH	Synchronous Digital Hierarchy
SONET	Synchronous Optical Network
SPE	SONET Synchronous Payload Envelope
STE	SONET Section Terminating Equipment
STS-3c	Synchronous Transfer Signal, level 3, concatenated
TC	Transmission Convergence
TP-MIC	Twisted-Pair Media Interface Connector
UNI	User-Network Interface
UTP	Unshielded Twisted Pair

1.3 Reference Configurations

The private UNI is described in the ATM User-Network Specification, Version 3.1[1], Section 1.6, User-Network Interface Configuration. This document specifies the link between a user device and the network equipment.

2. Physical Medium Dependent (PMD) Sublayer Specification

The PMD sublayer provides bit transmission capability for point-to-point communication between a user device and network equipment. The implementation of the PMD shall provide all the services required to transport a suitably coded digital bit stream across the link segment.

This PMD specification gives the requirements for a 155.52-Mb/s interface using Category-3 Unshielded Twisted Pair (UTP) or better quality cabling. The implication of using other cables is discussed in Annex B.

This specification is designed to operate over a 100-meter copper link consisting of UTP Category-3 UTP. The connection is duplex using a pair of wires for each direction of transmission.

2.1 Bit Rates and Bit Rate Symmetry

2.1.1 Bit Rates and Timing

Bit rate (data rate) refers to the logical bit rate for data (expressed in Mb/s). Encoded line rate (symbol rate) refers to the modulation rate of the electrical signal on the media (expressed in Mbaud).

(R) The bit rate shall be 155.52 Mb/s (the SONET STS-3c rate as described in ANSI T1.105[2]).

On a link connecting an ATM user device and an ATM network equipment, the transmitter at the ATM user device uses a transmit clock which is derived from its received line signal, i.e., the ATM user device is loop timed.* Loop timing is important for the cancellation of NEXT noise.

(R) In the temporary absence of a valid clock derived from the received signal, the transmitter at the user device shall use a free-running transmit clock that operates at the nominal bit rate with a tolerance of ±100 ppm.

(R) In a network equipment to network equipment connection, one device shall act as the user, which shall be loop timed.

(R) The transmitter at the user device shall use a transmit clock which is derived from its received line signal.

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* All measurements are taken at AOI.

2.1.2 Bit Rate Symmetry

(R) Interfaces shall be symmetric, i.e., the bit rates are the same in both transmit and receive directions.

2.2 Bit Error Rate (BER)

(R) The Active Input Interface (AII) shall operate with a BER not to exceed 10^{-10} when presented with an Active Output Interface (AOI) signal (i.e., a valid signal as specified in 2.4.3) transmitted through the cable plant specified in Section 2.6 Copper Link Characteristics with the worst-case attenuation and Near End Crosstalk (NEXT) loss as specified in TIA/EIA-568-A[3]. The cable plant encompasses all components between any two communicating stations which include cords, wall outlets, horizontal cables, cross-connect fields, and associated patch cords.

2.3 Jitter

(R) Jitter of the transmitter, τ, shall be obtained by transmitting an all ones pattern at the input of the encoder, shown in the functional block diagram in Figure 2-3, into the test load specified in Section 2.4.3.3 and measure the variation of the zero-crossings of the resulting waveform as shown in Figure 2-2. For all measurements, the network equipment transmitter clock is used as the reference clock. τ for network equipment shall not exceed 1.0 ns peak-to-peak and τ for user devices shall not exceed 4.0 ns peak-to-peak with an input from the network of the maximum specified jitter.

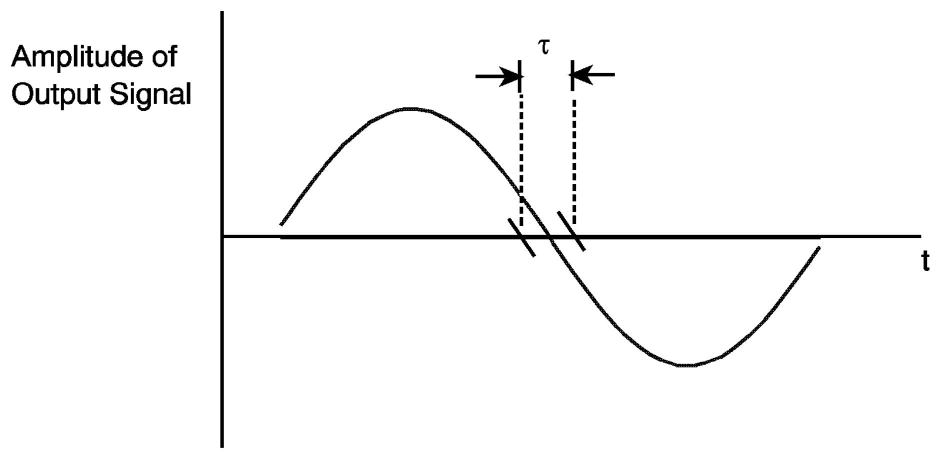

FIGURE 2-2 ILLUSTRATION OF TRANSMITTER JITTER

(R) Transmitters shall be capable of transmitting an all ones signal as observed at the input of the encoder functional block in the Block Diagram of Figure 2-3. At product level, some mechanism shall be provided.

2.4 Carrierless Amplitude Modulation/Phase Modulation

This PMD specification uses the Carrierless Amplitude Modulation/Phase Modulation (CAP) technique to provide bit transmission capability and bit timing. (This is the same technique as is described in the ATM Forum document af-phy-0018, “Mid-range Physical Layer Specification for Category-3 Unshielded Twisted-Pair.”[4]) The sublayer includes functions to generate and receive waveforms suitable for the medium, and the insertion and extraction of symbol timing information. The implementation of the PMD receives a bit stream from the TC sublayer, scrambles, encodes , and transmits the signal to the adjacent PMD sublayer over a Category-3 UTP link. The receiving implementation of the PMD decodes and descrambles the signal and delivers it as a bit stream to the TC sublayer. These operations are described below. Design principles for a CAP system are referenced in Annex A.

2.4.1 Transmit Functionality

The PMD sublayer is comprised of transmit functionality obtained from the blocks shown in Figure 2-3. Any implementation that produces the same functional behavior at the Active Output Interface is equally valid. The transmit function scrambles and encodes the bit stream received from the TC into an equivalent CAP encoded symbol stream and then into a modulated signal for presentation to the medium at the Active Output Interface.

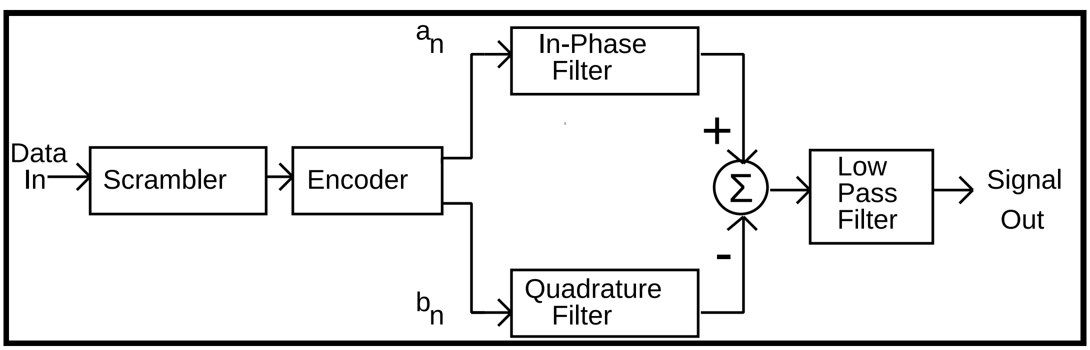

FIGURE 2-3 BLOCK DIAGRAM OF DIGITAL 64-CAP TRANSMITTER FUNCTIONALITY

The symbol stream from the encoder is divided into two paths, a_n and b_n, where n designates the n^{th} symbol period. The two symbol streams are sent to passband in-phase and quadrature shaping filters, respectively. The output of the in-phase filter and the negative of the output of the quadrature filter are summed into a single signal, the result passed through a low-pass filter, and then transmitted onto the twisted pairs.

2.4.2 Encoding

The amplitudes of the a_n and b_n components in the 64-CAP constellation shall maintain the relative values 1, 3, 5, and 7, with a tolerance of ±0.06, as depicted in the respective constellation diagram of Figures 2-5.

2.4.2.1 Operation at 155.52 Mb/s

(R) For 155.52 Mb/s, the encoding used shall be the 64-CAP code. The symbol rate is 25.92 Mbaud.

(R) For 64-CAP, the encoder shall map six data bits into a symbol as shown in Figure 2-4. Bits shall be mapped from the PMD scrambler (see Section 2.5) into the six bit symbol. The first bit out of the PMD scrambler into a given symbol shall be b_1.

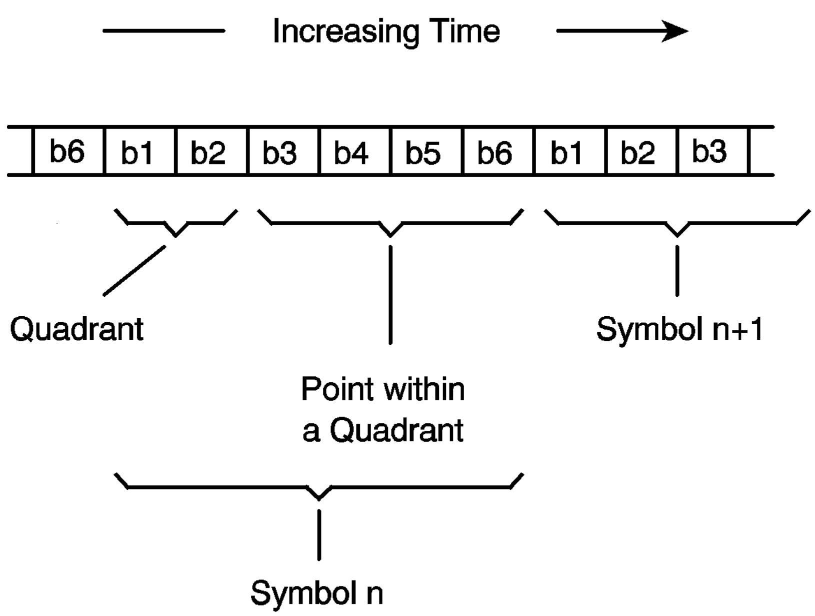

FIGURE 2-4 BIT-TO-SYMBOL MAPPING FOR 64-CAP

(R) For 64-CAP, the signal constellation shall be as shown in Figure 2-5.

Each incoming group of 6 bits is Gray encoded into a 64-CAP symbol. The relative levels of the amplitude of the symbols in each dimension are proportional to the four different levels, ±1, ±3, ±5, and ±7. Bits b_1b_2 (circled in Figure 2-5) designates the quadrant. Bits b_3b_4 b_5b_6 designates the point being used within the quadrant.

For example, an incoming bit stream 100101 would translate into the symbol: (a_n= -1, b_n= +5).

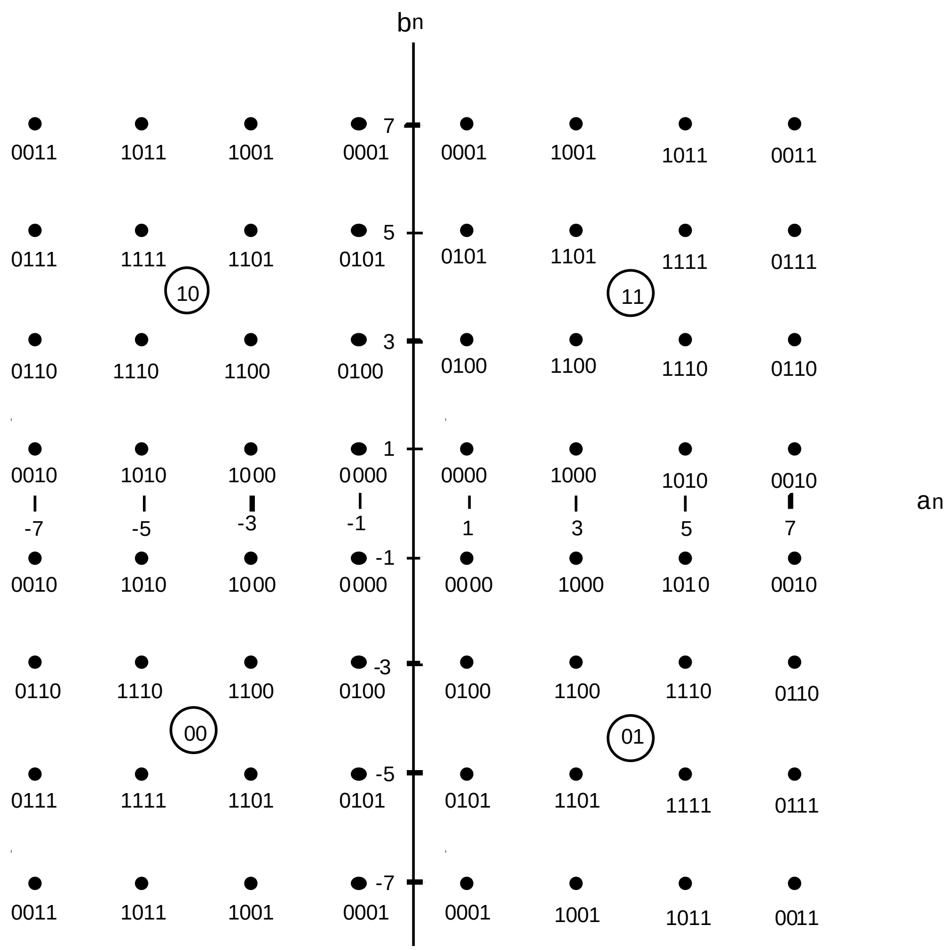

FIGURE 2-5 64-CAP SIGNAL CONSTELLATION

2.4.3 Active Output Interface

This section specifies the impulse response for the transmit filters, transmit level, and the transmit signal power spectrum of the AOI.

2.4.3.1 Impulse Response for the Transmit Filters

The impulse response of the in-phase and quadrature filters shown in the block diagram of Figure 2-3 is described as follows:

Let

$$g(t) = \frac{\sin\left[\frac{\pi t}{T}(1-\alpha)\right] + \frac{4\alpha t}{T}\cos\left[\frac{\pi t}{T}(1+\alpha)\right]}{\frac{\pi t}{T}\left[1-\left(\frac{4\alpha t}{T}\right)^2\right]}$$

$$\alpha = 0.15$$

be a square-root raised-cosine pulse with 15% excess bandwidth. The in-phase filter impulse response is defined as

$$f(t) = g(t)\cdot\cos(2\pi f_c t)$$

and the quadrature filter impulse response,

$$\tilde{f}(t) = g(t)\cdot\sin(2\pi f_c t)$$

where T is the symbol period, and f_c = 15 MHz is the center frequency.

The actual impulse responses of the transmitter will be truncated approximations of the above equations over a fixed interval such as $-4T < t < 4T$. (See Annex A for technical references.)

2.4.3.2 Active Output Signal Spectrum

(R) The Active Output signal shall have a power spectrum equivalent to the square root of a raised-cosine shaping with 15% excess bandwidth.

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(R) The normalized power spectrum of the Active Output signal of the 64-CAP transmitter shall fit within the template of the spectral envelope shown in Figure 2-6.

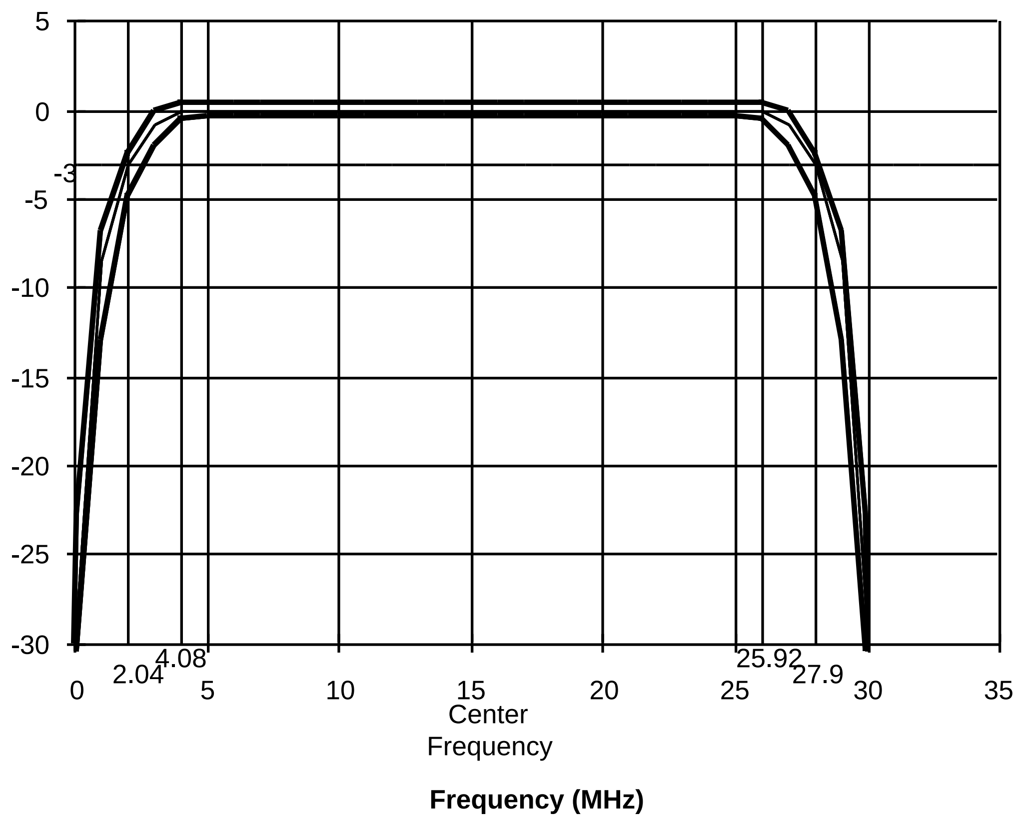

FIGURE 2-6 TEMPLATE FOR THE POWER SPECTRUM OF THE SIGNAL AT THE OUTPUT OF THE TRANSMITTER

Values are normalized to the value at the center frequency. Table 2-1 gives quantitative values for breakpoints of the curves in Figure 2-6. The frequency resolution of a spectrum analyzer when measuring the spectrum of Figure 2-6 should be 30 kHz or better.

TABLE 2-1 BREAKPOINTS FOR THE POWER SPECTRUM CURVES IN FIGURE 2-6

Frequency(MHz)	0	1	2	3	4	5 - 25	26	27	28	29	30
Upper Limit(dB)	-30	-6.8	-2.5	0	0.4	0.4	0.4	0	-2.5	-6.8	-30
Lower Limit(dB)	NA	-13	-4.9	-2.1	-0.6	-0.4	-0.6	-2.1	-4.9	-13	NA

Note: NA indicates that no lower boundary is specified for that frequency.

2.4.3.3 Voltage Output

(R) The test load shall consist of a single 100 ohm ±0.2% resistor connected across the transmit pins of the AOI. For frequencies less than 100 MHz, the series inductance of the resistor shall be less than 20 nH and the parallel capacitance shall be less than 2 pF.

(R) The peak-to-peak differential voltage measured across the transmit pins at the AOI shall be 4 V±0.2V peak-to-peak when terminated with the specified test load.

2.4.3.4 AOI Return Loss

The Return Loss of the AOI (RL_o) specifies the amount of the differential signal incident upon the AOI that is reflected.

(R) RL_o, specified at the AOI, shall be greater than 15 dB for the frequency range 1-30 MHz. The return loss shall be measured for a resistive test load range of 85-115 ohms. The return loss shall be measured while the implementation of the PMD is powered.

RL_o is defined in terms of the receiver impedance or as a differential reflected voltage:

$$RL_0 = 20\log\frac{|Z_r + Z_{ref}|}{|Z_r - Z_{ref}|} = 20\log\frac{|V_i|}{|V_r|}$$

where

Z_r is the impedance of the AOI,
Z_{ref} is the reference impedance (85-115 ohms),
V_i is the differential voltage incident upon the AOI, and
V_r is the differential voltage reflected from the AOI.

2.4.4 Receive Functionality

A CAP receiver decodes the incoming 64-CAP signal stream received from the Active Input Interface and converts it into an equivalent bit stream for presentation to the TC sublayer. Design principles for a CAP system are referenced in Annex A. An example of receiver equalizer start-up is described in Annex B.

(R) The receiver shall require no more than 500 ms to reach a state that achieves the BER specified in Section 2.2 from the time presented with a valid signal transmitted through the cable plant specified in Section 2.6, Copper Link Characteristics.

2.4.4.1 Receiver Return Loss

The Return Loss of the AII (RL_i) specified the amount of the differential signal incident upon the AII that is reflected.

(R) RL_i, specified at the AII, shall be greater than 16 dB for the frequency range 1-30 MHz. The return loss shall be measured for a resistive test load range of 85-115 ohms. The return loss shall be measured while the implementation of the PMD is powered.

RL_i is defined in terms of the receiver impedance or as a differential reflected voltage:

$$RL_i = 20\log\frac{|Z_r + Z_{ref}|}{|Z_r - Z_{ref}|} = 20\log\frac{|V_i|}{|V_r|}$$

where

Z_r is the impedance of the receiver,
Z_{ref} is the reference impedance (85-115 ohms),
V_i is the differential voltage incident upon the receiver, and
V_r is the differential voltage reflected from the receiver.

2.5 PMD Scrambler/Descrambler

(R) A self-synchronizing PMD scrambler and descrambler shall be provided in the implementation of the PMD.

The ability to disable the functionality of the scrambler and the descrambler respectively will significantly simplify the integration of future enhancements, diagnostics, and test implementations.

(R) A means shall be provided to disable the scrambler and/or the descrambler functionality.

For performance reasons, two different scrambler polynomials are used to ensure that the signal in one direction is uncorrelated to the signal in the other direction.

(R) The generating polynomial for network equipment scramblers and user device descramblers shall be:

$$GPN(x) = x^{23} + x^{18} + 1.$$

(R) The generating polynomial for user device scramblers and network equipment descramblers shall be:

$$GPU(x) = x^{23} + x^{5} + 1.$$

(R) In a network equipment to network equipment connection, the device acting as the user device shall use the scrambler and descrambler generating polynomials designated for the user devices.

2.6 Copper Link Characteristics

The copper medium consists of one or more sections of Category-3 UTP along with intermediate connectors required to connect sections together, and terminated at each end using the connectors specified in Section 2.9. The cable is interconnected to provide two continuous electrical paths, one for each direction.

(R) The cable and patch cords shall meet or exceed the requirements of TIA/EIA-568-A [3] for Category-3 horizontal cabling and flexible cordage respectively. This includes requirements on NEXT loss, attenuation and characteristic impedance.

(R) All connecting hardware (outlets, transition connectors, patch panels and cross-connect fields) shall meet or exceed the Category-3 electrical requirements for NEXT loss and attenuation specified in TIA/EIA-568-A[3].

The intent of these requirements is to minimize the effect of degradation of UTP connecting hardware on end to end system performance. However, it should be noted that the requirements are not sufficient by themselves to ensure adequate system performance. System performance also depends on the care with which the cabling plant, especially the connectors, is installed, and the total number of connections.

(R) The connector termination practices and UTP cable installation practices described in Chapter 10 of ANSI/TIA/EIA-568-A[3] shall be followed.

2.7 Link Length Using a Reference Channel Model

2.7.1 Operation at 155.52 Mb/s

The reference channel model as described in Annex E of ANSI/TIA/EIA-568-A[3] is defined to be a link consisting of 90 meters of Category-3 cable, 10 meters of Category-3 flexible cords, and four Category-3 connector pairs internal to the link.

(R) The composite channel attenuation shall meet the Category-3 attenuation performance limits defined in Annex E of ANSI/TIA/EIA-568-A[3].

(R) The composite channel NEXT loss shall meet the Category-3 NEXT loss performance limits defined in Annex E of ANSI/TIA/EIA-568-A[3].

Since the above two requirements are derived from the electrical performance of the reference channel model, the reference channel model (properly installed) is by definition a compliant link. Additionally, properly installed links consisting of no more than 90m of Category-3 UTP cable, no more than 10m of Category-3 flexible cords, and no more than four Category-3 connectors internal to the link are also examples of compliant links. Any installed link meeting the link attenuation and NEXT loss requirements of this section is compliant.

Annex B contains guidance on the use of cable types other than Category-3 UTP.

2.7.2 Operation at 51.84 Mb/s, 25.92 Mb/s, and 12.96 Mb/s

(O) Operation at 51.84, 25.92, and 12.96 Mb/s is optional. If this option is provided it must meet the requirement of this section.

(CR) Operation at 51.84 Mb/s, 25.92 Mb/s, and 12.96 Mb/s shall conform to the ATM Forum Mid-range Physical Layer Specification for Category-3 Unshielded Twisted Pair document.

2.8 Noise Environment

The noise environment is discussed in Annex C.

2.9 Media Interface Connectors

ATM user device and ATM network equipment implementing the PMD specification shall be attached to the twisted-pair copper link by Twisted-Pair Media Interface Connectors (TP-MIC). The media connection between a user device and a network equipment consists of a duplex cable assembly with TP-MIC modular plugs. To ensure interoperability between conforming user devices and network equipment, TP-MIC connectors are specified at the interfaces for user devices and network equipment.

2.9.1 Connectors for Category-3 UTP Cabling

(R) The cable assembly shall connect the corresponding pins of plugs at each end of the link (i.e., pin 1 to pin 1, pin 2 to pin 2, etc.).

This method of connection assures that the cable assembly is straight through (no cross-overs) and that the correct polarity is maintained.

2.9.1.1 UTP-MIC Modular Plug

(R) Each end of the Category-3 UTP copper link shall be terminated in an 8-contact modular plug as specified in IEC 603-7[5]. Each connector shall meet or exceed the electrical requirements for ANSI/TIA/EIA-568-A[3] Category-3 100-ohm UTP connecting hardware. An illustration of the plug is shown in Figure 2-7.

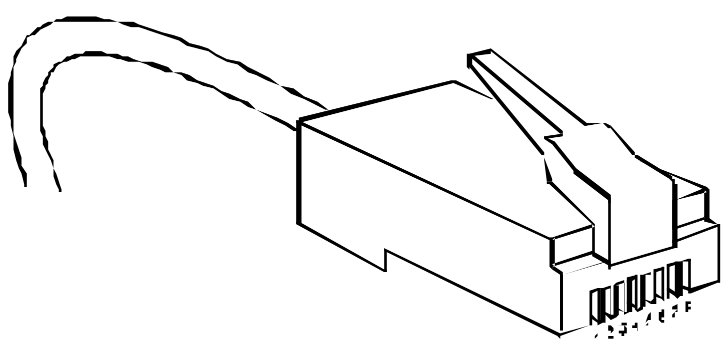

FIGURE 2-7 EXAMPLE OF A UTP-MIC MODULAR PLUG

2.9.1.2 UTP-MIC Jack

(R) The PMD MIC used to attach the PMD to the copper link specified in 2.6 shall be an 8-contact jack/socket connector as specified in IEC 603-7[5]. The connector shall meet or exceed the electrical requirements specified in ANSI/TIA/EIA-568-A for a Category-3 100-ohm UTP connector. These include specifications on NEXT loss. An illustration of the jack is shown in Figure 2-8.

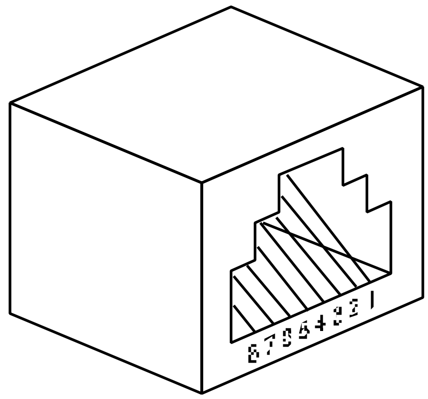

Figure 2-8 Example of a UTP-MIC Jack

(R) The assignment of contacts for TIA/EIA cable shall be as shown Table 2-2.

TABLE 2-2 CONTACT ASSIGNMENTS FOR UTP-MIC CONNECTORS

Contact	Signal at the User Device MIC	Signal at the Network Equipment MIC
1	Transmit+	Receive+
2	Transmit-	Receive-
3	Unused	Unused
4	Unused	Unused
5	Unused	Unused
6	Unused	Unused
7	Receive+	Transmit+
8	Receive-	Transmit-

These unused pairs may transport non-interfering signals providing the bit error rate of the pair in use meets the BER specified in Section 2.2.

3. Transmission Convergence (TC) PHY Sublayer Specification

The Transmission Convergence (TC) sublayer deals with physical aspects which are independent of the transmission medium characteristics. Most of the functions comprising the TC sublayer are involved with generating and processing a subset of the overhead bytes contained in the SONET based STS-3c frame. Unless otherwise described in this specification, the requirements for the TC functions are as defined for the private UNI as described in the ATM Forum ATM UNI Specification, Version 3.1, Section 2.1[1]. Error correction as described in ITU-T Recommendation I.432[6], if implemented, will not be effective. It is recommended that HEC single bit error *correction* not be used.

4. References

[1] ATM Forum, UNI Specification, Version 3.1, 1994.

[2] ANSI T1.105, Digital Hierarchy – Optical Interface Rates and Formats Specifications, 1991.

[3] Commercial Building and Wiring Telecommunications Wiring Standard, ANSI/TIA/EIA-568-A, 1995.

[4] ATM Forum af-phy-0018: Mid-range Physical Layer Specification for Category-3 Unshielded Twisted-Pair, 1994.

[5] IEC 603-7, Connectors for frequencies below 3 MHz for use with printed boards - Part 7: Detail specification for connectors, 8-way, including fixed and free connectors with common mating features, 1990.

[6] ITU-T Recommendation I.432, B-ISDN User-Network Interface – Physical Layer Specification, 1993.

[7] ISO/IEC 11801, Generic Cabling for Customer Premises, 1995.

ANNEXES

Annex A, annex B, and annex C are included for informative purposes only, and are not requirements for conformance to this document.

Annex A: Informational References on CAP Technology

J. J. Werner, "Tutorial on Carrierless AM/PM - Part I - Fundamentals and Digital CAP Transmitter," Contribution to ANSI X3T9.5 TP/PMD Working Group, Minneapolis, June 23, 1992.

J. J. Werner, "Tutorial on Carrierless AM/PM - Part II - Performance of Bandwidth-Efficient Line Codes," Contribution to ANSI X3T9.5 TP/PMD Working Group, Austin, February 16, 1993.

Gi-Hong Im and J. J. Werner, “Bandwidth-Efficient Digital Transmission up to 155 Mb/s over Unshielded Twisted Pair Wiring,” Conference Record, IEEE ICC’93, Geneva, May 23-26, 1993, pp. 1797-1803.

W. Y. Chen, G. H. Im, and J. J. Werner, "Design of Digital Carrierless AM/PM Transceivers," AT&T/Bellcore Contribution T1E1.4/92-149, August 19, 1992.

Copies of the tutorials on carrierless AM/PM can be obtained from:

Jean Paul Emard
Standards Secretariat, ANSI X3T9 Committee
+1 202 626 5740

Copies of “Bandwidth-Efficient Digital Transmission up to 155 Mb/s over Unshielded Twisted Pair Wiring” can be obtained from:

ASK IEEE
+ 1 800 949 4333 (for US customers)
+ 1 415 259 5040 (for all other customers)

Copies of "Design of Digital Carrierless AM/PM Transceivers" can be obtained from:

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1200 G Street, NW
Washington, D.C. 20005
+1 202 434 8841.

Annex B: The Use of Alternative Cable Types

Category-5 Cable and STP at 155.52 Mb/s

It is possible to support copper link lengths greater than 100 meters using cabling systems that have higher performance than Category-3 UTP, such as Category-5 UTP and STP. Both Category-5 UTP and STP have superior NEXT loss and attenuation characteristics, hence the NEXT loss to attenuation ratio (NIR) is higher. This permits operating over copper links in excess of 100 meters. However, some care has to be exercised when trading attenuation for crosstalk, and this is outside the scope of this document.

It is still possible to gain from the superior attenuation performance of Category-5 UTP and STP cable while retaining the channel specification requirements of section 2.7.1. This should permit a maximum reach of about 150m using a link made of Category-5 UTP or STP components and a receiver having a dynamic range which does not exceed what is required for a 100m category-3 cable. Links with lengths of 350m can be achieved with receivers having a dynamic range which is larger than the dynamic range required for a 100m Category-3 UTP cable, based on ACR.

If STP cabling is used, proper impedance termination (150Ω) of the line is strongly recommended.

The following table summarizes supportable link lengths for Category-3 UTP, Category-5 UTP, and STP cabling.

Table B-1 Supportable Link Lengths for 155.52 Mb/s

UTP - 3	100m
UTP - 5	150m/350m
STP	150m/350m

Other Cable Types

There are a variety of cable types which have attenuation and crosstalk loss characteristics that are different than those of Category-3 UTP that may be used to provide the copper-link function. ISO 11801 describes cabling that may meet the requirements of the copper-link specification, and possibly provide the copper-link function at lengths other than 100m. Link lengths using these cables is not specified in this document and must be determined, in terms relative to the length of Category-3 UTP, by the user/provider.

Estimates for the achievable link lengths for these cables can be determined using the following method. Let $L_x(f)$ and $L_a(f)$ be the worst case NEXT loss and attenuation/insertion loss (in dB) at frequency f, respectively, for a given cabling system. At frequency f, the NEXT loss-to-insertion loss ratio NIR(f) is defined as

$$NIR(f) = L_x(f) - L_a(f).$$

The link length that can be supported using the alternate cable system is estimated by determining the cable length for which $NIR(f) > NIR_{ref}(f)$ at all frequencies between 1 and 16 MHz. The reference, $NIR_{ref}(f)$, is determined from the link performance data for a 100 meter Category-3 link in Annex E of TIA/EIA-568-A. For example, $NIR_{ref}(f)$ at frequencies of 1 MHz and 16 MHz is 34.9 dB and 4.4 dB, respectively.

Annex C: Noise Environment

The environmental noise consists primarily of two types, radiated noise and conducted/impulse noise. The sources of the environmental noise are office equipment, building equipment, power mains, and local radio stations. It is recommended that PMD implementations provide immunity to both radiated noise and conducted noise signals from power mains specified in this annex.

Immunity to Conducted Noise

Immunity of the PMD implementation to impulse noise from power mains, when operating over the copper link Specified in 2.6, should be determined using the test methods described in IEC 801-4 with a test voltage of 0.5 kV. During the test the BER is permitted to degrade below that specified in Section 2.2. After the test has been completed the PMD should return to normal operation without operator intervention, and the BER of the PMD should not exceed that specified in Section 2.2.

Immunity to Radiated Noise

The implementation of the PMD should be tested using methods described in IEC 801-3. Immunity of the PMD implementation to radiated noise should be measured using the test methods described in IEC 801-3 with a radiated noise test level of Level 2 (3 V/m). The PMD should operate within the BER specified in Section 2.2 while the test is being conducted.