The ATM Forum
Technical Committee

# Mid-range Physical Layer Specification for Category 3 Unshielded Twisted-Pair

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Version 1.0
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## Preface

Since the publication of The ATM Forum ATM User-Network Interface Specification, Version 3.0 (UNI 3.0), the ATM Forum Technical Committee has completed the specification of additional physical layer interface agreements. These additional interfaces are:

- ATM Physical Medium Dependent Interface Specification for 155 Mb/s over Twisted Pair Cable
- Mid-range Physical Layer Specification for Category 3 Unshielded Twisted Pair
- DS1 Physical Layer Specification

This document contains the Mid-range Physical Layer Specification for Category 3 Unshielded Twisted Pair.

## Acknowledgment

The assistance of Rick Townsend who provided source material for this document is appreciated. Without his efforts this document could not have been assembled.

The material submitted is based upon documents that have been edited at various times by Daun Langston, Ken Brinkerhoff, Moshe DeLeon, Stanley Ooi, and David Foote. Their assistance as well as all the members of The ATM Forum who have brought contributions towards, discussed and reviewed the enclosed information is appreciated.

Greg Ratta, Chief Editor

# ATM Forum Technical Committee
# Mid-range Physical Layer Specification for Category 3 Unshielded Twisted-Pair

## 1. Introduction

This specification describes a physical layer for a mid-range private UNI over Category 3 unshielded twisted-pair cabling. This specification does not preclude extensions to support lower data rates over cables with worse characteristics than Category 3 Unshielded Twisted Pair or extensions to support higher data rates over cables with better characteristics than Category 3 Unshielded Twisted Pair.

## 1.1 Overview

This section specifies the physical layer electrical interface for a 51.84 Mb/s (and sub-rates) 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 1-1. 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<br>Cell scrambling/descrambling<br>Cell delineation (HEC)<br>Path signal identification (C2)<br>Frequency justification/Pointer processing (optional for transmit)<br>Scrambling/descrambling (SONET)<br>Transmission frame generation/recovery |
| Physical Media Dependent Sublayer | Bit timing<br>Line coding<br>Physical medium<br>Scrambling/descrambling |

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

## 1.2 Acronyms

| | |
|---|---|
| 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 |
| k-CAP | Carrierless Amplitude/Phase Modulation with k constellation points |
| DSn | Digital Signal, Level n |
| 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-1 | Synchronous Transfer Signal, level 1, the fundamental level of the SONET hierarchy. |
| 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 51.84 Mb/s interface using Category 3 Unshielded Twisted Pair (UTP) cabling. Optional sub-rate interfaces of 25.92 and 12.96 Mb/s are included for supporting a longer link or links that consist of cabling components that do not meet the specifications of Category 3 UTP. Greater range can be achieved by the use of higher quality (e.g. Category 5) cabling or by adopting one of the lower, optional bit rates.

The design goal of this specification is a total link length of 100m using Category 3 cables and interconnect components. 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

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 51.84 Mb/s (the SONET STS-1 rate as described in ANSI T1.105[2]).

Extensions to support lower data rates are optional. This PMD specification may also be used to specify the physical interface for link lengths that are longer than those specified for Category 3 UTP in EIA/TIA-568-A[3].

**(O)** Operation at 25.92 Mb/s and/or 12.96 Mb/s shall be optional (See Sections 2.5.2 Encoding and 2.8, Link Length Using a Reference Channel Model).

### 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 Section 2.5) transmitted through the cable plant specified in Section 2.7 Copper Link Characteristics with the worst-case attenuation and Near End Crosstalk (NEXT) loss as specified in EIA/TIA-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 Timing

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 data clock, i.e., the ATM user device is loop timed.

**(R)** The bit rate shall be the nominal rate of 51.84 Mb/s, or one of the optional nominal rates of 25.92 or 12.96 Mb/s, all with a tolerance of ±20 ppm for network equipment.

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

**(R)** In the 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.

## 2.4 Jitter

**(R)** Jitter of the transmitter, $\tau$, shall be obtained by transmitting an all ones pattern at the input of the encoder, shown in the Block Diagram in Figure 2-2, into the test load specified in Section 2.5.3.2. and measure the variation of the zero-crossings of the resulting waveform as shown in Figure 2-1. For all measurements, the network equipment transmitter clock is used as the reference clock. for network equipment shall not exceed 2.0 ns peak-to-peak and for user devices shall not exceed 4.0 ns peak-to-peak with an input from the network of the maximum specified 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 2-2.

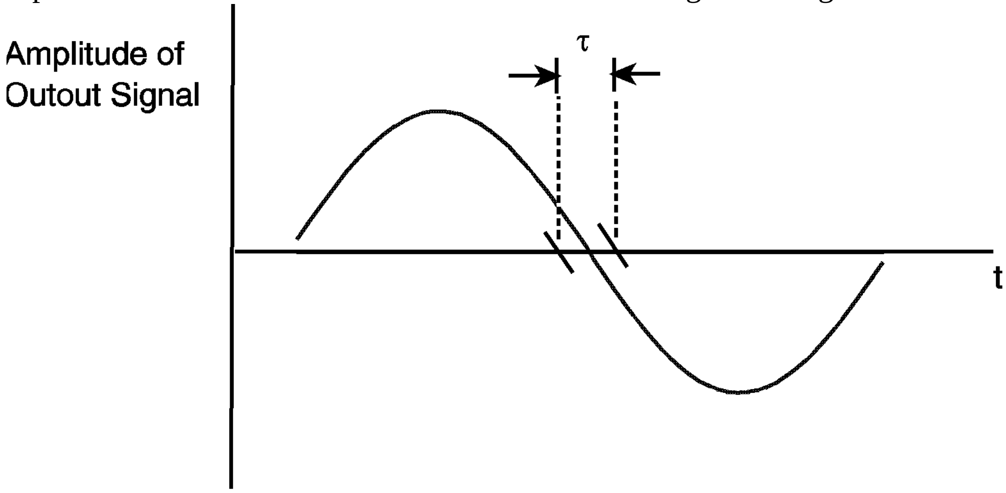


**FIGURE 2-1 ILLUSTRATION OF TRANSMITTER JITTER**

## 2.5 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. 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 descramblers 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.

### 2.5.1 Transmit Functionality

The PMD sublayer is comprised of transmit functionality obtained from the blocks shown in Figure 2-2. Any implementation that produces the same functional behaviour 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.

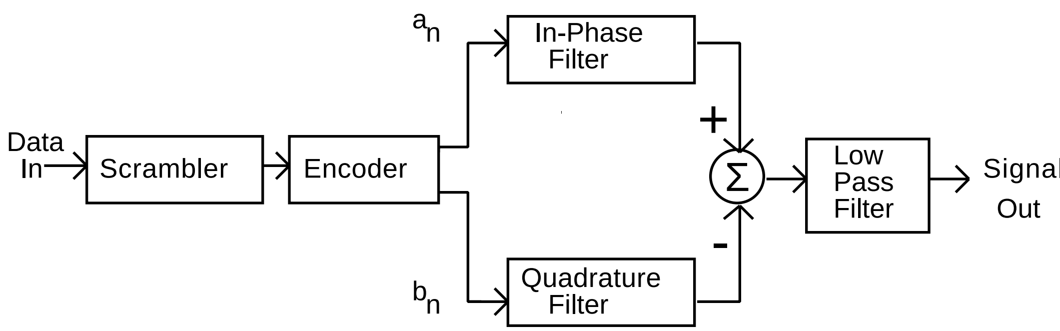


**FIGURE 2-2 BLOCK DIAGRAM OF DIGITAL 16-CAP TRANSMITTER FUNCTIONALITY**

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.

### 2.5.2 Encoding

The amplitudes of the $a_n$ and $b_n$ components in the k-CAP constellations shall maintain the relative values 1 and 3, with a tolerance of ±0.06, as depicted in the respective constellation diagrams of Figures 2-4, 2-6, and 2-7.

#### 2.5.2.1 Operation at 51.84 Mb/s

**(R)** For 51.84 Mb/s, the encoding used shall be the 16-CAP code. The symbol rate is 12.96 Mbaud.

**(R)** For 16-CAP, the encoder shall map data four data bits into a symbol as shown in Figure 2-4. Bits shall be mapped from the PMD scrambler (see Section 2.6) into the four bit symbol. The first bit out of the PMD scrambler into a given symbol shall be $b_1$.

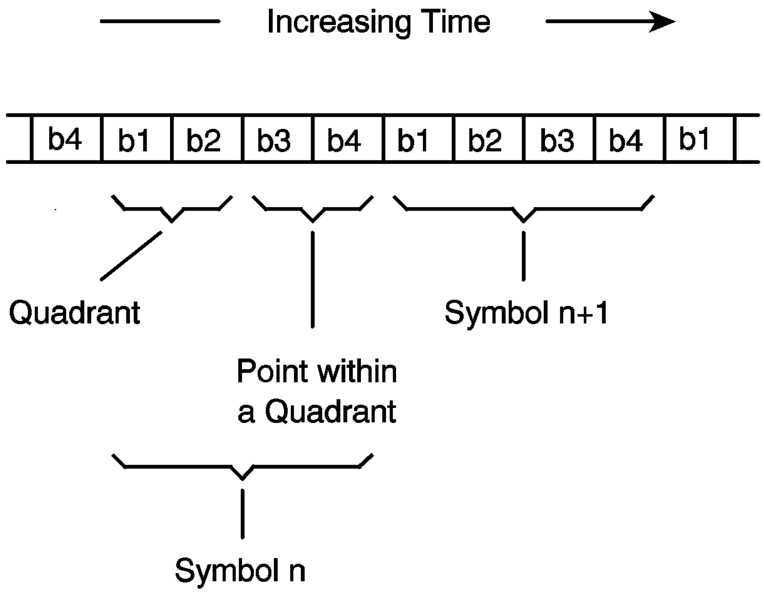


**FIGURE 2-3 BIT-TO-SYMBOL MAPPING FOR 16-CAP**

**(R)** For 16-CAP, the signal constellation shall be as shown in Figure 2-4.

Each incoming group of 4 bits is Gray encoded into a 16-CAP symbol. The relative levels of the amplitude of the symbols in each dimension are proportional to the four different levels, ±1 and ±3. Bits $b_1b_2$ (circled in Figure 2-4) designates the quadrant. Bits $b_3b_4$ designates the point being used within the quadrant.

For example, an incoming bit stream 10010110 would translate into two symbols:
($a_n$= +1, $b_n$= -3) and ($a_{n+1}$= -3, $b_{n+1}$= +1).

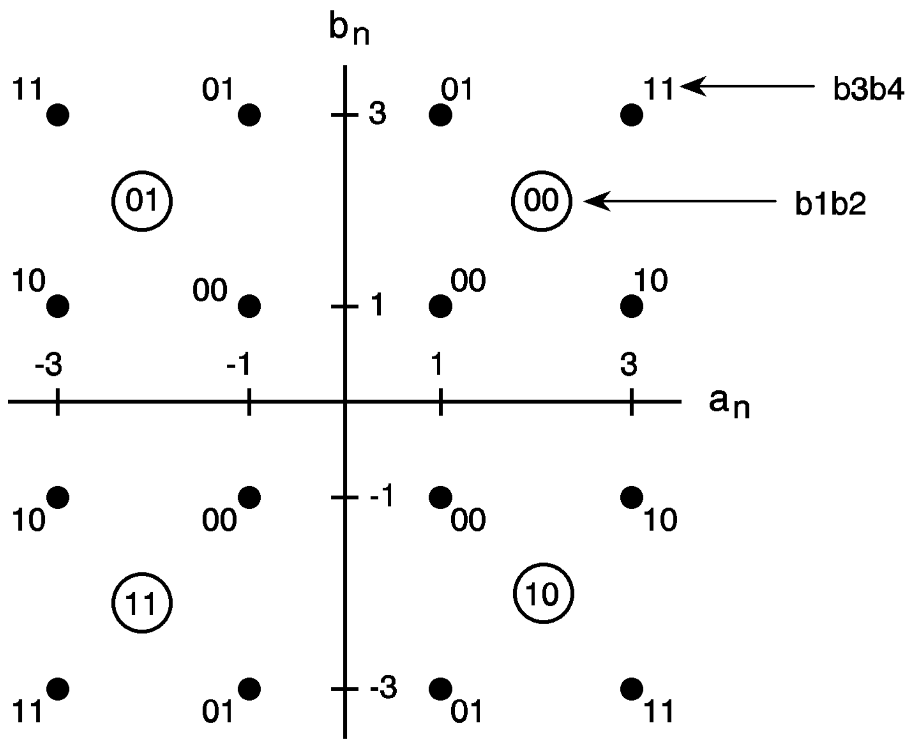


**FIGURE 2-4 16-CAP SIGNAL CONSTELLATION**

### 2.5.2.2 Operation at 25.92 Mb/s

Operation at 25.92 Mb/s is optional. However, if operation at 25.92 Mb/s is implemented, the following statements marked **CR** are required.

**(CR)** For 25.92 Mb/s, the encoding used shall be the 4-CAP code. The symbol rate shall be 12.96 Mbaud.

**(CR)** For 4-CAP, the encoder shall map two data bits into a symbol as shown in Figure 2-5. Bits shall be mapped from the PMD scrambler (see Section 2.6) into the two bit symbol. The first bit out of the PMD scrambler into a given symbol shall be $b_1$.

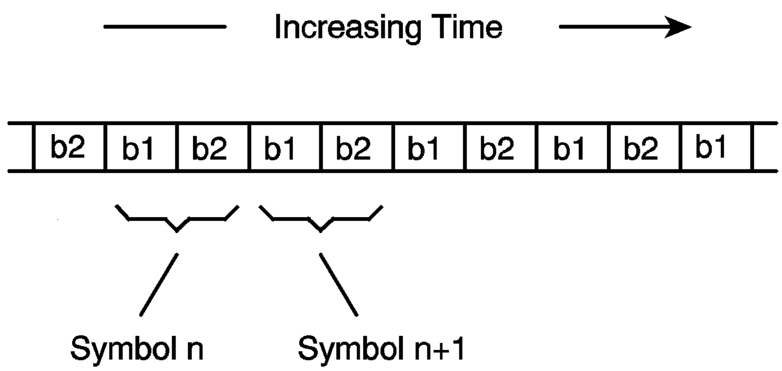


**FIGURE 2-5 BIT-TO-SYMBOL MAPPING FOR 4-CAP**

(CR) For 4-CAP, the signal constellation shall be as shown in Figure 2-6.

Each incoming group of 2 bits is Gray encoded into a 4-CAP symbol. The relative levels of the amplitude of the symbols in each dimension are proportional to the four different levels, ±1 and ±3.

For example, the first two symbols in an incoming bit stream 10010110 would translate into ($a_n$= +1, $b_n$= -3) and ($a_{n+1}$= -1, $b_{n+1}$= +3).

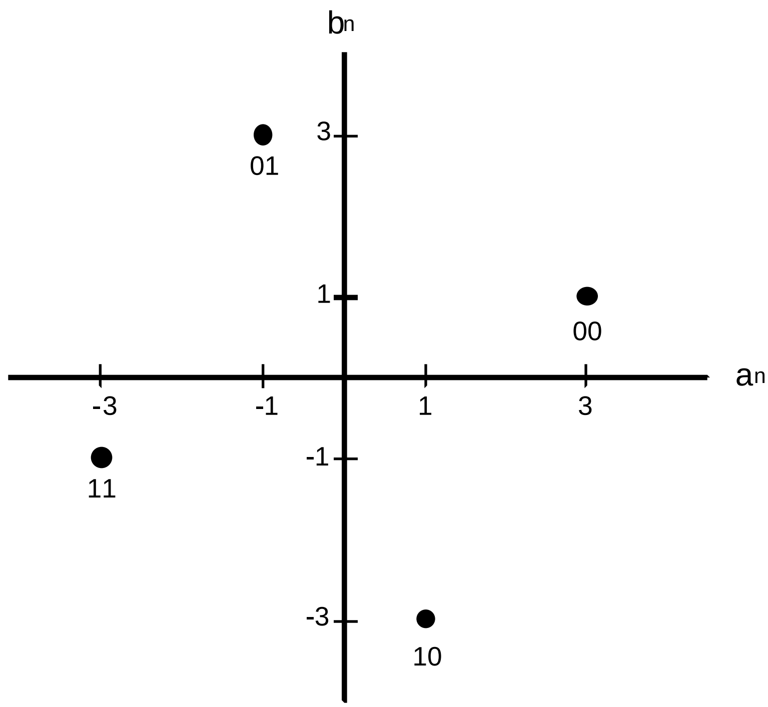


**FIGURE 2-6 4-CAP SIGNAL CONSTELLATION**

### 2.5.2.3 Operation at 12.96 Mb/s

Operation at 12.96 Mb/s is optional. However, if operation at 12.96 Mb/s is implemented, the following statements marked (CR) are required.

**(CR)** For 12.96 Mb/s, the encoding used shall be the 2-CAP code. The symbol rate shall be 12.96 Mbaud.

**(CR)** For 2-CAP, the encoder shall map each data bit into a symbol. Bits shall be mapped from the PMD scrambler (see Section 2.6) from left to right, each bit to be mapped into a symbol.

**(CR)** For 2-CAP, the signal constellation shall be as shown in Figure 2-7.

The relative levels of the amplitude of the symbols in each dimension are proportional to the two different levels, ±3 for $a_n$ and ±1 for $b_n$.

For example, the first two symbols in an incoming bit stream 10010110 would translate into ($a_n$= -3, $b_n$= -1) and ($a_{n+1}$= +3, $b_{n+1}$= +1).

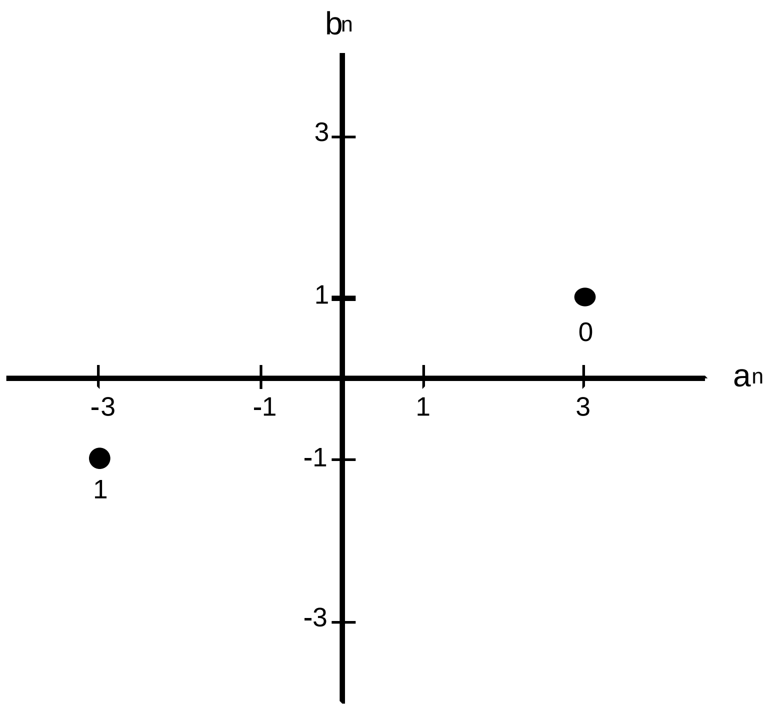


**FIGURE 2-7 2-CAP SIGNAL CONSTELLATION**

### 2.5.3 Active Output Interface

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

### 2.5.3.1 Impulse Response for the Transmit Filters

The impulse response of the in-phase and quadrature filters shown in Figure 2-2 is described as follows.
Let

$$g(t) = \begin{cases} \dfrac{4}{\pi} \dfrac{\cos[2\pi\, t/T]}{[1-(4t/T)^2]}, & t \neq \pm\dfrac{T}{4} \\ 1, & t = \pm\dfrac{T}{4} \end{cases}$$

be a square-root raised-cosine pulse with 100% excess bandwidth. The in-phase filter impulse response is defined as

$$f(t) = g(t) \cdot \cos(2\pi\, t/T)$$

and the quadrature filter impulse response,

$$\tilde{f}(t) = g(t) \cdot \sin(2\pi\, t/T)$$

where T is the symbol period.

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

Since the symbol rates for the required bit rate and the two optional bit rates are the same, the line interface components, including low-pass filter and transformer, can be identical for all three rates.

### 2.5.3.2 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 100% excess bandwidth.

**(R)** The normalized power spectrum of the Active Output signal of the k-CAP transmitter shall fit within the template of the spectral envelope shown in Figure 2-8.

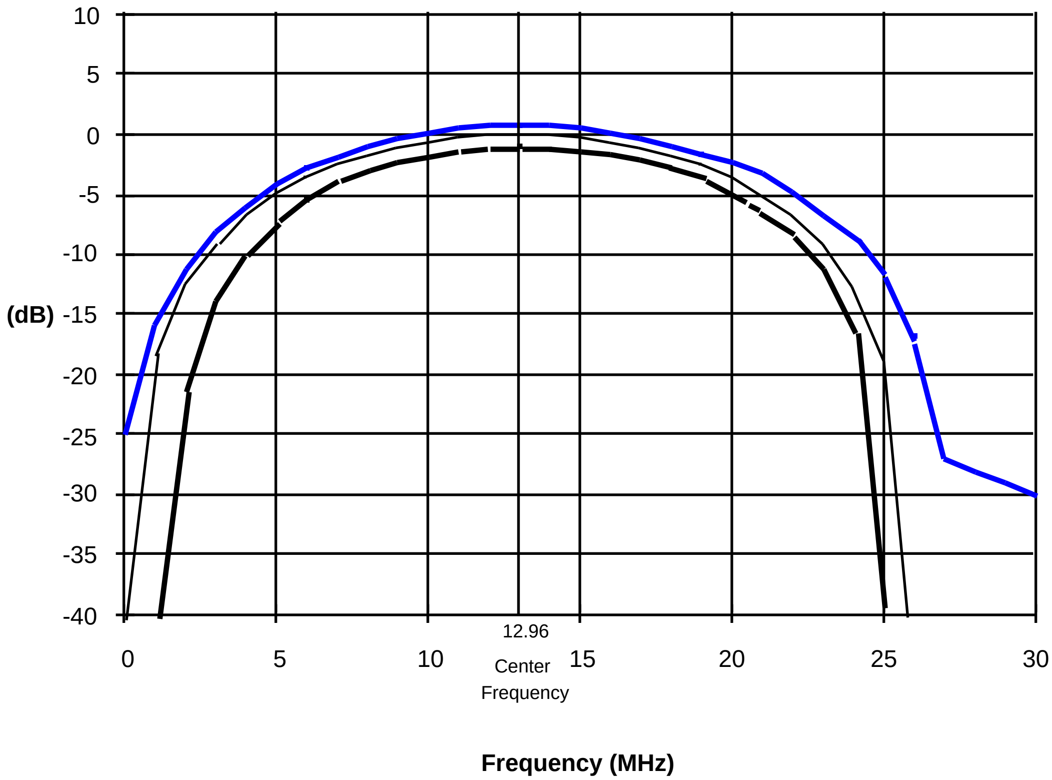


**FIGURE 2-8 TEMPLATE FOR THE POWER SPECTRUM OF THE SIGNAL AT THE OUTPUT OF THE TRANSMITTER**

Values are normalized to the mean value at the Center Frequency. Table 2-1 gives quantitative values for breakpoints of the curves in Figure 2-8. The frequency resolution of a spectrum analyzer when measuring the spectrum of Figure 2-8 should be 30 kHz or better.

**Table 2-1 Breakpoints for the Power Spectrum Curves in Figure 2-8**

| Frequency (MHz) | 0 | 1 | 2 | 3 | 5 | 7 | 9 | 11 | 13 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|
| Upper Limit (dB) | -25 | -15.9 | -11.1 | -8.1 | -4.1 | -1.7 | -0.2 | 0.6 | 0.8 | 0.5 |
| Lower Limit (dB) | NA | NA | -21.4 | -13.8 | -7.2 | -3.9 | -1.9 | -1.1 | -0.9 | -1.2 |

| Frequency (MHz) | 17 | 19 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|
| Upper Limit (dB) | -0.3 | -1.5 | -3.3 | -4.6 | -6.2 | -8.4 | -11.5 | -16.7 | -27 | -30 |
| Lower Limit (dB) | -2.0 | -3.5 | -5.9 | -7.8 | -10.9 | -15.8 | NA | NA | NA | NA |

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

### 2.5.3.3 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 4.0 ±0.2V when terminated with the specified test load.

### 2.5.3.4 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:

$$RL_o = 20 \log (|Z_r + Z_{ref}| / |Z_r - Z_{ref}|) = 20 \log (|V_i| / |V_r|)$$

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.

### 2.5.4 Receive Functionality

A CAP receiver decodes the incoming k-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 2.7 Copper Link Characteristics.

### 2.5.4.1 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 1-30MHz. 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:

$RL_i = 20 \log (|Z_r + Z_{ref}| / |Z_r - Z_{ref}|) = 20 \log (|V_i| / |V_r|)$
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.

## 2.6 PMD Scrambler/Descrambler

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

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:

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

## 2.7 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 2.10. 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 EIA/TIA-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 EIA/TIA-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 EIA/TIA-568-A[3] shall be followed.

## 2.8 Link Length Using a Reference Channel Model

### 2.8.1 Operation at 51.84 Mb/s

The reference channel model as described in Annex E of EIA/TIA-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 EIA/TIA-568-A[3].

**(R)** The composite channel NEXT loss shall meet the Category 3 NEXT loss performance limits defined in Annex E of EIA/TIA-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 4, 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 C contains guidance on the use of cable types other than Category 3 UTP.

### 2.8.2 Operation at 25.92 Mb/s

Operation at 25.92 Mb/s is achieved by changing the encoding to 4-CAP. The spectral properties of the signal are the same as Figure 2-9 and Table 2-1. However, it is still possible to achieve greater reach as the smaller number of constellation points are more widely separated, and, therefore, greater attenuation can be tolerated while still maintaining the required bit error rate. There is very little decrease in NEXT loss for cable lengths greater than 100m, and so the link NEXT loss requirement remains the same.

**(CR)** Systems operating at 25.92 Mb/s shall work over a channel having an attenuation no greater than 24.0 dB at 16 MHz and meeting the Category 3 link NEXT requirements of Annex E of EIA/TIA-568-A[3].

This requirement implies that any implementation of a 25.92 Mb/s system will operate over a link distance up to 170m of Category 3 cable.

### 2.8.3 Operation at 12.96 Mb/s

Operation at 12.96 Mb/s is achieved by changing the encoding to 2-CAP. The spectral properties of the signal are the same as Figure 2-7 and Table 2-1. However, it is still possible to achieve greater reach as the smaller number of constellation points are more widely separated, and, therefore, greater attenuation can be tolerated while still maintaining the required bit error rate. There is very little decrease in NEXT loss for cable lengths greater than 100m, and so the link NEXT loss requirement remains the same.

**(R)** Systems operating at 12.96 Mb/s shall work over any channel having an attenuation no greater than 27.8 dB at 16 MHz and meeting Category 3 link NEXT requirements of Annex E of EIA/TIA-568-A[3].

This requirement implies that any implementation of a 12.96 Mb/s system will operate over a link distance up to 200m of Category 3 cable.

## 2.9 Noise Environment

The noise environment is discussed in Annex D.

## 2.10 Media Interface Connectors

ATM user device and ATM network equipment implementing the mid-range PMD specification shall be attached to the twisted-pair medium 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 jacks. To ensure interoperability between conforming user devices and network equipment, TP-MIC connectors are specified at the interfaces for user devices and network equipment.

### 2.10.1 Connectors for Category 3 UTP Cabling

**(R)** The cable assembly shall connect the corresponding pins of plugs at either 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.

#### 2.10.1.1 UTP-MIC Modular Plug

**(R)** Each end of the Category 3 UTP link shall be terminated with Media Interface Connectors specified in Section 4 and Figure 1 of ISO 8877[4]. This connector is an 8-pin modular plug and shall meet or exceed the requirements for EIA/TIA-568-A[3] Category 3 100 ohm UTP connecting hardware. An illustration of the plug is shown in Figure 2-9.

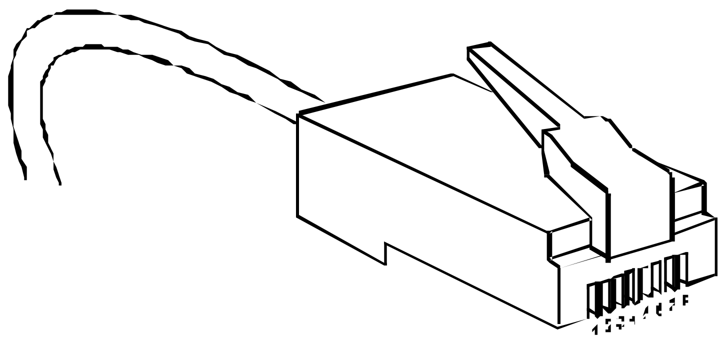

**FIGURE 2-9 EXAMPLE OF A UTP-MIC MODULAR PLUG**

#### 2.10.1.2 UTP-MIC Jack

**(R)** The jack/socket of the Category 3 UTP link shall be a connector specified in Section 4 and Figure 2 of ISO 8877[4]. The connector hardware used within this implementation of the PMD shall be an 8-contact jack and meet or exceed the electrical requirements of EIA/TIA Category 3 100 ohm UTP. These include specifications on NEXT loss. An illustration of the jack is shown in Figure 2-10.

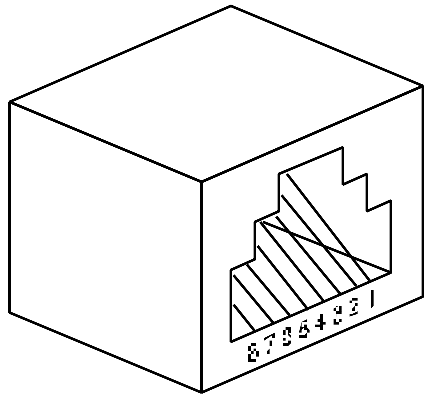


**FIGURE 2-10 EXAMPLE OF A UTP-MIC JACK**

**(R)** The assignment of contacts for EIA/TIA 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-1 frame. The description of the SONET based STS-1 frame format and overhead bytes will be covered in Section 3.3

### 3.1 SONET based TC Sublayer Functions

The B-ISDN independent TC sublayer functions and procedures involved at the UNI are defined in the relevant sections of ITU-T Recommendation I.432[5] and T1E1 B-ISDN Draft[6].
**(R)** Equipment supporting the mid-range PHY shall perform the SONET procedures related to STS-1 frame scrambling, timing and framing as defined in ITU-T Recommendation I.432[5] and T1E1 B-ISDN Draft[6].

### 3.2 Cell Specific TC Sublayer Functions

The B-ISDN specific TC sublayer contains functions necessary to adapt the service offered by the SONET based physical layer to the service required by the ATM layer. Some of these functions are not specified within SONET, but are required in the mid-range PHY. The B-ISDN specific physical layer functions are described in the following sections.

#### 3.2.1 HEC Generation/Verification

The entire header (including the HEC byte) is protected by the Header Error Control (HEC) sequence. The HEC code is contained in the last octet of the ATM cell header.
The HEC sequence code is capable of:

- Single bit error correction.
- Multiple-bit error detection.

**(R)** Equipment supporting the mid-range PHY shall implement error detection as defined in ITU-T Recommendation I.432[5] and T1E1 B-ISDN Draft[6].

Error correction as described in ITU-T Recommendation I.432[5], if implemented, is not effective. It is recommended that error correction not be implemented.

**(R)** Equipment supporting the mid-range PHY shall generate the HEC byte as described in ITU-T Recommendation I.432[5] and T1E1 B-ISDN Draft[6] including the recommended modulo 2 addition (XOR) of the pattern 01010101 to the HEC bits.

**(R)** The generator polynomial coefficient set used and the HEC sequence generation procedure shall be in accordance with ITU-T Recommendation I.432[5] and T1E1 B-ISDN Draft[6].

#### 3.2.2 Cell Scrambling and Descrambling

Cell Scrambling/Descrambling permits the randomization of the cell payload to avoid continuous non-variable bit patterns and improve the efficiency of the cell delineation algorithm.

**(R)** Equipment supporting the mid-range PHY shall implement the self synchronizing scrambler polynomial and procedures as defined in ITU-T Recommendation I.432[5] and T1E1 B-ISDN Draft[6].

### 3.2.3 Cell Mapping

The mapping of ATM cells is performed by aligning by row, the byte structure of every cell with the byte structure of the SONET based STS-1 payload capacity, e.g. Synchronous Payload Envelope, (SPE). The entire STS-1 payload capacity, *except for columns 30 and 59* (see below), is filled with cells, yielding a transfer capacity for ATM cells of 48.384 Mb/s. Because the STS-1 payload capacity is not an integer multiple of cell length, a cell may cross an SPE boundary* .

### 3.2.4 Cell Delineation

The cell delineation function permits the identification of cell boundaries in the payload. It uses the Header Error Control (HEC) field in the cell header.

**(R)** Equipment supporting the mid-range PHY shall perform cell delineation using the HEC based algorithm described in ITU-T Recommendation I.432[5] and T1E1 B-ISDN Draft[6].

**(O)** Equipment supporting the mid-range PHY may implement the cell delineation times in conformance with the state transition timing requirements as described in ITU-T Recommendation I.432[5] and T1E1 B-ISDN Draft[6]:

- The time to declare "Hunt state" once cell delineation is lost shall be 7 cell times.
- The time to declare "Sync state" once "Pre-Sync state" is obtained (e.g. one valid HEC) shall be 6 cell times.

### 3.2.5 ATM Payload Construction Indication

*The two columns, number 30 and 59, listed above, are fixed stuff columns. These columns are used to compensate for the difference between the bandwidth available in the STS-1 and Virtual Tributary Synchronous Payload Envelopes and the bandwidth required for the actual payload mapping, (i.e. DS1, DS2, DS3 and so on). The bytes in these columns have no defined value, see Section 3.3.1 for the actual transmitted value.

The construction of STS-1 SPE loaded with ATM cell is indicated through the STS path signal label (C2) byte in the STS Path Overhead (STS POH).

## 3.3 SONET based STS-1 Frame

This section defines the STS-1 frame structure and describes its overhead bytes. First, in Section 3.3.1, the frame structure is given and then, in Section 3.3.2, the description of the overhead bytes is provided.

### 3.3.1 Frame description

The format of the STS-1 frame used at the 51.84 Mb/s B-ISDN User-Network Interface is given in Figure 3-1.

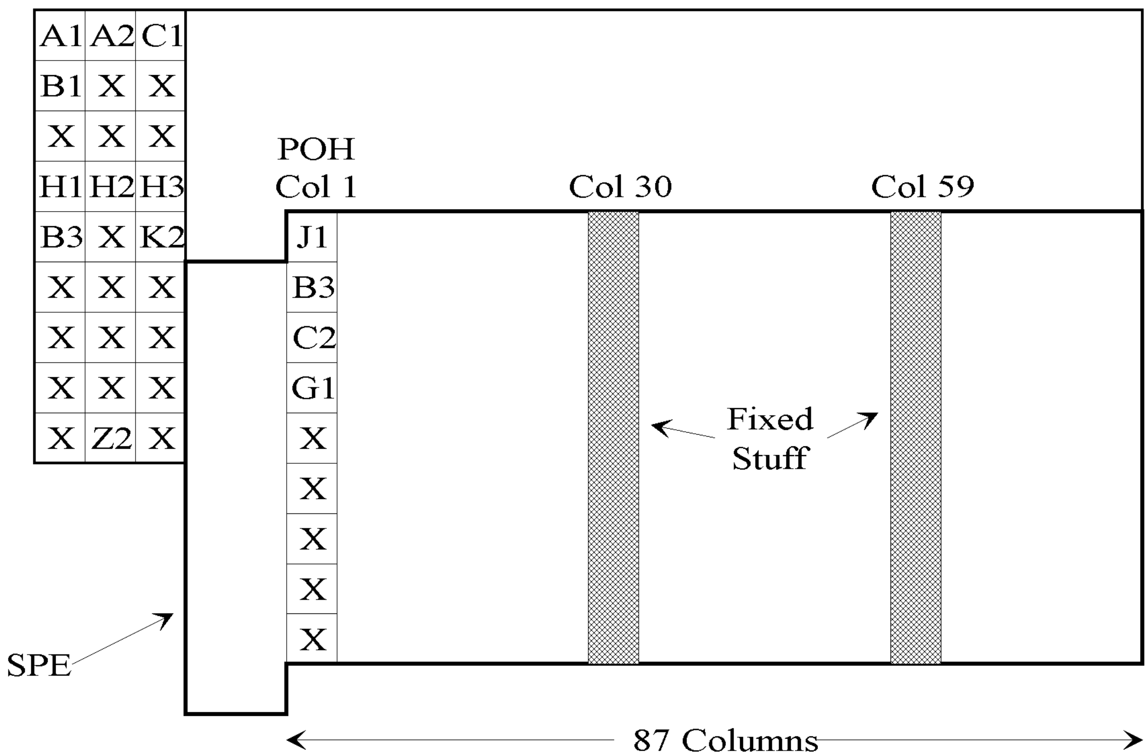


**FIGURE 3-1 SONET BASED STS-1 FRAME**

Active overhead bytes/bits: **A1**, **A2**, **C1**, **J1**, **B1**, **B3**, **C2**, **H1**(1-4,7,8), **H2**, **H3**, **G1**(1-5), **K2**(6-8), **Z2**(5-8)

All other bytes (shown by X) and partial bytes are reserved.
Shaded areas: Fixed Stuff bytes
Bits are numbered from left to right, 1 to 8 with bit 1 being the first to be transmitted.

**(R)** Transmitting equipment supporting the mid-range PHY shall encode all undefined overhead bytes/bits to zero patterns before scrambling and transmission.

**(R)** Receiving equipment supporting the mid-range PHY shall ignore all overhead bytes/bits undefined at the mid-range PHY.

**(R)** Transmitting equipment supporting the mid-range PHY shall encode all Fixed Stuff bytes, (e.g. shaded bytes in Figure 3-2), the contents of which may be any value with the constraint that the two bytes in each row be identical.

**(R)** The contents of the Fixed Stuff bytes are not placed in ATM cells. The BIP operations are applied to all bytes in the SONET[2] based payload.

### 3.3.2 Active Overhead Bytes Description

The following describes each of the overhead active bytes in the STS-1 frame.

#### 3.3.2.1 Framing Bytes: A1, A2

**(R)** Transmitting equipment supporting the mid-range PHY shall transmit in these bytes the values:

- A1: 11110110
- A2: 00101000

**(R)** Receiving equipment supporting the mid-range PHY shall check that A1 and A2 bytes have the value specified above and implement the states, (e.g. Out Of Frame, (OOF), Loss Of Frame, (LOF), and Loss Of Signal, (LOS)), and related procedures, defined in ITU-T Recommendation I.432[5] and T1E1 B-ISDN Draft[6] when detecting error patterns.

#### 3.3.2.2 STS-1 ID: C1

**(R)** Transmitting equipment supporting the mid-range PHY shall transmit in this byte the value: 00000001.

#### 3.3.2.3 Section Error Monitoring: B1

**(R)** Transmitting equipment supporting the mid-range PHY shall generate and transmit in the B1 byte, the bit interleaved parity 8 code using even parity over the bits in the previous STS-1 frame as specified in T1.105-1991[2].

**(O)** Receiving equipment supporting the mid-range PHY may check the B1 byte value in the received STS-1 frame and process it according to the algorithm, states and procedures defined in ITU-T Recommendation I.432[5]and T1E1 B-ISDN Draft[6].

### 3.3.2.4 New Data Flag, Pointer Value and Pointer Action Bytes: H1, H2, H3

**(R)** Transmitting equipment supporting the mid-range PHY can either support only fixed SPE or support floating SPE.

**(CR)** Transmitting equipment supporting the mid-range PHY which supports transmission of floating SPE shall transmit valid values in these bytes according to the algorithm specified in T1.105-1991[2].

**(CR)** Transmitting equipment supporting the mid-range PHY which only supports transmission of fixed SPE shall transmit the following values in these bytes:

(1) H1: 0110xx10
(2) H2: 00001010
(3) H3: 00000000
(4) OR, set all bits in these three bytes to 1 if Path AIS, (Alarm Indication Signal), is issued, (see below).

**NOTE:** The pointer value is fixed to 1000001010, (20A HEX), which is 522 decimal. This fixes the J1 byte to immediately follow the C1 byte.

**(R)** Transmitting equipment supporting the mid-range PHY shall generate Path AIS by setting all bits in H1, H2 and H3 bytes to 1, (as well as all bits in the payload), in the cases defined in ITU-T Recommendation I.432[5] and T1E1 B-ISDN Draft[6], (e.g. LOF, LOS, LOP and Line AIS).

**(R)** Receiving equipment supporting the mid-range PHY shall process the H1, H2 and H3 bytes according to the algorithm, states, (including Loss Of Pointer, (LOP)), and procedures specified in ITU-T Recommendation I.432[5], and T1E1 B-ISDN Draft[6] and T1.105-1991[2].

### 3.3.2.5 Line Error Monitoring: B2

**(R)** Transmitting equipment supporting the mid-range PHY shall generate and transmit in the B2 byte, the bit interleaved parity 8 code using even parity over the bits in the previous STS-1 Line overhead and Envelope Capacity as specified in T1.105-1991[2].

**(O)** Receiving equipment supporting the mid-range PHY may check the B2 byte value in the received STS-1 frame and process it according to the algorithm, states and procedures defined in ITU-T Recommendation I.432[5] and T1E1 B-ISDN Draft[6].

### 3.3.2.6 Line Status: K2 bits 6-8

**(O)** Transmitting equipment supporting the mid-range PHY may generate and transmit in the K2 byte bits 6-8, the Line AIS, Line RDI, and removal of Line RDI, according to the states, (e.g. LOS, LOF and incoming Line AIS), and procedures defined in ITU-T Recommendation I.432[5] and T1E1 B-ISDN Draft.[6]

**(O)** Receiving equipment supporting the mid-range PHY may check the K2 byte bits 6-8, and act upon detecting Line AIS, Line RDI and removal of Line RDI, according to the states and procedures defined in ITU-T Recommendation I.432[5] and T1E1 B-ISDN Draft[6].

**(CR)** If this field is not used, it must be set to a zero pattern before scrambling and transmission.

### 3.3.2.7 Line Far End Block Error, (FEBE): Z2 bits 5-8

**(O)** Transmitting equipment supporting the mid-range PHY may transmit in these bits the count of B2 errors according to the definition in ITU-T Recommendation I.432[5] and T1E1 B-ISDN Draft[6].

**(O)** Receiving equipment supporting the mid-range PHY may process the count of B2 errors transmitted in these bits according to the states and procedures defined in ITU-T Recommendation I.432[5] and T1E1 B-ISDN Draft[6].

**(CR)** If this field is not used, it must be set to a zero pattern before scrambling and transmission.

### 3.3.2.8 Path Trace: J1

**(O)** Equipment supporting the mid-range PHY can perform facility testing by repetitively sending the appropriate 64 byte code in the J1 POH byte as defined in ITU-T Recommendation I.432[5] and T1E1 B-ISDN Draft[6].

**(CR)** If this field is not used, it must be set to a zero pattern before scrambling and transmission.

### 3.3.2.9 Path Error Monitoring: B3

**(R)** Transmitting equipment supporting the mid-range PHY shall generate and transmit in the B3 byte, the bit interleaved parity 8 code using even parity over the bits in the previous STS-1 SPE as specified in T1.105-1991[2].

**(R)** Receiving equipment supporting the mid-range PHY shall check the B3 byte value in the received STS-1 frame and process it according to the algorithm, states and procedures in ITU-T Recommendation I.432[5] and T1E1 B-ISDN Draft[6].

### 3.3.2.10 Path Signal Label: C2

**(R)** Transmitting equipment supporting the mid-range PHY shall transmit in the C2 byte the value 00010011.

**(O)** Receiving equipment supporting the mid-range PHY may check the C2 byte value and if detecting a value other than the one specified above act according to the states and procedures defined in ITU-T Recommendation I.432[5] and T1E1 B-ISDN Draft[6].

### 3.3.2.11 Path Status: G1 bits 1-5

**(R)** Equipment supporting the mid-range PHY shall detect the Out-of-Cell Delineation (OCD) anomaly when the HEC coding rule is determined to be incorrect 7 consecutive times for the incoming signal. A Loss-Of-Cell (LCD) Delineation state shall be declared after persistence of the OCD anomaly for a time period of 4 ms, at which time the "Path RDI" shall be generated and transmitted.

**(R)** Transmitting equipment supporting the mid-range PHY shall generate and transmit in the G1 bit 5 the Path RDI, (Remote Defect Indicator), and the in bits 1-4 the count of B3 errors, (Far End Block Error, FEBE), according to the states, (B3 errors for bits 1-4 and LOS, LOF, Line AIS, Path AIS and LOC for RDI), and procedures defined in ITU-T Recommendation I.432[5] and T1E1 B-ISDN Draft[6].

**(R)** Receiving equipment supporting the mid-range PHY may check the G1 byte value and if detecting Path RDI or Path FEBE, act according to the states and procedures defined in ITU-T Recommendation I.432[5] and T1E1 B-ISDN Draft[6].

## 3.4 Frame Duration

The TC includes the transmission and reception of the 810 bytes STS-1 frame as described in Section 3.3.1. The different rates are achieved as follows:

**(R)** 51.84 Mb/s: frames repeat at 125 microsecond intervals.

**(CR)** 25.92 Mb/s: frames repeat at 250 microsecond intervals.

**(CR)** 12.96 Mb/s: frames repeat at 500 microsecond intervals.

### 3.5 References

[1] ATM User-Network Specification, Version 3.1, 1994.

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

[3] Commercial Building & Wiring Telecommunications Wiring Standard, EIA/TIA-568-A Standard, Letter Ballot, 1994.

[4] ISO 8877, Information processing systems – Interface connector and contact assignments fro ISDN basic access interface located at reference points S and T, 1991.

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

[6] ANSI T1E1.2/94-002R1, Broadband ISDN and DS1/ATM User-Network Interfaces: Physical Layer Specification.

## 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.

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 these contributions may be obtained from:

ATIS
Mary Cloyd tel: +1 202 434 8841
Suite 500
1200 G Street, NW
Washington, D.C. 20005.

## Annex B: An Example of Receiver Equalizer Start-Up

Start-up for a CAP receiver is an implementation issue. If the receiver's equalizer consists of two parallel fractionally spaced adaptive filters, the following simple procedure is adequate.

(1) A set of initial coefficients is loaded into the two filters.

(2) Let the equalizer converge with the slicer set to two levels on each dimension (i.e. 4-CAP).

(3) After initial convergence, the slicer is set to four levels on each dimension and continues to converge. Correct convergence may be verified by correct delineation of ATM cells.

(4) If correct convergence is not observed for a period of time, go to 1.

# Annex C: The Use of Alternative Cable Types

## *Category 5 Cable at 51.84 Mb/s*

It is possible to achieve greater than 100m reach by the use of higher performance, Category 5 cable. This is superior in both its NEXT loss and attenuation performance, and so the attenuation to crosstalk ratio (ACR) is very much higher, which offers the prospect of much greater reach. 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 cable while retaining the channel specification requirements of section 2.7.1. This should permit a maximum reach of about 160m using a link made of Category 5 components and a receiver having a dynamic range which does not exceed what is required for a 100m category 3 cable. Links with lengths substantially in excess of 160m can be achieved with receivers having a dynamic range which is larger than the dynamic range required for a 100m Category 3 UTP cable.

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

**Table C-1 Supportable Link Lengths for Allowable Bit Rates**

| | Bit Rates | | |
|---|---|---|---|
| Cable Type | 51.84 Mb/s | 25.92 Mb/s | 12.96 Mb/s |
| Category 3 | 100m | 170m | 200m |
| Category 5 | 160m | 270m | 320m |

## *Other Cable Types*

There are a variety of cable types which have attenuation and crosstalk characteristics that are different than those of Category 3 which may be used to provide the copper link function. ISO 11801 describes cabling which 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 Lx(f) and La(f) be the worst case NEXT loss and attenuation/insertion loss (in dB) at frequency for a given cabling system. At frequency f, the NEXT loss-to-insertion loss ratio NIR(f) is defined as

NIR(f) = Lx(f) - La(f).

The link length that can be supported using the alternate cable system is estimated by determining the cable length for which NIR(f) > NIFref(f) at all frequencies between 1 and 16 MHz.  The reference, NIRref(f), is determined from the link performance data for Category 3 in Annex E of EIA/TIA-568-A as follows:

at 51.84 Mb/s determine NIRref(f) for a 100m Category 3 cable
at 25.92 Mb/s determine NIRref(f) for a 170m Category 3 cable
at 12.96 Mb/s determine NIRref(f) for a 200m Category 3 cable.

For example, at the sub-rate of 25.92 Mb/s, NIRref(f) at frequencies of 1 and 16 MHz is 30.7 and -10.5 dB, respectively.

# Annex D: Noise Environment

The noise environment consists of two primary, external contributors: induced impulse noise from other office and building equipment and other, non-impulse background radiation.

### *Impulse Noise*

The implementation of the PMD, operating over the specified cable plant, should recover without operator intervention when subjected to 0.5 kV impulse noise (fast transient) as described in IEC 801-4, Level 2. The implementation of the PMD should be tested using the methods described in IEC 801-4.

### *Electromagnetic Susceptibility*

The implementation of the PMD should operate within the specified BER during the 3 V/m field EMC test described in IEC 801-3, Level 2. The implementation of the PMD should be tested using methods described in IEC 801-3.