



**ATM Forum
Technical Committee**

**PHY Specification for the
45Mbps and 155Mbps Rates**

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1 INTRODUCTION

1.1 Purpose

This specification describes three Physical Layer interfaces that can be used to transport ATM cells that were originally described in af-uni-0010.002, ATM User-Network Interface Specification V3.1. This specification supersedes af-uni-0010.002 since it is being deprecated. All original references have been left intact.

1.2 Changes from UNI 3.1

All of the physical layer portions of the original UNI 3.1 have not been carried forward into this specification. The following commonly designed interfaces have been brought forward:

- SONET STS-3C Physical Layer Interface
- DS3 Physical Layer Interface
- Physical Layer for 155 Mbps Interface

In order to advance the new specification, the following interfaces have been removed:

- Physical Layer for 100 Mbps Multimode Fiber Interface
- STP Physical Medium Dependent Specification
- E3 Physical Layer Interface
- E4 Physical Layer Interface

1.3 Definition of Compliance

This document uses three levels for indicating the degree of compliance necessary for specific functions/procedures/coding associated with the interface:

- **Requirement (R):** functions, procedures and coding necessary for operational compatibility.
- **Option (O):** functions, procedures and coding that may be useful, but are not necessary for operational compatibility.

This section provides specifications for physical layer ATM interfaces for the public and private User-Network Interface (UNI). Currently 44.736 Mbps, and two 155.52 Mbps interfaces are specified.

An implementation is compliant if it supports any non-null subset of the interfaces specified in this section.

Given that SONET/SDH is an international standard, it is expected that SONET hierarchy-based interfaces will be a means for attaining interoperability in the long term for both the public and

private UNI. However, for various availability and/or economic reasons, other physical layers are specified to accelerate the deployment of interoperable¹ ATM equipment.

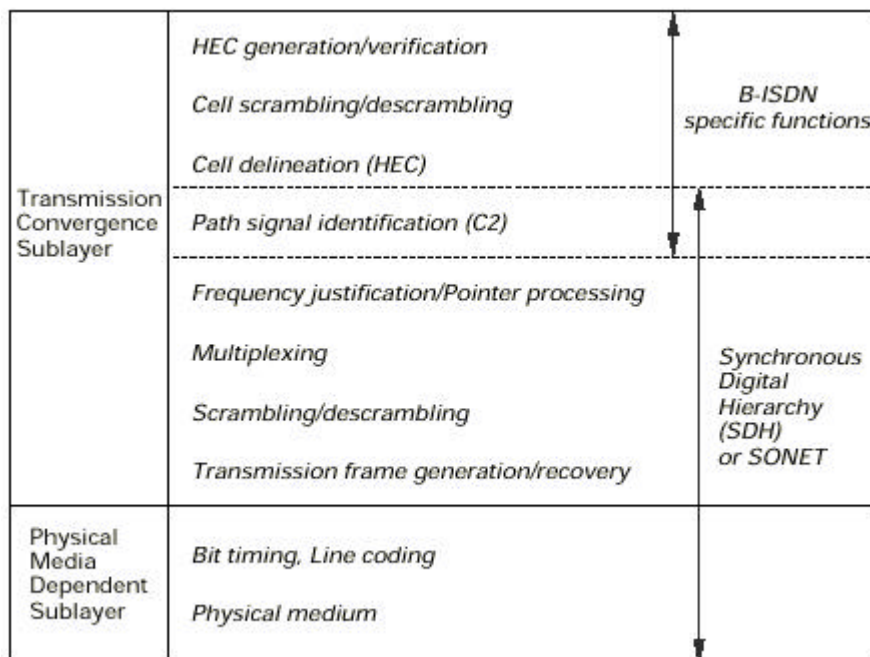
¹ Interoperability can only be achieved if both ATM systems implement the same physical layer.

2 Physical Layer Interfaces Specification

2.1 SONET STS-3c Physical Layer Interface

This section specifies the physical layer for a 155.52 Mbps STS-3c frame applicable at both the public and private User-Network Interface (UNI). The transmission system is based on the Synchronous Optical Network (SONET) standards which provides, through a framing structure, the payload envelope necessary for the transport of ATM cells. SONET also includes overhead bytes for the carriage of OAM information. The SONET OAM functions residing in the physical layer management (M-plane) are covered in section 2.1.2. The functions of the physical layer (U-plane) are grouped into the Physical Media Dependent (PMD) sublayer and the Transmission Convergence (TC) sublayer (see Figure 2-1).

Figure 2-1 Physical Layer Functions (U-plane)



2.1.1 Physical Layer U-plane Specification

2.1.1.1 Physical Media Dependent (PMD) Specification

The Physical Media Dependent (PMD) sublayer deals with aspects which are dependent on the transmission medium selected. The PMD sublayer specifies physical medium and transmission (e.g. bit timing, line coding) characteristics and does not include framing or overhead information.

2.1.1.1.1 Physical Medium Characteristics at 155.52 Mbps

The physical characteristics of the UNI at the UB, TB and SB reference points are defined in ANSI T1E1.2/94-002R1 (e.g., OC-3 SMF, OC-3 MMF). Other SONET physical medium specifications could be defined in the future.

(R) The physical medium characteristics at the UNI shall be compliant with the SONET PMD criteria specified in T1E1.2/94-002R1.

2.1.1.2 Transmission Convergence (TC) Sublayer Specification

The Transmission Convergence (TC) sublayer deals with physical layer aspects which are independent of the transmission medium characteristics. Most of the functions comprising the TC sublayer are involved with generating and processing some overhead bytes contained in the SONET STS-3c frame. The description of SONET STS-3c frame format and overhead bytes involved at the UNI will be covered in section 2.1.1.3

2.1.1.2.1 B-ISDN Independent TC Sublayer Functions

The B-ISDN independent TC sublayer functions and procedures involved at the UNI are defined in the relevant sections of ANSI T1E1.2/94-002R1.

(R) Equipment supporting the UNI shall process and generate all mandatory active overhead bytes (see section 2.1.1.3) listed in T1E1.2/94-002R1 and in accordance with TR-NWT-000253 Issue 2.

(R) Equipment supporting the UNI shall perform the SONET procedures related to STS-1 signal concatenation, STS-3c frame scrambling, timing and framing as defined in T1E1.2/94-002R1.

2.1.1.2.2 B-ISDN Specific TC Sublayer Functions

The B-ISDN specific TC sublayer contains functions necessary to adapt the service offered by the SONET physical layer to the service required by the ATM layer. As shown in Figure 2-1, some of these functions are not specified within SONET, but are required at the UNI. The B-ISDN specific physical layer functions listed in Figure 2-1 are described in the following sections.

2.1.1.2.2.1 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 (ref. section 3.3).

The HEC sequence code is capable of:

- single-bit error correction
- multiple-bit error detection

At the transmission side, the HEC is computed based on a specified polynomial. At the receiver two modes of operation are defined: correction mode and detection mode. In correction mode only a single-bit error can be corrected while detection mode provides for multiple-bit error detection. In “detection mode” all cells with detected errors in the header are discarded.

(R) Equipment supporting the UNI shall implement error detection as defined in ITU-T Recommendation I.432.

(O) Equipment supporting the UNI may also implement single bit error correction in addition to error detection. In this case, the two modes of operation shall interact in accordance to the procedure defined in ITU-T Recommendation I.432 and T1E1.2/94-002R1.

(R) Equipment supporting the UNI shall generate the HEC byte as described in ITU-T Recommendation I.432.

(R) The generator polynomial, coset used and the HEC sequence generation procedure shall be in accordance with ITU-T Recommendation I.432.

2.1.1.2.2.2 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 UNI shall implement the self synchronizing scrambler polynomial and procedures as defined in ITU-T Recommendation I.432.

2.1.1.2.2.3 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 STS-3c payload capacity (Synchronous Payload Envelope). The entire STS-3c payload capacity is filled with cells, yielding a transfer capacity for ATM cells of 149.760 Mbps. Because the STS-3c payload capacity is not an integer multiple of the cell length, a cell may cross an SPE boundary.

(R) Equipment supporting the UNI shall map ATM cells into the SONET STS-3c SPE as specified in T1E1.2/94-002R1 and T1.105-1991 (see also ITU-T recommendations I.432 and G.709).

2.1.1.2.2.4 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 UNI shall perform cell delineation using the HEC based algorithm described in I.432.

(O) Equipment supporting the UNI may implement the cell delineation state-machine in conformance with the following state transition timing requirements:

- the time to declare “Hunt State” once cell delineation is lost shall be less than 7 cell times.
- the time to declare “Sync State” once “Pre-Sync State” is obtained (i.e. one valid HEC) shall be less than 6 cell times.

2.1.1.2.2.5 ATM Payload Construction Indication

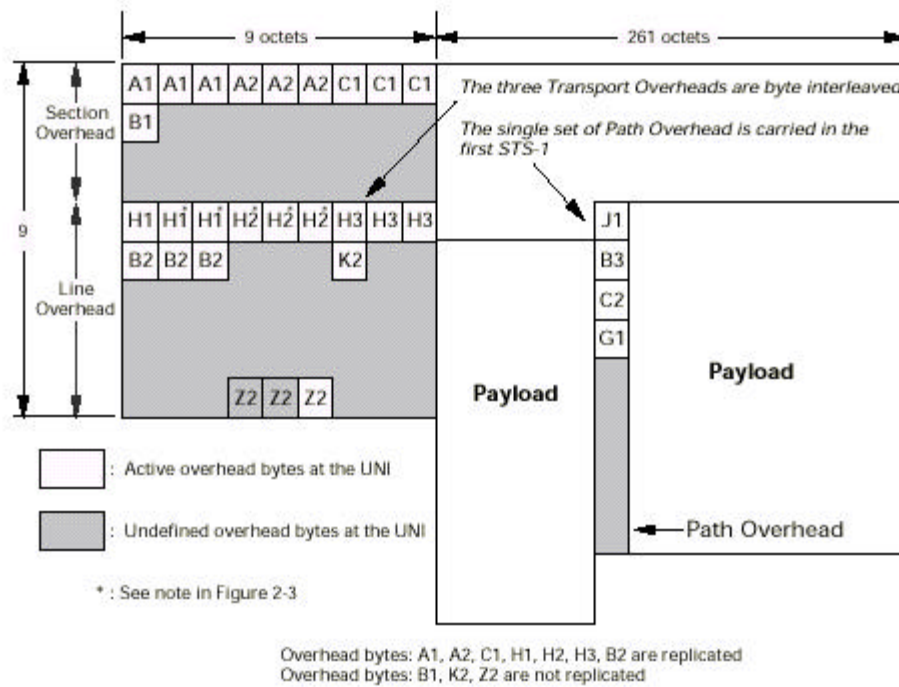
The construction of the STS-3c SPE loaded with ATM cells is indicated through the STS path signal label (C2) byte in the STS Path Overhead (STS POH).

(R) Equipment supporting the UNI shall set the C2 byte of the STS-3c POH to value 00010011 as defined in T1E1.2/94-002R1.

2.1.1.3 SONET STS-3c Frame at the UNI

The format of the STS-3c frame used at the 155.52 Mbps B-ISDN User-Network interface is given in Figure 2-2. The description of the overhead bytes that must be activated at the UNI is given in Figure 2-3. A more detailed description on the STS-3c frame construction and overhead bytes is given in ANSI T1.105.

Figure 2-2 SONET STS-3c at the UNI



(R) Transmitting equipment supporting the UNI shall encode all undefined overhead bytes/bits to zero patterns before scrambling and transmission.

(R) Receiving equipment supporting the UNI shall ignore all overhead bytes/bits undefined at the UNI (including the Data Communications Channels).

Figure 2-3 SONET Overhead Bytes at the UNI

| Overhead | Coding | Definition |
|------------------|------------------------------|--|
| A1, A2 | A1: 11110110, A2: 00101000 | Framing Bytes (note 3) |
| C1 | 00000001-00000010-00000011 | STS-1 Identifiers (note 3) |
| B1 | BIP-8 | Section Error Monitoring (previous STS-3c) |
| B2 | BIP-24 (STS-3c) | Line Error Monitoring |
| H1 (1-4) | 0110 (norm) ,1001 (act) | New Data Flag (indicates change in pointer value) |
| H1-H2 (7-16) | 0000000000-1100001110 | Pointer Value (note 1) |
| H1*, H2* | 10010011, 11111111 | Concatenation Indication (note 1) |
| H3 | | Pointer Action (note 3) |
| K2 (6-8) | 111, 110, any non 110 values | Line AIS, Line RDI, Removal of Line RDI |
| 3rd Z2 byte(2-8) | B2 Error Count | Line FEBE (up to [(8 times 3) +1] values for STS-3c) |
| J1 | | STS Path Trace |
| B3 | BIP-8 | Path Error Monitoring (previous SPE) |
| C2 | 00010011 | Path Signal Level Indicator |
| G1 (1-4) | B3 Error Count | Path FEBE (up to 9 legal values) |
| G1 (5) | 0 or 1 | Path RDI (note 2) |

* note 1: Bits of H1,H2 bytes are set to all 1's for Path AIS

note 2: Also used to indicate loss of cell delineation

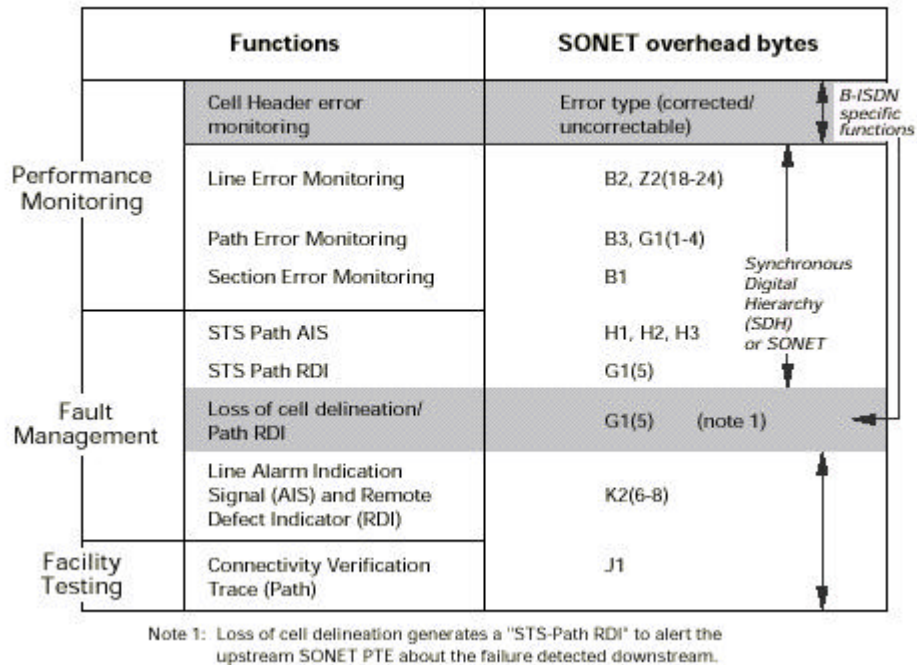
note 3: For all replicated overhead bytes (see Figure 2-2)

2.1.2 Physical Layer Operation and Maintenance Specification (M-plane)

This section identifies the physical layer OAM² functions and procedures involved over the UNI. These functions are defined in standards documents and are grouped into three categories for illustrative purposes: Performance monitoring, Fault Management and Facility Testing as shown in Figure 2-4.

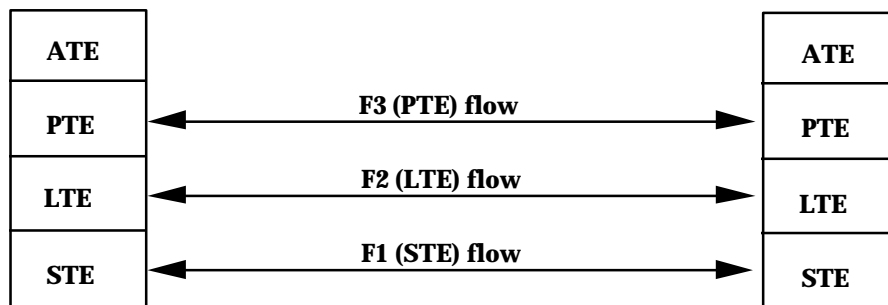
² The Administration (A) part of the OAM functions is not covered within this document.

Figure 2-4 Physical Layer Management at the UNI



- Performance Monitoring includes functions that gather information about the network and network element behavior in order to evaluate and report on their performance.
- Fault Management functions provide detection, isolation and correction of failure conditions in the network.
- Facility Testing (Path Trace) permits verification of the connection continuity between two Path Terminating Equipments.

Figure 2-5 shows the OAM flows defined for the exchange of operations information between nodes in the network access (including customer premises nodes). At the physical layer (F1, F2, F3 flows), the exchange of information is done via well defined overhead bytes within the SONET framing structure (see section 2.1.1.3). The ATM layer information flows will be carried via OAM cells at the F4, F5 level (see ATM Layer Management section). Figure 2-6 gives an example of equipment configuration and the associated OAM flow at the UNI. A detailed explanation of OAM layers and information flows is given in ITU-T I.610.

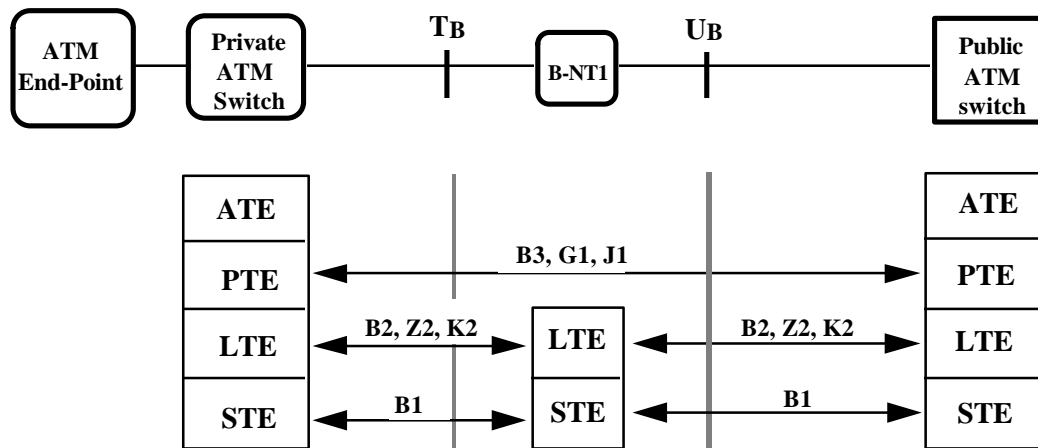
Figure 2-5 SONET Physical Layer OAM flow

ATE: ATM Terminating Equipment

PTE: SONET Path Terminating Equipment

LTE: SONET Line Terminating Equipment

STE: SONET Section Terminating Equipment

Figure 2-6 Example of OAM flow at the UNI

2.1.2.1 B-ISDN Independent Operation and Maintenance Functions

The B-ISDN independent Operation and Maintenance functions at the UNI are performed by SONET Section, Line and Path terminating equipment involved at the UNI. The following subsections define the subset (with some minor modification) of the Operation and maintenance functions defined in ANSI T1E1.2/94-002R1.

2.1.2.1.1 Performance Monitoring

Performance Monitoring at the SONET level mainly involves detecting Coding Violations by using the B1 byte at the section level, B2, Z2 bytes at the line level and B3 byte, G1(1-4) bits at the path level. Monitoring is performed across the UNI by calculating the section BIP-8, line BIP-24 and Path

BIP-8 of the incoming signal and comparing the values obtained with the one encoded in the proper bytes by the transmitting end. The Line and Path Far End Block Error (FEBE) signals are used to convey back to the upstream equipment the number of BIP errors detected by the Line or Path terminating equipment.

(R) Equipment supporting the UNI shall perform the Performance Monitoring functions included in T1E1.2/94-002R1 in accordance with the procedures described there.

2.1.2.1.2 Fault Management

Fault management actions at the UNI can be triggered by incoming signal failures, equipment failures, detection or removal of Alarm Indication Signal (AIS) or Remote Defect Indicator (RDI) signal. The failures detected on the incoming signal are: Loss of Signal (LOS), Loss of Frame (LOF), Loss of Pointer (LOP), and Signal Label Mismatch.

(R) Equipment supporting the UNI shall perform the Fault Management functions (Alarm Surveillance) included in T1E1.2/94-002R1 in accordance with the procedures described there.

2.1.2.1.3 Facility testing

(O) Equipment supporting the UNI can perform facility testing by repetitively sending the appropriate 64 byte code in the J1 POH byte as defined in T1E1.2/94-002R1.

2.1.2.2 B-ISDN Specific Operation and Maintenance Functions

The B-ISDN specific Operation and Maintenance functions at the UNI include:

- Modified or extended SONET functions for the UNI
- Additional functions included at the Transmission Convergence (TC) sublayer to meet the ATM based UNI specific needs.

2.1.2.2.1 Loss of Cell Delineation

The Loss of Cell Delineation (LCD) event causes the generation of a SONET "Path RDI" alarm to alert the upstream SONET PTE of the failure detected downstream. Preceding the LCD defect state is an Out of Cell Delineation (OCD) anomaly which, when checked for persistence, becomes LCD.

(R) Equipment supporting the UNI shall detect the out-of-cell Delineation (OCD) anomaly consistent with the procedures described in T1E1.2/94-002R1.

(R) Equipment supporting the UNI shall declare an LCD defect after persistence of the OCD anomaly and generate the SONET "Path RDI" as described in T1E1.2/94-002R1.

2.2 DS3 Physical Layer Interface

This section is based upon T1E1.2/94-002R1. The functions of the DS3 physical layer are grouped into the Physical Media Dependent (PMD) sublayer and the Transmission Convergence (TC) sublayer as shown in Figure 2-7.

Figure 2-7 Physical Layer Functions

| | |
|---|--|
| <p>Transmission Convergence Sublayer</p> | <p><i>HEC generation/verification</i></p> <p><i>PLCP Framing and Cell Delineation</i></p> <p><i>Path Overhead utilization</i></p> <p><i>PLCP Timing (125 usec clock recovery)</i></p> <p><i>Nibble Stuffing</i></p> |
| <p>Physical Media Dependent Sublayer</p> | <p><i>Bit timing, Line coding</i></p> <p><i>Physical medium</i></p> |

2.2.1 Format at 44.736 Mbps

The 44.736 Mbps interface, if used, shall comply with the specifications in this section.

The interface format at the physical layer is based on asynchronous DS3 using the C-Bit Parity application (ITU-T G.703, ANSI T1.107, and ANSI T1.107a). Use of the C-Bit Parity application is the default mode of operation. However, equipment supporting C-Bit Parity interfaces with equipment that does not support C-Bit Parity, then the equipment supporting C-Bit Parity must be capable of “dropping back” into a mode of operation that allows interoperation with equipment that does not support C-Bit Parity.

To carry ATM traffic over existing DS3 44.736 Mbps communication facilities, a Physical Layer Convergence Protocol (PLCP) for DS3 is defined. This PLCP is a subset of the PLCP defined in IEEE P802.6. Mapping of ATM cells into the DS3 is accomplished by inserting the 53 byte ATM cells into the DS3 PLCP (Figure 2-8). The PLCP is then mapped into the DS3 information payload. Extraction of ATM cells from the DS3 operates in the analogous reverse procedure, i.e. by framing on the PLCP and then simply extracting the ATM cells directly.

(R) Equipment supporting C-Bit Parity interfacing with equipment that does not support C-Bit Parity shall be capable of “dropping back” into a clear channel mode of operation.

Figure 2-8 DS3 PLCP Frame (125 us)

| PLCP Framing | | POI | POH | PLCP Payload | |
|-----------------------------|------------|------------|------------|------------------|---------------------|
| A1 | A2 | P11 | Z6 | First ATM Cell | |
| A1 | A2 | P10 | Z5 | ATM Cell | |
| A1 | A2 | P9 | Z4 | ATM Cell | |
| A1 | A2 | P8 | Z3 | ATM Cell | |
| A1 | A2 | P7 | Z2 | ATM Cell | |
| A1 | A2 | P6 | Z1 | ATM Cell | |
| A1 | A2 | P5 | X | ATM Cell | |
| A1 | A2 | P4 | B1 | ATM Cell | |
| A1 | A2 | P3 | G1 | ATM Cell | |
| A1 | A2 | P2 | X | ATM Cell | |
| A1 | A2 | P1 | X | ATM Cell | |
| A1 | A2 | P0 | C1 | Twelfth ATM Cell | Trailer |
| 1 Octet | 1 Octet | 1 Octet | 1 Octet | 53 Octets | 13 or 14 Nibbles |
| Object of BIP-8 Calculation | | | | | |

POI = Path overhead Indicator

POH = Path Overhead

BIP-8 = Bit Interleaved Parity - 8

X = Unassigned - Receiver required to ignore

2.2.1.1 PLCP Format

The ATM Physical Layer Convergence Protocol (PLCP) for DS3 defines the mapping of ATM cells onto existing DS3 facilities.

The DS3 PLCP consists of a 125 us frame within a standard DS3 payload. Note that there is no fixed relationship between the DS3 PLCP frame and the DS3 frame, i.e. the DS3 PLCP may begin anywhere inside the DS3 payload. The DS3 PLCP frame, Figure 2-7, consists of 12 rows of ATM cells, each preceded by 4 octets of overhead. Although the DS3 PLCP is not aligned to the DS3 framing bits, the octets in the DS3 PLCP frame are nibble aligned to the DS3 payload envelope. Nibble³ stuffing is required after the twelfth cell to frequency justify the 125 μs PLCP frame. Nibbles begin after the control bits (F, X, P, C or M) of the DS3 frame. Note that the stuff bits are never used

³ A nibble is 4 bits.

in the DS3, i.e. the payload is always inserted. Octets comprising the DS3 PLCP frame are described in the following sections.

Order of transmission of all PLCP bits, shown in Figure 2-7, is from left to right and top to bottom. The figures represent the most significant bit (MSB) on the left and the least significant bit (LSB) on the right.

2.2.1.2 PLCP Overhead Utilization

(R) The following PLCP overhead bytes/nibbles are required to support the coding/functions (as defined) across the UNI:

- A1 - Frame Alignment
- A2 - Frame Alignment
- B1 - Bit Interleaved Parity
- C1 - Cycle/Stuff Counter
- G1 - PLCP Path Status
- Px - Path Overhead Identifier
- Zx - Growth Octets
- Trailer Nibbles

2.2.1.2.1 Framing Octets (A1, A2)

The PLCP framing octets use the same framing pattern used in SONET and SDH.

(R) These octets are defined as A1=11110110, A2=00101000.

2.2.1.2.2 Bit Interleaved Parity - 8 (B1)

The Bit Interleaved Parity - 8 (BIP-8) field supports path error monitoring.

(R) The BIP-8 shall be calculated over a 12 x 54 octet structure consisting of the Path Overhead (POH) field and the associated ATM cells (648 octets) of the previous PLCP frame. It is an 8 bit code in which the n^{th} bit of the BIP-8 code calculates the even parity of the n^{th} bit of each octet covered by the BIP-8. Thus, it provides for 8 separate even parity calculations.

2.2.1.2.3 Cycle/Stuff Counter (C1)

The Cycle/Stuff Counter provides a nibble stuffing opportunity cycle and length indicator for the PLCP frame. A stuffing opportunity occurs every third frame of a 3 frame (375 μs) stuffing cycle. The value of the C1 code is used as an indication of the phase of the 375 μs stuffing opportunity cycle (see Figure 2-9).

(R) A trailer containing 13 nibbles shall be used in the first frame of the 375 μs stuffing opportunity cycle. A Trailer of 14 nibbles shall be used in the second frame. The third frame provides a nibble

stuffing opportunity. A Trailer containing 14 nibbles shall be used in the third frame if a stuff occurs. If not, the Trailer shall contain 13 nibbles.

Figure 2-9 Cycle/Stuff Counter Definition

| C1 Code | Frame Phase of Cycle | Trailer Length |
|----------|----------------------|----------------|
| 11111111 | 1 | 13 |
| 00000000 | 2 | 14 |
| 01100110 | 3 (no stuff) | 13 |
| 10011001 | 3 (stuff) | 14 |

2.2.1.2.4 PLCP Path Status (G1)

Figure 2-10 illustrates the G1 octet subfields: a 4-bit Far End Block Error (FEBE), a 1-bit RAI (Yellow), and 3 X bits (X bits are ignored).

Figure 2-10 PLCP Path Status (G1) Definition

| Far End Block Error (FEBE) | RAI (Yellow) | X - X - X |
|----------------------------|--------------|-----------|
| 4 Bits | 1 Bit | 3 Bits |

(R) FEBE shall provide a count of 0 to 8 BIP-8 errors received in the previous frame, i. e., G1 (FEBE)=0000 through G1 (FEBE)=1000. If not implemented, G1 (FEBE) shall be set to 1111. Any other value of G1 than described above, would be caused by other errors and is interpreted as 0 errors.

(R) RAI (Yellow) shall alert the transmitting PLCP that a received failure indication has been declared along the path. When an incoming failure condition is detected which persists for a “soaking period” (typically 2 - 10 seconds), an RAI shall be sent to the far end by setting G1 (RAI)=1. The RAI shall be detected when G1 (RAI)=1 for 10 consecutive PLCP frames. The indication is cleared by setting G1 (RAI)=0 when the incoming failure has ceased for 15 ± 5 seconds. At the receiving end, removal of the RAI signal is recognized by detecting G1 (RAI)=0 for 10 consecutive PLCP frames.

2.2.1.2.5 Path Overhead Identifier (P0-P11)

The Path Overhead Identifier (POI) indexes the adjacent Path Overhead (POH) octet of the DS3 PLCP. Figure 2-11 provides the coding for each of the POI octets.

Figure 2-11 POI Code Definition

| POI | POI Code | Associated POH |
|------------|-----------------|-----------------------|
| P11 | 00101100 | Z6 |
| P10 | 00101001 | Z5 |
| P9 | 00100101 | Z4 |
| P8 | 00100000 | Z3 |
| P7 | 00011100 | Z2 |
| P6 | 00011001 | Z1 |
| P5 | 00010101 | X |
| P4 | 00010000 | B1 |
| P3 | 00001101 | G1 |
| P2 | 00001000 | X |
| P1 | 00000100 | X |
| P0 | 00000001 | C1 |

X - Receiver Ignores

(R) The POI coding in Figure 2-11 shall be supported.

2.2.1.2.6 Growth Octets (Z1-Z6)

The Growth Octets are reserved for future use.

(R) The growth octets shall be set to $Z_i=00000000$, by the transmitter ($i=1, 2, \dots, 6$). The receiver shall be capable of ignoring the value contained in these fields.

2.2.1.2.7 Trailer Nibbles

(R) The contents of each of the 13/14 Trailer nibbles shall be 1100.

2.2.2 ATM Transfer Capability

Because of the overhead induced by the PLCP, the nominal bit rate available for the transport of ATM cells in the DS3 PLCP shall be 40.704 Mbps.

2.2.3 Timing

(R) The PLCP frame from the network equipment to the customer shall have timing traceable to a Primary Reference Source (PRS).

(R) The incoming PLCP frame from the customer to the network equipment shall be traceable to a PRS. The customer may use the clock recovered from the PLCP or other source traceable to a PRS.

2.2.4 Cell Payload Scrambling

For some DS3 physical links, cell scrambling can provide a solution to some transmission equipment unexpected behavior sensitive to bit patterns in the ATM cell payload (e.g., “101010...” or “00000000...” patterns). Another solution to this problem would be to disable alarm monitoring/reporting on transmission equipment. Alarm disablement however, reduces alarm visibility and fault isolation capability.

(R) Equipment supporting the DS3 based UNI shall implement the Cell Payload Scrambler (self synchronizing) as defined in ITU-T I.432.

Note 1: The use of scrambling/descrambling may increase the bit error rate through error multiplication.

Note 2: Some equipment built to earlier versions of this interface specification may have the ability to operate with the scrambler disabled.

2.2.5 Cell Delineation

Because the cells are in predetermined locations within the PLCP, framing on the DS3 and then on the PLCP is sufficient to delineate cells.

2.2.6 HEC Generation/Verification

The Header Error Control (HEC) covers the entire cell header. Support of bit error detection based on the HEC field is mandatory.

The transmitter calculates the HEC value for the first four octets of the cell header, and inserts the results into the HEC field, the last octet of the header. The HEC field shall be an 8-bit sequence. It shall be the remainder of the division (modulo 2) by the generator polynomial x^8+x^2+x+1 of the polynomial x^8 multiplied by the content of the header excluding the HEC field. The pattern 01010101 is XORed with the 8-bit remainder before being inserted in the last octet of the header [1].

(R) Equipment supporting the UNI shall implement HEC error detection as defined in ITU-T Recommendation I.432.

(O) Equipment supporting the UNI may also implement single bit error correction in addition to error detection. In this case, the two modes of operation shall interact in accordance to the procedure defined in ITU-T Recommendation I.432 and T1E1.2/94-002R1.

(R) Equipment supporting the UNI shall generate the HEC byte as described in ITU-T Recommendation I.432.

(R) The generator polynomial and coset used shall be in accordance with ITU-T Recommendation I.432.

2.3 Physical Layer for 155 Mbps Interface

This section specifies the Physical Layer for a 155.52 Mbps private UNI. The functions of the Physical Layer (U-plane) are grouped into the Physical Media Dependent (PMD) sublayer and the Transmission Convergence (TC) sublayer as shown in Figure 2-12. The transmission system is based on a framing structure which provides the transport of ATM cells which exactly matches the cell payload rate of ITU-T Recommendation I.432. It also provides overhead bytes for the carriage of OAM information.

Figure 2-12 Physical Layer Functions (U-plane)

| | |
|---|--|
| <p>Transmission Convergence Sublayer</p> | <p><i>Cell delineation</i></p> <p><i>125 usec clock recovery</i></p> <p><i>HEC generation/verification</i></p> |
| <p>Physical Media Dependent Sublayer</p> | <p><i>Bit timing, Line coding</i></p> <p><i>Physical medium</i></p> |

2.3.1 Fiber Physical Medium Dependent Specification

The PMD provides the digital baseband point-to-point communication between stations and switches in the ATM LAN. The PMD shall provide all the services required to transport a suitably coded digital bit stream across the link segment.

This PMD specification outlines the requirements for a 155 Mbps (194.4 MBaud) 1300 nm multimode fiber interface. This provides for a physical interface between the switch and the host which is a full duplex, fiber optic connection. A 62.5/125 micron, graded index, multimode fiber, with a minimum modal bandwidth of 500 MHz-km, shall be used as the communication link. Alternatively, a 50 micron core fiber may be supported as the communication link. The interface should be able to operate up to 2 km maximum with the 62.5/125 micron fiber, at a wavelength of 1300 nm. The maximum link length may be shortened when 50 micron fiber is incorporated. The PMD specified in this section has the following general characteristics:

- Provide a means of coupling the TC to the fiber optic segment by way of the Active Interface.

- Provide for driving up to 2 km of fiber optic cable between two fiber optic interfaces.
- Meet the topology and distance requirements of the building and wiring standard, EIA/TIA 568.

2.3.2 Line Rates and Bit Timing

The non-encoded line frequency is 155.52 Mbps, which is identical to the SONET STS-3 rate described in [1]. This rate is derived from the insertion of one Physical Layer unit for every 26 data cells. With the 8B/10B block code described below, the resultant media transmission rate is 194.40 Mbaud.

(R) The encoded line rate shall be 194.40 Mbaud.

A receiver must first acquire bit synchronization, before attempting to align received bytes. This time is measured from the receipt of a valid input to the time the receiver is synchronized to the bit stream and delivering valid re-timed data within the BER objective of the system.

(R) Bit synchronization shall occur in not more than 1 ms.

2.3.2.1 Fiber Optic Medium Characteristics.

The fiber optic medium consists of one or more sections of fiber optic cable containing one or more optical fibers as specified below along with any intermediate connectors required to connect sections together and terminated at each end in the optical connector plug as specified in 2.4.1.3. The optical fibers are interconnected to provide two continuous light paths which are connected to the port pair at each end. Each light path connects to a transmit port at one end and a receive port at the other end.

(R) The optical medium requirements are satisfied by the 62.5/125 micrometer nominal diameter fiber specified in IEC 793-2, type A1b with the exceptions noted below. The system can operate, subject to certain restrictions, with a variety of optical fibers. However, performance to this specification and interoperability between different vendors' equipment is assured only through the use of the optical fiber specified in this section.

This specification was developed on the basis of an attenuation value of less than or equal to 1.5 dB/km, when measured at a wavelength of 1300 nm. Higher loss fiber may be used for shorter fiber pair lengths.

(R) Each optical fiber shall have a modal bandwidth-length product of not less than 500 MHz-km at a wavelength of 1300 nm.

(R) Each optical fiber shall have a zero dispersion wavelength in the range 1295 nm to 1365 nm and a dispersion slope not exceeding 0.110 ps/nm²-km. Each optical fiber shall have a dispersion characteristic in the range shown in Figure 2-13.

Figure 2-13 Chromatic Dispersion Requirements

| Zero Dispersion Wavelength Lambda (0); nm | Maximum Dispersion Slope S ₀ ; ps/nm ² -km |
|--|---|
| 1295 - 1300 | [Lambda(0) - 1190] / 1000 |
| 1300 - 1348 | 0.110 |
| 1348 - 1365 | [1458 - Lambda(0)] / 1000 |

2.3.2.2 Optical Medium Connector Plug and Socket.

(R) Each end of the fiber optic cable shall be terminated in BFOC/2.5 connector plugs (one per fiber), as specified in IEC 86B (Secretariat) 127. The corresponding mating connector sockets shall be used on all network elements covered by this specification to which the fiber optic cable attaches. In-line or patch panel connectors may be of other types, provided they meet the connector loss requirement below.

The use of the SC connector as an alternative to the BFOC/2.5 is under review in TR-41.8.1.

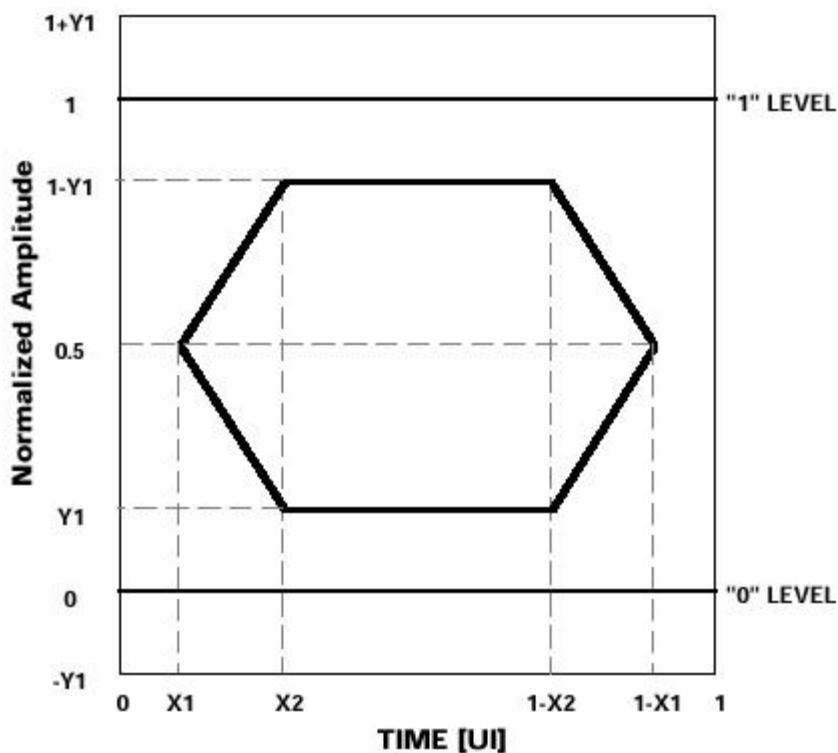
(R) Optical Connector Loss is assumed to have a maximum insertion loss of 1.0 dB (see Note below). Connectors with different loss characteristics may be used as long as any additional loss is compensated for elsewhere in the fiber loss budget.

Note: Per test method EIA/TIA 455/34, Method A (Factory Testing) or EIA/TIA-455-59 (Field Testing).

2.3.2.3 Optical Characteristics

(R) The transmit (Active Output Interface [AOI]) and receive (Active Input Interface [AII]) parameters for the 155 Mbps Multimode Fiber interface are summarized in Figure 2-14 and 2-16. The parameters must be met over the temperature, voltage, and lifetime range of the system. Optical measurements shall be made with the Active Output Interface (AOI) terminated with the optical connector specified in 2.4.1.3. and the optical fiber specified in section 2.4.1.2. Fiber length shall be sufficient to ensure equilibrium mode distribution.

Note: Transmit and receive optical parameters refer to optical power in the respective fiber. Typically fibers require 1 to 5 meters to establish equilibrium mode distribution.

Figure 2-15 MMF Eye Diagram for the Transmitter

(R) The BER shall be less than one part in 10^{10} , when measured between end-points on the UNI physical layer⁴, for all combinations of valid optical transmit parameters, valid optical receive parameters, and allowable media.

Figure 2-16 AII Optical Receive Parameters

| Parameter | Units | Value |
|---|-------|--------|
| Nominal baud | Mbaud | 194.40 |
| Baud Rate Tolerance | ppm | 100 |
| Optical Receive Average Power Range | | |
| - Min. | dBm | -29 |
| - Max. | dBm | -14 |
| Center Wavelength | | |
| - Min. | nm | 1270 |
| - Max. | nm | 1380 |
| Optical Receive Pulse Rise and Fall Times (10% to 90%) | | |
| - Min. | ns | 0.6 |
| - Max. | ns | 3.0 |
| AII Optical Receive Data Dependent Jitter | ns | ± 1.0 |
| Optical Receive Pulse Duty Cycle Distortion | ns | ± 0.5 |
| Optical Receive Pulse Random Jitter | ns | ± 0.5 |

⁴ Including bit timing recovery.

2.3.3 Transmission Convergence (TC) Specification

The Transmission Convergence (TC) sublayer deals with physical layer aspects which are independent of the physical media characteristics. Most of the functions comprising the TC sublayer are involved with generating and processing of some of the overhead bytes contained in the transmission format overhead and ATM cell header.

2.3.3.1 Line Coding

(R) The 8B/10B transmission code specified in the Fiber Channel Physical Layer document [2], sections 10.1 and 10.2, shall be the encoding protocol utilized in the Physical Layer. Other than the K28.2, K28.5 and K28.7 special characters described below, use of other valid special characters is for further study.

Owing to the use of an error multiplying block coding scheme, this interface may impose a service limitation. This error multiplication may impact the cell discard rate.

(R) The byte alignment pattern shall be the K28.5 of the 8B/10B code. The receiver shall present a properly aligned byte stream after the receipt of two K28.5 special characters within a 5 byte window. The first byte received after the second K28.5 shall have valid byte alignment.

2.3.3.2 Transmission Frame Structure

The maximum transfer rate for ATM layer data is 149.760 Mbps. This rate has been chosen to exactly match the cell payload described in [1]. The transmission frame structure is used to transport cells from the ATM Layer and to provide 125 microsecond synchronization.

(R) Figure 2-21 describes the sequence of cells in a Physical Layer frame. Each set consists of a sequence equivalent to 27 cells of 53 octets. The first 53 octets is the Physical Layer Overhead Unit which provides byte synchronization, frame synchronization and Physical Layer OAM. This is followed by 26 ATM layer cells. Cell rate decoupling is performed by adding unassigned cells to the data stream. The unassigned cell header is as defined in ITU-T Recommendation I.361. The payload transmission rate for data cells is exactly 149.76 Mbps ($155.52 * 26/27 = 149.76$).

Figure 2-17 Physical Layer Frame Format

| Physical Layer Overhead Unit | | Cell 1-26 |
|------------------------------|--------------------|-----------------------------|
| Frame Delimiter 5 bytes | PL OAM 48 bytes | Data Cells 53 bytes/cell |

The Frame Delimiter field is used to place special codes to provide byte and frame synchronization. These are described in Section 2.4.3.3. The Physical Layer Overhead Unit is used to signal PL-OAM at the UNI. The 6th byte in the Overhead Unit contains the PL-OAM bits which are currently defined in section 2.4.4. This byte is depicted below in Figure 2-22. Unused bytes within the Physical Layer Overhead Unit shall be Hex 00 with other values for further study.

Figure 2-18 Byte 6 Definition

| Bit 8 | Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| 0 | 0 | 0 | 0 | 0 | AIS | EFI | FERF |

(R) The TC only passes valid, non-Physical Layer cells to the ATM Layer. Physical Layer cells and cells with invalid HEC are not forwarded to the ATM layer.

2.3.3.3 Frame and Cell Delineation

Cell boundaries are synchronous with respect to frame structure. The K28.5/K28.7 ordered pair provides positive frame synchronization; the first byte of the first data cell follows the K28.7 symbol by 49 data bytes.

(R) Figure 2-23 describes the synchronization sequence used in the first five symbols of the transmission frame. The structure of the Physical Layer Overhead Unit (PL-OU) header consists of 4 K28.5 special characters followed by a K28.7 special character.

Figure 2-19 Synchronization Symbols

| Symbol 0 | Symbol 1 | Symbol 2 | Symbol 3 | Symbol 4 |
|----------|----------|----------|----------|----------|
| K28.5 | K28.5 | K28.5 | K28.5 | K28.7 |

2.3.3.4 125 μ sec Clock recovery

This 125 μ sec Strobe and 125 μ sec Reserved symbols provide a mechanism to deliver a 125 μ sec clock across the transmission link. It is normally used in one direction across the UNI. The 125 μ sec reference clock may be derived from any source, be it local to the switch, recovered from a SONET input or from any other mechanism. The K28.2 special character is placed in the data stream to explicitly realize the 125 μ sec Strobe. It may be inserted between any two symbols of the data stream, and is considered part of the transmission frame (PL-OU and 26 ATM cells) which contains the symbol that precedes it. The first symbol location in the Physical Layer Overhead Unit is the 125 μ sec Reserved Symbol. Normally, the 125 μ sec Reserved Symbol (a K28.5 special character) is

transmitted along with the rest of the PL-OU. If a 125 usec Strobe was transmitted in the previous transmission frame, the 125 μ sec Reserved Symbol is deleted.

(O) The K28.2 special character is transmitted to explicitly realize the 125 μ sec Strobe anywhere in the data stream. It may be inserted between any two symbols of the data stream, and is considered part of the transmission frame which contains the symbol that precedes it. The 125 μ sec Reserved Symbol (K28.5) from the PL-OU is removed if the 125 μ sec Strobe was transmitted in the previous transmission frame.

(O) The first byte of the first data cell in the transmission frame follows the K28.7 special character by 49 non-Strobe symbols.

(R) All receivers must terminate the 125 μ sec Strobe. The K28.7 special character is used as the reference marker for the frame, and the K28.2 special character is ignored for all frame synchronization purposes.

2.3.3.5 HEC Generation/Verification

The Header Error Control (HEC) covers the entire cell header. For the private UNI, only the detection of bit errors is described. Support of bit error detection based on the HEC field is mandatory.

The transmitter calculates the HEC value for the first four octets of the cell header, and inserts the results into the HEC field, the last octet of the header. The HEC field shall be an 8-bit sequence. It shall be the remainder of the division (modulo 2) by the generator polynomial x^8+x^2+x+1 of the polynomial x^8 multiplied by the content of the header excluding the HEC field. The pattern 01010101 is XORed with the 8-bit remainder before being inserted in the last octet of the header [1].

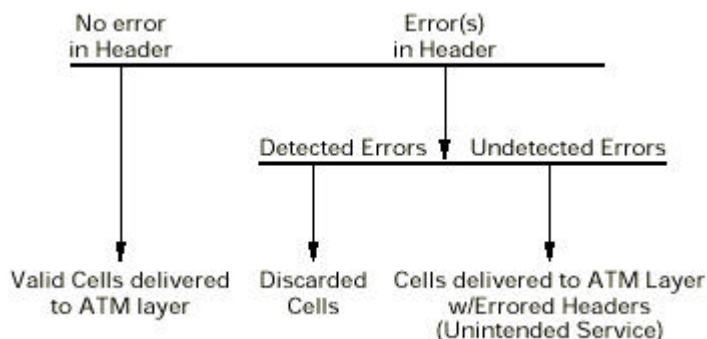
(R) Equipment supporting the UNI shall implement HEC error detection as defined in ITU-T Recommendation I.432.

(R) Equipment supporting the UNI shall generate the HEC byte as described in ITU-T Recommendation I.432.

(R) The generator polynomial and coset used shall be in accordance with ITU-T Recommendation I.432.

Figure 2-24 depicts the HEC verification flow on the receive side. The TC will not forward any cell to the ATM layer which has an incorrect HEC value.

(R) On detection of a header error, the cell shall be discarded.

Figure 2-20 HEC Verification Flow

2.3.4 Physical Layer Operation and Maintenance Specification (M-plane)

The following PL-OAM functions associated with the 155 Mbps UNI have been identified and are described below. These functions provide for transmission and reception of maintenance signals and low level link performance monitoring. This PL-OAM information is carried in the Physical Layer Overhead Unit described in section 2.4.3.2.

Maintenance signals are defined for the physical layer to indicate the detection and location of a transmission failure. These signals are:

(R) Far End Receive Failure (FERF): FERF is used to alert the associated upstream termination point that a failure has been detected downstream. FERF is signaled upon the loss of frame synchronization or loss of the incoming signal. This failure is continuously indicated by a logical 1 in the Physical Layer Overhead Unit until frame synchronization has been achieved.

A link transmission performance monitoring signal is defined for the physical layer to detect and report link transmission errors. This signal is used to provide a low level indication of degraded link error performance and is defined as follows:

(R) Errored Frame Indicator (EFI): EFI is used to alert the associated upstream termination point that a frame has been received that contained an 8B/10B code rule violation⁵. An EFI flag is set upon the reception of one or more code rule violations within an incoming frame and is signaled to the upstream termination point by a logical 1 in the next available Physical Layer Overhead Unit in the outgoing frame.

(R) Alarm Indication Signal (AIS): AIS is used to alert the associated downstream termination point that a failure has been detected upstream. AIS is signaled upon the loss of frame synchronization or loss of the incoming signal. This failure is continuously indicated by a logical 1 in bit three of byte six in the Physical Layer Overhead Unit until frame synchronization has been achieved. Logical 0 in this position indicates normal operation.

⁵ No other action is required for code rule violation.

The number of consecutive AIS assertions to indicate an alarm condition needs further definition.

3 References

[1] ITU-T Recommendation I.432, "B-ISDN User-Network Interface - Physical Layer Specification", ITU-T SGXVIII, June 1992.

[2] FC-P/91-001R2.1 "Fiber Channel Physical Layer (FC-PH)", Revision 2.1, Working Draft, May 25, 1991.

4 Appendix A

Table 1 is a cross-reference between the references originally found within the UNI3.1 Specification and updates/newer specifications that may be applicable. Updates were not made to the original references within this specification to preclude existing implementation becoming no longer compliant.

Table 1 Known Cross-References

| Original Reference | Current Version | Title |
|-----------------------|--------------------------------------|--|
| T1E1.2/94-002R1 | ANSI T1.646-1995 | Broadband ISDN - Physical Layer Specification for User-Network Interfaces Including DS1/ATM (Supercedes ANSI T1.624-1993) 5/1995 |
| | T1.416.03 | Network to Customer Installation Interfaces - Synchronous Optical Network (SONET) Physical Media |
| ITU-T Rec. I.432 | ITU-T Rec. I.432.1 (02/99) | B-ISDN user-network interface - Physical layer specification: 155 520 kbit/s and 622 080 kbit/s operation |
| | ITU-T Rec. I.432.2 (02/99) | B-ISDN user-network interface - Physical layer specification: 1544 kbit/s and 2048 kbit/s operation |
| | ITU-T Rec. I.432.3 (02/99) | B-ISDN user-network interface - Physical layer specification: 51 840 kbit/s operation |
| | ITU-T Rec. I.432.4 (02/99) | B-ISDN user-network interface - Physical layer specification: 25 600 kbit/s operation |
| | ITU-T Rec. I.432.5 (02/99) | B-ISDN user-network interface - Physical layer specification: 25 600 kbit/s operation |
| TR-NWT-000253 Issue 2 | GR-253-CORE, Issue 3, September 2000 | Synchronous Optical Network (SONET) Transport Systems: Common Generic Criteria |
| T1.105-1991 | ANSI T1.105-1995 | Synchronous Optical Network (SONET) - Basic Description including Multiplex Structure, Rates and Formats 10/1995 |
| | ANSI T1.105.01-1998 | Synchronous Optical Network (SONET) - Automatic Protection 4/1998 |
| | ANSI T1.105.02-1995 | Synchronous Optical Network (SONET) - Payload Mappings 5/1995 |
| | ANSI T1.105.03-1994 | Synchronous Optical Network (SONET) - Jitter at Network Interfaces 3/1994 |
| | ANSI T1.105.03a-1995 | Supplement ANSI T1.105.03a-1995 5/1995 |
| | ANSI T1.105.03b-1997 | Supplement ANSI T1.105.03b-1997 4/1997 |
| | ANSI T1.105.04-1995 | Synchronous Optical Network (SONET) - Data Communication Channel Protocol and Architectures 12/1995 |
| | ANSI T1.105.05-1994 | Synchronous Optical Network (SONET) - |

| | | |
|------------------|--|--|
| | | Tandem Connection Maintenance 3/1994 |
| | ANSI T1.105.06-1996 | Synchronous Optical Network (SONET) - Physical Layer Specification (Revision of ANSI T1.106-1988) 3/1996 |
| | ANSI T1.105.07-1996 | Synchronous Optical Network (SONET) - Sub-STS-1 Interface Rates and Formats Specification 12/1996 |
| | ANSI T1.105.07a-1997 | Supplement ANSI T1.105.07a-1997 12/1997 |
| | ANSI T1.105.09-1996 | Synchronous Optical Network (SONET) - Network Element Timing and Synchronization 8/1996 |
| ANSI T1.105 | ANSI T1.105-1995 | Synchronous Optical Network (SONET) - Basic Description including Multiplex Structure, Rates and Formats 10/1995 |
| | ANSI T1.105.01-1998 | Synchronous Optical Network (SONET) - Automatic Protection 4/1998 |
| | ANSI T1.105.02-1995 | Synchronous Optical Network (SONET) - Payload Mappings 5/1995 |
| | ANSI T1.105.03-1994 | Synchronous Optical Network (SONET) - Jitter at Network Interfaces 3/1994 |
| | ANSI T1.105.03a-1995 | Supplement ANSI T1.105.03a-1995 5/1995 |
| | ANSI T1.105.03b-1997 | Supplement ANSI T1.105.03b-1997 4/1997 |
| | ANSI T1.105.04-1995 | Synchronous Optical Network (SONET) - Data Communication Channel Protocol and Architectures 12/1995 |
| | ANSI T1.105.05-1994 | Synchronous Optical Network (SONET) - Tandem Connection Maintenance 3/1994 |
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| | ANSI T1.105.07a-1997 | Supplement ANSI T1.105.07a-1997 12/1997 |
| | ANSI T1.105.09-1996 | Synchronous Optical Network (SONET) - Network Element Timing and Synchronization 8/1996 |
| ITU-T I.610 | ITU-T Rec. I.610 (02/99) | B-ISDN operation and maintenance principles and functions |
| | ITU-T Rec. I.610 Amend.1 (03/00) | Amendment 1 to Recommendation I.610 - To be published |
| | ITU-T Rec. I.610 Corr.1 (03/00) | Corrigendum 1 to Recommendation I.610 - To be published |
| ITU-T Rec. G.709 | Combined into ITU-T Rec. G.707 (10/00) | Network node interface for the Synchronous Digital Hierarchy (SDH) |
| ITU-T G.703 | ITU-T Rec. G.703 (10/98) | Physical/electrical characteristics of hierarchical digital interfaces |
| ANSI T1.107 | ANSI T1.107-1995 | Digital Hierarchy - Formats Specifications |

| | | |
|--|--|---|
| | | 7/1995 |
| ANSI T1.107a | Combined into T1.107 | |
| IEEE P802.6 | IEEE 8802-6:1994 | DQDB Access Method (802.6), Information technology-- Telecommunications and information exchange between systems--Local and metropolitan area networks--Specific Requirements--Part 6: Distributed Queue Dual Bus (DQDB) Access method and physical layer specifications |
| | IEEE 802.6j-1995 | Supplement to 802.6-1994: Connection- Oriented Service on a DQDB Subnetwork of a MAN |
| IEC 793-2, type A1b | IEC 60793-2 Ed. 4.0 b:1998 | Optical fibres - Part 2: Product specifications 86A |
| BFOC/2.5 | TIA/EIA-475E000 | Sectional Specification for Fiber Optic Connectors - Type BFOC/2.5 |
| | IEC 60874-10 | Connectors for optical fibres and cables - Part 10: Sectional specification - Fibre optic connector type BFOC/2,5 |
| | IEC 60874-14 | Connectors for optical fibres and cables - Part 14: Sectional specification for fibre optic connector - Type SC |
| IEC 86B (Secretariat) 127 | IEC 60869-1 Ed. 3.0 b:1999 | Fiber optic attenuators - Part 1: Generic specification 86B |
| TR-41.8.1 | | |
| EIA/TIA 455/34, Method A (Factory Testing) | TIA/EIA-455-34A, FOTP- 34, Dec 1995 | Interconnection Device Insertion Loss Test |
| EIA/TIA-455-59 (Field Testing) | EIA/TIA-455-59, FOTP- 59, Dec 1989 | Measurement of Fiber Point Defects Using an OTDR |

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|------------------|-------------------------------|---|
| ANSI/IEEE 802.5 | IEEE 8802-5:1998 | Token Ring Access Method (802.5) Information technology-- Telecommunications and information exchange between systems--Local and metropolitan area networks--Specific requirements--Part 5: Token Ring Access Method and Physical Layer Specification |
| | IEEE 8802-5:1998/Amd.1 | Information technology-- Telecommunications and information exchange between systems--Local and metropolitan area networks--Specific Requirements--Part 5 Token ring access method and physical layer specifications-- Admendment1: Dedicated Token Ring Operation and Fibre Optic Media |
| | IEEE 802.5c-1991 | Supplement to 802.5-1989, Recommended Practice for Dual Ring Operation with Wrapback Reconfiguration |
| | IEEE 802.5t-2000 | IEEE Standard for Information technology- Telecommunications and information exchange between systems-Local and metropolitan area networks-Specific requirements-Amendment to Part 5: Token Access Method and Physical Layer Specifications |
| EIA/TIA 568 | TIA/EIA-568-A | Commercial Building Telecommunications Cabling Standard |
| | TIA/EIA-568-A-2 | Corrections and Additions to TIA/EIA- 568-A Addendum to TIA/EIA-568-A |
| | TIA/EIA-568-A-5 | Transmission Performance Specifications for 4-Pair 100 Ohm Category 5e Cabling A |
| | TIA/EIA-568-A-1 | Propagation Delay and Delay Skew Specifications for 100 Ohm 4-Pair Cable Addendum |
| | TIA/EIA-568-A-3 | Addendum No. 3 to TIA/EIA-568-A |
| | TIA/EIA-568-A-4 | Production Modular Cord NEXT Loss Test Method and Requirements for Unshielded Twisted Pair |
| | ANSI/TIA/EIA-568-B.3- 2000 | Optical Fiber Cabling Components Standard |
| ITU-T Rec. I.361 | ITU-T Rec. I.361 (02/99) | B-ISDN ATM layer specification |