OPTICAL INTERNETWORKING FORUM

Very Short Reach (VSR) OC-192/STM-64 Interface Based on Parallel Optics

OIF-VSR4-01.0

December 18, 2000

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4. Document Revision History

1. Version 0.1 – Draft – Baseline text
2. Version 1.0 – changes and clarifications based on feedback of the working group (edited 4/24/00)
3. Version 1.1 – corrections to the “reference numbers” in Section 8 text
4. Version 2.0 – changes based on feedback from recent Straw Ballot comments (edited 8/7/00)
5. Version 2.1 – changes based on breakout discussions at OIF PLL-WG meeting (Barcelona 8/16/00)
6. Version 2.2 – changed original document number “OIF2000.044.6” to “OIF-VSR4-01.0” as a result of the OIF Technical Committee Principal Ballot #8 approved for adoption as an OIF Implementation Agreement (12/18/00)

5. Project Summary

(Not Applicable -- This section intentionally left blank)

6. Introduction

This technical document describes a functional low-cost SONET/SDH OC-192 interface for very short reach (VSR) applications.

The VSR interface utilizes vertical cavity surface emitting laser (VCSEL)-based parallel optics technology. To leverage this VSR low cost technology a mapping of the OC-192 frame onto the parallel optical links is defined as well as a method of detecting and re-assembling the OC-192 frame.

The target performance of the VSR interface is to transmit the OC-192 data over 300m of 62.5 μm-core multimode (MM) ribbon fiber cable.

Section 7 of this document defines the converter IC functions for mapping from the OC-192 framer interface to the parallel optical interface. Section 8 defines the parallel optical interface. The electrical interface from the framer conforms to the common electrical interface defined in [1]

6.1. Application

The application of the OC-192 VSR interface is to interconnect co-located equipment.

Examples of equipment that is often co-located within a CO and often interconnected are:

Routers,
Dense Wavelength Division Multiplexer (DWDM) terminals, and
SONET/SDH Add-Drop Multiplexers (ADMs).

6.2. Functional Overview

The OC-192 VSR is a bi-directional interface. A functional block diagram (enclosed within the dotted line) is illustrated in Figure 1. The framer-serdes interface (FSI) is OIF99.102 compliant. The parallel optics interface (POI) is described in Section 8.

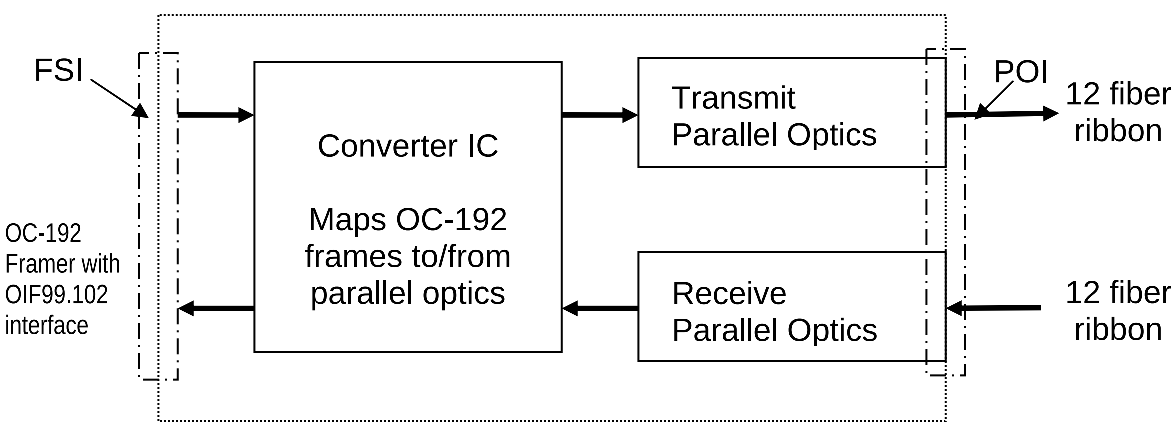

Figure 1: Functional block diagram of OC-192 VSR interface

7. Converter IC Functional Description

7.1. Transmit Direction

The Framer-SerdesSerDes Interface should shall conform to [1], but does not exclude other implementations. This interface is a 16-bit x 622Mb/s LVDS interface (see Figure 2). 16-bit-word alignment shall be required (as shown in Figure 3) on the 16-bit X 622MHz input (transmit) to the Converter IC data interface. This requirement is not part

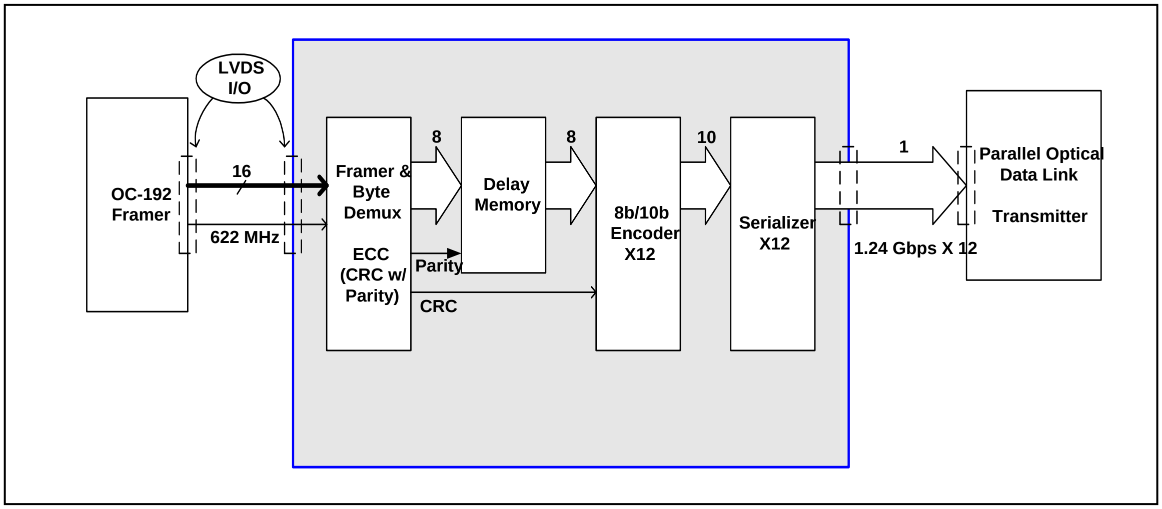

Figure 2: Transmit direction block diagram

of [1], but is unique to the Converter IC. As defined in [1], the transmit data interface is source synchronous (i.e. the required 1.244 Gb/s high-speed data is synchronous with the 622MHz clock received from the OC-192 framer chip).

7.1.1. OC192 Mapping to Data Channels

7.1.1.1. The OC-192 frame shall be byte-wise striped across the 10 data channels (as shown in Figure 3).

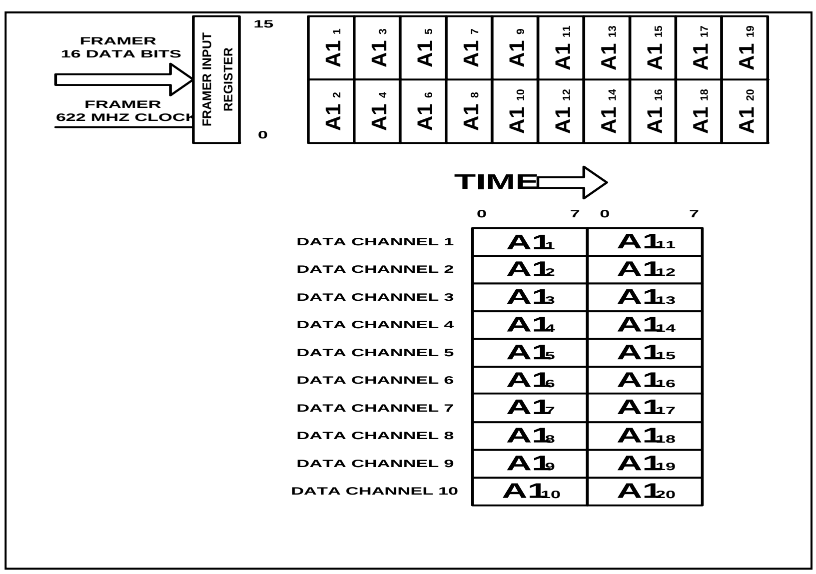

Figure 3: Bit mapping from framer to 10 data channels

7.1.1.2. The first byte of the OC-192 frame shall be transmitted on channel 1, and the striping continues across the channels.

7.1.1.3. The transmit clock, sourced from the OC-192 framer shall be used to acquire the 16 framer bits at 622Mb/s. This clock also generates the 1.244GHz clock for the I/O to the parallel optical transmitter link.

7.1.2. Protection Channel

A 'protection' channel shall be created by performing a bit-wise XOR operation of the 10 data channels to create a parity bit. The protection channel shall be transmitted on Channel #11. If any of the ten channels fail, the data can be recovered at the receiver from the protection channel (see Figure 4).

NOTE: The user can optionally choose to have or not to have the receiver recover the data from a failed channel, however, the Protection Channel (as well as the EDC, as described below – Section 7.1.3) is always transmitted.

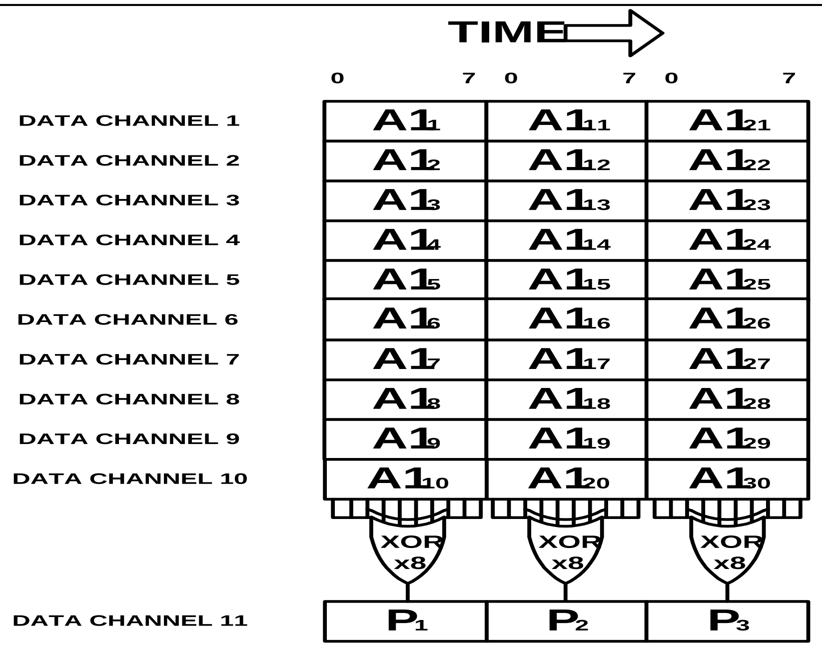

Figure 4: Diagram showing XORing for the Protection Channel (DC #11)

7.1.3. Error Detection Channel (EDC)

An error detection channel is created by calculating the CRCs on each data channel and transmitting them. The 12th channel shall be the "error detection" channel (EDC). It is created by calculating a separate CRC16 over 24 bytes of data (defined as "virtual blocks") from each of the other 11 channels of data. Again, the user can optionally choose to have or not to have the receiver compute and compare the CRC on the received data (including the Protection Channel and EDC), however, the EDC is always transmitted.

7.1.3.1. A "virtual block" is defined as having a length of 24 bytes. On each channel, the boundaries of the SONET frame and the virtual blocks shall match for the first virtual block in that channel

7.1.3.2. To calculate the CRC in each virtual block, the CCITT CRC16 polynomial shall be used ($X^{16}+X^{12}+X^5+1$).

7.1.3.3. The virtual block in the EDC shall be transmitted in parallel with the virtual blocks of the data channels from which the CRC's are calculated (see figure 5)

7.1.3.4. As shown in Figure 5, the EDC (Channel #12) virtual block will be comprised of one 16-bit CRC for each virtual block from the other 11 channels. The final two bytes of the EDC's virtual block shall contain the CRC16 which is calculated over the first 22 bytes of the EDC virtual block

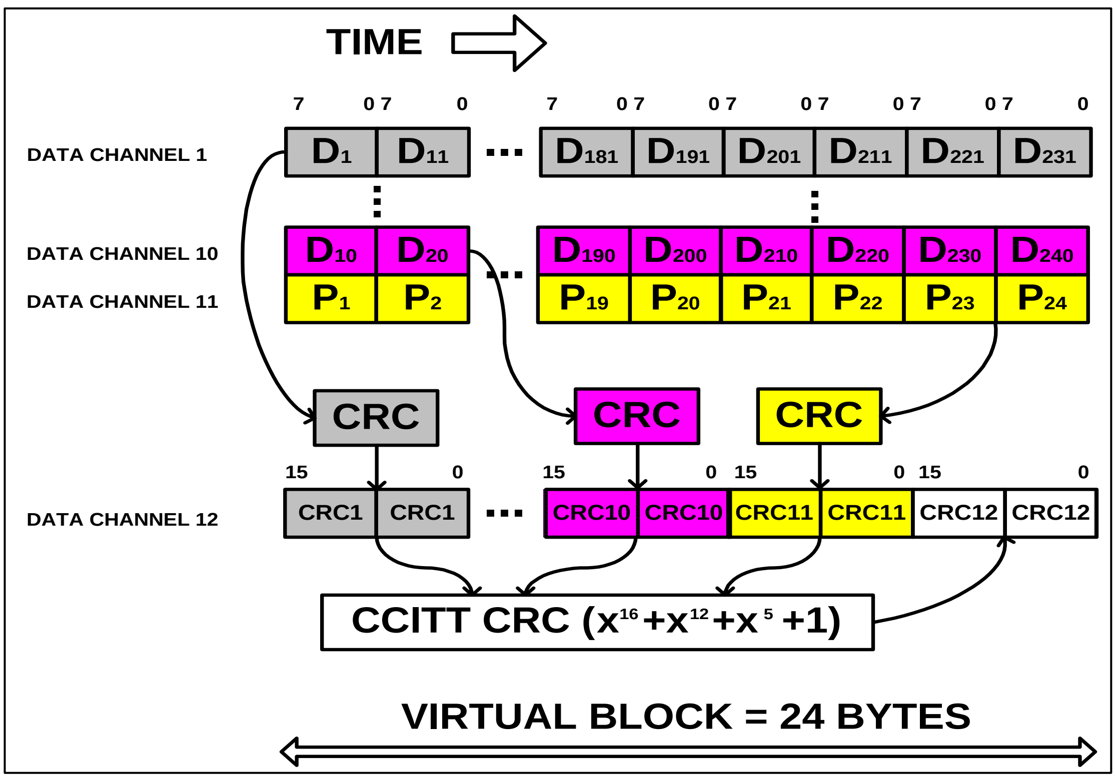

Figure 5: CRC Generation for the EDC Channel #12

7.1.3.5. At the beginning of each virtual block, the CRC registers shall be initialized to 16'hfff. The CRC is then calculated with the input bit '0' (LSB) of the first byte of the virtual block being shifted into the polynomial first.

7.1.3.6. After the 24-byte virtual block has been shifted into the polynomial, the CRC value is buffered (as shown in Figure 6)

7.1.3.7. The register corresponding to the CRC MSB is labeled as CRC Bit15 (see Figure 6)

7.1.3.8. Note that Bits 8-15 of the 16-bit CRC for data channel 1 shall be transmitted first; followed by bits 0-7 of the CRC for data channel 1. The 16-bit CRCs for data channels 2 through 10 and for the protection channel (11) follow. Finally, the 16-bit CRC calculated over the first 22 bytes of the EDC channel are transmitted as the last two bytes of the EDC virtual block (see Figure 5).

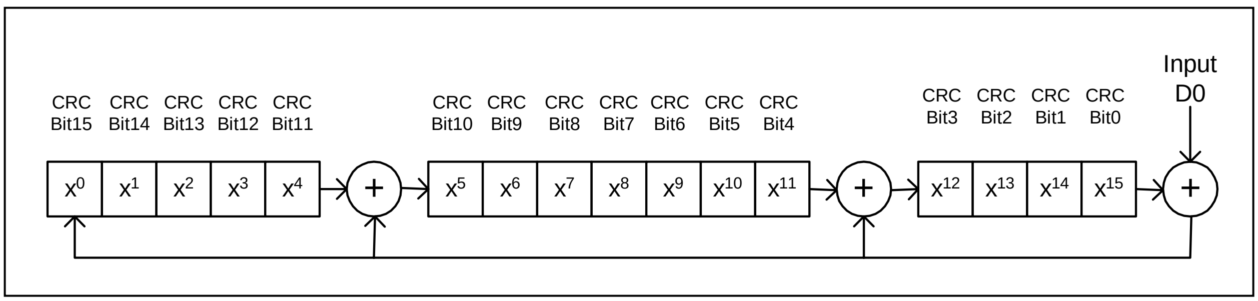

Figure 6: Diagram: Diagram of CRC generation

7.1.4. Frame Delimiting

Due to the parallel nature of the transmission media, each data channel may arrive at the receiver with different transmission delays (i.e. skew). A frame delimiter is used on each data channel to aid in realignment.

7.1.4.1. The first three SONET/SDH A1 bytes on each data channel shall be overwritten with 8b/10b codewords that form a frame delimiter that the receiver will recognize. Frame delimiter codewords are also transmitted in the corresponding byte positions of the protection and error detection channels, overwriting three parity bytes and three CRC bytes respectively. Frame delimiters aid in the de-skewing circuitry at the receiver. The codewords used are shown in Table 1.

Codeword name	Octet value	Current RD-	Current RD+
		abcdei fghj	abcdei fghj
K28.5	BC	001111 1010	110000 0101
D3.1 (ch.1-6)	23	110001 1001	110001 1001
D21.2 (ch.7-12)	55	101010 0101	101010 0101

Table 1: 8b/10b codewords used in the frame delimiter

7.1.4.2. The frame delimiters for channels 1-6 and channels 7-12 shall be different to allow detection of the polarity of the patchcord (and therefore channel order) at the receiver

7.1.4.3. The frame delimiters shall consist of codewords. The first A1 byte is overwritten by a K28.5, the second A1 byte is overwritten by D3.1 (for channels 1-6) or D21.2 (for channels 7-12) depending on the channel number, and the third A1 byte is overwritten by a K28.5. (see Figure 7 & 8)

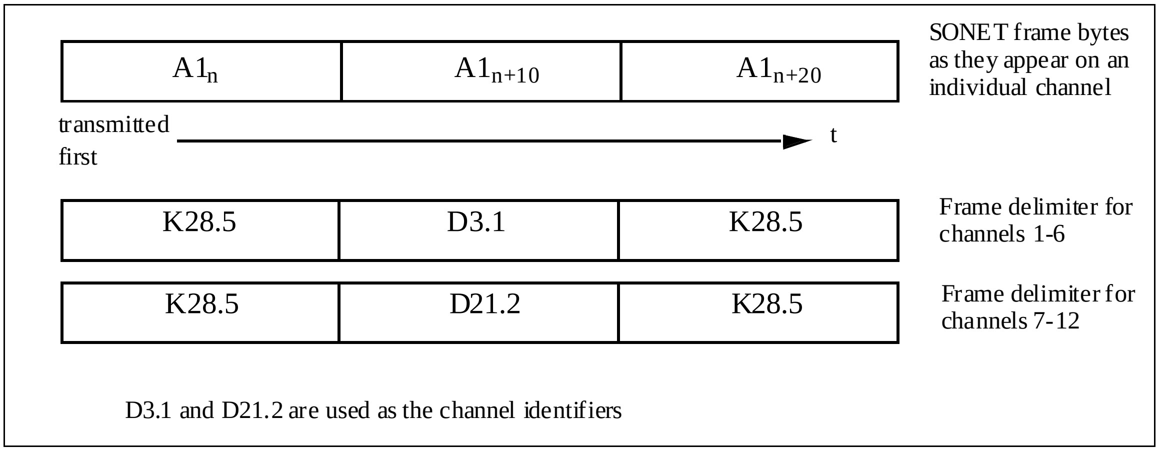

Figure 7: Format of the Frame Delimiter

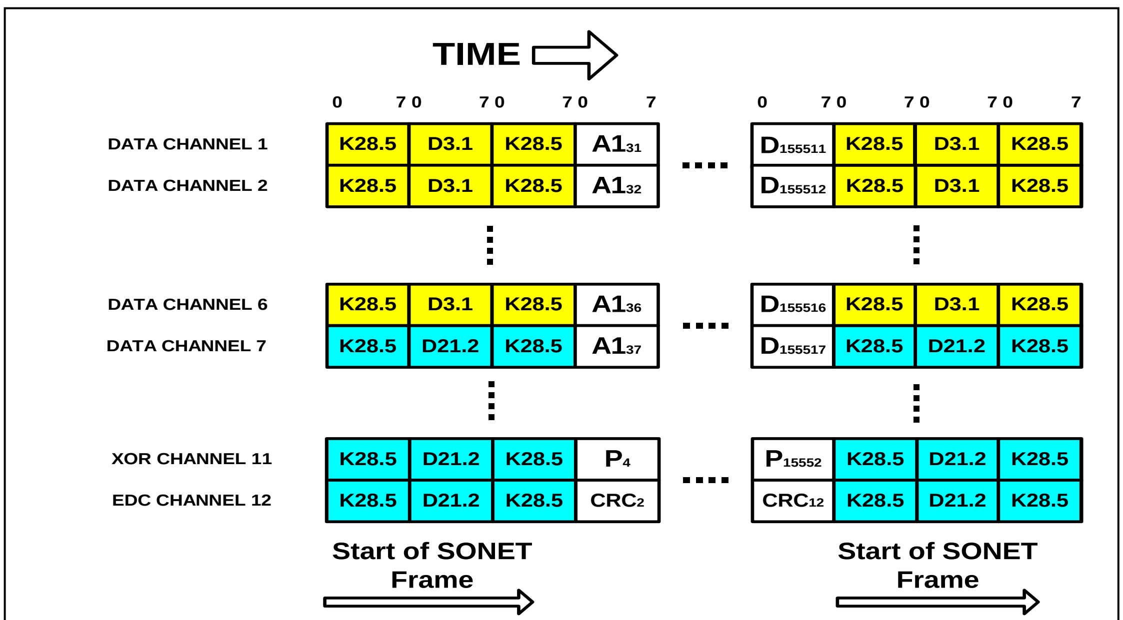

Figure 8: Frame delimiter insertion

7.1.5. 8b/10b Encoding

To ensure a DC-balanced, high-transition-rate transmission signal, each channel shall be 8b/10b encoded. Details of the 8b/10b code are given in [2].

7.2. The Receive Direction

In the receive direction, the optical signals from the 12 parallel fibers are converted to electrical data streams by the parallel optical module as shown in Figures 1 and 9. The resulting 1.244 Gb/s data streams enter the receiver section of the converter where a recovered clock is derived from the data on a per-channel basis. Subsequently, the data streams are 8B/10B decoded. Using the frame delimiters present in each data stream for alignment purposes, the channels are de-skewed. The converter uses an algorithm to find the frame delimiters which is tolerant of local bit errors that may affect an individual frame delimiter. The frame delimiters in the 10 data channels are overwritten with A1 bytes, restoring the original SONET framing. The converter finally reassembles the data channels into a 16 bit16-bit wide data bus operating at 622 Mb/s.

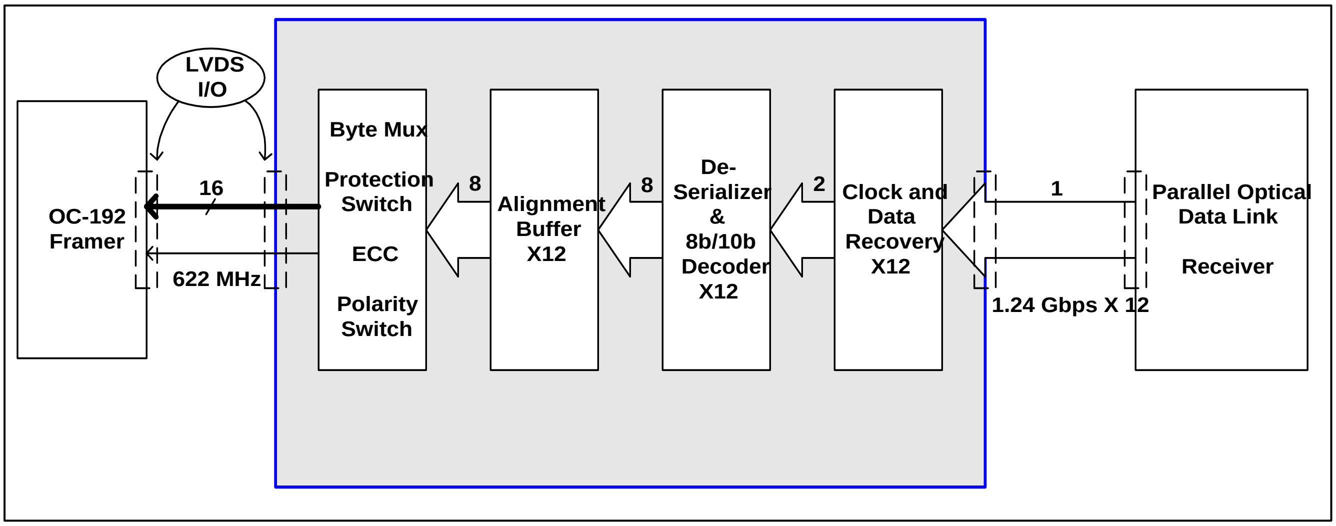

Figure 9: Receive Direction Block Diagram

7.2.1. Deskew at the Receive Side

The receiver shall have a minimum interchannel skew tolerance of 80 ns.

7.2.2. Auto-Detection of Fiber Ribbon Cable Crossover

The receiver shall detect (through the D3.1 and D21.2 frame delimiters) whether the fiber ribbon cable has a crossover and will internally account for this to ensure correct data byte ordering at the output.

7.2.3. Loss of Synchronization (LOSyn)

Loss of synchronization (LOSyn) is a state that shall exist when a channel is considered to be transmitting invalid data. The receiver shall detect a loss of synchronization on any single channel within the 10 data channels. A LOSyn recovery scheme (i.e. state machine) shall be implemented based on looking for 8b/10b codeword violations within groupings of 4 codewords defined as "codeblocks".

Editor's Note: An implementation example of a LOSyn state machine for reacquistionreacquisition of synchronization is described in Appendix E at the end of this document.

If LOSyn is detected on one or more data channels, all data on all channels shall be overwritten with zeros until the LOSyn condition is cleared. If channel protection is enabled (Section 7.2.4), then LOSyn in a single data channel can be compensated for and data will not be overwritten with zeros.

7.2.4. Channel Protection (optional)

It is possible to recover the data from a single failed channel through use of the protection channel. The protection channel is always sent by the transmitter, but use of it at the receiver is optional. The recovery procedure is as follows.

7.2.4.1. A protection switch is triggered by the detection of loss of synchronization (LOSyn) on one of the data channels.

7.2.4.2. If a single channel failure is detected, the data from that channel is recovered at the receiver by reconstructing it from the protection channel by XORing the Protection Channel with the 9 valid data channels.

7.2.4.3. The reconstructed data channel shall always be written with A1 bytes in place of the frame delimiters automatically.

7.2.5. Error Correction in the Receiver (optional)

Using the protection channel, it is possible to correct errored blocks in the data channels. This is accomplished by computing the CRC for the received data and comparing it to the transmitted CRC on the EDC. If an error is detected, the errored block can be extracted from the protection channel. The error detection channel is always sent by the transmitter, but this feature can be optionally enabled at the receiver.

7.2.5.1. A 16-bit CRC shall be calculated for each virtual block in each channel in the same manner as described in Section 7.1.3. The receiver in the “converter” compares received and recalculated CRCs to determine whether any error occurred during transmission. The error correction shall be performed in the receiver converter after all the channels are aligned

7.2.5.2. The 16-bit CRC for the virtual block on the EDC shall be calculated first and if it matches the transmitted 16-bit CRC, then the EDC virtual block is assumed to be error free allowing error correction to be performed. The 16-bit CRC shall then be calculated for the Protection Channel virtual block. Again if it matches the transmitted CRC error correction can then be performed on the 10 data channels. If an error is detected in either the protection channel or EDC, no further error correction can be performed on that virtual block. If no errors are detected, the 16-bit CRC is calculated for each of the ten data channels. If an error is found in a channel, the errored virtual block is replaced by reconstructing the correct data from the protection channel. If more than one data channel is determined to have an error in the same virtual block, then no error correction is performed. Figure 10 shows a flow chart illustrating the error correction decision sequence.

7.2.5.3. If the virtual block contains the frame delimiter (which occurs every 648 virtual blocks), then error correction is not performed as the first three bytes of the EDC are overwritten by the frame delimiter.

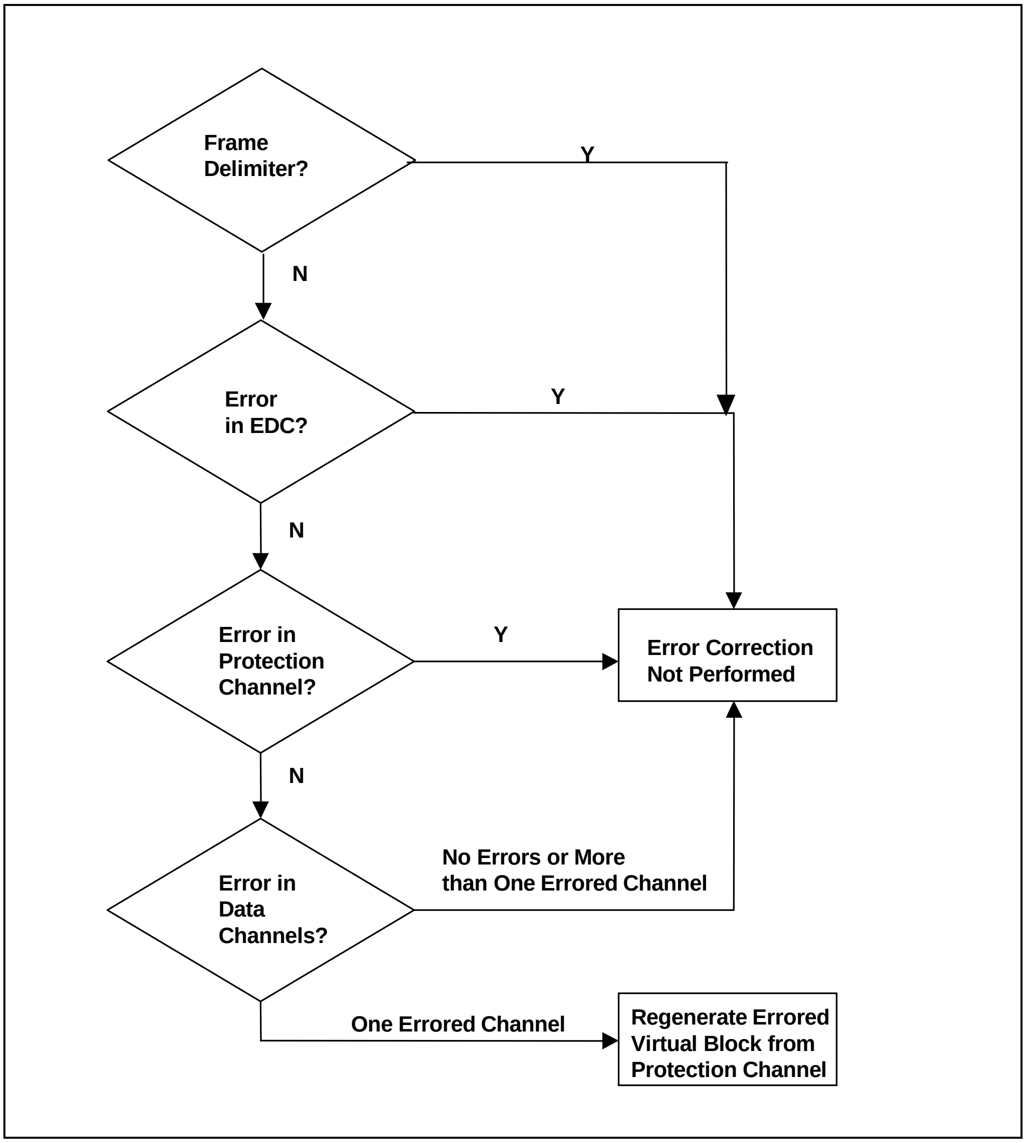

Figure 10 Receiver error correction flowchart

8. Optical Interface Specifications

This section describes the optical physical layer for a full duplex electro-optic interface at the Physical Layer. Section 8.1 provides the optical parameter requirements for the interface; Section 8.2 provides specifications for the fiber and connector; and Section 8.3 describes the necessary measurement techniques.

8.1. Optical Interface Requirements

Editor Notes: The optical link specifications rely heavily on the Gigabit Ethernet standard [2] and the corresponding Gigabit Ethernet optical link model [3,4]. The specifications listed in Sec. 8.2 are not identical to the GbE standard; i.e. the specifications have been modified where necessary to meet design constraints imposed by engineering parallel components. The extinction ratio specification has been adjusted for the reduced current swing requirements of laser arrays; a crosstalk immunity measurement was added to prevent link performance degradation due to operation in a parallel environment; the data rate (1.244160 Gb/s) differs slightly from Gigabit Ethernet (1.25 Gb/s). The Gigabit Ethernet link model [3,4] has been used to model all changes in the values from the original Gigabit Ethernet specifications [2]. The values specified in this section are worst case, end-of-life values and must be satisfied over the full range of operating conditions. The optical link design objective of a BER<10^{-12} shall be met for the worst case combination of values in the following specifications.

The reference-cabling model is illustrated in Figure 11. The figure shows the maximum of 4 connectors allowed in the link. Measurements of the transmitter (Tx) optical parameters are made at Point #1, when the jumper from the Tx is 2m long. Measurements of the receiver (Rx) optical parameters are made at Point #4, when the jumper to the Rx is 2m long. All measurement techniques described in Section 8.3 are for measurements made at these test points.

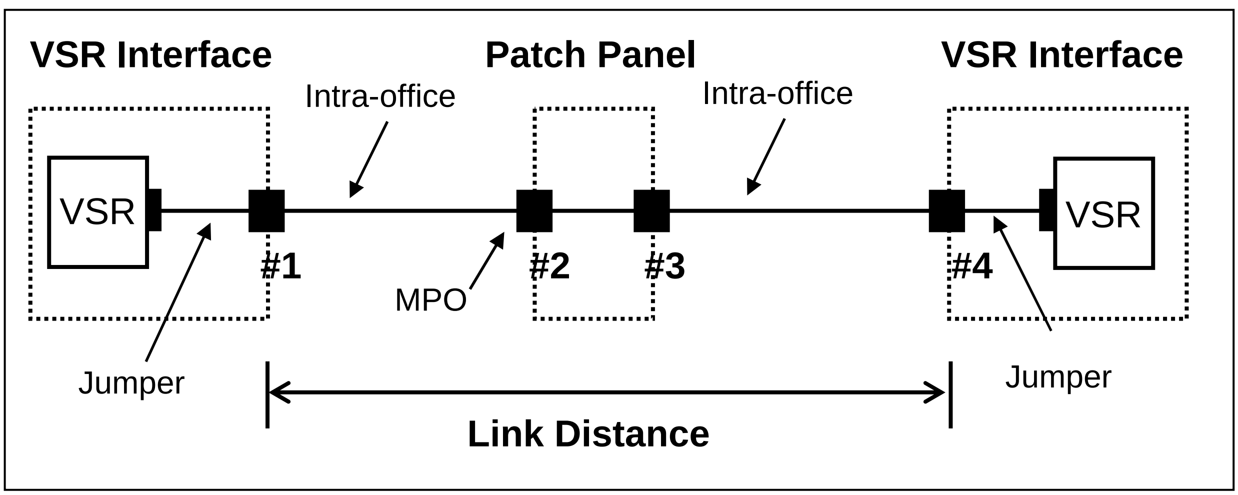

Figure 11: Reference-cabling model

8.1.1. Transmitter Specification

The transmitters for the VSR link shall have 12 lasers emitting into 12 separate fibers in a fiber ribbon cable. Each laser shall individually meet all the specifications listed in Table 2. Furthermore, all elements in the transmitter arrays for the VSR link shall also meet a transmit eye mask measurement as discussed in Sec. 8.3.

Table 2 - Transmitter Characteristics

Parameter	Min.	Max	Units
Transmit[1,2]			
Data rate	1.244160 ± 20ppm		Gb/s
P_{out}	-10	-3[3]	dBm
λ_c	830	860	nm
Extinction ratio	6		dB
$\Delta\lambda_{rms}$		0.85	nm
T_{rise}/T_{fall} (20-80%)		260	ps
RIN		-117	dB/Hz
Transmitter Skew[4]		5	ns

Footnotes:

1. All specifications are per channel and at the end of a 2m patchcord
2. In the event of accidental transmitter to transmitter connection, no damage shall occur that will prevent the continued operation of the transmitter module within specification.
3. Maximum output power for combined channels will also be compliant with FDA Class 1 and IEC Class 3A eye safety requirements (all channels aggregated).
4. The maximum skew introduced across the 12 channels from electrical input to optical output by the transmitter module shall be 5ns.

8.1.2. Receiver Specification

The receivers for the VSR link shall have 12 receiving elements, one for each of the 12 separate fibers in a fiber ribbon cable. Each receiving element shall individually meet all the specifications listed in Table 3.

Receiver [5]	Min	Max	Units
Data rate	1.244160 ± 20ppm		Gb/s
P_{in}	-16[6]	-3	dBm
λ_c	830	860	nm
Return loss	12		dB
Stressed Receive sensitivity	-13.65		dBm
Vertical eye closure penalty	2.6		dB
Receiver electrical 3dB upper cutoff frequency (GHz)		1.500	GHz
Signal detect – asserted[7]		-19	dBm
Signal detect -- de-asserted	-26		dBm
Signal detect hysteresis	1	4	dB
Input Skew[8]		75	ns
Receiver Skew[9]		5	ns

Table 3 - Receiver Characteristics

Footnotes:

5. All receiver specifications are per channel.
6. Receiver sensitivity shall be such that the BER $\leq 10^{-12}$ with the minimum optical power, worst case extinction ratio including the optical path penalty (includes 2.0dB loss for connectors), and the maximum crosstalk possibility. The *maximum crosstalk possibility* is defined as the 'victim' receiver operating at its sensitivity limit and the 'aggressor' receivers on both sides operating at 6dB higher incident power.
7. Signal detect signal is asserted when all channels are active. Signal is de-asserted when one or more channel's power drops below threshold.
8. The maximum skew at the input to the receiver across the 12 channels shall be 75ns.
9. The maximum skew introduced across the 12 channels from optical input to electrical output by the receiver module shall be 5ns.

8.1.3. Link Power Budget and Penalties

The specifications in this section are based on a per channel data rate of 1.244160Gb/s data rate, with a maximum guaranteed link distance of 300m. Calculation of optical link performance was conducted with [3,4] and the values given in Table 3 and 4.

Parameter	**Specification**
Fiber	62.5 μm MM fiber
Fiber Cable Max. Attenuation	3.75 dB/km
Min. Modal bandwidth(1)	400 MHz.km
Link Power Budget	6.0 dB
Maximum Number of Connectors	4
Maximum Connector Loss (per Connector)	0.5 dB
Minimum Operating range	2-300 m
Unallocated Margin in Link Power Budget	0.60 dB

Table 4: Link power budget and penalties for worst-case link parameters

(1) Fiber which is guaranteed to provide 500m transmission for Gigabit Ethernet operating at 850nm meets this requirement (see 8.2.2)

8.1.4. Jitter Specification

The jitter specification for the VSR link shall meet the same jitter specification as in the GbE specification (2, Sec. 38.5). Jitter values for the model link shown in Figure 11 are given in Table 5. Note that the TP2 in the Gigabit Ethernet specification (2, 38.2.1) is equivalent to Point #1 in Figure 11, and TP3 in the Gigabit Ethernet specification (2, 38.2.1) is equivalent to Point #4 in Figure 11. Implementations shall conform to the normative values highlighted in bold; other values are informative.

Compliance Point	Total Jitter(a)	Deterministic Jitter
	UI	UI
Point #1	**0.431**	**0.200**
Point #1 to Point #4	0.170	0.050
Point #4	**0.510**	**0.250**

Table 5 – Jitter specification for link shown in Figure 11

(a) Total jitter is composed deterministic and random components. The allowed random jitter equals the allowed total jitter minus the actual deterministic jitter at that point.

8.2. <u>Optical Fiber and Connector Specification</u>

8.2.1. The fiber optic ribbon cable shall contain 12 parallel fibers.

8.2.2. Each fiber shall meet the requirements specified in IEC 793-2: 1992 Type A1b (62.5μm multimode) with the exceptions noted in Table 5.

8.2.3. The ribbon cable shall have a maximum differential skew between fibers of 100 ps/m.

Editor's Note: At the time of writing, there is no standardized fiber that meets the requirements set out in Table 4. A number of vendors are seeking products that meet these requirements but until it becomes standardized it is unable to be specified. Currently 62.5μm fiber which is guaranteed to provide 500m transmission for 1000-Base SX [2] operation meets these requirements. For the purpose calculating the optical link budget an effective modal bandwidth of 400 MHz.km was used to describe this fiber. This fiber will allow link operation up to the designated target distance.
Work is currently underway in TIA FO2.2 to standardize multimode fiber characterization with laser launches. For reference see:
(a) Draft FOTP 203: Launched Power Distribution Measurement Procedure for Graded-Index Multimode Fiber Transmitters
(b) Draft FOTP 204: Measurement of Bandwidth on Multimode Fiber

8.2.4. Connector Specification

The preferred optical connector shall be the MTP™ (MPO) with twelve MM fiber terminations. The orientation of the terminated cable is "keyed" and conforms to IEC standard 1754.7 as shown in Figure 12.

8.2.4.1. The maximum connector loss shall be 0.5dB per mating.

8.2.4.2. Component termination for equipment using OC192 VSR interfaces, the externally accessible transmit and receive optical connectors shall be male connectors.

Note: MTP optical connectors have both male and female versions. While female-female connection is possible, care should be made to prevent this as it will not meet connector loss specifications.

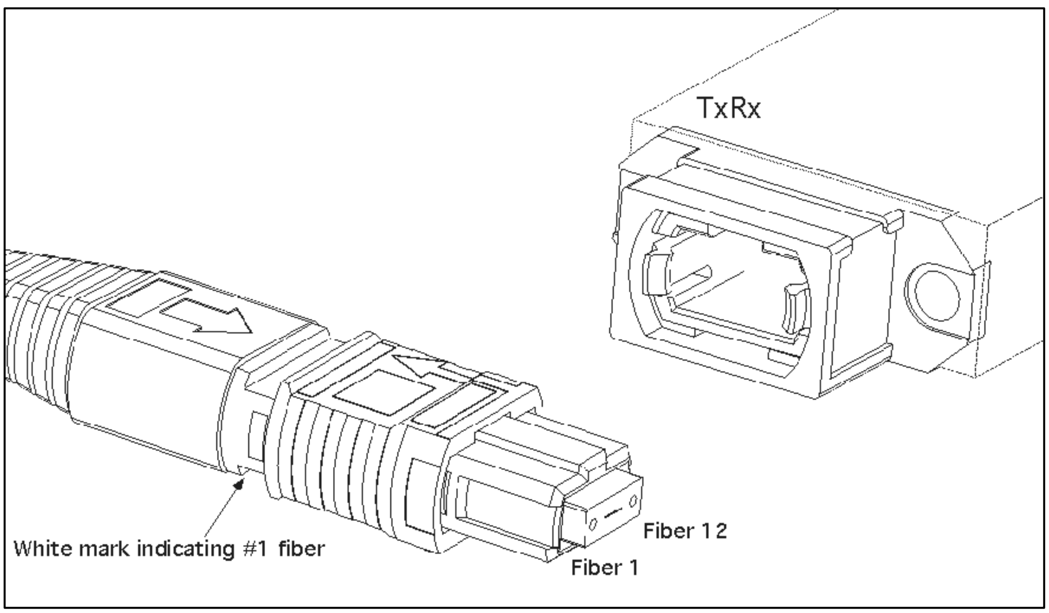

Figure 12: MTP connector interface orientation and parallel optical link receptacle

8.3. Measurement of the Optical Parameters

All measurement of the optical parameters shall be made through a 2m optical patch cable.

8.3.1. Center Wavelength and Spectral Width

The center wavelength and spectral width shall be measured as in [2, Sec. 38.6.1.]

8.3.2. Optical power measurements

The optical power shall be measured as in [2, Sec. 38.6.2.]

8.3.3. Extinction Ratio Measurements

The extinction ratio shall be measured as in [2, Sec. 38.6.3].

8.3.4. Relative Intensity Noise (RIN) Measurements

The RIN shall be measured as in [2, Sec. 38.6.4.]

8.3.5. Eye Mask Test

In order to ensure interoperability among vendor components and systems, an eye mask test shall be performed. The filtered eye mask test shall be measured as in [2, Sec. 38.6.5].

8.3.6. Transmitter Rise/Fall Characteristics

The transmit rise/fall characteristics shall be measured as [2, Sec. 38.6.6].

8.3.7. Receiver Sensitivity Measurements

1. Receivers shall be tested for sensitivity in conformance with [2, Sec. 38.6.7] Additionally there is a crosstalk requirement for the testing.
2. The receiver shall meet the required sensitivity specification with the required conformance test signal with the worst case crosstalk condition of maximum optical power received by the 2 adjacent channels.
3. The adjacent channels shall meet all the specifications in Table 2 and 3.

8.3.8. Receiver 3dB electrical upper cutoff frequency

The receiver 3dB electrical upper cutoff frequency shall be measured as [2, Sec. 38.6.12].

8.3.9. Jitter measurements

The jitter measurements shall be measured as in [2, Sec. 38.6.8 and 38.6.9].

9. APPENDICES

Appendix A: Glossary

Appendix B: Open Issues / current work items

Appendix C: List of companies belonging to OIF when document is approved

Appendix D: References

1. SFI-4 (OIF1999.102) “Proposal for a common electrical interface between SONET frame and serializer/deserializer parts for OC-192 interfaces” Optical Internetworking Forum – Physical Link Layer Working Group

2. IEEE 802.3 Information Technology – Telecommunications and information exchange between systems – Local and metropolitan networks specific requirements – Part 3: “Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications”

3. "Evaluation of Gb/s laser based fiber LAN links: Review of the Gigabit Ethernet model", Mark C. Nowell, David G. Cunningham, Delon C. (Del) Hanson and Leonid Kazovsky, Optical and Quantum Electronics, vol.32, pages 169-192, 2000.

4. "The Gigabit Ethernet Optical Link Model", Chapter 9, Gigabit Ethernet Networking, D. Cunningham, W. Lane, Macmillan Technical Publishing, 1999. ISBN: 1-57870-062-0.

Appendix E: Design Informational Example of LOSyn State Machine

E.1. The LOSyn algorithm shall be based on looking for 8b/10b codeword violations within groupings of 4 codewords defined as codeblocks. If such a violation occurs within a codeblock, it is considered an invalid codeblock.

E.2. By using the detection of codeword violations within codeblocks, the LOSyn state machine shall not only be robust to a burst of errors but also be fast enough on a single channel failure to allow protection to occur before any of the SONET/SDH alarms are triggered

E.3. The reacquisition of synchronization from a LOSyn condition can follow the procedures of a state machine similar to the one shown (in Figure E1).

E.4. A channel functioning normally with continuously valid data remains in State A. The occurrence of consecutive invalid codeblocks causes sequential advancement to States B through E. While in States B through D, a single valid codeblock causes a one state return movement toward State A. LOSyn status is reached and corrective action is taken when a channel arrives at State E. When in State E, if two valid frame delimiters are encountered without the detection of any invalid codeblocks, synchronization is acquired and the channel regains State A. When Power-on or Reset occurs, LOSyn is assumed until two valid frame delimiters with no intervening invalid codeblocks are encountered.

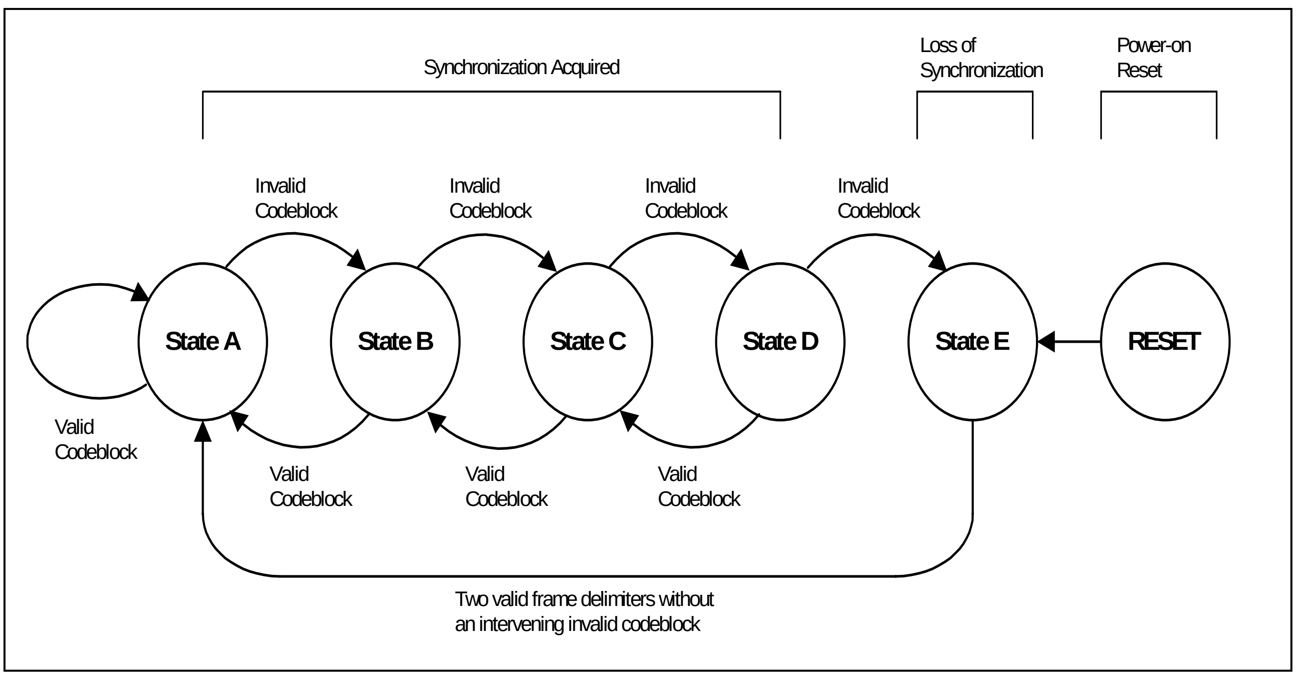

Figure E1: LOSyn state machine example for reacquisition of synchronization