



DRAFT MIPI Alliance Specification for Camera Serial Interface 2 (**CSI-2**)

Draft Version 1.01.00 Revision 0.04 – 2 April 2009

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37 c/o IEEE-ISTO
38 445 Hoes Lane
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MIPI Alliance Specification for Camera Serial Interface 2 (CSI-2)

1 Overview

1.1 Scope

The Camera Serial Interface 2 specification defines an interface between a peripheral device (camera) and a host processor (baseband, application engine). The purpose of this document is to specify a standard interface between a camera and a host processor for mobile applications.

A host processor in this document means the hardware and software that performs essential core functions for telecommunication or application tasks. The engine of a mobile terminal includes hardware and the functions, which enable the basic operation of the mobile terminal. These include, for example, the printed circuit boards, RF components, basic electronics, and basic software, such as the digital signal processing software.

1.2 Purpose

Demand for increasingly higher image resolutions is pushing the bandwidth capacity of existing host processor-to-camera sensor interfaces. Common parallel interfaces are difficult to expand, require many interconnects and consume relatively large amounts of power. Emerging serial interfaces address many of the shortcomings of parallel interfaces while introducing their own problems. Incompatible, proprietary interfaces prevent devices from different manufacturers from working together. This can raise system costs and reduce system reliability by requiring “hacks” to force the devices to interoperate. The lack of a clear industry standard can slow innovation and inhibit new product market entry.

CSI-2 provides the mobile industry a standard, robust, scalable, low-power, high-speed, cost-effective interface that supports a wide range of imaging solutions for mobile devices.

2 Terminology

The MIPI Alliance has adopted Section 13.1 of the *IEEE Standards Style Manual*, which dictates use of the words “shall”, “should”, “may”, and “can” in the development of documentation, as follows:

The word *shall* is used to indicate mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).

The use of the word *must* is deprecated and shall not be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

The use of the word *will* is deprecated and shall not be used when stating mandatory requirements; *will* is only used in statements of fact.

The word *should* is used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required; or that (in the negative form) a certain course of action is deprecated but not prohibited (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

All sections are normative, unless they are explicitly indicated to be informative.

2.1 Definitions

Lane: A differential conductor pair, used for data transmission. For CSI-2 a data Lane is unidirectional.

Packet: A group of two or more bytes organized in a specified way to transfer data across the interface. All packets have a minimum specified set of components. The byte is the fundamental unit of data from which packets are made.

Payload: Application data only – with all sync, header, ECC and checksum and other protocol-related information removed. This is the “core” of transmissions between application processor and peripheral.

Sleep Mode: Sleep mode (SLM) is a leakage level only power consumption mode.

Transmission: The time during which high-speed serial data is actively traversing the bus. A transmission is comprised of one or more packets. A transmission is bounded by SoT (Start of Transmission) and EoT (End of Transmission) at beginning and end, respectively.

Virtual Channel: Multiple independent data streams for up to four peripherals are supported by this specification. The data stream for each peripheral is a Virtual Channel. These data streams may be interleaved and sent as sequential packets, with each packet dedicated to a particular peripheral or channel. Packet protocol includes information that links each packet to its intended peripheral.

420 **2.2 Abbreviations**

421 e.g. For example (Latin: *exempli gratia*)

422 i.e. That is (Latin: *id est*)

423 **2.3 Acronyms**

424 BER Bit Error Rate

425 CIL Control and Interface Logic

426 CRC Cyclic Redundancy Check

427 CSI Camera Serial Interface

428 CSPS Chroma Sample Pixel Shifted

429 DDR Dual Data Rate

430 DI Data Identifier

431 DT Data Type

432 ECC Error Correction Code

433 EoT End of Transmission

434 EXIF Exchangeable Image File Format

435 FE Frame End

436 FS Frame Start

437 HS High Speed; identifier for operation mode

438 HS-RX High-Speed Receiver (Low-Swing Differential)

439 HS-TX High-Speed Transmitter (Low-Swing Differential)

440 I2C Inter-Integrated Circuit

441 JFIF JPEG File Interchange Format

442 JPEG Joint Photographic Expert Group

443 LE Line End

444 LLP Low Level Protocol

445 LS Line Start

446 LSB Least Significant Bit

447	LP	Low-Power; identifier for operation mode
448	LP-RX	Low-Power Receiver (Large-Swing Single Ended)
449	LP-TX	Low-Power Transmitter (Large-Swing Single Ended)
450	MIPI	Mobile Industry Processor Interface
451	MSB	Most Significant Bit
452	PF	Packet Footer
453	PH	Packet Header
454	PI	Packet Identifier
455	PT	Packet Type
456	PHY	Physical Layer
457	PPI	PHY Protocol Interface
458	RGB	Color representation (Red, Green, Blue)
459	RX	Receiver
460	SCL	Serial Clock (for CCI)
461	SDA	Serial Data (for CCI)
462	SLM	Sleep Mode
463	SoT	Start of Transmission
464	TX	Transmitter
465	ULPS	Ultra-low Power State
466	VGA	Video Graphics Array
467	YUV	Color representation (Y for luminance, U & V for chrominance)
468		

3 References

- [PHIL01] *THE I 2C-BUS SPECIFICATION*, version 2.1, Philips Semiconductors, January 2000
- [MIP101] *MIPI Alliance Specification for D-PHY*, version 0.90.00, MIPI Alliance, 8 October 2007

4 Overview of CSI-2

The CSI-2 specification defines standard data transmission and control interfaces between transmitter and receiver. Data transmission interface (referred as CSI-2) is unidirectional differential serial interface with data and clock signals; the physical layer of this interface is the *MIPI Alliance Specification for D-PHY* [MIPI01]. Figure 1 illustrates connections between CSI-2 transmitter and receiver, which typically are a camera module and a receiver module, part of the mobile phone engine.

The control interface (referred as CCI) is a bi-directional control interface compatible with I2C standard.

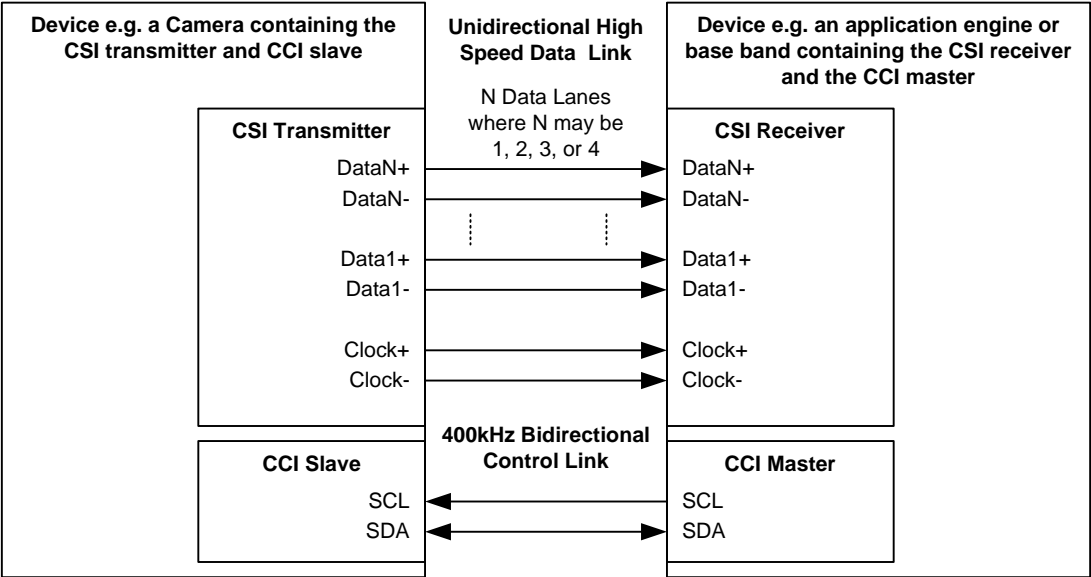
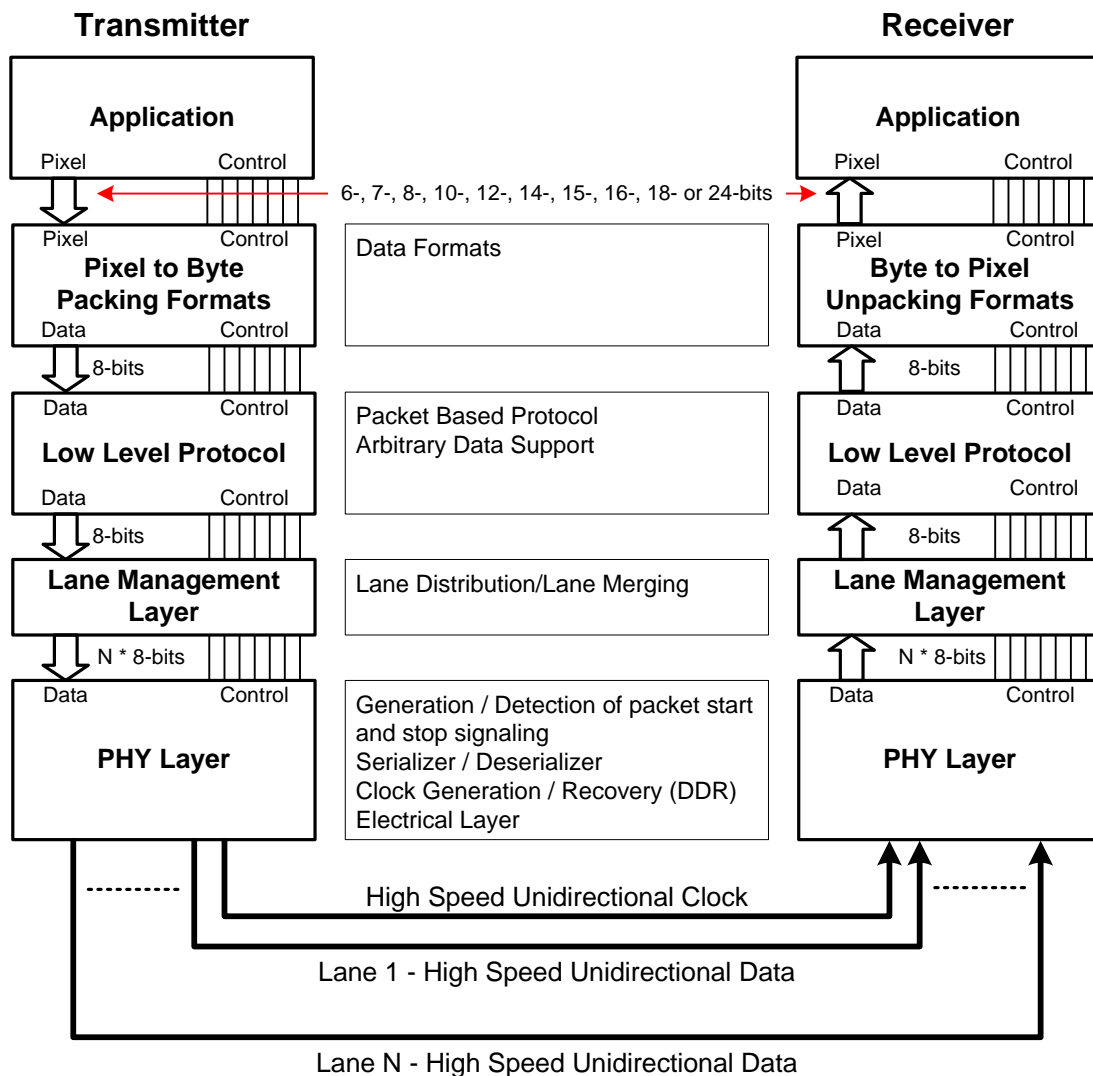


Figure 1 CSI-2 and CCI Transmitter and Receiver Interface

483 **5 CSI-2 Layer Definitions**484
485 **Figure 2 CSI-2 Layer Definitions**

486 Figure 2 defines the conceptual layer structure used in CSI-2. The layers can be characterized as follows:

- 487 • **PHY Layer.** The PHY Layer specifies the transmission medium (electrical conductors), the
488 input/output circuitry and the clocking mechanism that captures “ones” and “zeroes” from the
489 serial bit stream. This part of the specification documents the characteristics of the transmission
490 medium, electrical parameters for signaling and the timing relationship between clock and data
491 Lanes.

492 The mechanism for signaling Start of Transmission (SoT) and End of Transmission (EoT) is
493 specified as well as other “out of band” information that can be conveyed between transmitting
494 and receiving PHYs. Bit-level and byte-level synchronization mechanisms are included as part of
495 the PHY.

496 The PHY layer is described in [MIPI01].

- 497 • **Protocol Layer.** The Protocol layer is composed of several layers, each with distinct
498 responsibilities. The CSI-2 protocol enables multiple data streams using a single interface on the
499 host processor. The Protocol layer specifies how multiple data streams may be tagged and
500 interleaved so each data stream can be properly reconstructed.
 - 501 • **Pixel/Byte Packing/Unpacking Layer.** The CSI-2 supports image applications with varying
502 pixel formats from six to twenty-four bits per pixels. In the transmitter this layer packs pixels
503 from the Application layer into bytes before sending the data to the Low Level Protocol layer.
504 In the receiver this layer unpacks bytes from the Low Level Protocol layer into pixels before
505 sending the data to the Application layer. Eight bits per pixel data is transferred unchanged by
506 this layer.
 - 507 • **Low Level Protocol.** The Low Level Protocol (LLP) includes the means of establishing bit-
508 level and byte-level synchronization for serial data transferred between SoT (Start of
509 Transmission) and EoT (End of Transmission) events and for passing data to the next layer.
510 The minimum data granularity of the LLP is one byte. The LLP also includes assignment of
511 bit-value interpretation within the byte, i.e. the “Endian” assignment.
 - 512 • **Lane Management.** CSI-2 is Lane-scalable for increased performance. The number of data
513 Lanes may be one, two, three or four depending on the bandwidth requirements of the
514 application. The transmitting side of the interface distributes (“distributor” function) the
515 outgoing data stream to one or more Lanes. On the receiving side, the interface collects bytes
516 from the Lanes and merges (“merger” function) them together into a recombined data stream
517 that restores the original stream sequence.
- 518 Data within the Protocol layer is organized as packets. The transmitting side of the interface
519 appends header and optional error-checking information on to data to be transmitted at the Low
520 Level Protocol layer. On the receiving side, the header is stripped off at the Low Level Protocol
521 layer and interpreted by corresponding logic in the receiver. Error-checking information may be
522 used to test the integrity of incoming data.
- 523 • **Application Layer.** This layer describes higher-level encoding and interpretation of data
524 contained in the data stream. The CSI-2 specification describes the mapping of pixel values to
525 bytes.

526 The normative sections of the specification only relate to the external part of the Link, e.g. the data and bit
527 patterns that are transferred across the Link. All internal interfaces and layers are purely informative.

6 Camera Control Interface (CCI)

CCI is a two-wire, bi-directional, half duplex, serial interface for controlling the transmitter. CCI is compatible with the fast mode variant of the I2C interface. CCI shall support 400kHz operation and 7-bit Slave Addressing.

A CSI-2 receiver shall be configured as a master and a CSI-2 transmitter shall be configured as a slave on the CCI bus. CCI is capable of handling multiple slaves on the bus. However, multi-master mode is not supported by CCI. Any I2C commands that are not described in this section shall be ignored and shall not cause unintended device operation. Note that the terms master and slave, when referring to CCI, should not be confused with similar terminology used for D-PHY's operation; they are not related.

Typically, there is a dedicated CCI interface between the transmitter and the receiver.

CCI is a subset of the I2C protocol, including the minimum combination of obligatory features for I2C slave devices specified in the I2C specification. Therefore, transmitters complying with the CCI specification can also be connected to the system I2C bus. However, care must be taken so that I2C masters do not try to utilize those I2C features that are not supported by CCI masters and CCI slaves

Each CCI transmitter may have additional features to support I2C, but that is dependent on implementation. Further details can be found on a particular device's data sheet.

This specification does not attempt to define the contents of control messages sent by the CCI master. As such, it is the responsibility of the CSI-2 implementer to define a set of control messages and corresponding frame timing and I2C latency requirements, if any, that must be met by the CCI master when sending such control messages to the CCI slave.

The CCI defines an additional data protocol layer on top of I2C. The data protocol is presented in the following sections.

6.1 Data Transfer Protocol

The data transfer protocol is according to I2C standard. The START, REPEATED START and STOP conditions as well as data transfer protocol are specified in *The I²C Specification* [PHIL01].

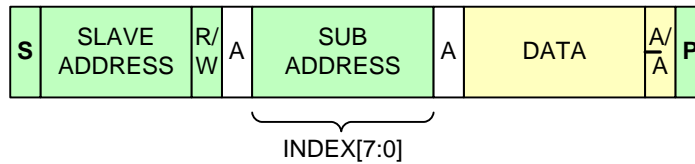
6.1.1 Message Type

A basic CCI message consists of START condition, slave address with read/write bit, acknowledge from slave, sub address (index) for pointing at a register inside the slave device, acknowledge signal from slave, in write operation data byte from master, acknowledge/negative acknowledge from slave and STOP condition. In read operation data byte comes from slave and acknowledge/negative acknowledge from master. This is illustrated in Figure 3.

The slave address in the CCI is 7-bit.

The CCI supports 8-bit index with 8-bit data or 16-bit index with 8-bit data. The slave device in question defines what message type is used.

Message type with 8-bit index and 8-bit data (7-bit address)



Message type with 16-bit index and 8-bit data (7-bit address)

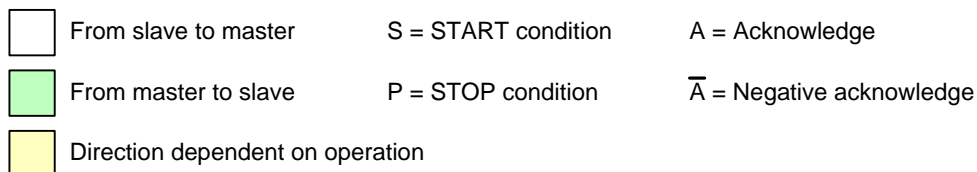
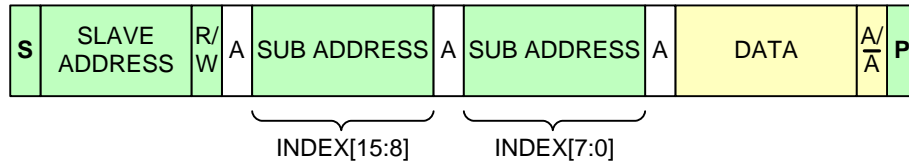


Figure 3 CCI Message Types

6.1.2 Read/Write Operations

The CCI compatible device shall be able to support four different read operations and two different write operations; single read from random location, sequential read from random location, single read from current location, sequential read from current location, single write to random location and sequential write starting from random location. The read/write operations are presented in the following sections.

The index in the slave device has to be auto incremented after each read/write operation. This is also explained in the following sections.

6.1.2.1 Single Read from Random Location

In single read from random location the master does a dummy write operation to desired index, issues a repeated start condition and then addresses the slave again with read operation. After acknowledging its slave address, the slave starts to output data onto SDA line. This is illustrated in Figure 4. The master terminates the read operation by setting a negative acknowledge and stop condition.

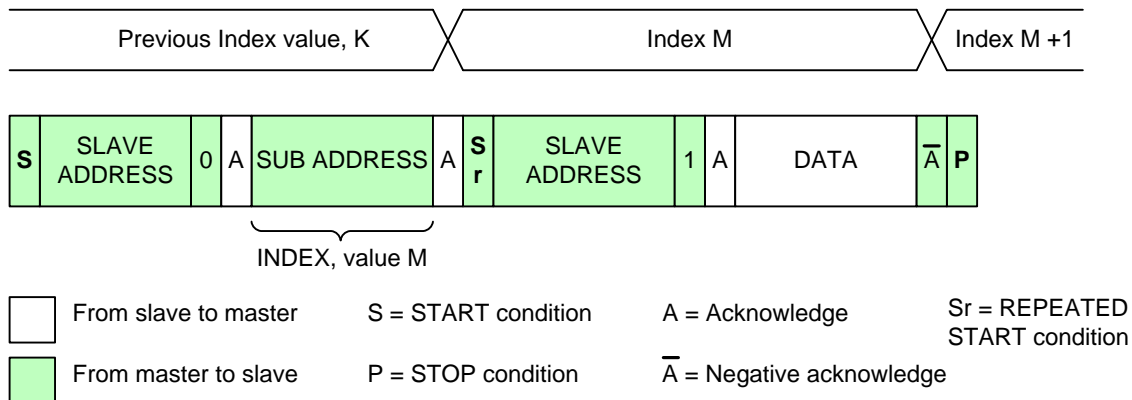


Figure 4 CCI Single Read from Random Location

6.1.2.2 Single Read from the Current Location

It is also possible to read from last used index by addressing the slave with read operation. The slave responds by setting the data from last used index to SDA line. This is illustrated in Figure 5. The master terminates the read operation by setting a negative acknowledge and stop condition.

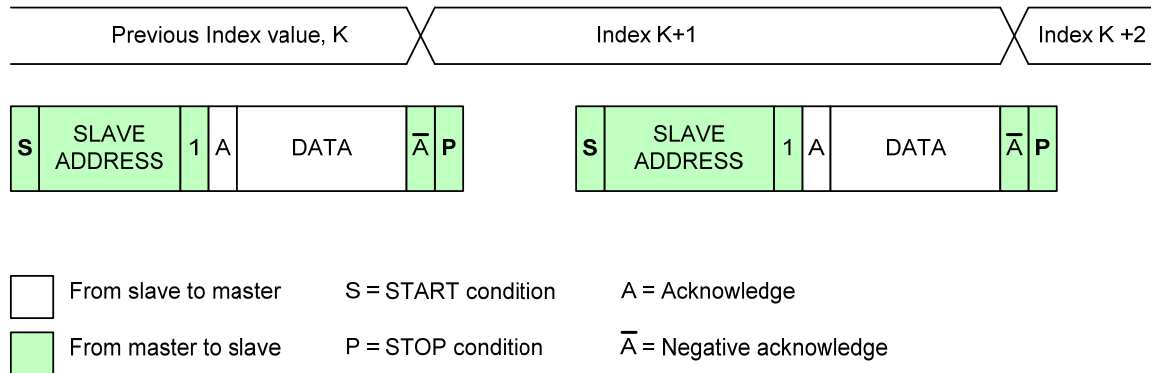


Figure 5 CCI Single Read from Current Location

6.1.2.3 Sequential Read Starting from a Random Location

The sequential read starting from a random location is illustrated in Figure 6. The master does a dummy write to the desired index, issues a repeated start condition after an acknowledge from the slave and then addresses the slave again with a read operation. If a master issues an acknowledge after received data it acts as a signal to the slave that the read operation continues from the next index. When the master has read the last data byte it issues a negative acknowledge and stop condition.

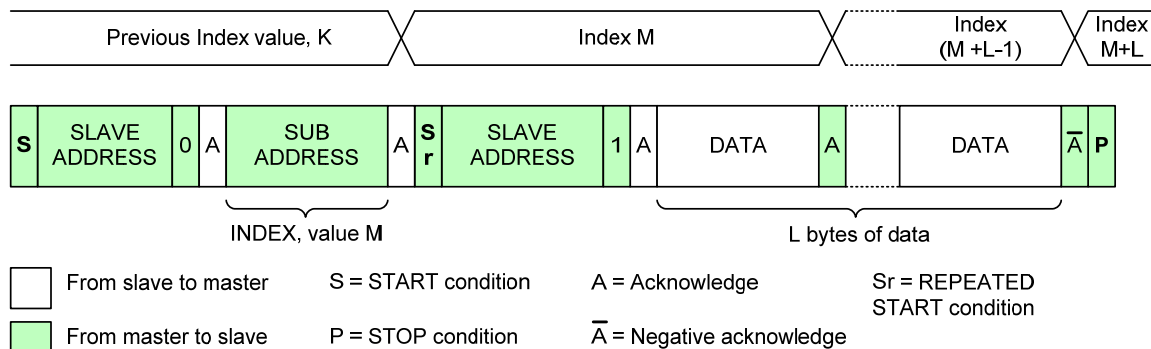


Figure 6 CCI Sequential Read Starting from a Random Location

6.1.2.4 Sequential Read Starting from the Current Location

A sequential read starting from the current location is similar to a sequential read from a random location. The only exception is there is no dummy write operation. The command sequence is illustrated in Figure 7. The master terminates the read operation by issuing a negative acknowledge and stop condition.

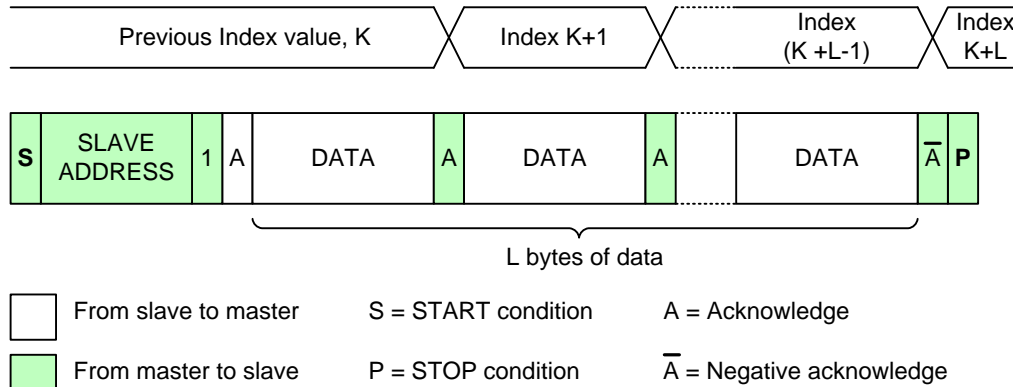


Figure 7 CCI Sequential Read Starting from the Current Location

6.1.2.5 Single Write to a Random Location

A write operation to a random location is illustrated in Figure 8. The master issues a write operation to the slave then issues the index and data after the slave has acknowledged the write operation. The write operation is terminated with a stop condition from the master.

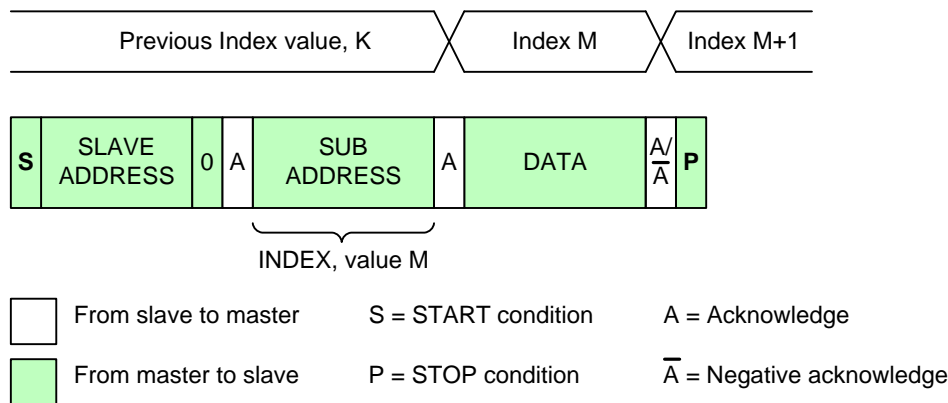


Figure 8 CCI Single Write to a Random Location

6.1.2.6 Sequential Write

The sequential write operation is illustrated in Figure 9. The slave auto-increments the index after each data byte is received. The sequential write operation is terminated with a stop condition from the master.

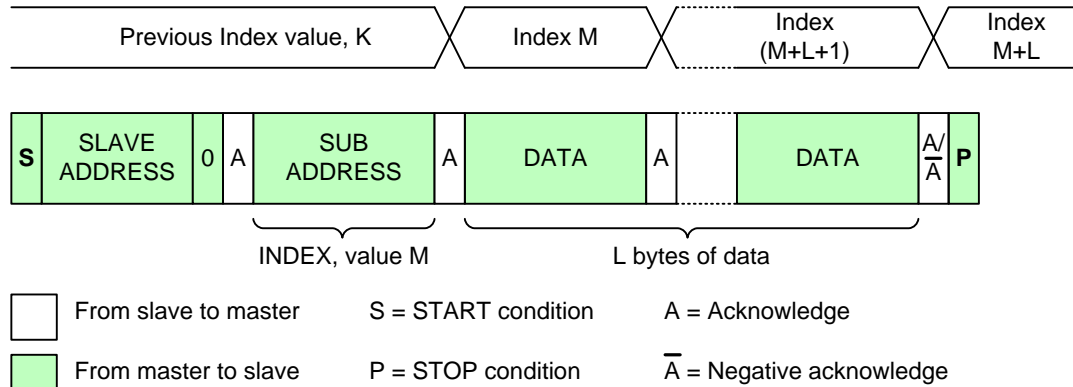


Figure 9 CCI Sequential Write Starting from a Random Location

6.2 CCI Slave Addresses

For camera modules having only raw Bayer output the 7-bit slave address should be 011011Xb, where X = 0 or 1. For all other camera modules the 7-bit slave address should be 011110Xb.

6.3 CCI Multi-Byte Registers

6.3.1 Overview

Peripherals contain a wide range of different register widths for various control and setup purposes. The CSI-2 specification supports the following register widths:

- 8-bit – generic setup registers
- 16-bit – parameters like line-length, frame-length and exposure values
- 32-bit – high precision setup values
- 64-bit – for needs of future sensors

In general, the byte oriented access protocols described in the sections above provide an efficient means to access multi-byte registers. However, the registers should reside in a byte-oriented address space, and the address of a multi-byte register should be the address of its first byte. Thus, addresses of contiguous multi-byte registers will not be contiguous. For example, a 32-bit register with its first byte at address 0x8000 can be read by means of a sequential read of four bytes, starting at random address 0x8000. If there is an additional 4-byte register with its first byte at 0x8004, it could then be accessed using a four-byte Sequential Read from the Current Location protocol.

The motivation for a general multi-byte protocol rather than fixing the registers at 16-bits width is flexibility. The protocol to be described below provides a way of transferring 16-bit, 32-bit or 64-bit values over a 16-bit index, 8-bit data, two-wire serial link while ensuring that the bytes of data transferred for a multi-byte register value are always consistent (temporally coherent).

Using this protocol a single CCI message can contain one, two or all of the different register widths used within a device.

The MS byte of a multi-byte register shall be located at the lowest address and the LS byte at the highest address.

The address of the first byte of a multi-byte register may, or may not be, aligned to the size of the register; i.e., a multiple of the number of register bytes. The register alignment is an implementation choice between processing optimized and bandwidth optimized organizations. There are no restrictions on the number or mix of multi-byte registers within the available 64K by 8-bit index space, with the exception that rules for the valid locations for the MS bytes and LS bytes of registers are followed.

Partial access to multi-byte registers is not allowed. A multi-byte register shall only be accessed by a single sequential message. When a multi-byte register is accessed, its first byte is accessed first, its second byte is accessed second, etc.

When a multi-byte register is accessed, the following re-timing rules must be followed:

- For a Write operation, the updating of the register shall be deferred to a time when the last bit of the last byte has been received
- For a Read operation, the value read shall reflect the status of all bytes at the time that the first bit of the first byte has been read

Section 6.3.3 describes example behavior for the re-timing of multi-byte register accesses.

Without re-timing data may be corrupted as illustrated in Figure 10 and Figure 11 below.

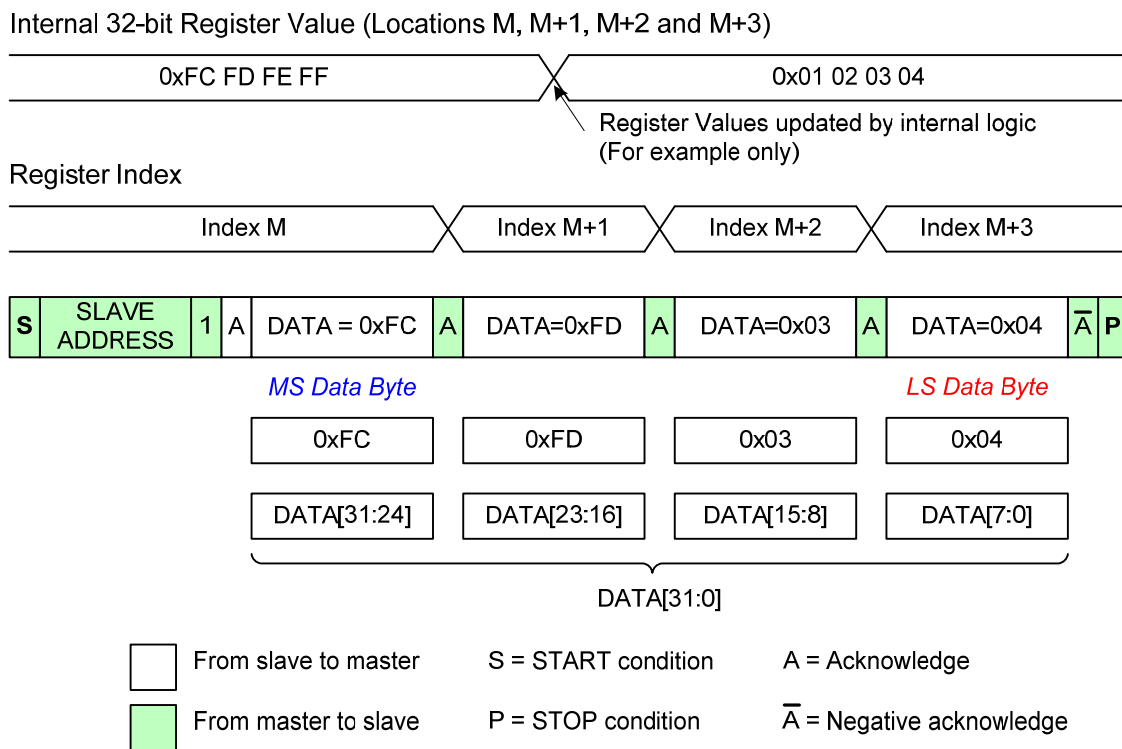


Figure 10 Corruption of a 32-bit Wide Register during a Read Message

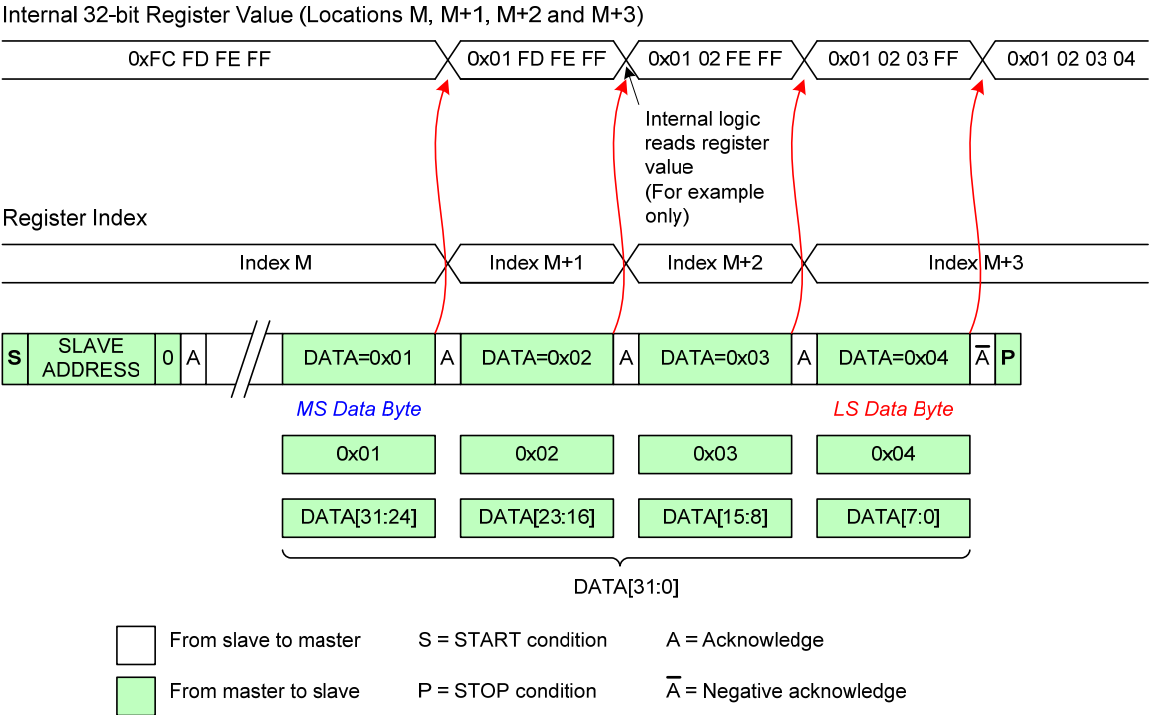


Figure 11 Corruption of a 32-bit Wide Register during a Write Message

6.3.2 The Transmission Byte Order for Multi-byte Register Values

This is a normative section.

The first byte of a CCI message is always the MS byte of a multi-byte register and the last byte is always the LS byte.

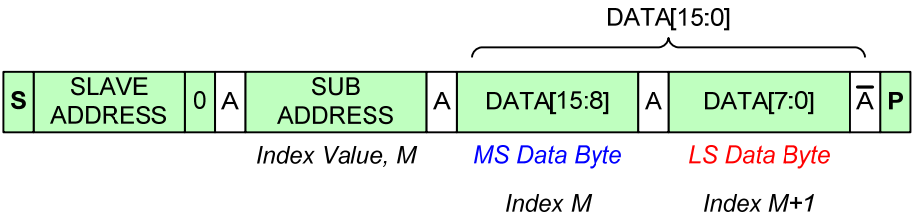


Figure 12 Example 16-bit Register Write

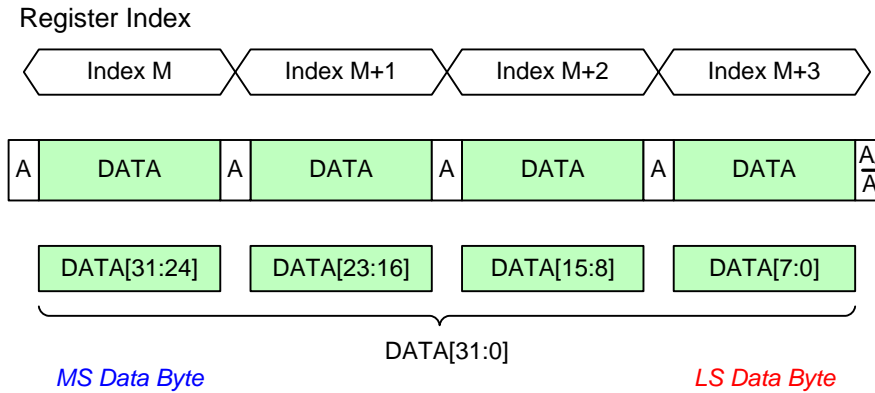


Figure 13 Example 32-bit Register Write (address not shown)

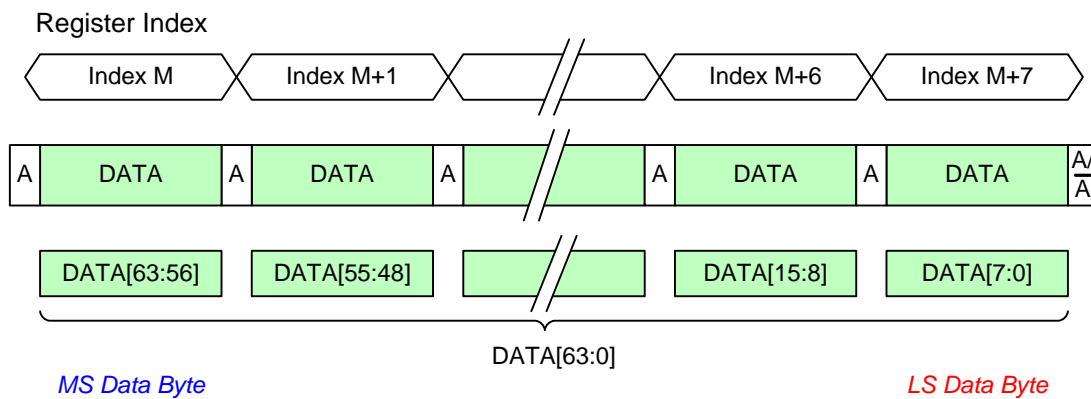


Figure 14 Example 64-bit Register Write (address not shown)

6.3.3 Multi-Byte Register Protocol

This is an informative section.

Each device may have both single and multi-byte registers. Internally a device must understand what addresses correspond to the different register widths.

6.3.3.1 Reading Multi-byte Registers

To ensure that the value read from a multi-byte register is consistent, i.e. all bytes are temporally coherent, the device internally transfers the contents of the register into a temporary buffer when the MS byte of the register is read. The contents of the temporary buffer are then output as a sequence of bytes on the SDA line. Figure 15 and Figure 16 illustrate multi-byte register read operations.

The temporary buffer is always updated unless the read operation is incremental within the same multi-byte register.

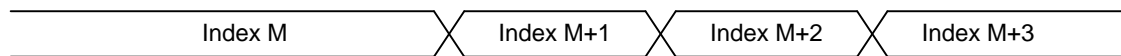
Internal 16-bit Register Value (Locations M and M+1)



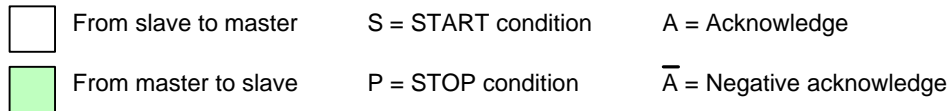
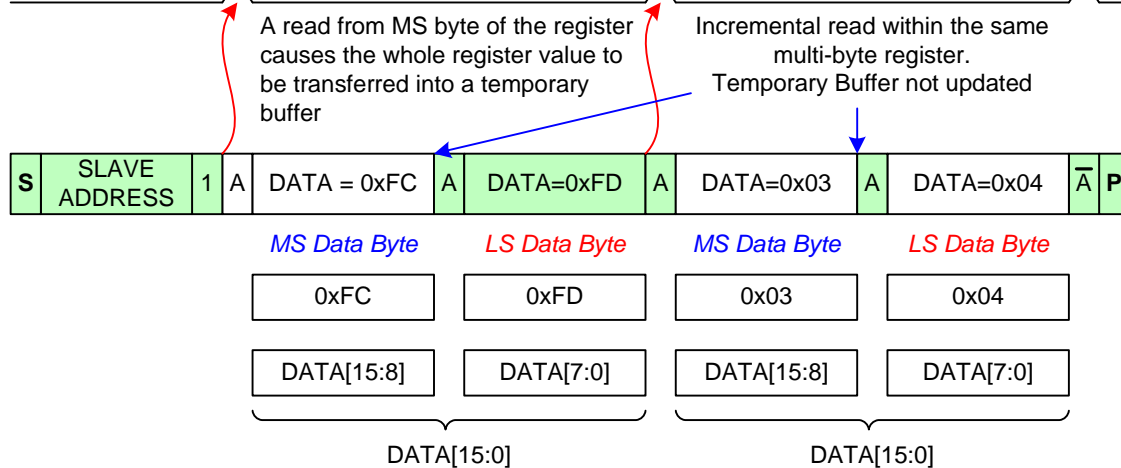
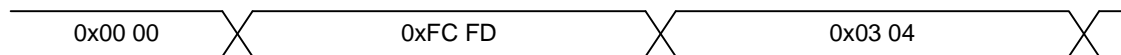
Internal 16-bit Register Value (Locations M+2 and M+3)



Register Index



Temporary Buffer

**Figure 15 Example 16-bit Register Read**

In this definition there is no distinction made between whether the register is accessed incrementally via separate, single byte read messages with no intervening data writes or via a single multi-location read message. This protocol purely relates to the behavior of the index value.

Examples of when the temporary buffer is updated are as follows:

- The MS byte of a register is accessed
- The index has crossed a multi-byte register boundary
- Successive single byte reads from the same index location
- The index value for the byte about to be read is the same or less than the previous index

Unless the contents of a multi-byte register are accessed in an incremental manner the values read back are not guaranteed to be consistent.

The contents of the temporary buffer are reset to zero by START and STOP conditions.

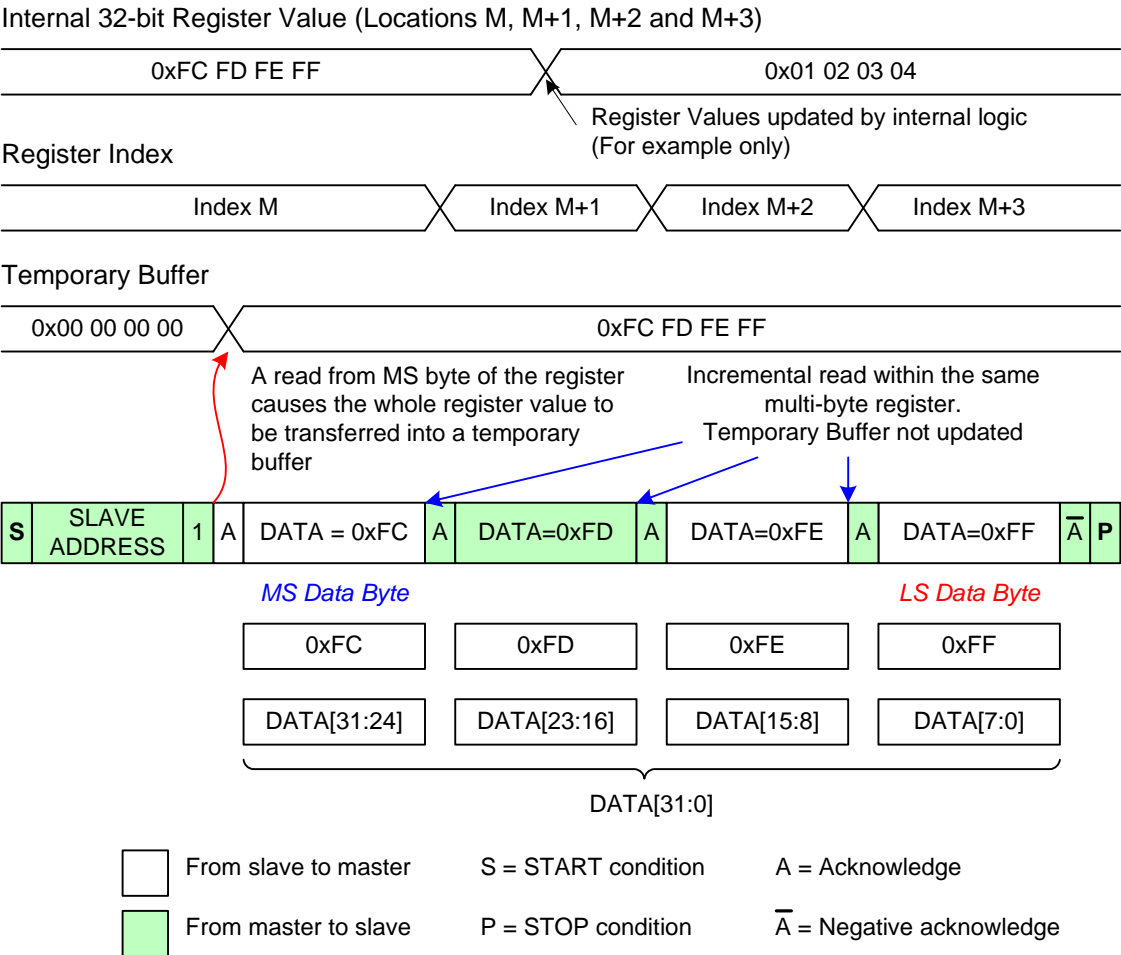


Figure 16 Example 32-bit Register Read

6.3.3.2 Writing Multi-byte Registers

To ensure that the value written is consistent, the bytes of data of a multi-byte register are written into a temporary buffer. Only after the LS byte of the register is written is the full multi-byte value transferred into the internal register location. Figure 17 and Figure 18 illustrate multi-byte register write operations.

CCI messages that only write to the LS or MS byte of a multi-byte register are not allowed. Single byte writes to a multi-byte register addresses may cause undesirable behavior in the device.

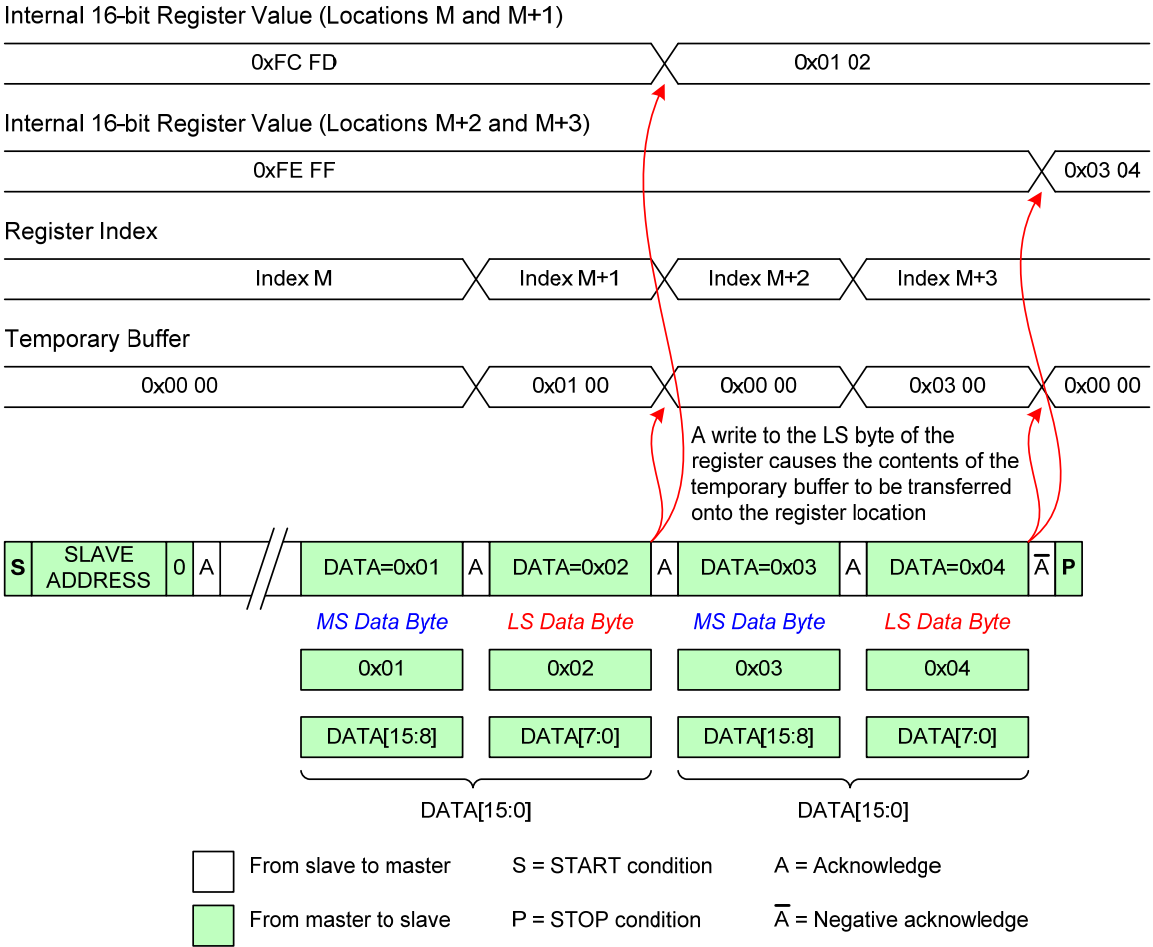


Figure 17 Example 16-bit Register Write

Internal 32-bit Register Value (Locations M, M+1, M+2 and M+3)

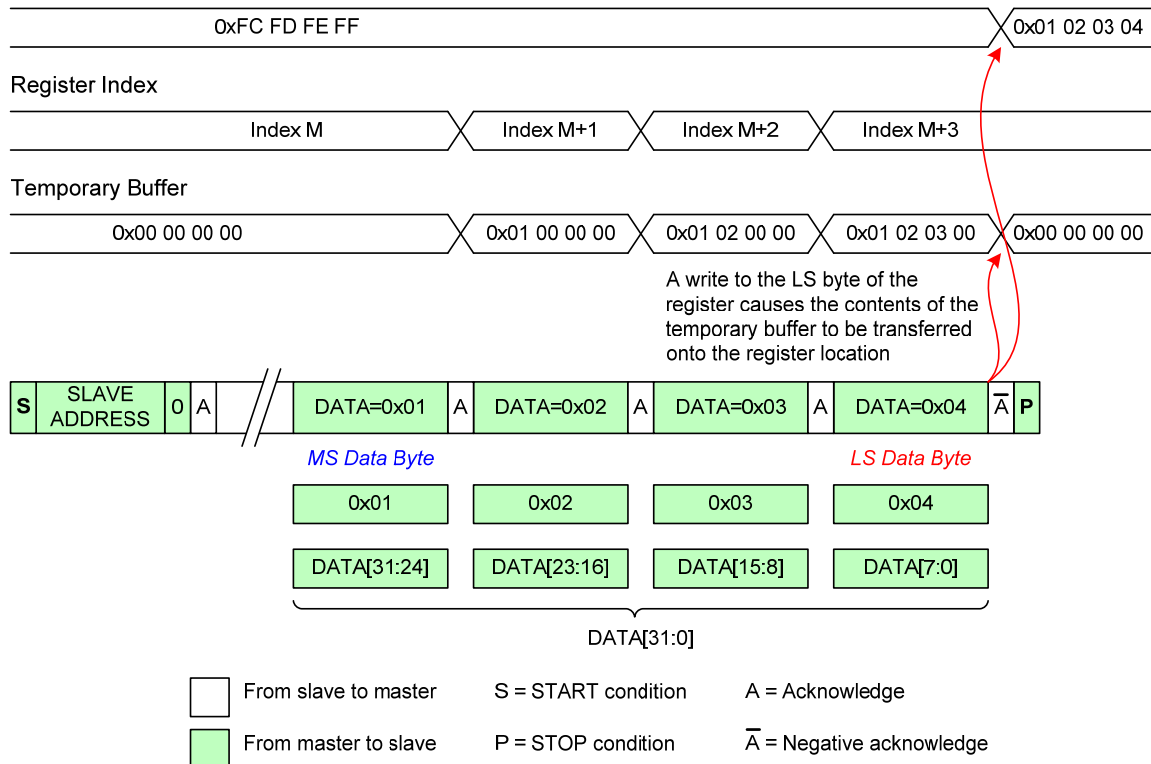


Figure 18 Example 32-bit Register Write

6.4 Electrical Specifications and Timing for I/O Stages

The electrical specification and timing for I/O stages conform to I²C Standard- and Fast-mode devices. Information presented in Table 1 is from [PHIL01].

Table 1 CCI I/O Characteristics

Parameter	Symbol	Standard-mode		Fast-mode		Unit
		Min.	Max.	Min.	Max.	
LOW level input voltage	V _{IL}	-0.5	0.3V _{DD}	-0.5	0.3 V _{DD}	V
HIGH level input voltage	V _{IH}	0.7V _{DD}	Note 1	0.7V _{DD}	Note 1	V
Hysteresis of Schmitt trigger inputs V _{DD} > 2V V _{DD} < 2V	V _{HYS}	N/A N/A	N/A N/A	0.05V _{DD} 0.1V _{DD}	- -	V
LOW level output voltage (open drain) at 3mA sink current V _{DD} > 2V V _{DD} < 2V	V _{OL1} V _{OL3}	0 N/A	0.4 N/A	0 0	0.4 0.2V _{DD}	V

Parameter	Symbol	Standard-mode		Fast-mode		Unit
		Min.	Max.	Min.	Max.	
HIGH level output voltage	V_{OH}	N/A	N/A	$0.8V_{DD}$		V
Output fall time from V_{IHmin} to V_{ILmax} with bus capacitance from 10 pF to 400 pF	t_{OF}	-	250	$20+0.1C_B$ Note 2	250	ns
Pulse width of spikes which shall be suppressed by the input filter	t_{SP}	N/A	N/A	0	50	ns
Input current each I/O pin with an input voltage between 0.1 V_{DD} and 0.9 V_{DD}	I_I	-10	10	-10 Note 3	10 Note 3	μA
Input/Output capacitance (SDA)	$C_{I/O}$	-	8	-	8	pF
Input capacitance (SCL)	C_I	-	6	-	6	pF

709 Notes:

710 1. Maximum $V_{IH} = V_{DDmax} + 0.5V$

711 2. C_B = capacitance of one bus line in pF

712 3. I/O pins of Fast-mode devices shall not obstruct the SDA and SCL line if V_{DD} is switched off

713

Table 2 CCI Timing Specification

Parameter	Symbol	Standard-mode		Fast-mode		Unit
		Min.	Max.	Min.	Max.	
SCL clock frequency	f_{SCL}	0	100	0	400	kHz
Hold time (repeated) START condition. After this period, the first clock pulse is generated	$t_{HD;STA}$	0.4	-	0.6	-	μs
LOW period of the SCL clock	t_{LOW}	4.7	-	1.3	-	μs
HIGH period of the SCL clock	t_{HIGH}	4.0	-	0.6	-	μs
Setup time for a repeated START condition	$t_{SU;STA}$	4.7	-	0.6	-	μs
Data hold time	$t_{HD;DAT}$	0 Note 2	3.45 Note 3	0 Note 2	0.9 Note 3	μs
Data set-up time	$t_{SU;DAT}$	250	-	100 Note 4	-	ns
Rise time of both SDA and SCL signals	t_R	-	1000	$20+0.1C_B$ Note 5	300	ns
Fall time of both SDA and SCL signals	t_F	-	300	$20+0.1C_B$ Note 5	300	ns
Set-up time for STOP condition	$t_{SU;STO}$	4.0	-	0.6	-	μs
Bus free time between a STOP	t_{BUF}	4.7	-	1.3	-	μs

Parameter	Symbol	Standard-mode		Fast-mode		Unit
		Min.	Max.	Min.	Max.	
and START condition						
Capacitive load for each bus line	C_B	-	400	-	400	pF
Noise margin at the LOW level for each connected device (including hysteresis)	V_{nL}	$0.1V_{DD}$	-	$0.1V_{DD}$	-	V
Noise margin at the HIGH level for each connected device (including hysteresis)	V_{nH}	$0.2V_{DD}$	-	$0.2V_{DD}$	-	V

Notes:

1. All values referred to $V_{IHmin} = 0.7V_{DD}$ and $V_{ILmax} = 0.3V_{DD}$
2. A device shall internally provide a hold time of at least 300 ns for the SDA signal (referred to the V_{IHmin} of the SCL signal) to bridge the undefined region of the falling edge of SCL
3. The maximum $t_{HD:DAT}$ has only to be met if the device does not the LOW period (t_{LOW}) of the SCL signal
4. A Fast-mode I2C-bus device can be used in a Standard-mode I2C-bus system, but the requirement $t_{SU:DAT} \geq 250$ ns shall be then met. This will be automatically the case if the device does not stretch the LOW period of the SCL signal. If such device does stretch the low period of SCL signal, it shall output the next data bit to the SDA line $t_{rMAX} + t_{SU:DAT} = 1000 + 250 = 1250$ ns (according to the Standard-mode I2C bus specification) before the SCL line is released.
5. C_B = total capacitance of one bus line in pF.

The CCI timing is illustrated in Figure 19.

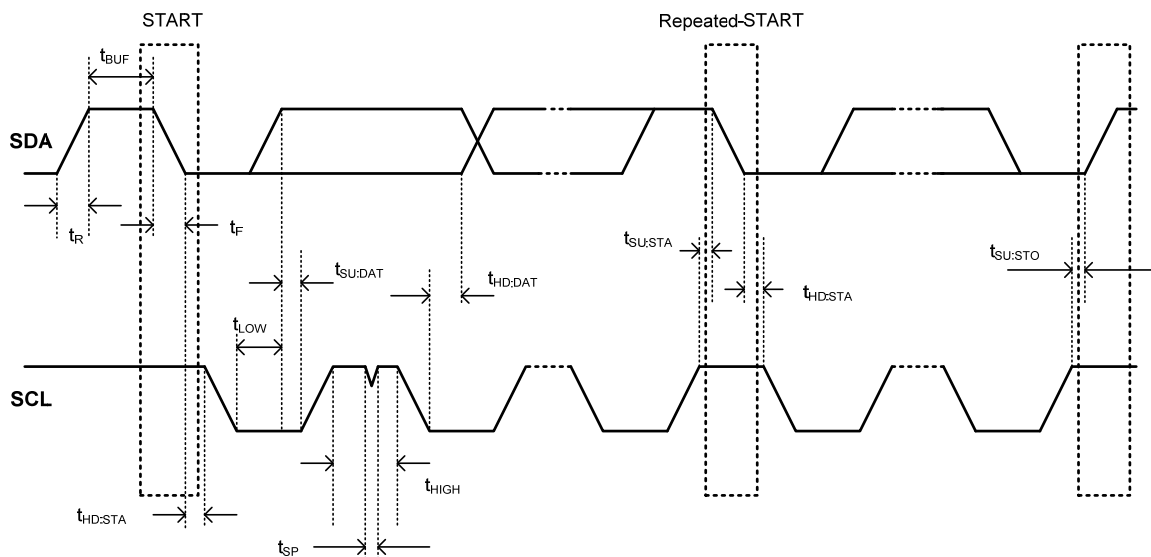


Figure 19 CCI Timing

7 Physical Layer

The CSI-2 uses the [MIPI01] physical layer.

The physical layer for a CSI-2 implementation is composed of between one and four unidirectional data Lanes and one clock Lane. All CSI-2 transmitters and receivers shall support continuous clock behavior on the Clock Lane, and optionally may support non-continuous clock behavior.

For continuous clock behavior the Clock Lane remains in high-speed mode generating active clock signals between the transmission of data packets.

For non-continuous clock behavior the Clock Lane enters the LP-11 state between the transmission of data packets.

The minimum physical layer requirement for a CSI-2 transmitter is

- Data Lane Module: Unidirectional master, HS-TX, LP-TX and a CIL-MFEN function
- Clock Lane Module: Unidirectional master, HS-TX, LP-TX and a CIL-MCNN function

The minimum physical layer requirement for a CSI-2 receiver is

- Data Lane Module: Unidirectional slave, HS-RX, LP-RX, and a CIL-SFEN function
- Clock Lane Module: Unidirectional slave, HS-RX, LP-RX, and a CIL-SCNN function

All CSI-2 implementations shall support forward escape ULPS on all Data Lanes.

8 Multi-Lane Distribution and Merging

CSI-2 is a Lane-scalable specification. Applications requiring more bandwidth than that provided by one data Lane, or those trying to avoid high clock rates, can expand the data path to two, three, or four Lanes wide and obtain approximately linear increases in peak bus bandwidth. The mapping between data at higher layers and the serial bit stream is explicitly defined to ensure compatibility between host processors and peripherals that make use of multiple data Lanes.

Conceptually, between the PHY and higher functional layers is a layer that handles multi-Lane configurations. In the transmitter, the layer distributes a sequence of packet bytes across N Lanes, where each Lane is an independent unit of physical-layer logic (serializers, etc.) and transmission circuitry. In the receiver, it collects incoming bytes from N Lanes and consolidates (merges) them into complete packets to pass into the packet decomposer.

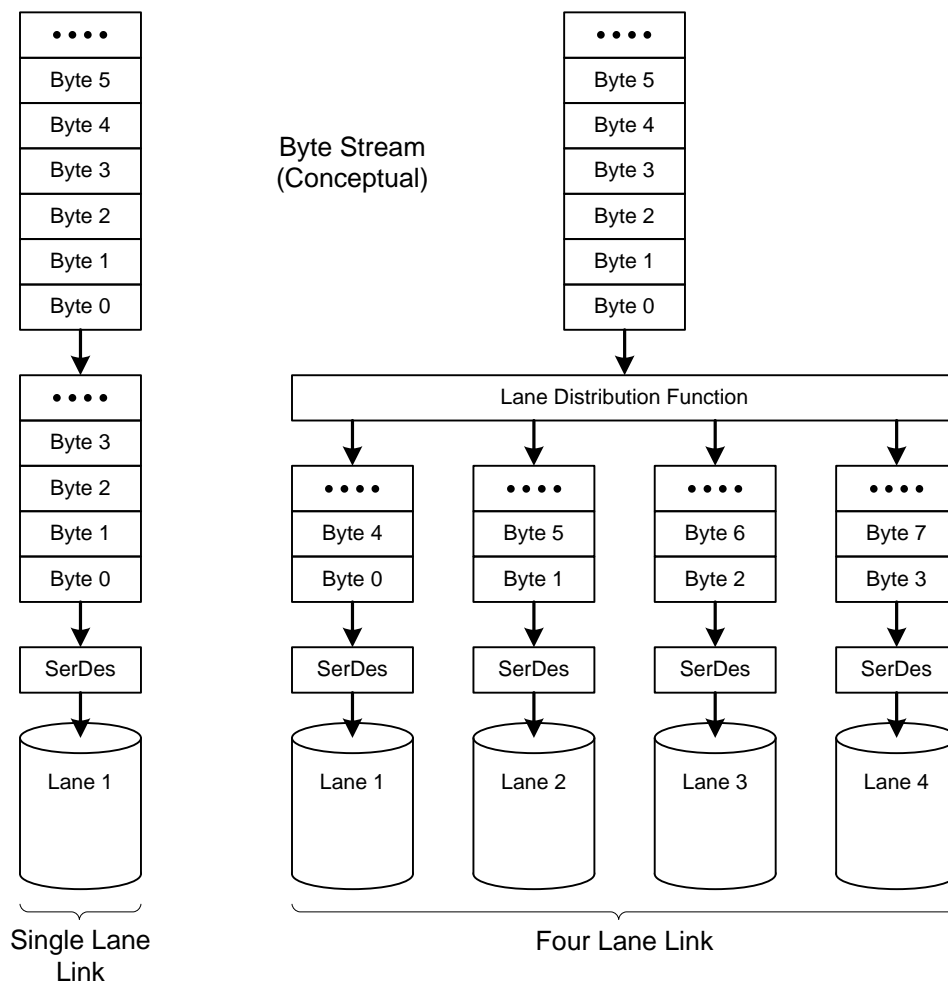


Figure 20 Conceptual Overview of the Lane Distributor Function

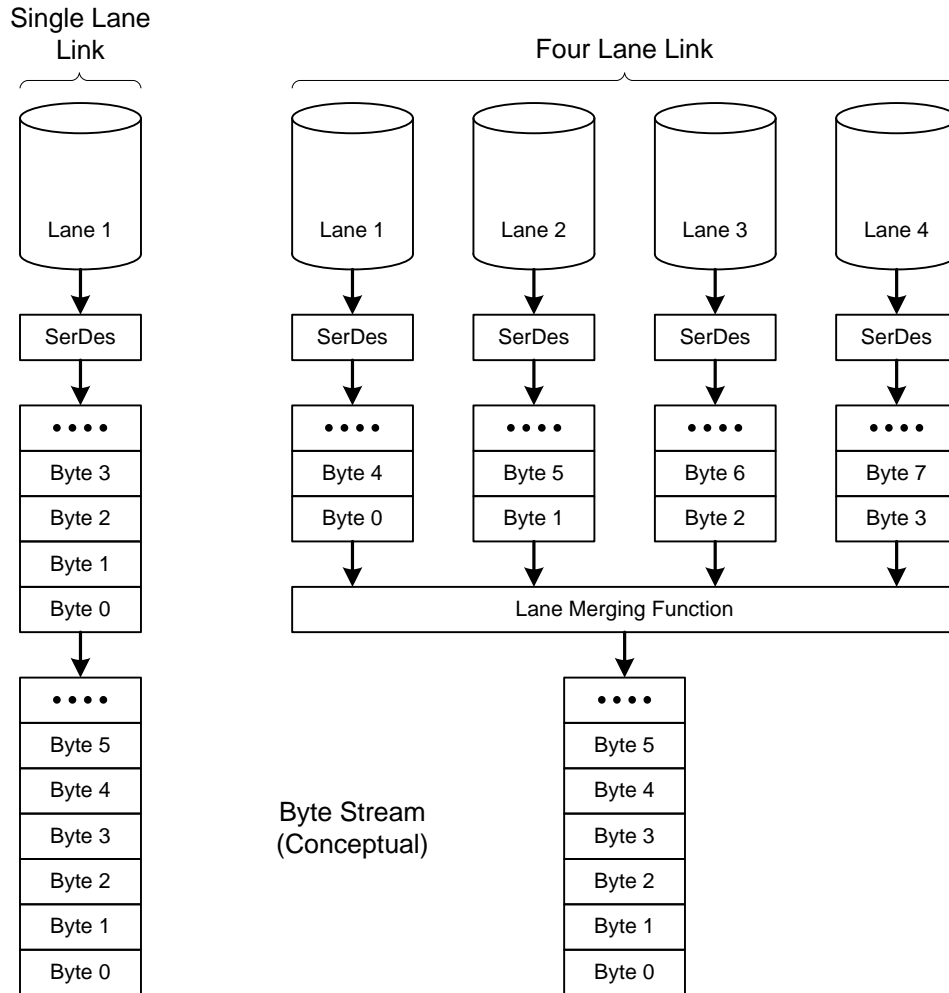


Figure 21 Conceptual Overview of the Lane Merging Function

The Lane distributor takes a transmission of arbitrary byte length, buffers up N bytes (where N = number of Lanes), and then sends groups of N bytes in parallel across N Lanes. Before sending data, all Lanes perform the SoT sequence in parallel to indicate to their corresponding receiving units that the first byte of a packet is beginning. After SoT, the Lanes send groups of successive bytes from the first packet in parallel, following a round-robin process.

Examples:

- 2-Lane system (Figure 22): byte 0 of the packet goes to Lane 1, byte 1 goes to Lane 2, byte 2 to Lane 1, byte 3 goes to Lane 2, byte 4 goes to Lane 1 and so on.
- 3-Lane system (Figure 23): byte 0 of the packet goes to Lane 1, byte 1 goes to Lane 2, byte 2 to Lane 3, byte 3 goes to Lane 1, byte 4 goes to Lane 2 and so on.
- 4-Lane system (Figure 24): byte 0 of the packet goes to Lane 1, byte 1 goes to Lane 2, byte 2 to Lane 3, byte 3 goes to Lane 4, byte 4 goes to Lane 1 and so on

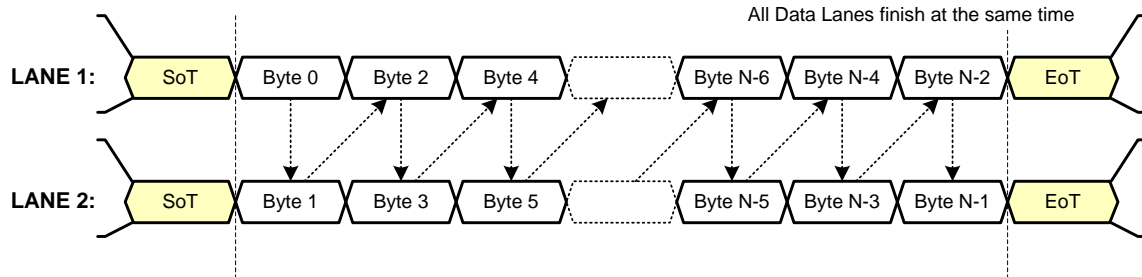
At the end of the transmission, there may be “extra” bytes since the total byte count may not be an integer multiple of the number of Lanes, N. One or more Lanes may send their last bytes before the others. The Lane distributor, as it buffers up the final set of less-than-N bytes in parallel for sending to N data Lanes, de-asserts its “valid data” signal into all Lanes for which there is no further data.

Each D-PHY data Lane operates autonomously.

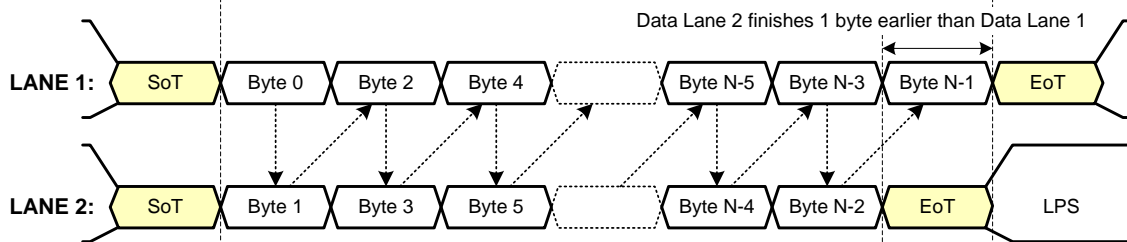
Although multiple Lanes all start simultaneously with parallel “start packet” codes, they may complete the transaction at different times, sending “end packet” codes one cycle (byte) apart.

The N PHYs on the receiving end of the link collect bytes in parallel, and feed them into the Lane-merging layer. This reconstitutes the original sequence of bytes in the transmission, which can then be partitioned into individual packets for the packet decoder layer.

Number of Bytes, N, transmitted is an integer multiple of the number of lanes:



Number of Bytes, N, transmitted is NOT an integer multiple of the number of lanes:



KEY:

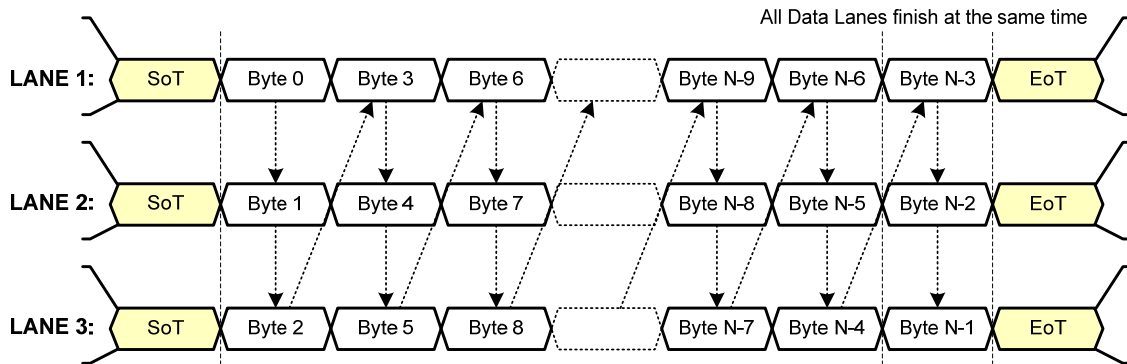
LPS – Low Power State

SoT – Start of Transmission

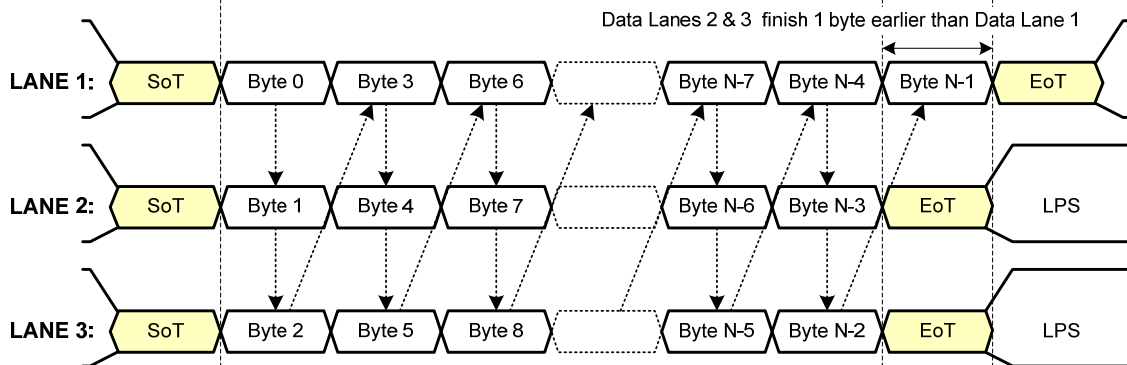
EoT – End of Transmission

Figure 22 Two Lane Multi-Lane Example

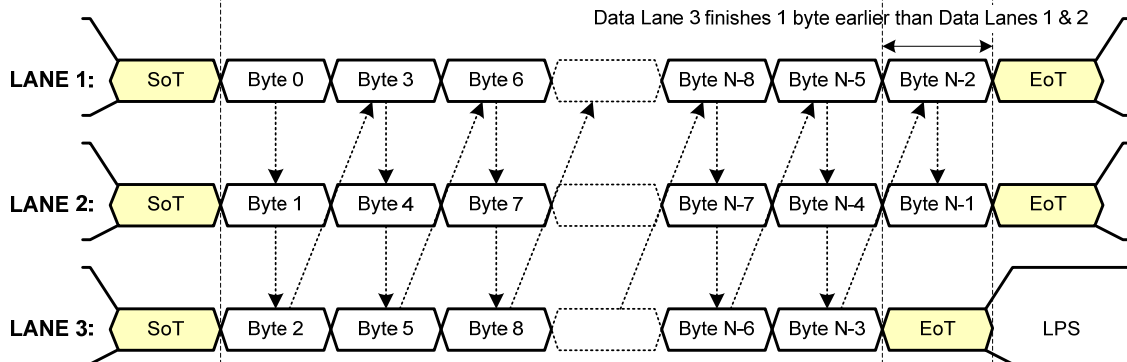
Number of Bytes, N , transmitted is an integer multiple of the number of lanes:



Number of Bytes, N , transmitted is NOT an integer multiple of the number of lanes (Example 1):



Number of Bytes, N , transmitted is NOT an integer multiple of the number of lanes (Example 2):



KEY:

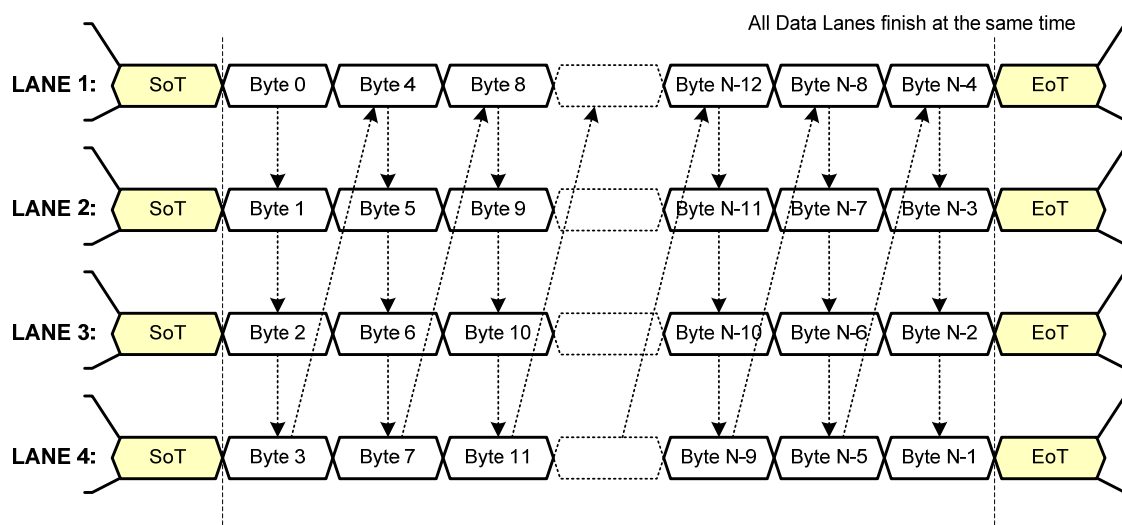
LPS – Low Power State

SoT – Start of Transmission

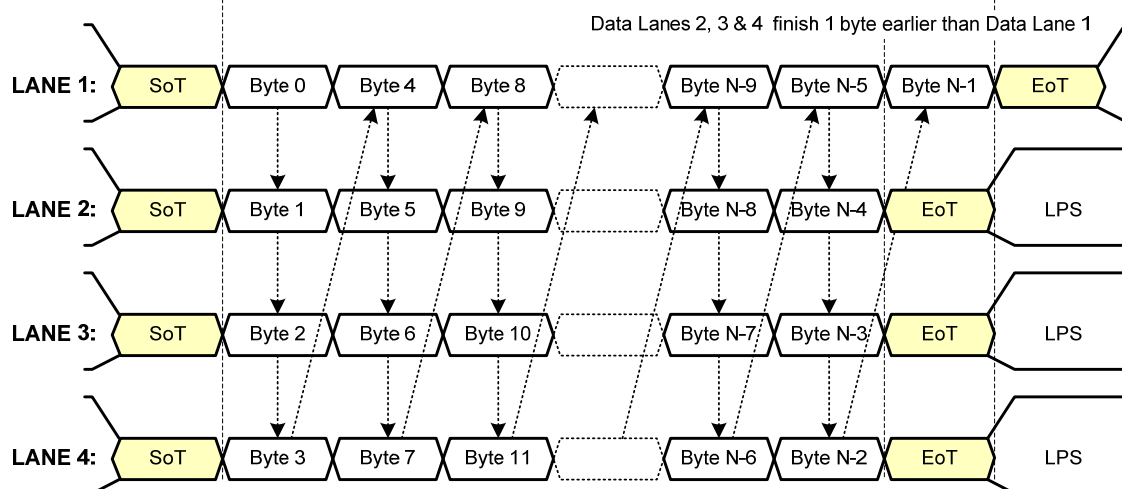
EoT – End of Transmission

Figure 23 Three Lane Multi-Lane Example

Number of Bytes, N, transmitted is an integer multiple of the number of lanes:



Number of Bytes, N, transmitted is NOT an integer multiple of the number of lanes:



KEY:

LPS – Low Power State

SoT – Start of Transmission

EoT – End of Transmission

Figure 24 Four Lane Multi-Lane Example

8.1 Multi-Lane Interoperability

The Lane distribution and merging layers shall be reconfigurable via the Camera Control Interface when more than one data Lane is used.

An "N" data Lane receiver shall be connected with an "M" data Lane transmitter, by CCI configuration of the Lane distribution and merging layers within the CSI-2 transmitter and receiver when more than one data Lane is used. Thus, a receiver with four data Lanes shall work with transmitters with one, two, three or four data Lanes. Likewise, a transmitter with four data Lanes shall work with receivers with four or fewer data Lanes. Transmitter Lanes 1 to M shall be connected to the receiver Lanes 1 to M.

Two cases:

- If $M \leq N$ then there is no loss of performance – the receiver has sufficient data Lanes to match the transmitter (Figure 25 and Figure 26).
- If $M > N$ then there may be a loss of performance (e.g. frame rate) as the receiver has fewer data Lanes than the transmitter (Figure 27 and Figure 28).

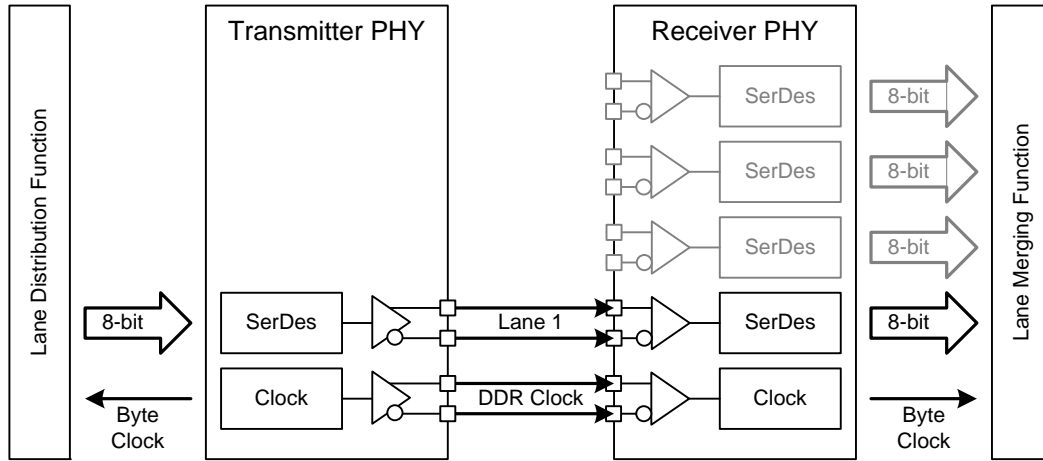


Figure 25 One Lane Transmitter and Four Lane Receiver Example

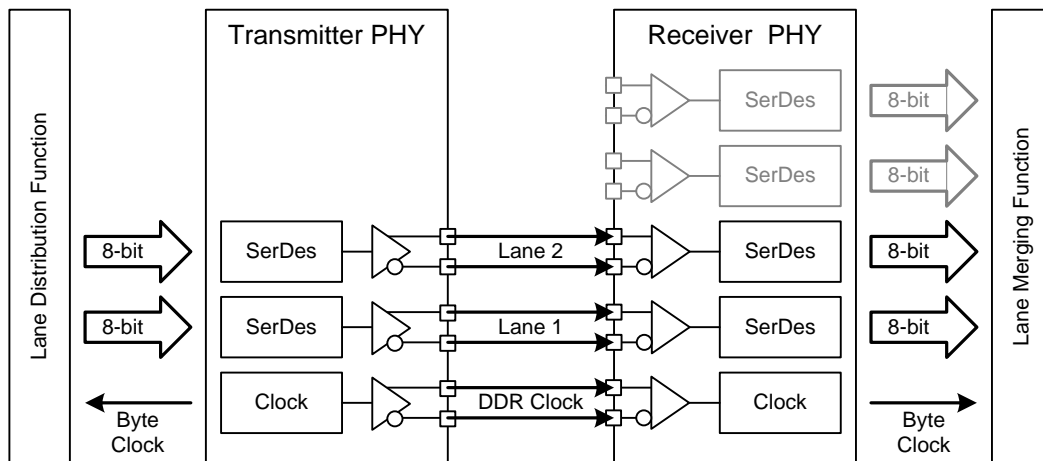


Figure 26 Two Lane Transmitter and Four Lane Receiver Example

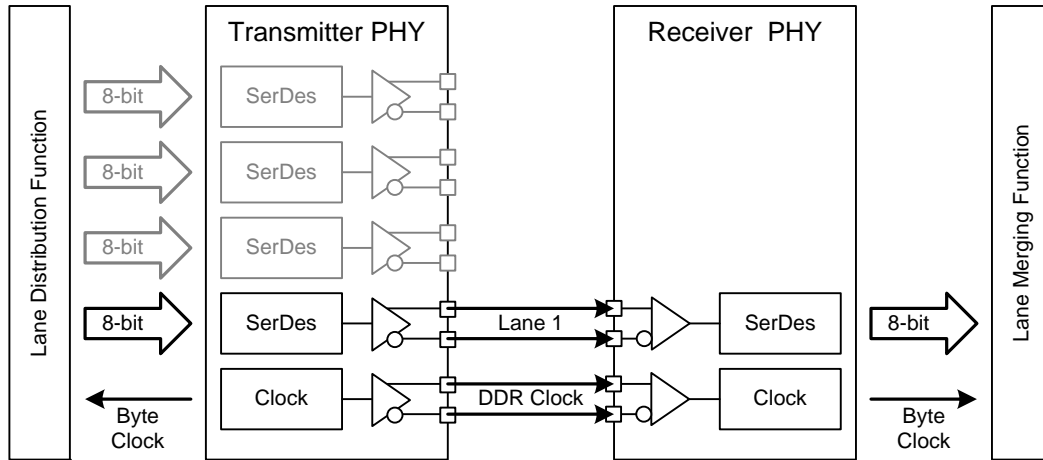


Figure 27 Four Lane Transmitter and One Lane Receiver Example

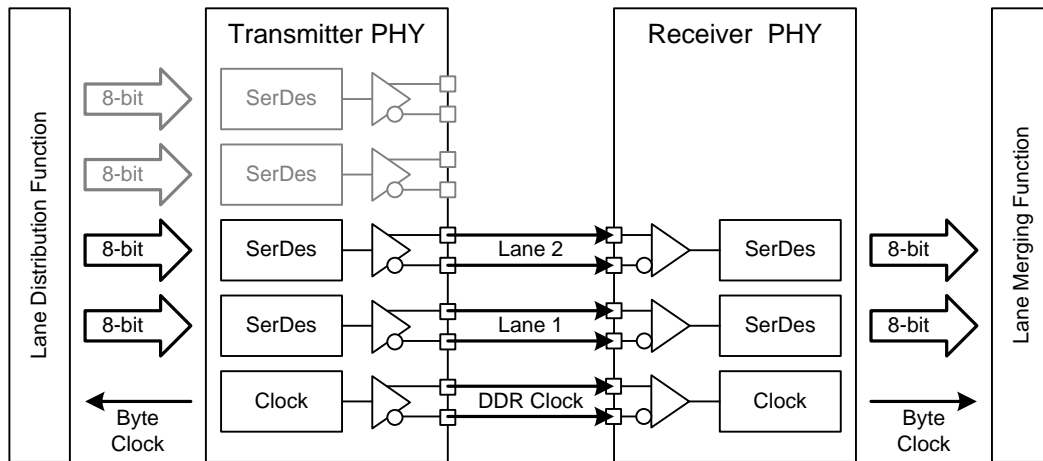


Figure 28 Four Lane Transmitter and Two Lane Receiver Example

9 Low Level Protocol

The Low Level Protocol (LLP) is a byte orientated, packet based protocol that supports the transport of arbitrary data using Short and Long packet formats. For simplicity, all examples in this section are single Lane configurations.

Low Level Protocol Features:

- Transport of arbitrary data (Payload independent)
- 8-bit word size
- Support for up to four interleaved virtual channels on the same link
- Special packets for frame start, frame end, line start and line end information
- Descriptor for the type, pixel depth and format of the Application Specific Payload data
- 16-bit Checksum Code for error detection.

DATA:

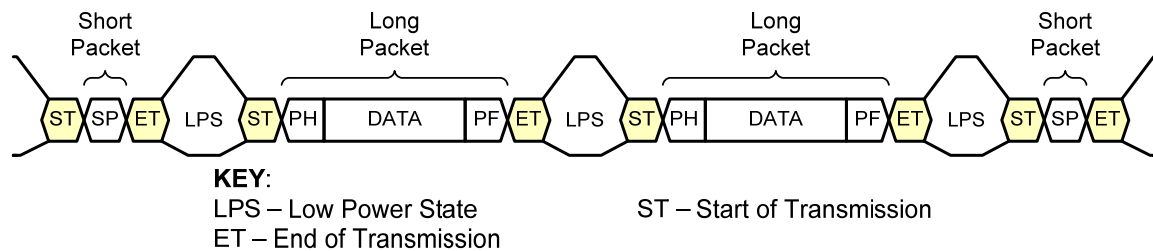


Figure 29 Low Level Protocol Packet Overview

9.1 Low Level Protocol Packet Format

Two packet structures are defined for low-level protocol communication: Long packets and Short packets. For each packet structure exit from the low power state followed by the Start of Transmission (SoT) sequence indicates the start of the packet. The End of Transmission (EoT) sequence followed by the low power state indicates the end of the packet.

9.1.1 Low Level Protocol Long Packet Format

Figure 30 shows the structure of the Low Level Protocol Long Packet. A Long Packet shall be identified by Data Types 0x10 to 0x37. See Table 3 for a description of the Data Types. A Long Packet shall consist of three elements: a 32-bit Packet Header (PH), an application specific Data Payload with a variable number of 8-bit data words and a 16-bit Packet Footer (PF). The Packet Header is further composed of three elements: an 8-bit Data Identifier, a 16-bit Word Count field and an 8-bit ECC. The Packet footer has one element, a 16-bit checksum. See sections 9.2 through 9.5 for further descriptions of the packet elements.

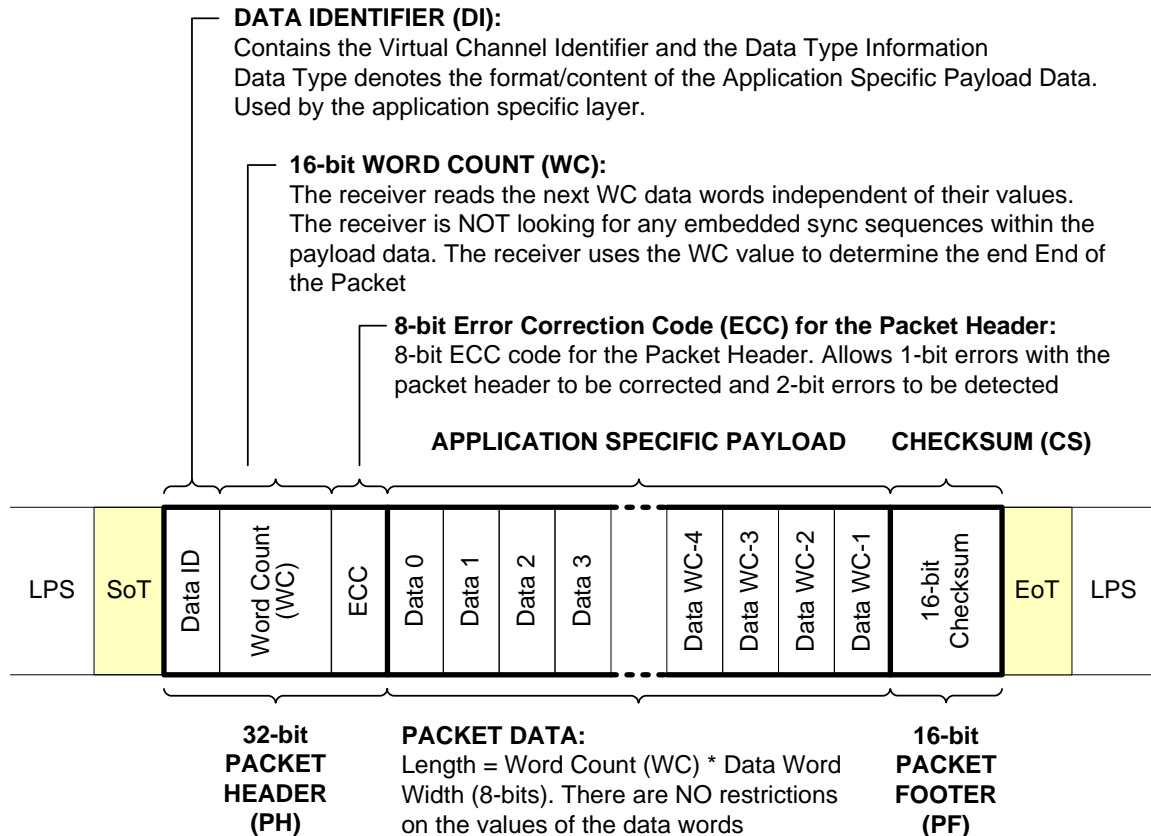


Figure 30 Long Packet Structure

The Data Identifier defines the Virtual Channel for the data and the Data Type for the application specific payload data.

The Word Count defines the number of 8-bit data words in the Data Payload between the end of the Packet Header and the start of the Packet Footer. Neither the Packet Header nor the Packet Footer shall be included in the Word Count.

The Error Correction Code (ECC) byte allows single-bit errors to be corrected and 2-bit errors to be detected in the packet header. This includes both the data identifier value and the word count value.

After the end of the Packet Header the receiver reads the next Word Count * 8-bit data words of the Data Payload. While reading the Data Payload the receiver shall not look for any embedded sync codes. Therefore, there are no limitations on the value of a data word.

Once the receiver has read the Data Payload it reads the checksum in the Packet Footer. In the generic case, the length of the Data Payload shall be a multiple of 8-bit data words. In addition, each data format may impose additional restrictions on the length of the payload data, e.g. multiple of four bytes.

Each byte shall be transmitted least significant bit first. Payload data may be transmitted in any byte order restricted only by data format requirements. Multi-byte elements such as Word Count, Checksum and the Short packet 16-bit Data Field shall be transmitted least significant byte first.

After the EoT sequence the receiver begins looking for the next SoT sequence.

9.1.2 Low Level Protocol Short Packet Format

Figure 31 shows the structure of the Low Level Protocol Short Packet. A Short Packet shall be identified by Data Types 0x00 to 0x0F. See Table 3 for a description of the Data Types. A Short Packet shall contain only a Packet Header; a Packet Footer shall not be present. The Word Count field in the Packet Header shall be replaced by a Short Packet Data Field.

For Frame Synchronization Data Types the Short Packet Data Field shall be the frame number. For Line Synchronization Data Types the Short Packet Data Field shall be the line number. See Table 6 for a description of the Frame and Line synchronization Data Types.

For Generic Short Packet Data Types the content of the Short Packet Data Field shall be user defined.

The Error Correction Code (ECC) byte allows single-bit errors to be corrected and 2-bit errors to be detected in the Short Packet.

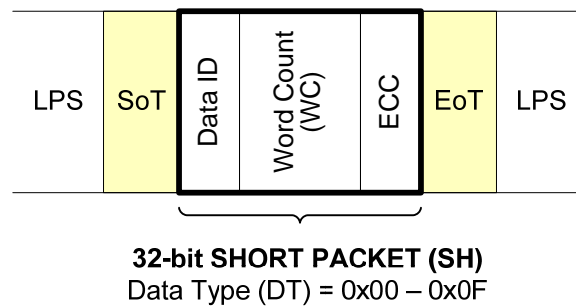


Figure 31 Short Packet Structure

9.2 Data Identifier (DI)

The Data Identifier byte contains the Virtual Channel Identifier (VC) value and the Data Type (DT) value as illustrated in Figure 32. The Virtual Channel Identifier is contained in the two MS bits of the Data Identifier Byte. The Data Type value is contained in the six LS bits of the Data Identifier Byte.

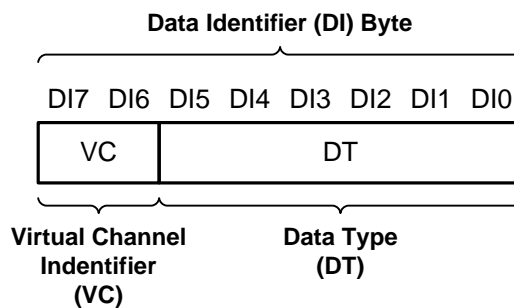


Figure 32 Data Identifier Byte

9.3 Virtual Channel Identifier

The purpose of the Virtual Channel Identifier is to provide separate channels for different data flows that are interleaved in the data stream.

The Virtual channel identifier number is in the top two bits of the Data Identifier Byte. The Receiver will monitor the virtual channel identifier and de-multiplex the interleaved video streams to their appropriate

channel. A maximum of four data streams is supported; valid channel identifiers are 0 to 3. The virtual channel identifiers in the peripherals should be programmable to allow the host processor to control how the data streams are de-multiplexed. The principle of logical channels is presented in the Figure 33.

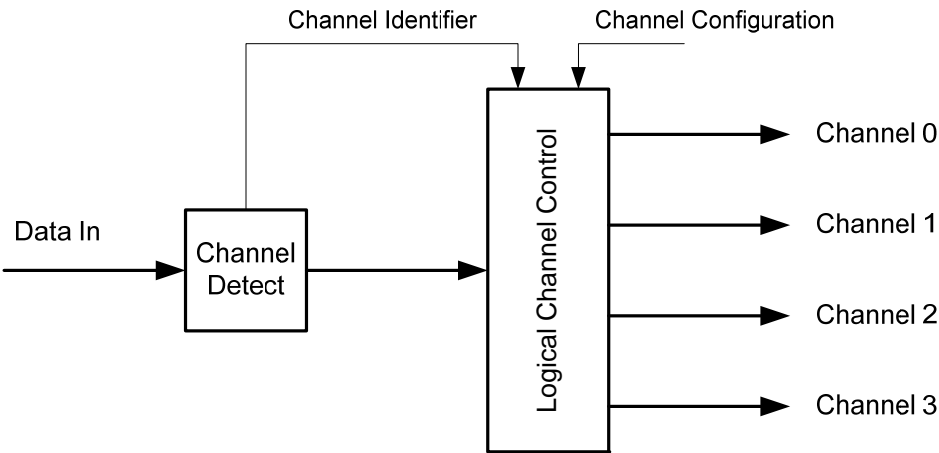


Figure 33 Logical Channel Block Diagram (Receiver)

Figure 34 illustrates an example of data streams utilizing virtual channel support.

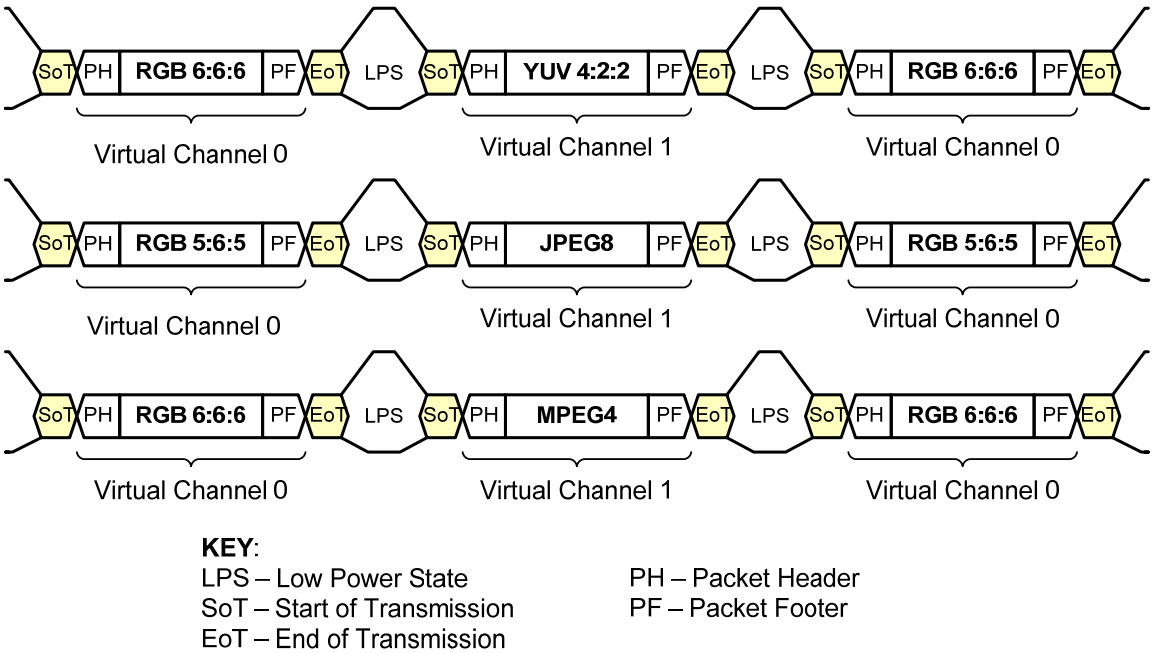


Figure 34 Interleaved Video Data Streams Examples

9.4 Data Type (DT)

The Data Type value specifies the format and content of the payload data. A maximum of sixty-four data types are supported.

There are eight different data type classes as shown in Table 3. Within each class there are up to eight different data type definitions. The first two classes denote short packet data types. The remaining six classes denote long packet data types.

894 For details on the short packet data type classes refer to section 9.8.

895 For details on the five long packet data type classes refer to section 11.

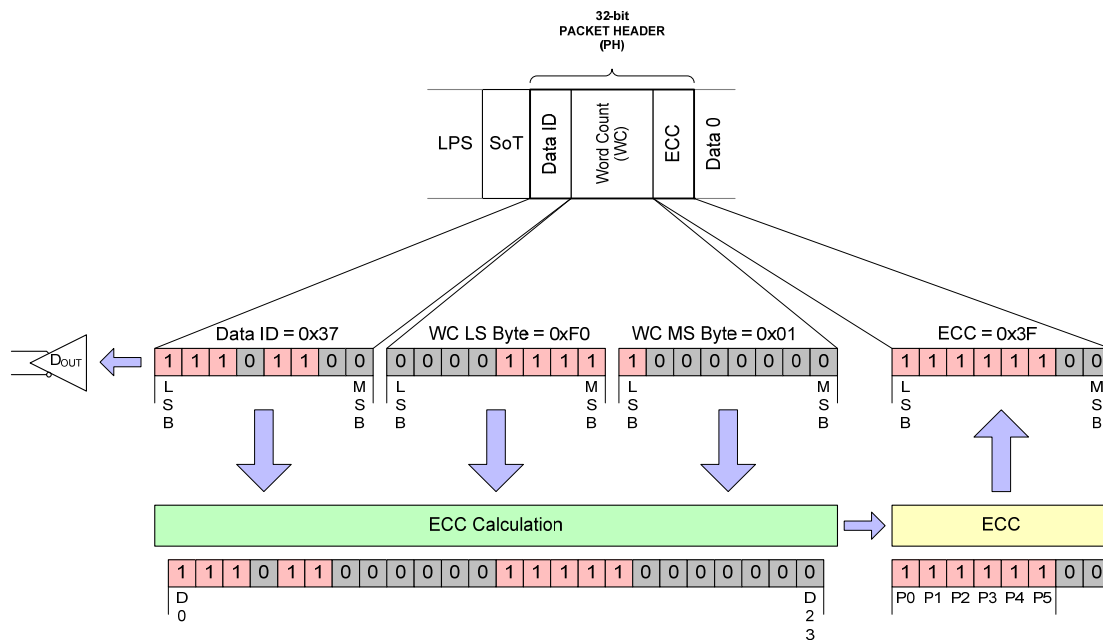
896 **Table 3 Data Type Classes**

Data Type	Description
0x00 to 0x07	Synchronization Short Packet Data Types
0x08 to 0x0F	Generic Short Packet Data Types
0x10 to 0x17	Generic Long Packet Data Types
0x18 to 0x1F	YUV Data
0x20 to 0x27	RGB Data
0x28 to 0x2F	RAW Data
0x30 to 0x37	User Defined Byte-based Data
0x38 to 0x3F	Reserved

897 9.5 Packet Header Error Correction Code

898 The correct interpretation of the data identifier and word count values is vital to the packet structure. The
 899 Packet Header Error Correction Code byte allows single-bit errors in the data identifier and the word count
 900 to be corrected and two-bit errors to be detected. The 24-bit subset of the code described in section 9.5.2
 901 shall be used. Therefore, bits 7 and 6 of the ECC byte shall be zero. The error state based on ECC decoding
 902 shall be available at the Application layer in the receiver.

903 The Data Identifier field DI[7:0] shall map to D[7:0] of the ECC input, the Word Count LS Byte (WC[7:0])
 904 to D[15:8] and the Word Count MS Byte (WC[15:8]) to D[23:16]. This mapping is shown in Figure 35,
 905 which also serves as an ECC calculation example.



906 **Figure 35 24-bit ECC Generation Example**

9.5.1 General Hamming Code Applied to Packet Header

The number of parity or error check bits required is given by the Hamming rule, and is a function of the number of bits of information transmitted. The Hamming rule is expressed by the following inequality:

$$d + p + 1 \leq 2^p \quad \text{where } d \text{ is the number of data bits and } p \text{ is the number of parity bits.}$$

The result of appending the computed parity bits to the data bits is called the Hamming code word. The size of the code word c is obviously $d + p$, and a Hamming code word is described by the ordered set (c, d) . A Hamming code word is generated by multiplying the data bits by a generator matrix \mathbf{G} . This multiplication's result is called the code word vector $(c_1, c_2, c_3, \dots, c_n)$, consisting of the original data bits and the calculated parity bits. The generator matrix \mathbf{G} used in constructing Hamming codes consists of \mathbf{I} (the identity matrix) and a parity generation matrix \mathbf{A} :

$$\mathbf{G} = [\mathbf{I} \mid \mathbf{A}]$$

The packet header plus the ECC code can be obtained as: $\text{PH} = \text{p} * \mathbf{G}$ where p represents the header (24 or 64 bits) and \mathbf{G} is the corresponding generator matrix.

Validating the received code word r , involves multiplying it by a parity check to form s , the syndrome or parity check vector: $\text{s} = \mathbf{H} * \text{PH}$ where PH is the received packet header and \mathbf{H} is the parity check matrix:

$$\mathbf{H} = [\mathbf{A}^T \mid \mathbf{I}]$$

If all elements of s are zero, the code word was received correctly. If s contains non-zero elements, then at least one error is present. If a single bit error is encountered then the syndrome s is one of the elements of \mathbf{H} which will point to the bit in error. Further, in this case, if the bit in error is one of the parity bits, then the syndrome will be one of the elements on \mathbf{I} , else it will be the data bit identified by the position of the syndrome in \mathbf{A}^T .

9.5.2 Hamming-modified Code

The error correcting code used is a 7+1bits Hamming-modified code (72,64) and the subset of it is 5+1bits or (30,24). Hamming codes use parity to correct one error or detect two errors, but they are not capable of doing both simultaneously, thus one extra parity bit needs to be added. The code used, is build to allow same syndromes to correct first 24-bits in a 64-bit sequence and those syndromes to be 6-bits wide. To specify in a compact way the encoding of parity and decoding of syndromes, the following matrix is used:

Table 4 ECC Syndrome Association Matrix

	d2d1d0							
d5d4d3	0b000	0b001	0b010	0b011	0b100	0b101	0b110	0b111
0b000	0x07	0x0B	0x0D	0x0E	0x13	0x15	0x16	0x19
0b001	0x1A	0x1C	0x23	0x25	0x26	0x29	0x2A	0x2C
0b010	0x31	0x32	0x34	0x38	0x1F	0x2F	0x37	0x3B
0b011	0x43	0x45	0x46	0x49	0x4A	0x4C	0x51	0x52
0b100	0x54	0x58	0x61	0x62	0x64	0x68	0x70	0x83
0b101	0x85	0x86	0x89	0x8A	0x3D	0x3E	0x4F	0x57

	d2d1d0							
d5d4d3	0b000	0b001	0b010	0b011	0b100	0b101	0b110	0b111
0b110	0x8C	0x91	0x92	0x94	0x98	0xA1	0xA2	0xA4
0b111	0xA8	0xB0	0xC1	0xC2	0xC4	0xC8	0xD0	0xE0

Each cell in the matrix represents a syndrome and the first twenty-four cells (the orange rows) are using the first three or five bits to build the syndrome. Each syndrome in the matrix is MSB left aligned:

e.g. 0x07=0b0000_0111=P7P6P5P4P3P2P1P0

The top row defines the three LSB of data position bit, and the left column defines the three MSB of data position bit (there are 64-bit positions in total).

e.g. 37th bit position is encoded 0b100_101 and has the syndrome 0x68.

To derive the parity P0 for 24-bits, the P0's in the orange rows will define if the corresponding bit position is used in P0 parity or not.

e.g. $P0_{24\text{-bits}} = D0 \wedge D1 \wedge D2 \wedge D4 \wedge D5 \wedge D7 \wedge D10 \wedge D11 \wedge D13 \wedge D16 \wedge D20 \wedge D21 \wedge D22 \wedge D23$

Similar, to derive the parity P0 for 64-bits, all P0's in Table 5 will define the corresponding bit positions to be used.

To correct a single-bit error, the syndrome has to be one of the syndromes Table 4, which will identify the bit position in error. The syndrome is calculated as:

$S = P_{\text{SEND}} \wedge P_{\text{RECEIVED}}$ where P_{SEND} is the 8/6-bit ECC field in the header and P_{RECEIVED} is the calculated parity of the received header.

Table 5 represents the same information as the matrix in Table 4, organized such that will give a better insight on the way parity bits are formed out of data bits. The orange area of the table has to be used to form the ECC to protect a 24-bit header, whereas the whole table has to be used to protect a 64-bit header.

Table 5 ECC Parity Generation Rules

Bit	P7	P6	P5	P4	P3	P2	P1	P0	Hex
0	0	0	0	0	0	1	1	1	0x07
1	0	0	0	0	1	0	1	1	0x0B
2	0	0	0	0	1	1	0	1	0x0D
3	0	0	0	0	1	1	1	0	0x0E
4	0	0	0	1	0	0	1	1	0x13
5	0	0	0	1	0	1	0	1	0x15
6	0	0	0	1	0	1	1	0	0x16
7	0	0	0	1	1	0	0	1	0x19
8	0	0	0	1	1	0	1	0	0x1A
9	0	0	0	1	1	1	0	0	0x1C
10	0	0	1	0	0	0	1	1	0x23

Bit	P7	P6	P5	P4	P3	P2	P1	P0	Hex
11	0	0	1	0	0	1	0	1	0x25
12	0	0	1	0	0	1	1	0	0x26
13	0	0	1	0	1	0	0	1	0x29
14	0	0	1	0	1	0	1	0	0x2A
15	0	0	1	0	1	1	0	0	0x2C
16	0	0	1	1	0	0	0	1	0x31
17	0	0	1	1	0	0	1	0	0x32
18	0	0	1	1	0	1	0	0	0x34
19	0	0	1	1	1	0	0	0	0x38
20	0	0	0	1	1	1	1	1	0x1F
21	0	0	1	0	1	1	1	1	0x2F
22	0	0	1	1	0	1	1	1	0x37
23	0	0	1	1	1	0	1	1	0x3B
24	0	1	0	0	0	0	1	1	0x43
25	0	1	0	0	0	1	0	1	0x45
26	0	1	0	0	0	1	1	0	0x46
27	0	1	0	0	1	0	0	1	0x49
28	0	1	0	0	1	0	1	0	0x4A
29	0	1	0	0	1	1	0	0	0x4C
30	0	1	0	1	0	0	0	1	0x51
31	0	1	0	1	0	0	1	0	0x52
32	0	1	0	1	0	1	0	0	0x54
33	0	1	0	1	1	0	0	0	0x58
34	0	1	1	0	0	0	0	1	0x61
35	0	1	1	0	0	0	1	0	0x62
36	0	1	1	0	0	1	0	0	0x64
37	0	1	1	0	1	0	0	0	0x68
38	0	1	1	1	0	0	0	0	0x70
39	1	0	0	0	0	0	1	1	0x83
40	1	0	0	0	0	1	0	1	0x85
41	1	0	0	0	0	1	1	0	0x86
42	1	0	0	0	1	0	0	1	0x89
43	1	0	0	0	1	0	1	0	0x8A
44	0	0	1	1	1	1	0	1	0x3D

Bit	P7	P6	P5	P4	P3	P2	P1	P0	Hex
45	0	0	1	1	1	1	1	0	0x3E
46	0	1	0	0	1	1	1	1	0x4F
47	0	1	0	1	0	1	1	1	0x57
48	1	0	0	0	1	1	0	0	0x8C
49	1	0	0	1	0	0	0	1	0x91
50	1	0	0	1	0	0	1	0	0x92
51	1	0	0	1	0	1	0	0	0x94
52	1	0	0	1	1	0	0	0	0x98
53	1	0	1	0	0	0	0	1	0xA1
54	1	0	1	0	0	0	1	0	0xA2
55	1	0	1	0	0	1	0	0	0xA4
56	1	0	1	0	1	0	0	0	0xA8
57	1	0	1	1	0	0	0	0	0xB0
58	1	1	0	0	0	0	0	1	0xC1
59	1	1	0	0	0	0	1	0	0xC2
60	1	1	0	0	0	1	0	0	0xC4
61	1	1	0	0	1	0	0	0	0xC8
62	1	1	0	1	0	0	0	0	0xD0
63	1	1	1	0	0	0	0	0	0xE0

9.5.3 ECC Generation on TX Side

This is an informative section.

The ECC can be easily implemented using a parallel approach as depicted in Figure 36 for a 64-bit header.

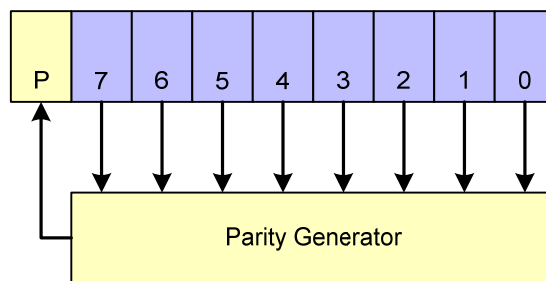


Figure 36 64-bit ECC Generation on TX Side

And Figure 37 for a 24-bit header:

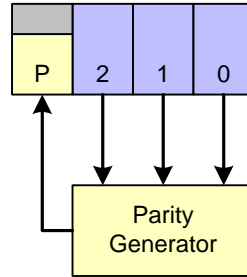


Figure 37 24-bit ECC Generation on TX Side

The parity generators are based on Table 5.

$$\text{e.g. } P_{3_{24\text{-bit}}} = D1 \wedge D2 \wedge D3 \wedge D7 \wedge D8 \wedge D9 \wedge D13 \wedge D14 \wedge D15 \wedge D19 \wedge D20 \wedge D21 \wedge D23$$

9.5.4 Applying ECC on RX Side

Applying ECC on RX side involves generating a new ECC for the received packet, computing the syndrome using the new ECC and the received ECC, decoding the syndrome to find if a single-error has occurred and if so, correct it.

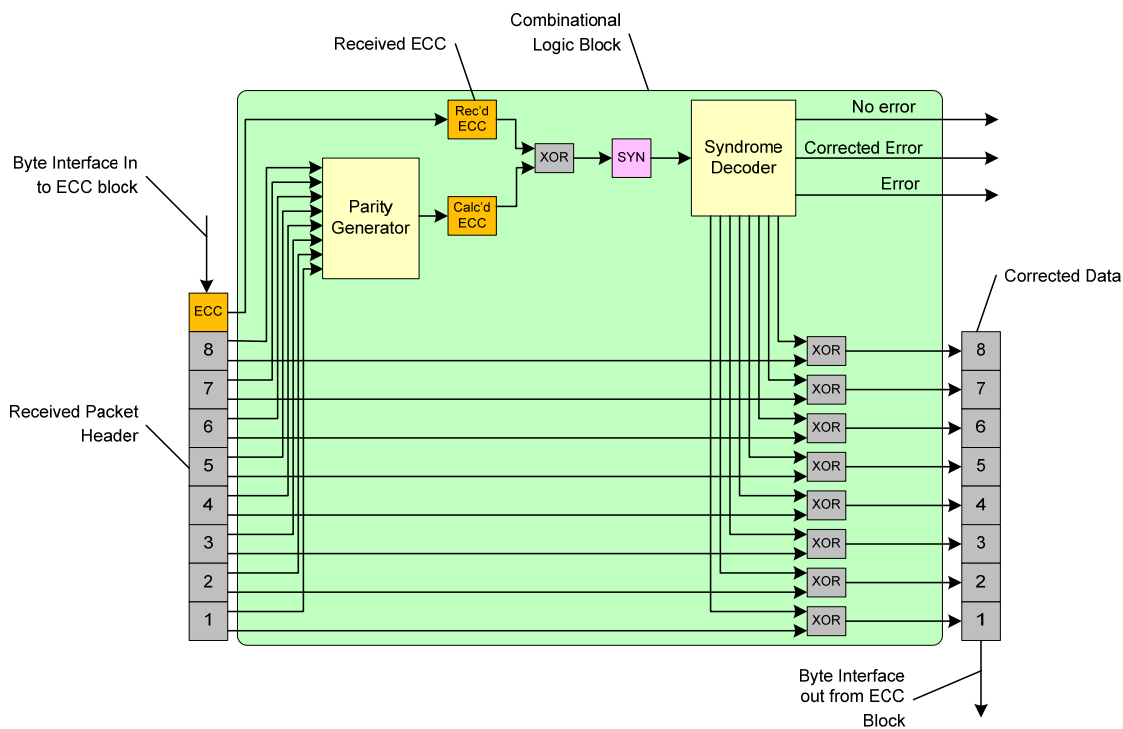


Figure 38 64-bit ECC on RX Side Including Error Correction

Decoding the syndrome has three aspects:

- Finding if the packet has any errors (if syndrome is 0, no errors are present)
- Checking if a single error has occurred by searching Table 5, if the syndrome is one of the entries in the table, then a single bit error has occurred and the corresponding bit is affected, thus this position in the data stream needs to be complemented. Also, if the syndrome is one of the rows of the identity matrix I, then one of the parity bits are in error. If the syndrome cannot be identified,

then a higher order error has occurred and the error flag will be set (the stream is corrupted and cannot be restored).

- Correcting the single error detected, as indicated above.

The 24-bit implementation uses fewer terms to calculate the parity and thus the syndrome decoding block is much simpler than the 64-bit implementation.

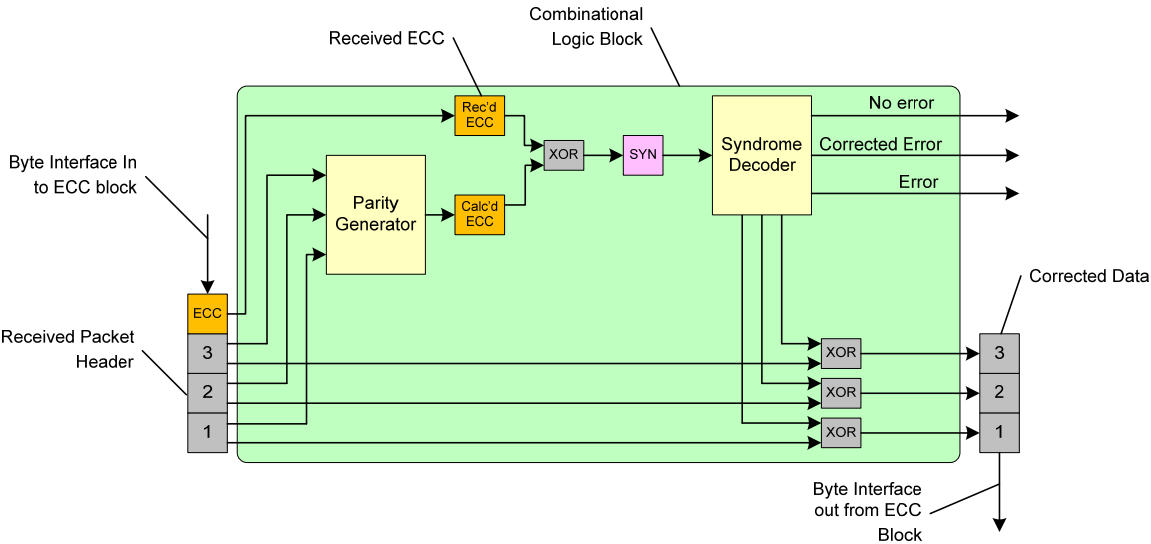


Figure 39 24-bit ECC on RX side Including Error Correction

9.6 Checksum Generation

To detect possible errors in transmission, a checksum is calculated over each data packet. The checksum is realized as 16-bit CRC. The generator polynomial is $x^{16}+x^{12}+x^5+x^0$.

The transmission of the checksum is illustrated in Figure 40.

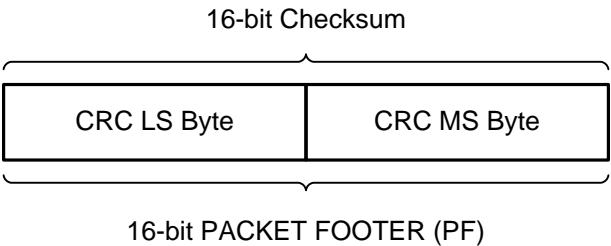


Figure 40 Checksum Transmission

The 16-bit checksum sequence is transmitted as part of the Packet Footer. When the Word Count is zero, the CRC shall be 0xFFFF.

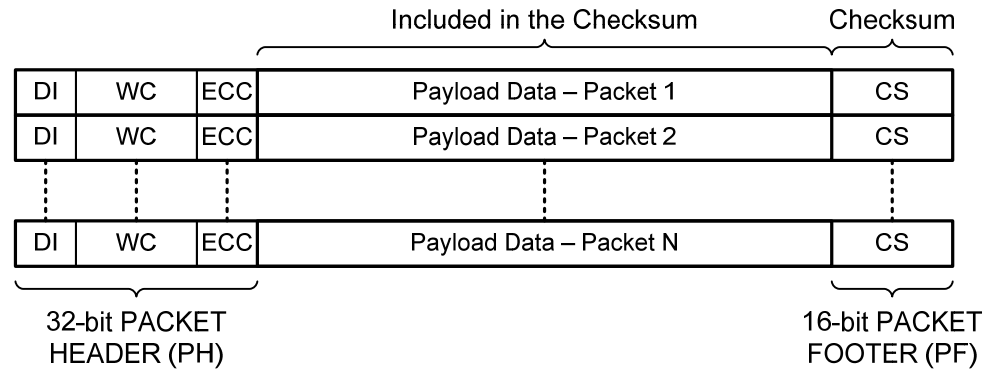


Figure 41 Checksum Generation for Packet Data

The definition of a serial CRC implementation is presented in Figure 42. The CRC implementation shall be functionally equivalent with the C code presented in Figure 43. The CRC shift register is initialized to 0xFFFF at the beginning of each packet. After all payload data has passed through the CRC circuitry, the CRC circuitry contains the checksum. The 16-bit checksum produced by the C code in Figure 43 equals the final contents of the C[15:0] shift register shown in Figure 42. The checksum is then sent over CSI-2 bus to the receiver to verify that no errors have occurred in the transmission.

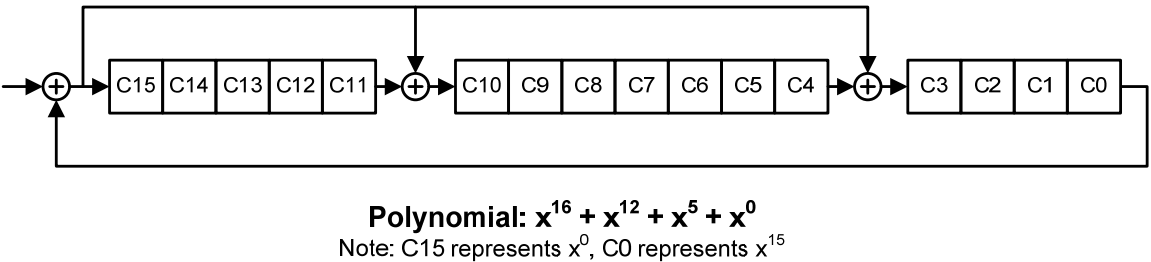


Figure 42 Definition of 16-bit CRC Shift Register

```

#define POLY 0x8408    /* 1021H bit reversed */

unsigned short crc16(char *data_p, unsigned short length)
{
    unsigned char i;
    unsigned int data;
    unsigned int crc = 0xffff;

    if (length == 0)
        return (unsigned short)(crc);
    do
    {
        for (i=0, data=(unsigned int)0xff & *data_p++;
             i < 8;i++, data >= 1)
        {
            if ((crc & 0x0001) ^ (data & 0x0001))
                crc = (crc >> 1) ^ POLY;
            else
                crc >>= 1;
        }
    } while (--length);

    // Uncomment to change from little to big Endian
    // crc = ((crc & 0xff) << 8) | ((crc & 0xff00) >> 8);

    return (unsigned short)(crc);
}

```

Figure 43 16-bit CRC Software Implementation Example

The data and checksum are transmitted least significant byte first. Each bit within a byte is transmitted least significant bit first.

```

Data:
FF 00 00 02 B9 DC F3 72 BB D4 B8 5A C8 75 C2 7C 81 F8 05 DF FF 00 00 01
Checksum LS byte and MS byte:
F0 00
Data:
FF 00 00 00 1E F0 1E C7 4F 82 78 C5 82 E0 8C 70 D2 3C 78 E9 FF 00 00 01
Checksum LS byte and MS byte:
69 E5

```

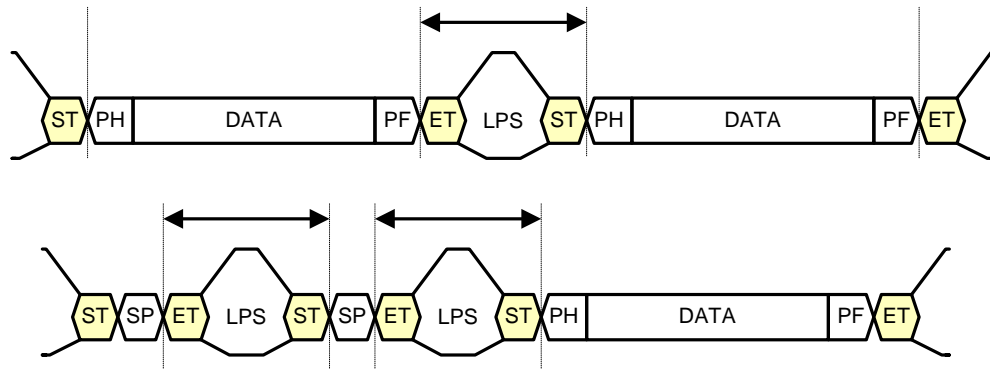
9.7 Packet Spacing

Between Low Level Protocol packets there must always be a transition into and out of the Low Power State (LPS). Figure 44 illustrates the packet spacing with the LPS.

The packet spacing does not have to be a multiple of 8-bit data words as the receiver will resynchronize to the correct byte boundary during the SoT sequence prior to the Packet Header of the next packet.

SHORT / LONG PACKET SPACING:

Variable - always a LPS between packets

**KEY:**

LPS – Low Power State
 ST – Start of Transmission
 ET – End of Transmission

PH – Packet Header
 PF – Packet Footer
 SP – Short Packet

Figure 44 Packet Spacing**9.8 Synchronization Short Packet Data Type Codes**

Short Packet Data Types shall be transmitted using only the Short Packet format. See section 9.1.2 for a format description.

Table 6 Synchronization Short Packet Data Type Codes

Data Type	Description
0x00	Frame Start Code
0x01	Frame End Code
0x02	Line Start Code (Optional)
0x03	Line End Code (Optional)
0x04 to 0x07	Reserved

9.8.1 Frame Synchronization Packets

Each image frame shall begin with a Frame Start (FS) Packet containing the Frame Start Code. The FS Packet shall be followed by one or more long packets containing image data and zero or more short packets containing synchronization codes. Each image frame shall end with a Frame End (FE) Packet containing the Frame End Code. See Table 6 for a description of the synchronization code data types.

For FS and FE synchronization packets the Short Packet Data Field shall contain a 16-bit frame number. This frame number shall be the same for the FS and FE synchronization packets corresponding to a given frame.

The 16-bit frame number, when used, shall be non-zero to distinguish it from the use-case where frame number is inoperative and remains set to zero.

The behavior of the 16-bit frame number shall be as one of the following

- Frame number is always zero – frame number is inoperative.
- Frame number increments by 1 for every FS packet with the same Virtual Channel and is periodically reset to one e.g. 1, 2, 1, 2, 1, 2, 1, 2 or 1, 2, 3, 4, 1, 2, 3, 4

The frame number must be a non-zero value.

9.8.2 Line Synchronization Packets

Line synchronization packets are optional.

For Line Start (LS) and Line End (LE) synchronization packets the Short Packet Data Field shall contain a 16-bit line number. This line number shall be the same for the LS and LE packets corresponding to a given line. Line numbers are logical line numbers and are not necessarily equal to the physical line numbers

The 16-bit line number, when used, shall be non-zero to distinguish it from the case where line number is inoperative and remains set to zero.

The behavior of the 16-bit line number shall be as one of the following:

- Line number is always zero – line number is inoperative.
- Line number increments by one for every LS packet within the same Virtual Channel and the same Data Type. The line number is periodically reset to one for the first LS packet after a FS packet. The intended usage is for progressive scan (non- interlaced) video data streams. The line number must be a non-zero value.
- Line number increments by the same arbitrary step value greater than one for every LS packet within the same Virtual Channel and the same Data Type. The line number is periodically reset to a non-zero arbitrary start value for the first LS packet after a FS packet. The arbitrary start value may be different between successive frames. The intended usage is for interlaced video data streams.

9.9 Generic Short Packet Data Type Codes

Table 7 lists the Generic Short Packet Data Types.

Table 7 Generic Short Packet Data Type Codes

Data Type	Description
0x08	Generic Short Packet Code 1
0x09	Generic Short Packet Code 2
0x0A	Generic Short Packet Code 3
0x0B	Generic Short Packet Code 4
0x0C	Generic Short Packet Code 5
0x0D	Generic Short Packet Code 6
0x0E	Generic Short Packet Code 7
0x0F	Generic Short Packet Code 8

The intention of the Generic Short Packet Data Types is to provide a mechanism for including timing information for the opening/closing of shutters, triggering of flashes, etc within the data stream. The intent of the 16-bit User defined data field in the generic short packets is to pass a data type value and a 16-bit

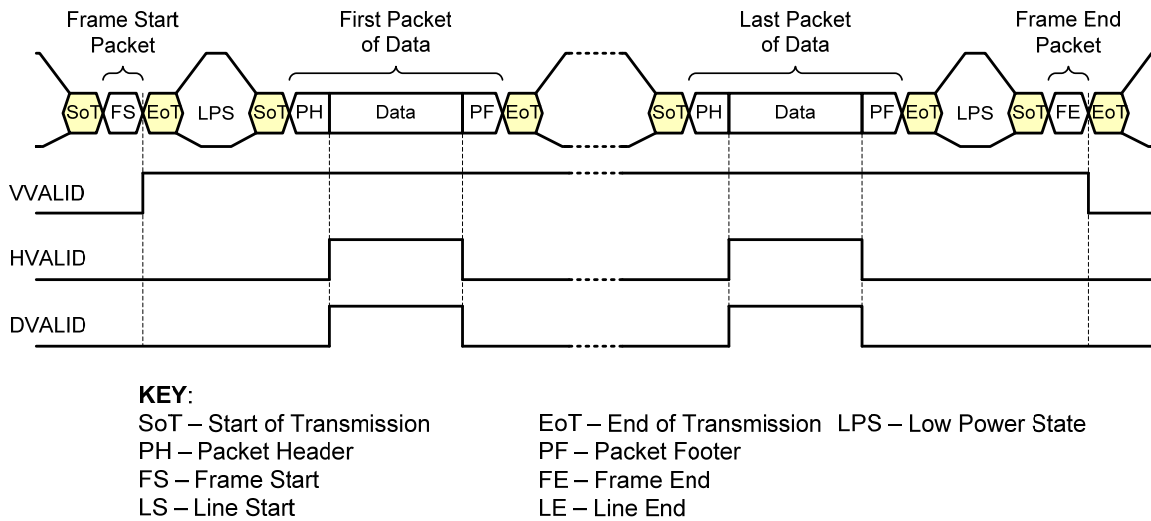
1069 data value from the transmitter to application layer in the receiver. The CSI-2 receiver shall pass the data
 1070 type value and the associated 16-bit data value to the application layer.

1071 9.10 Packet Spacing Examples

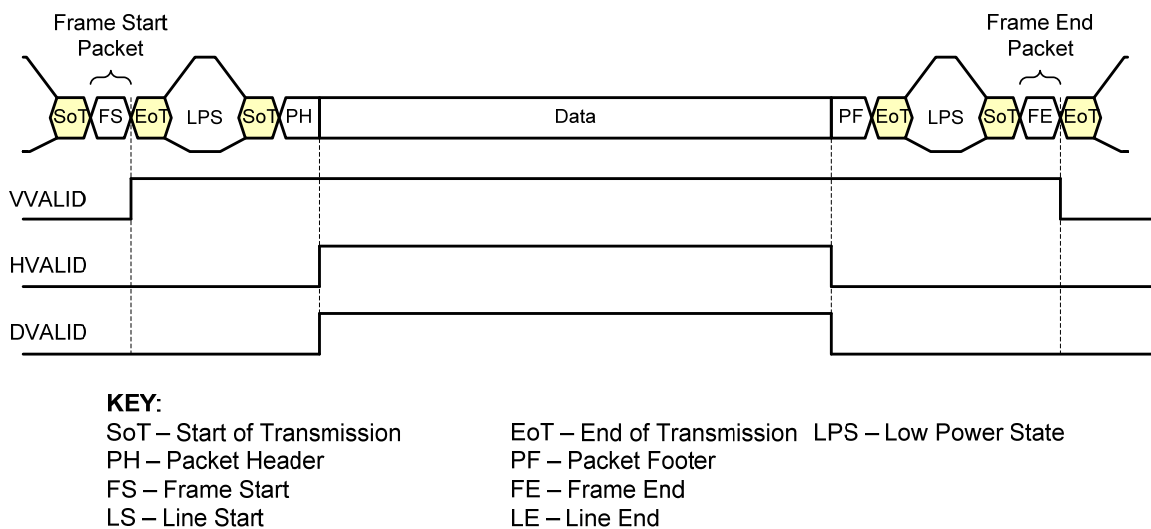
1072 Packets are separated by an EoT, LPS, SoT sequence as defined in [MIPI01].

1073 Figure 45 and Figure 46 contain examples of data frames composed of multiple packets and a single
 1074 packet, respectively.

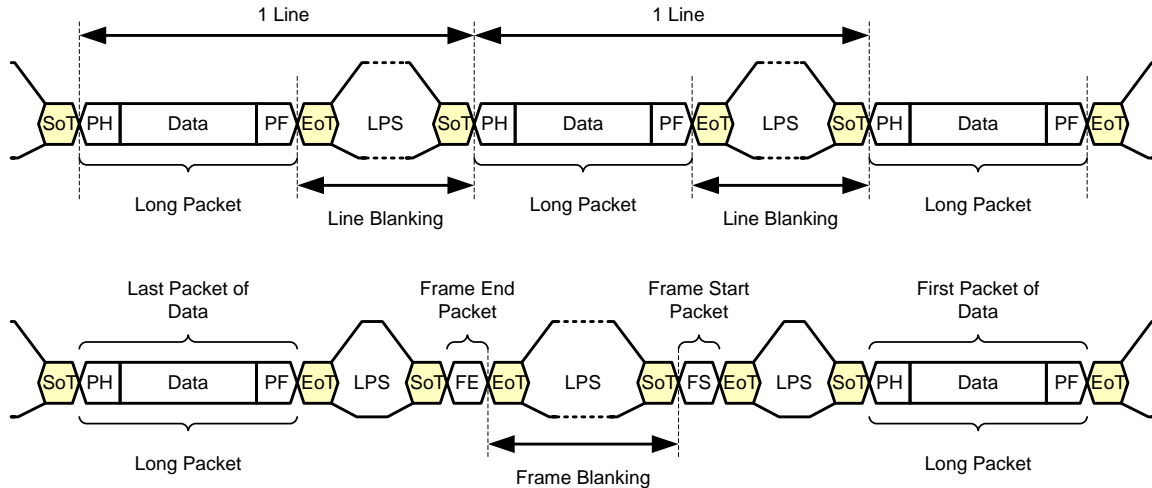
1075 Note that the VVALID, HVALID and DVALID signals in the figures in this section are only concepts to
 1076 help illustrate the behavior of the frame start/end and line start/end packets. The VVALID, HVALID and
 1077 DVALID signals do not form part of the specification.



1078
 1079
 1080 **Figure 45 Multiple Packet Example**



1081
 1082 **Figure 46 Single Packet Example**

**KEY:**

SoT – Start of Transmission

PH – Packet Header

FS – Frame Start

LS – Line Start

EoT – End of Transmission LPS – Low Power State

PF – Packet Footer

FE – Frame End

LE – Line End

Figure 47 Line and Frame Blanking Definitions

The period between the Packet Footer of one long packet and the Packet Header of the next long packet is called the Line Blanking Period.

The period between the Frame End packet in frame N and the Frame Start packet in frame N+1 is called the Frame Blanking Period (Figure 47).

The Line Blanking Period is not fixed and may vary in length. The receiver should be able to cope with a near zero Line Blanking Period as defined in [MIPI01]. The transmitter defines the minimum time for the Frame Blanking Period. The Frame Blanking Period duration should be programmable in the transmitter.

Frame Start and Frame End packets shall be used.

Recommendations (informative) for frame start and end packet spacing:

- The Frame Start packet to first data packet spacing should be as close as possible to the minimum packet spacing
- The last data packet to Frame End packet spacing should be as close as possible to the minimum packet spacing

The intention is to ensure that the Frame Start and Frame End packets accurately denote the start and end of a frame of image data. A valid exception is when the positions of the Frame Start and Frame End packets are being used to convey pixel level accurate vertical synchronization timing information.

The positions of the Frame Start and Frame End packets can be varied within the Frame Blanking Period in order to provide pixel level accurate vertical synchronization timing information. See Figure 48.

Line Start and Line End packets shall be used for pixel level accurate horizontal synchronization timing information.

The positions of the Line Start and Line End packets, if present, can be varied within the Line Blanking Period in order to provide pixel accurate horizontal synchronization timing information. See Figure 49.

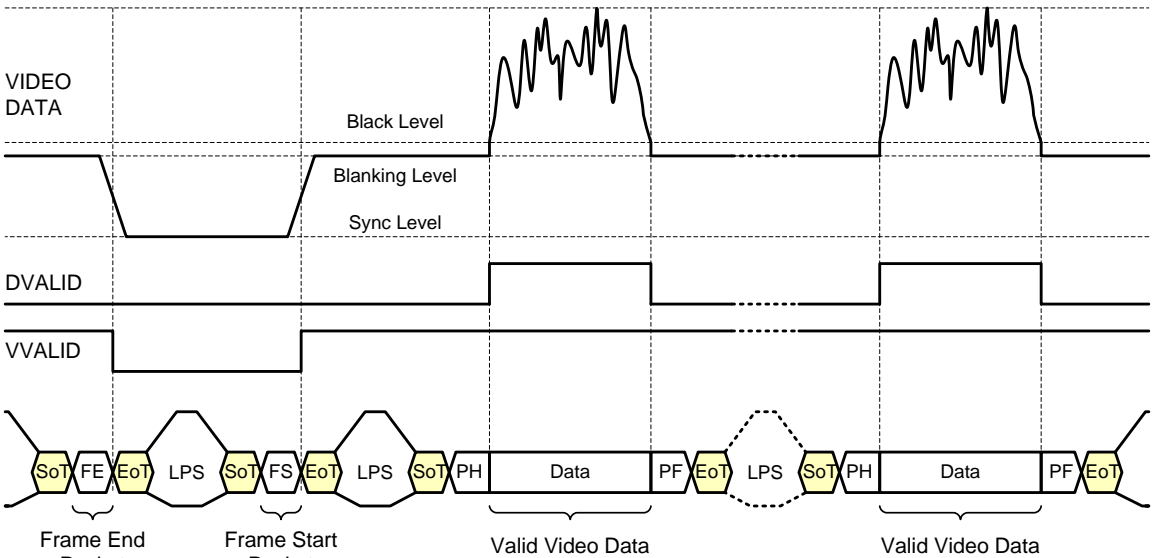


Figure 48 Vertical Sync Example

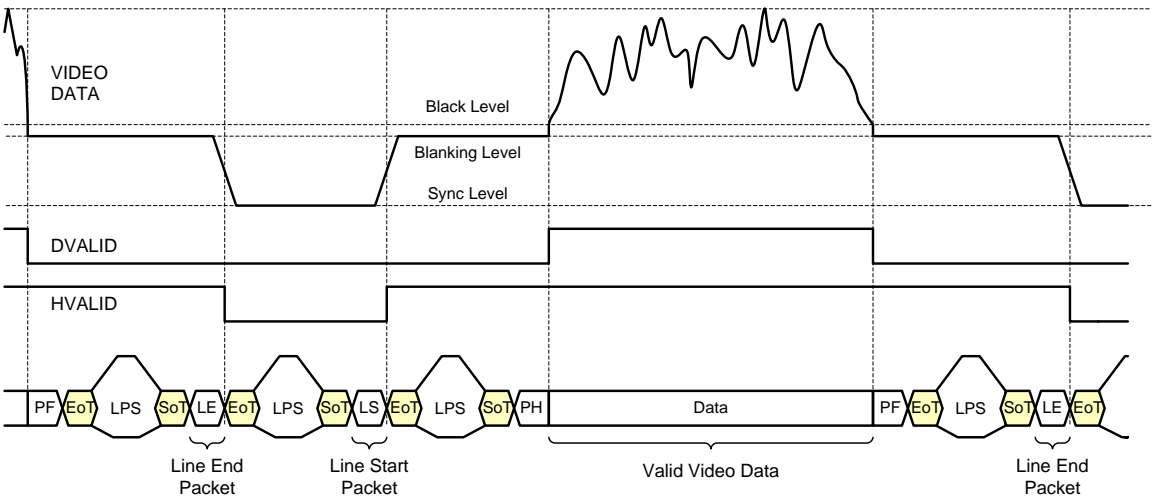


Figure 49 Horizontal Sync Example

9.11 Packet Data Payload Size Rules

For YUV, RGB or RAW data types, one long packet shall contain one line of image data. Each long packet of the same Data Type shall have equal length when packets are within the same Virtual Channel and when packets are within the same frame. An exception to this rule is the YUV420 data type which is defined in section 11.2.2.

For User Defined Byte-based Data Types, long packets can have arbitrary length. The spacing between packets can also vary.

The total size of data within a long packet for all data types shall be a multiple of eight bits. However, it is also possible that a data type's payload data transmission format, as defined elsewhere in this specification, imposes additional constraints on payload size. In order to meet these constraints it may sometimes be necessary to add some number of "padding" pixels to the end of a payload e.g., when a packet with the RAW10 data type contains an image line whose length is not a multiple of four pixels as required by the RAW10 transmission format as described in Section 11.4.4. The values of such padding pixels are not specified.

9.12 Frame Format Examples

This is an informative section.

This section contains three examples to illustrate how the CSI-2 features can be used.

- General Frame Format Example, Figure 50
- Digital Interlaced Video Example, Figure 51
- Digital Interlaced Video with accurate synchronization timing information, Figure 52

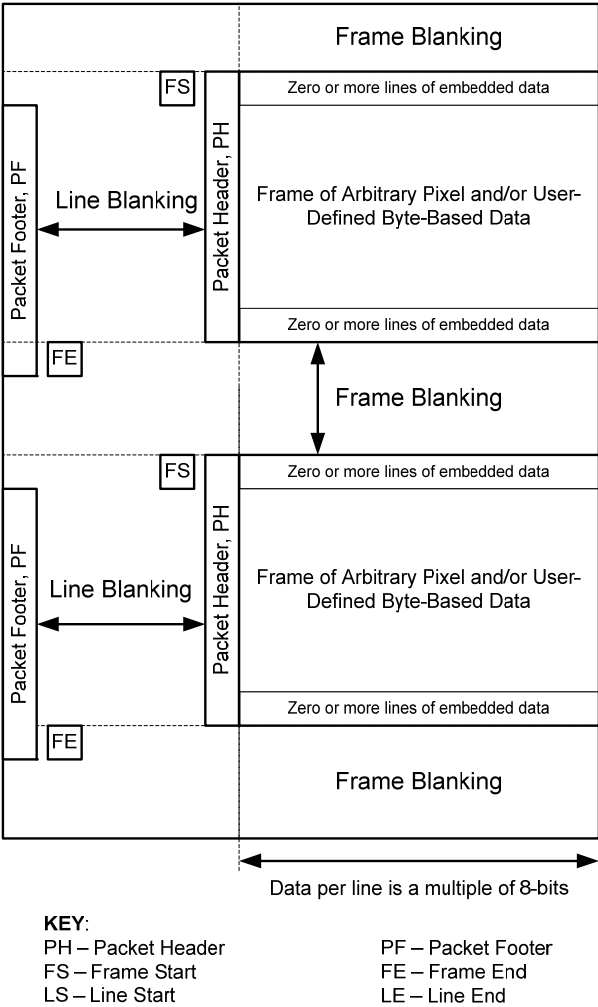
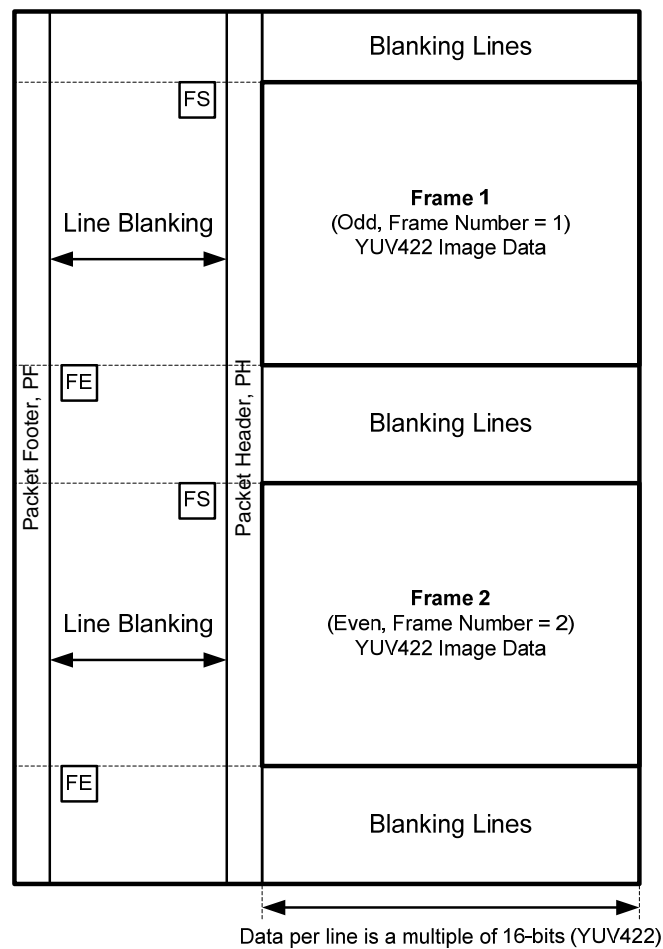


Figure 50 General Frame Format Example



KEY:
PH – Packet Header
FS – Frame Start
LS – Line Start
PF – Packet Footer
FE – Frame End
LE – Line End

Figure 51 Digital Interlaced Video Example

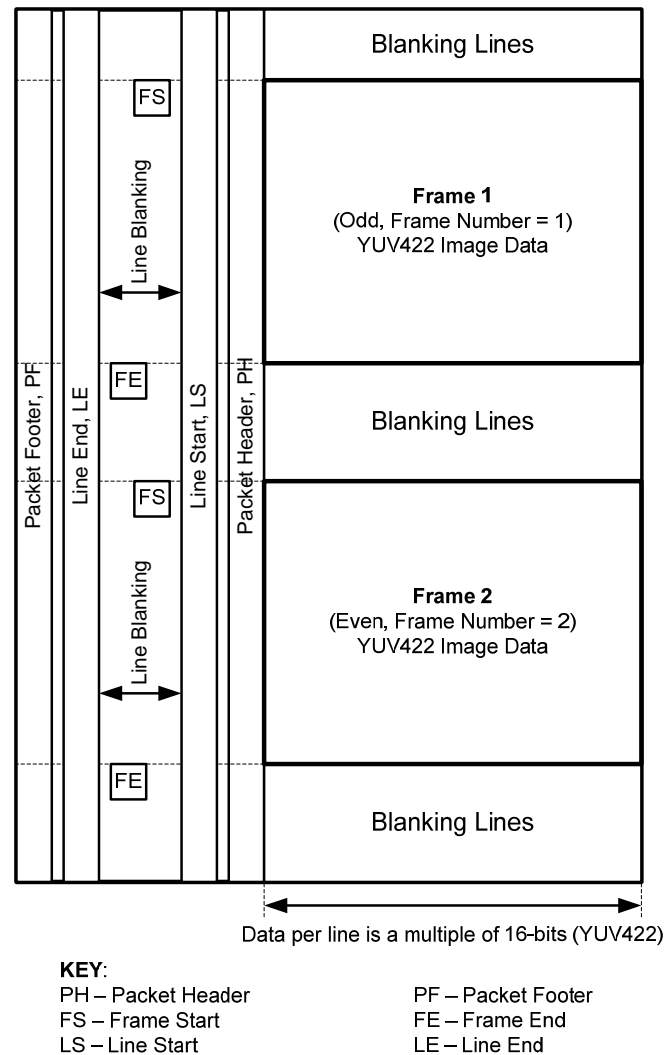


Figure 52 Digital Interlaced Video with Accurate Synchronization Timing Information

9.13 Data Interleaving

The CSI-2 supports the interleaved transmission of different image data formats within the same video data stream.

There are two methods to interleave the transmission of different image data formats:

- Data Type
- Virtual Channel Identifier

The above methods of interleaved data transmission can be combined in any manner.

9.13.1 Data Type Interleaving

The Data Type value uniquely defines the data format for that packet of data. The receiver uses the Data Type value in the packet header to de-multiplex data packets containing different data formats as illustrated in Figure 53. Note, in the figure the Virtual Channel Identifier is the same in each Packet Header.

The packet payload data format shall agree with the Data Type code in the Packet Header as follows:

- For defined image data types – any non-reserved codes in the range 0x18 to 0x3F – only the single corresponding MIPI-defined packet payload data format shall be considered correct
- Reserved image data types – any reserved codes in the range 0x18 to 0x3F – shall not be used. No packet payload data format shall be considered correct for reserved image data types
- For generic long packet data types (codes 0x10 thru 0x17) and user-defined, byte-based (codes 0x30 – 0x37), any packet payload data format shall be considered correct
- Generic long packet data types (codes 0x10 thru 0x17) and user-defined, byte-based (codes 0x30 – 0x37), should not be used with packet payloads that meet any MIPI image data format definition
- Synchronization short packet data types (codes 0x00 thru 0x07) shall consist of only the header and shall not include payload data bytes
- Generic short packet data types (codes 0x08 thru 0x0F) shall consist of only the header and shall not include payload data bytes

Data formats are defined further in section 11.

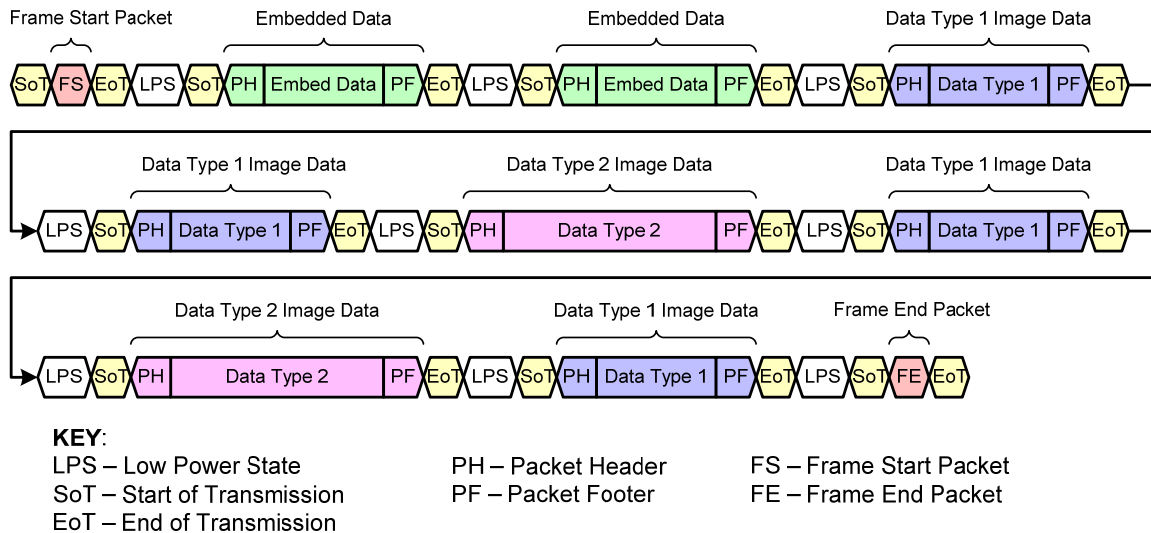
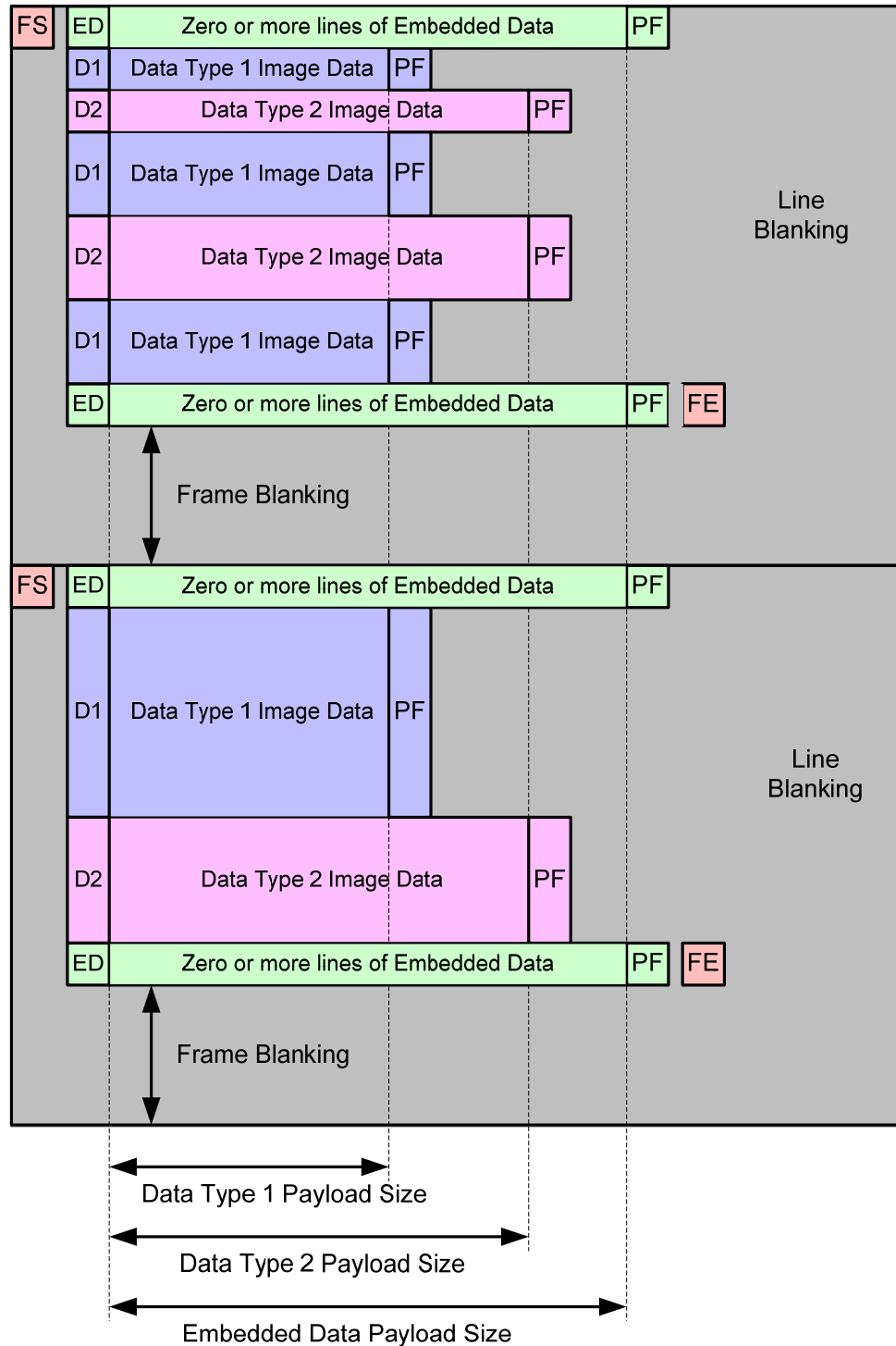


Figure 53 Interleaved Data Transmission using Data Type Value

All of the packets within the same virtual channel, independent of the Data Type value, share the same frame start/end and line start/end synchronization information. By definition, all of the packets, independent of data type, between a Frame Start and a Frame End packet within the same virtual channel belong to the same frame.

Packets of different data types may be interleaved at either the packet level as illustrated in Figure 54 or the frame level as illustrated in Figure 55. Data formats are defined in section 11.

**KEY:**

LPS – Low Power State

FS – Frame Start

FE – Frame End

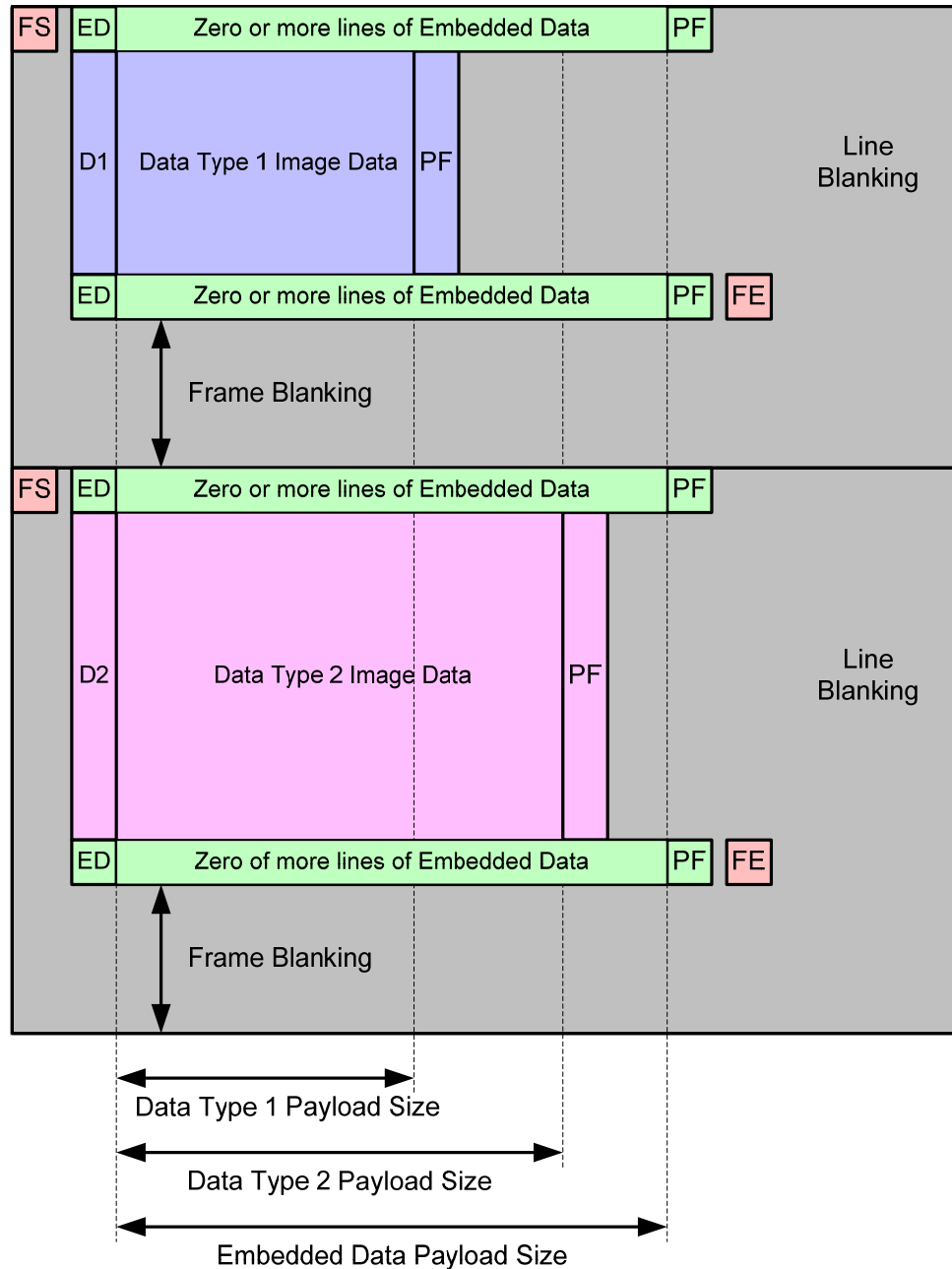
PF – Packet Footer

ED – Packet Header containing Embedded Data type code

D1 – Packet Header containing Data Type 1 Image Data Code

D2 – Packet Header containing Data Type 2 Image Data Code

Figure 54 Packet Level Interleaved Data Transmission

**KEY:**

LPS – Low Power State

FS – Frame Start

FE – Frame End

PF – Packet Footer

ED – Packet Header containing Embedded Data type code

D1 – Packet Header containing Data Type 1 Image Data Code

D2 – Packet Header containing Data Type 2 Image Data Code

Figure 55 Frame Level Interleaved Data Transmission**9.13.2 Virtual Channel Identifier Interleaving**

The Virtual Channel Identifier allows different data types within a single data stream to be logically separated from each other. Figure 56 illustrates data interleaving using the Virtual Channel Identifier.

Each virtual channel has its own Frame Start and Frame End packet. Therefore, it is possible for different virtual channels to have different frame rates, though the data rate for both channels would remain the same.

In addition, Data Type value Interleaving can be used for each virtual channel thereby allowing different data types within a virtual channel and thus a second level of data interleaving.

Therefore, receivers should be able to de-multiplex different data packets based on the combination of the Virtual Channel Identifier and the Data Type value. For example, data packets containing the same Data Type value but transmitted on different virtual channels are considered to belong to different frames (streams) of image data.

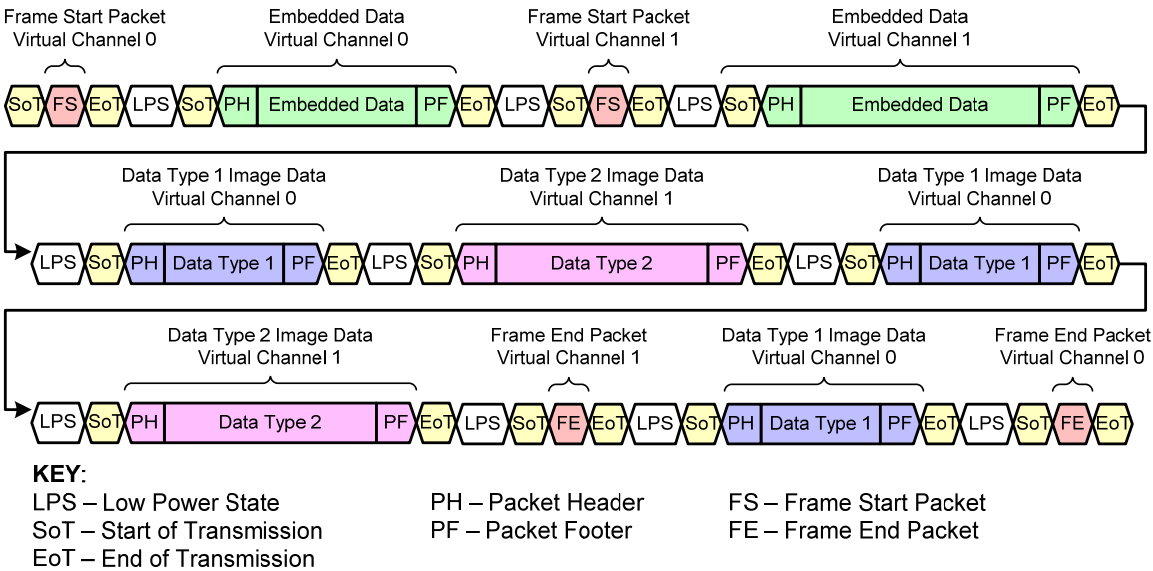


Figure 56 Interleaved Data Transmission using Virtual Channels

10 Color Spaces

The color space definitions in this section are simply references to other standards. The references are included only for informative purposes and not for compliance. The color space used is not limited to the references given.

10.1 RGB Color Space Definition

In this specification, the abbreviation RGB means the nonlinear sR'G'B' color space in 8-bit representation based on the definition of sRGB in IEC 61966.

The 8-bit representation results as RGB888. The conversion to the more commonly used RGB565 format is achieved by scaling the 8-bit values to five bits (blue and red) and six bits (green). The scaling can be done either by simply dropping the LSBs or rounding.

10.2 YUV Color Space Definition

In this specification, the abbreviation YUV refers to the 8-bit gamma corrected Y'CBCR color space defined in ITU-R BT601.4.

11 Data Formats

The intent of this section is to provide a definitive reference for data formats typically used in CSI-2 applications. Table 8 summarizes the formats, followed by individual definitions for each format. Generic data types not shown in the table are described in section 11.1. For simplicity, all examples are single Lane configurations.

The formats most widely used in CSI-2 applications are distinguished by a “primary” designation in Table 8. Transmitter implementations of CSI-2 should support at least one of these primary formats. Receiver implementations of CSI-2 should support all of the primary formats.

The packet payload data format shall agree with the Data Type value in the Packet Header. See Section 9.4 for a description of the Data Type values.

Table 8 Primary and Secondary Data Formats Definitions

Data Format	Primary	Secondary
YUV420 8-bit (legacy)		S
YUV420 8-bit		S
YUV420 10-bit		S
YUV420 8-bit (CSPS)		S
YUV420 10-bit (CSPS)		S
YUV422 8-bit	P	
YUV422 10-bit		S
RGB888	P	
RGB666		S
RGB565	P	
RGB555		S
RGB444		S
RAW6		S
RAW7		S
RAW8	P	
RAW10	P	
RAW12		S
RAW14		S
Generic 8-bit Long Packet Data Types	P	
User Defined Byte-based Data (Note 1)	P	

Notes:

- Compressed image data should use the user defined, byte-based data type codes

1220 For clarity the Start of Transmission and End of Transmission sequences in the figures in this section have
1221 been omitted.

1222 **11.1 Generic 8-bit Long Packet Data Types**

1223 Table 9 defines the generic 8-bit Long packet data types.

1224 **Table 9 Generic 8-bit Long Packet Data Types**

Data Type	Description
0x10	Null
0x11	Blanking Data
0x12	Embedded 8-bit non Image Data
0x13	Reserved
0x14	Reserved
0x15	Reserved
0x16	Reserved
0x17	Reserved

1225 **11.1.1 Null and Blanking Data**

1226 For both the null and blanking data types the receiver must ignore the content of the packet payload data.

1227 A blanking packet differs from a null packet in terms of its significance within a video data stream. A null
1228 packet has no meaning whereas the blanking packet may be used, for example, as the blanking lines
1229 between frames in an ITU-R BT.656 style video stream.

1230 **11.1.2 Embedded Information**

1231 It is possible to embed extra lines containing additional information to the beginning and to the end of each
1232 picture frame as presented in the Figure 57. If embedded information exists, then the lines containing the
1233 embedded data must use the embedded data code in the data identifier.

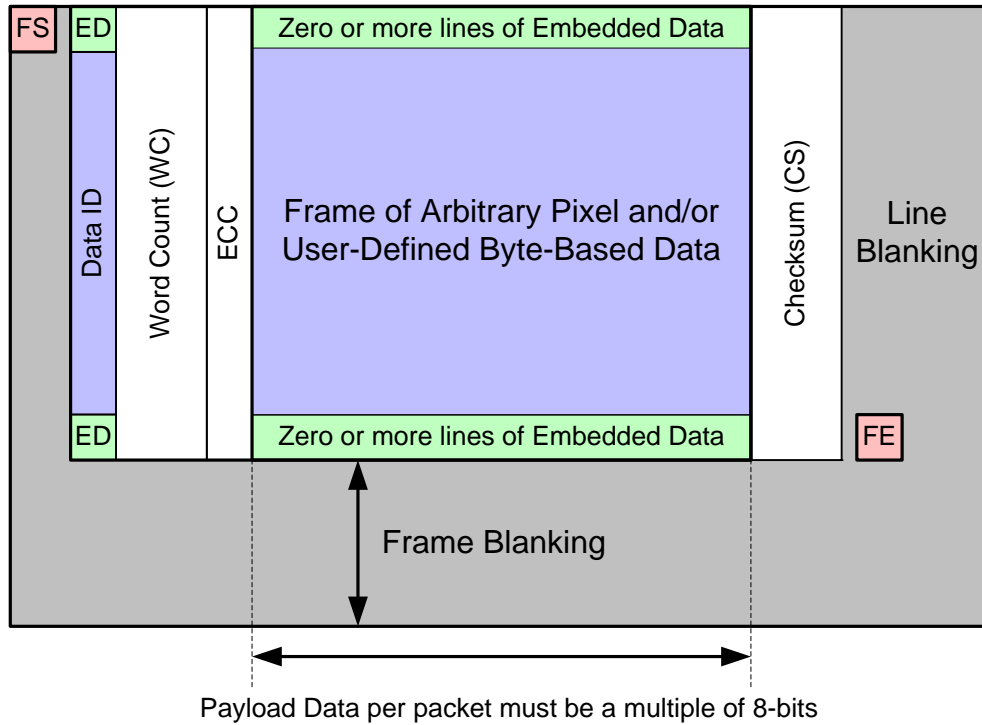
1234 There may be zero or more lines of embedded data at the start of the frame. These lines are termed the
1235 frame header.

1236 There may be zero or more line of embedded data at the end of the frame. These lines are termed the frame
1237 footer.

1238 **11.2 YUV Image Data**

1239 Table 10 defines the data type codes for YUV data formats described in this section. The number of lines
1240 transmitted for the YUV420 data type shall be even.

1241 YUV420 data formats are divided into legacy and non-legacy data formats. The legacy YUV420 data
1242 format is for compatibility with existing systems. The non-legacy YUV420 data formats enable lower cost
1243 implementations.

**KEY:**

LPS – Low Power State

ECC – Error Correction Code

FS – Frame Start

LS – Line Start

DI – Data Identifier

CS – Checksum

FE – Frame End

LE – Line End

WC – Word Count

ED – Embedded Data

Figure 57 Frame Structure with Embedded Data at the Beginning and End of the Frame**Table 10 YUV Image Data Types**

Data Type	Description
0x18	YUV420 8-bit
0x19	YUV420 10-bit
0x1A	Legacy YUV420 8-bit
0x1B	Reserved
0x1C	YUV420 8-bit (Chroma Shifted Pixel Sampling)
0x1D	YUV420 10-bit (Chroma Shifted Pixel Sampling)
0x1E	YUV422 8-bit
0x1F	YUV422 10-bit

11.2.1 Legacy YUV420 8-bit

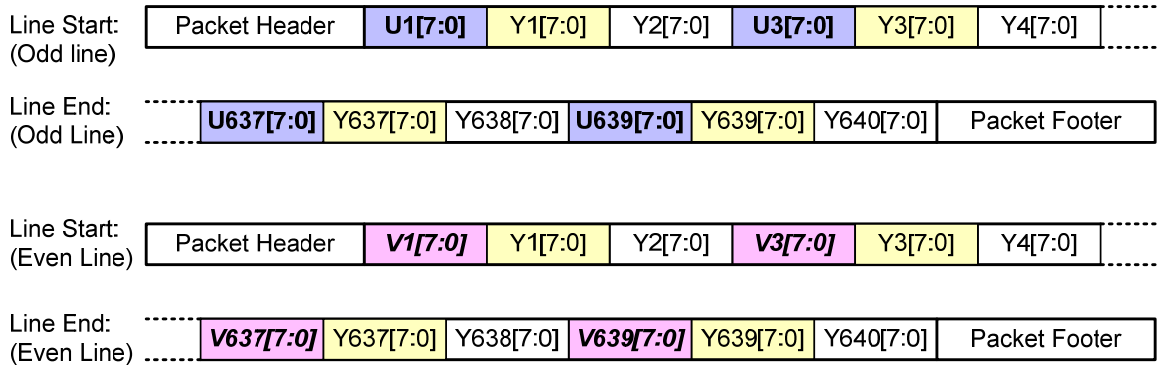
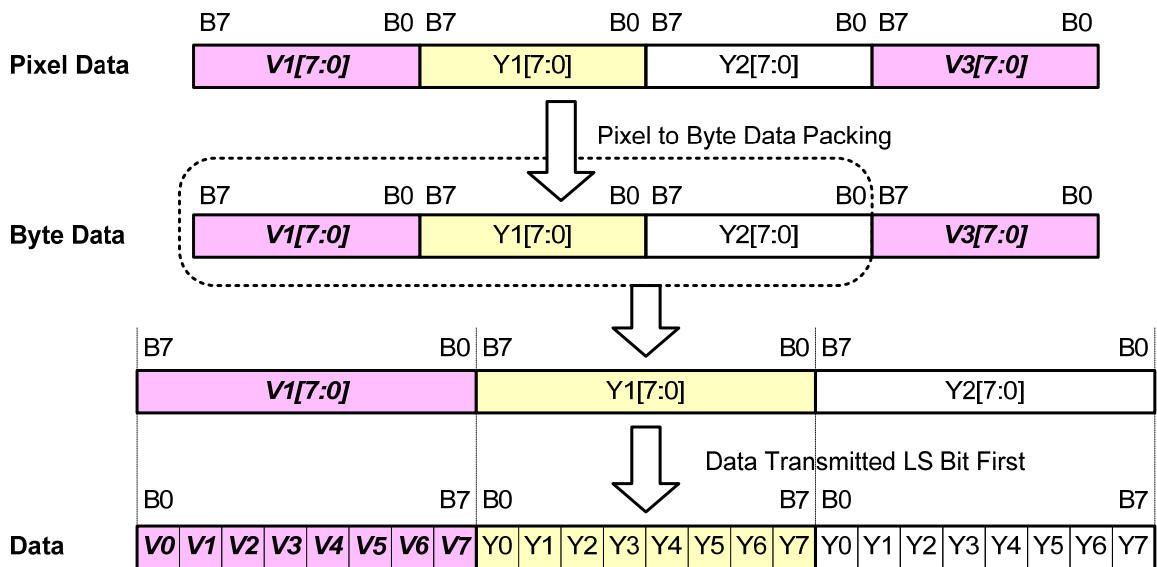
Legacy YUV420 8-bit data transmission is performed by transmitting UYY... / VYY... sequences in odd / even lines. U component is transferred in odd lines (1,3,5...) and V component is transferred in even lines (2,4,6...). This sequence is illustrated in Figure 58.

Table 11 specifies the packet size constraints for YUV420 8-bit packets. Each packet must be a multiple of the values in the table.

Table 11 Legacy YUV420 8-bit Packet Data Size Constraints

Pixels	Bytes	Bits
2	3	24

Bit order in transmission follows the general CSI-2 rule, LSB first. The pixel to byte mapping is illustrated in Figure 59.

**Figure 58 Legacy YUV420 8-bit Transmission****Figure 59 Legacy YUV420 8-bit Pixel to Byte Packing Bitwise Illustration**

There is one spatial sampling option

- H.261, H.263 and MPEG1 Spatial Sampling (Figure 60).

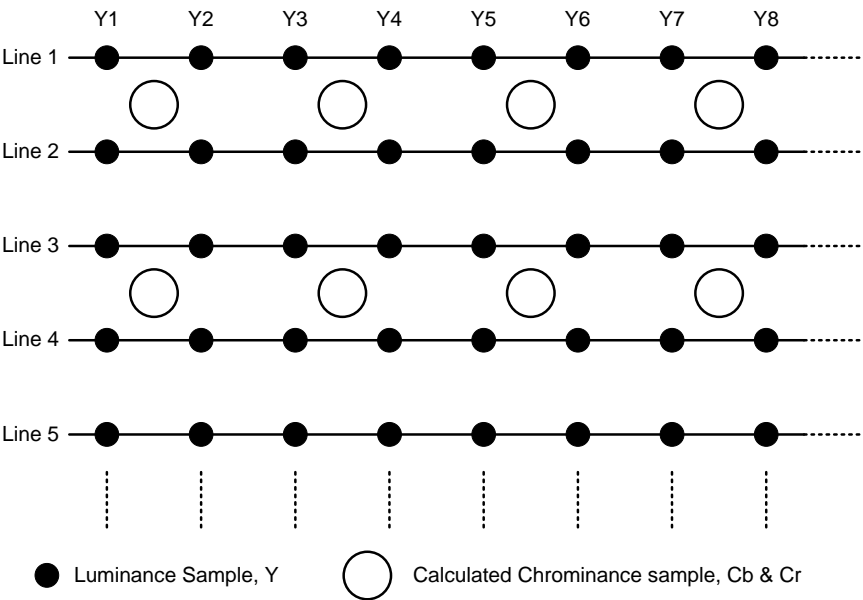


Figure 60 Legacy YUV420 Spatial Sampling for H.261, H.263 and MPEG 1

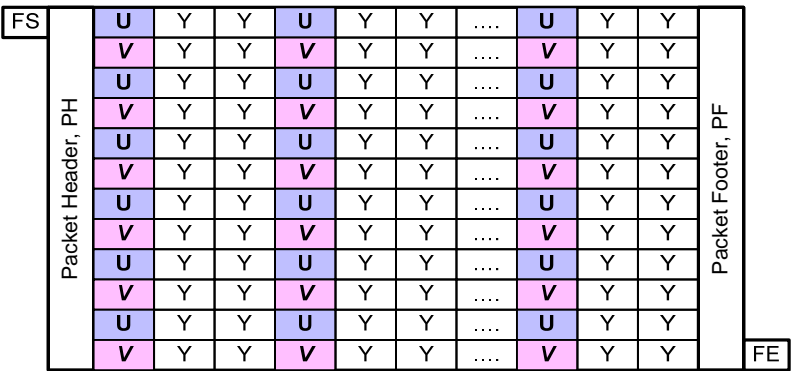


Figure 61 Legacy YUV420 8-bit Frame Format

11.2.2 YUV420 8-bit

YUV420 8-bit data transmission is performed by transmitting YYYY... / UYVYUYVY... sequences in odd / even lines. Only the luminance component (Y) is transferred for odd lines (1, 3, 5...) and both luminance (Y) and chrominance (U and V) components are transferred for even lines (2, 4, 6...). The format for the even lines (UYVY) is identical to the YUV422 8-bit data format. The data transmission sequence is illustrated in Figure 62.

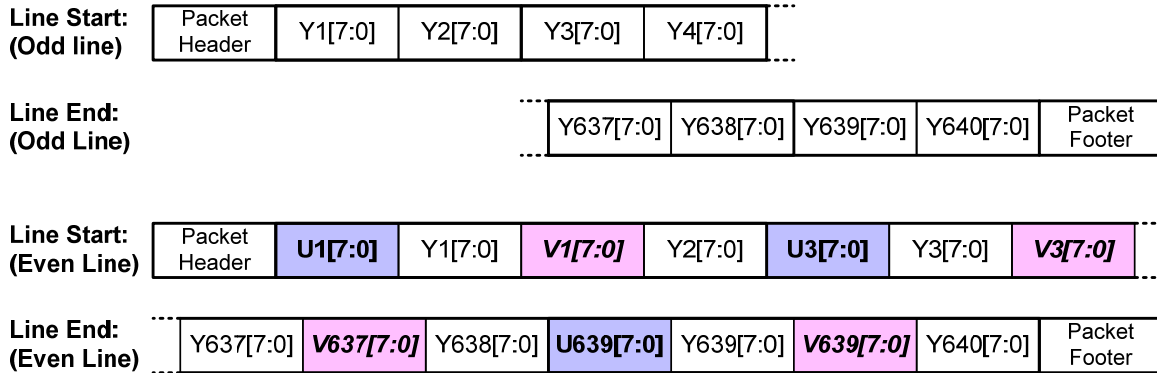
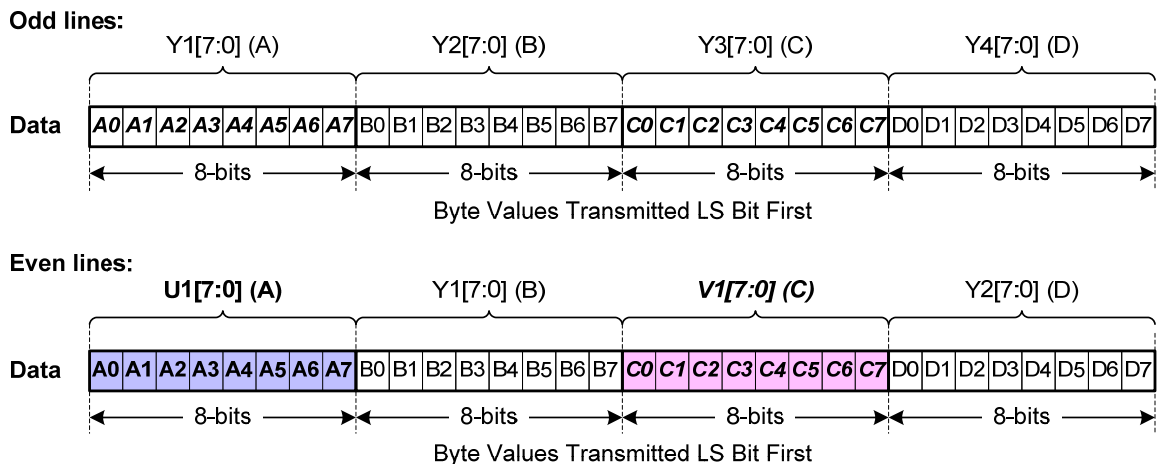
The payload data size, in bytes, for even lines (UYVY) is double the payload data size for odd lines (Y). This is exception to the general CSI-2 rule that each line shall have an equal length.

Table 12 specifies the packet size constraints for YUV420 8-bit packets. Each packet must be a multiple of the values in the table.

Table 12 YUV420 8-bit Packet Data Size Constraints

Odd Lines (1, 3, 5...) Luminance Only, Y			Even Lines (2, 4, 6...) Luminance and Chrominance, UYVY		
Pixels	Bytes	Bits	Pixels	Bytes	Bits
2	2	16	2	4	32

Bit order in transmission follows the general CSI-2 rule, LSB first. The pixel to byte mapping is illustrated in Figure 63.

**Figure 62 YUV420 8-bit Data Transmission Sequence****Figure 63 YUV420 8-bit Pixel to Byte Packing Bitwise Illustration**

There are two spatial sampling options

- H.261, H.263 and MPEG1 Spatial Sampling (Figure 64).
- Chroma Shifted Pixel Sampling (CSPS) for MPEG2, MPEG4 (Figure 65).

Figure 66 shows the YUV420 frame format.

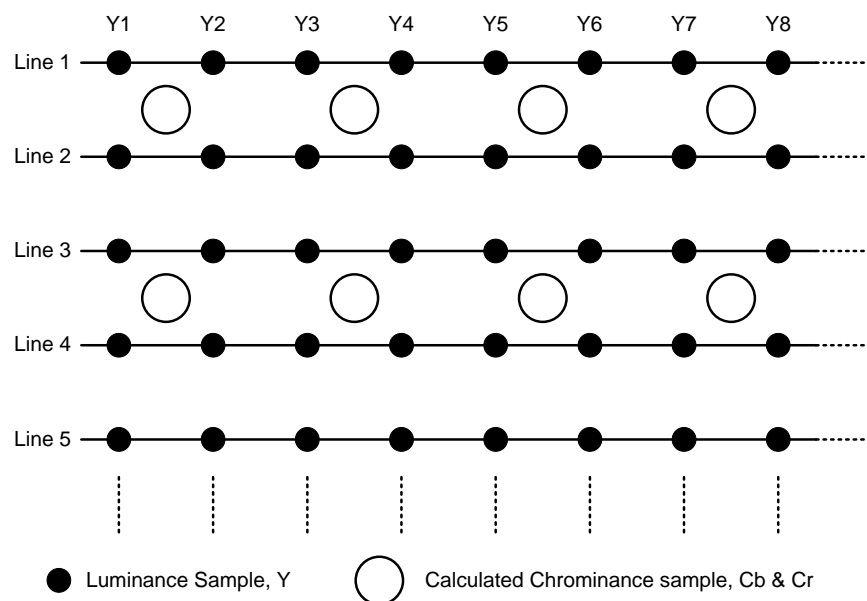


Figure 64 YUV420 Spatial Sampling for H.261, H.263 and MPEG 1

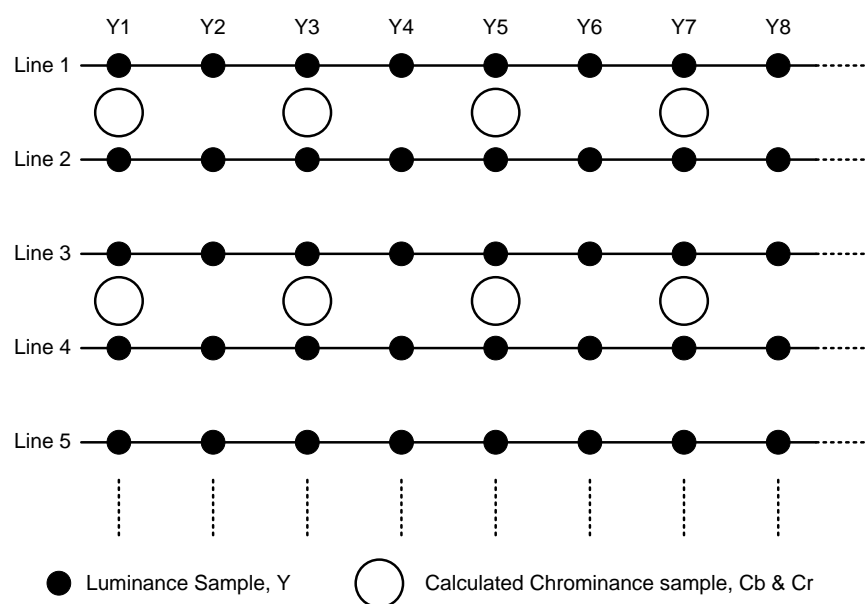


Figure 65 YUV420 Spatial Sampling for MPEG 2 and MPEG 4

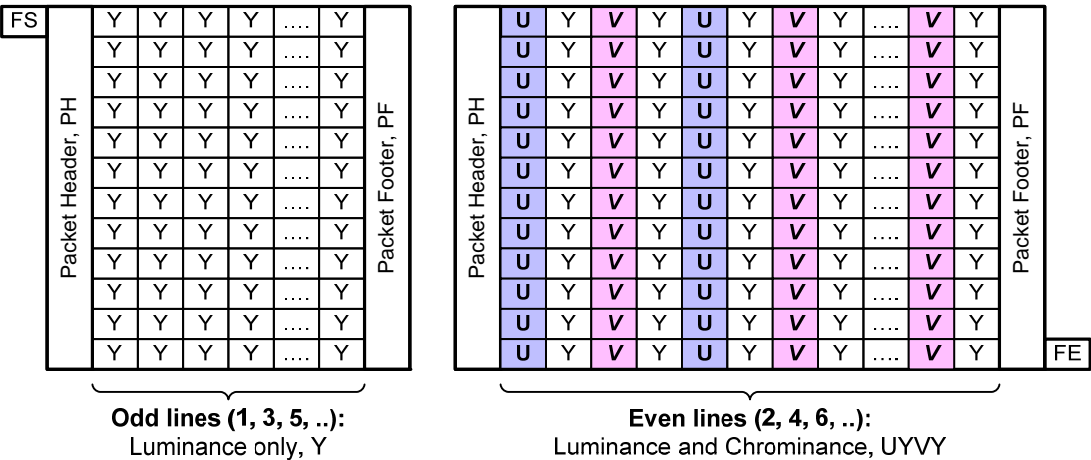


Figure 66 YUV420 8-bit Frame Format

11.2.3 YUV420 10-bit

YUV420 10-bit data transmission is performed by transmitting YYYYY... / UYVYUYVY... sequences in odd / even lines. Only the luminance component (Y) is transferred in odd lines (1, 3, 5...) and both luminance (Y) and chrominance (U and V) components transferred in even lines (2, 4, 6...). The format for the even lines (UYVY) is identical to the YUV422 –10-bit data format. The sequence is illustrated in Figure 67.

The payload data size, in bytes, for even lines (UYVY) is double the payload data size for odd lines (Y). This is exception to the general CSI-2 rule that each line shall have an equal length.

Table 13 specifies the packet size constraints for YUV420 10-bit packets. The length of each packet must be a multiple of the values in the table.

Table 13 YUV420 10-bit Packet Data Size Constraints

Odd Lines (1, 3, 5...) Luminance Only, Y			Even Lines (2, 4, 6...) Luminance and Chrominance, UYVY		
Pixels	Bytes	Bits	Pixels	Bytes	Bits
4	5	40	4	10	80

Bit order in transmission follows the general CSI-2 rule, LSB first. The pixel to byte mapping is illustrated in Figure 68.

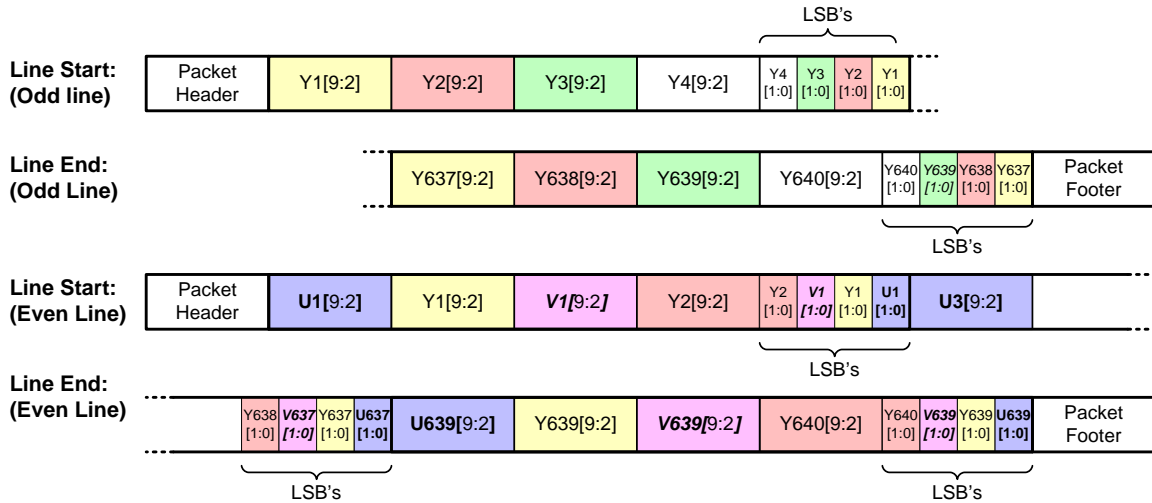


Figure 67 YUV420 10-bit Transmission

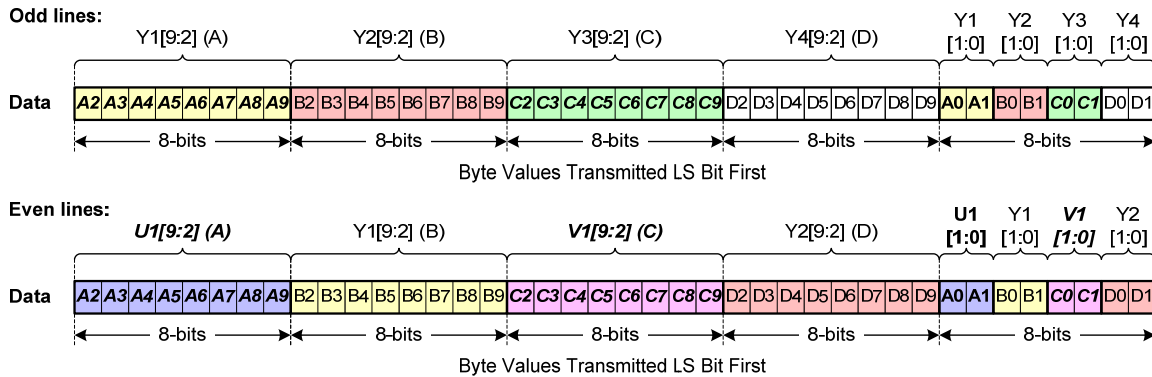


Figure 68 YUV420 10-bit Pixel to Byte Packing Bitwise Illustration

The pixel spatial sampling options are the same as for the YUV420 8-bit data format.

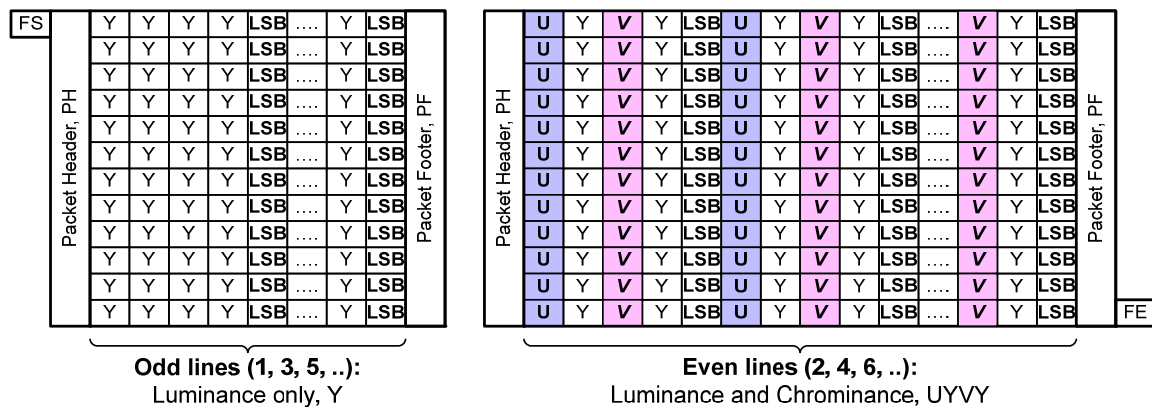


Figure 69 YUV420 10-bit Frame Format

11.2.4 YUV422 8-bit

YUV422 8-bit data transmission is performed by transmitting a UYVY sequence. This sequence is illustrated in Figure 70.

Table 14 specifies the packet size constraints for YUV422 8-bit packet. The length of each packet must be a multiple of the values in the table.

Table 14 YUV422 8-bit Packet Data Size Constraints

Pixels	Bytes	Bits
2	4	32

Bit order in transmission follows the general CSI-2 rule, LSB first. The pixel to byte mapping is illustrated in Figure 71.

Line Start: Packet Header U1[7:0] Y1[7:0] V1[7:0] Y2[7:0] U3[7:0]

Line End: Y638[7:0] U639[7:0] Y639[7:0] V639[7:0] Y640[7:0] Packet Footer

Figure 70 YUV422 8-bit Transmission

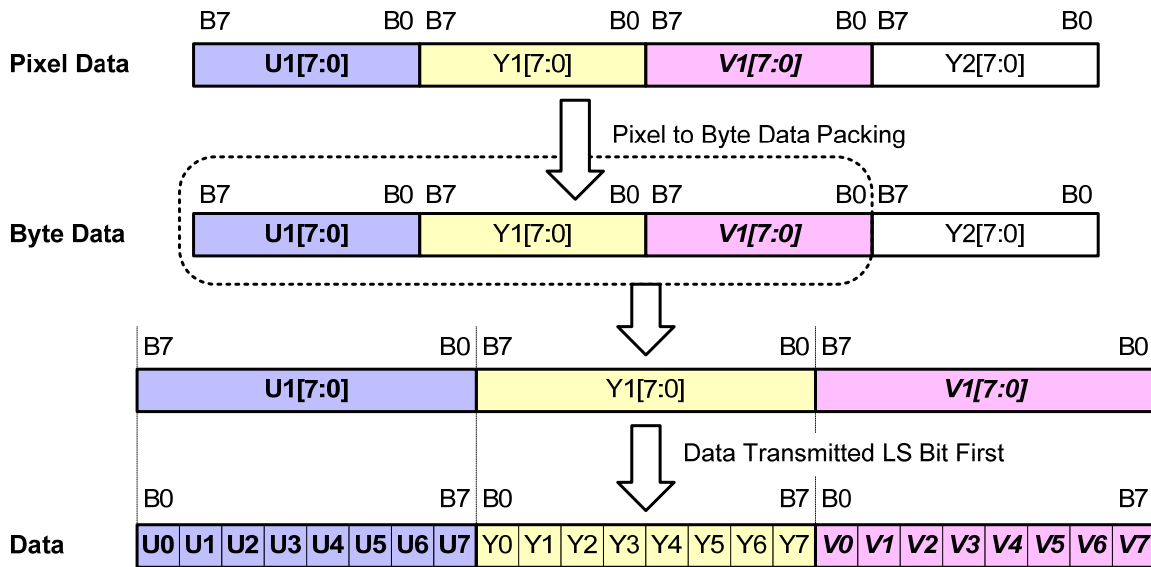


Figure 71 YUV422 8-bit Pixel to Byte Packing Bitwise Illustration

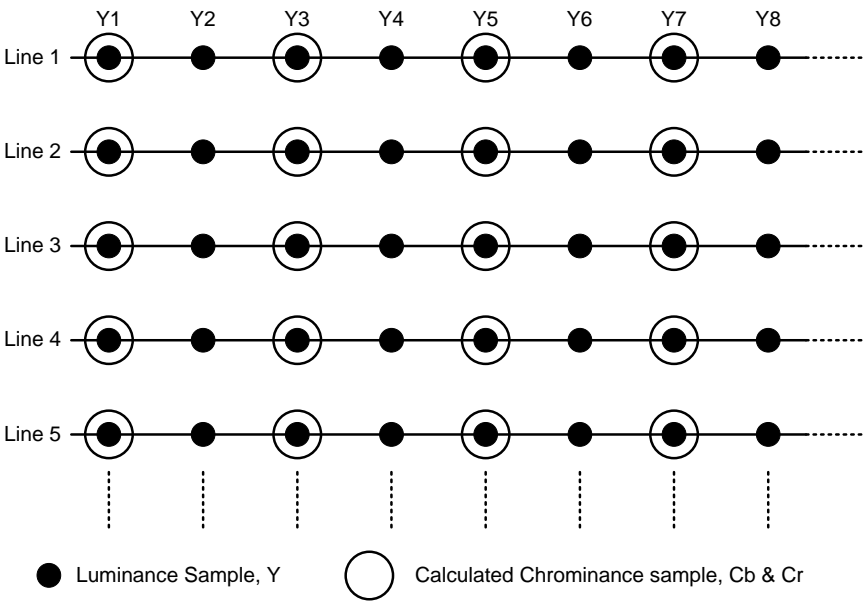


Figure 72 YUV422 Co-sited Spatial Sampling

The pixel spatial alignment is the same as in CCIR-656 standard. The frame format for YUV422 is presented in Figure 73.

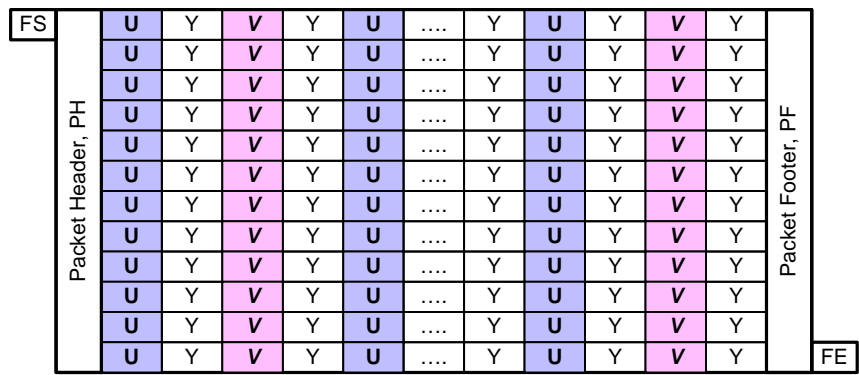


Figure 73 YUV422 8-bit Frame Format

11.2.5 YUV422 10-bit

YUV422 10-bit data transmission is performed by transmitting a UYVY sequence. This sequence is illustrated in Figure 74.

Table 15 specifies the packet size constraints for YUV422 10-bit packet. The length of each packet must be a multiple of the values in the table.

Table 15 YUV422 10-bit Packet Data Size Constraints

Pixels	Bytes	Bits
2	5	40

Bit order in transmission follows the general CSI-2 rule, LSB first. The pixel to byte mapping is illustrated in Figure 75.

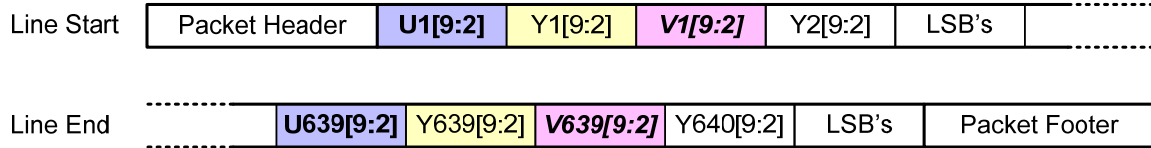
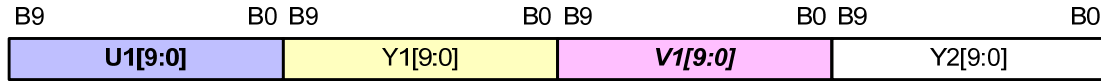
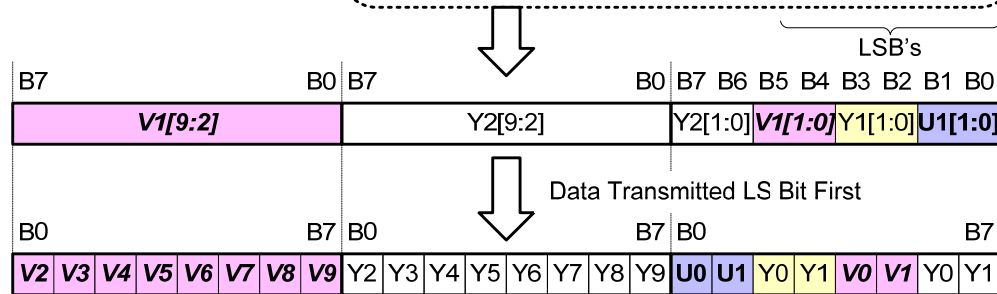
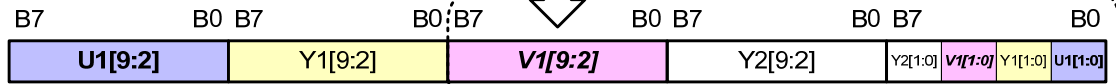


Figure 74 YUV422 10-bit Transmitted Bytes

Pixel Data:



Byte Data:



Data

Figure 75 YUV422 10-bit Pixel to Byte Packing Bitwise Illustration

The pixel spatial alignment is the same as in the YUV422 8-bit data case. The frame format for YUV422 is presented in the Figure 76.

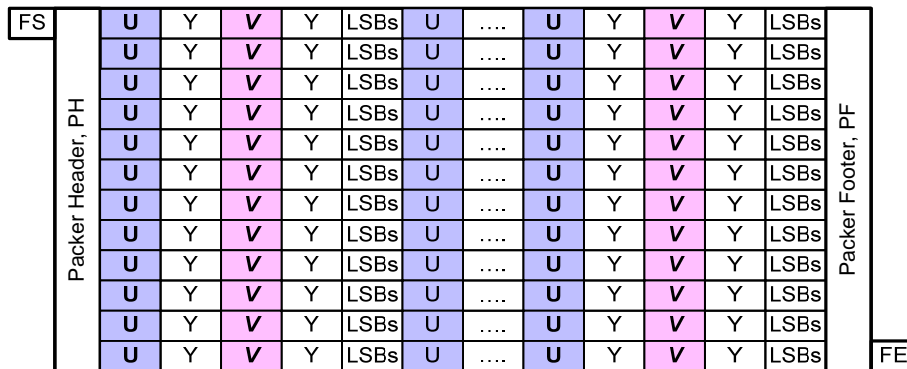


Figure 76 YUV422 10-bit Frame Format

11.3 RGB Image Data

Table 16 defines the data type codes for RGB data formats described in this section.

Table 16 RGB Image Data Types

Data Type	Description
0x20	RGB444
0x21	RGB555
0x22	RGB565
0x23	RGB666
0x24	RGB888
0x25	Reserved
0x26	Reserved
0x27	Reserved

11.3.1 RGB888

RGB888 data transmission is performed by transmitting a BGR byte sequence. This sequence is illustrated in Figure 77. The RGB888 frame format is illustrated in Figure 79.

Table 17 specifies the packet size constraints for RGB888 packets. The length of each packet must be a multiple of the values in the table.

Table 17 RGB888 Packet Data Size Constraints

Pixels	Bytes	Bits
1	3	24

Bit order in transmission follows the general CSI-2 rule, LSB first. The pixel to byte mapping is illustrated in Figure 78.

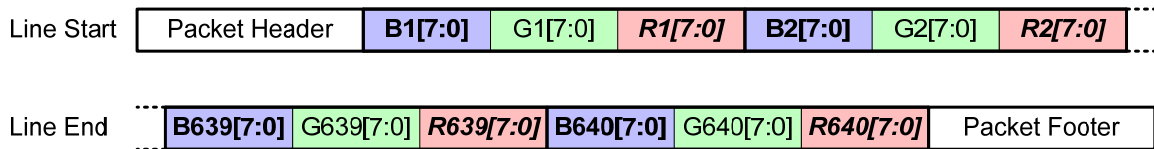


Figure 77 RGB888 Transmission

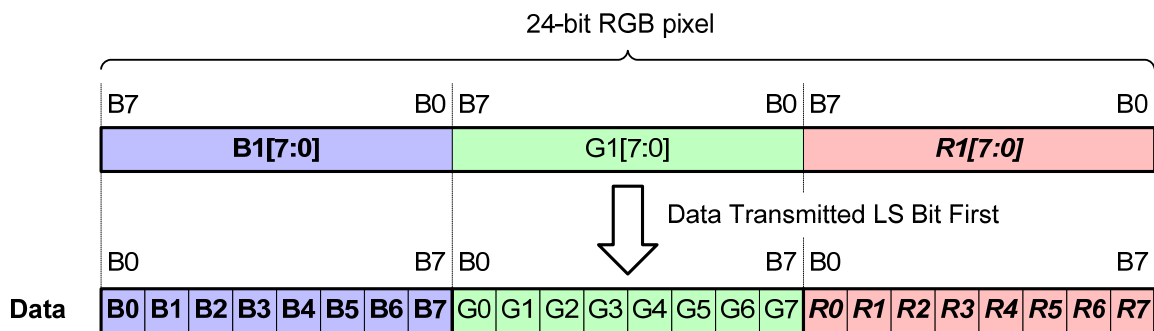


Figure 78 RGB888 Transmission in CSI-2 Bus Bitwise Illustration

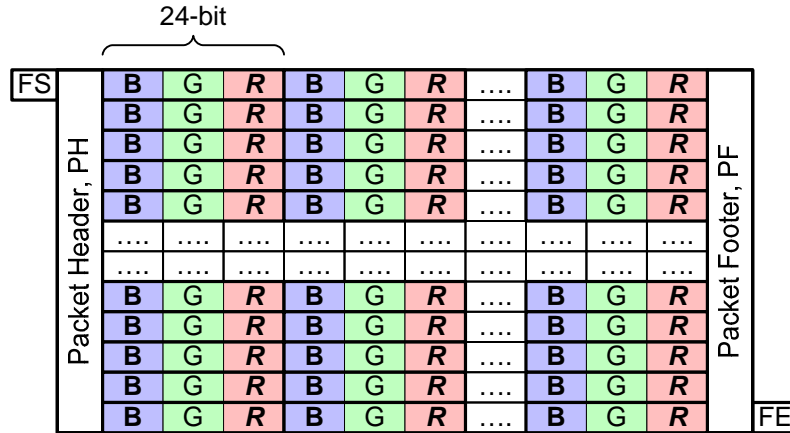


Figure 79 RGB888 Frame Format

11.3.2 RGB666

RGB666 data transmission is performed by transmitting B0..5 G0..5 R0..5 (18-bit) sequence. This sequence is illustrated in Figure 80. The frame format for RGB666 is presented in the Figure 82.

Table 18 specifies the packet size constraints for RGB666 packets. The length of each packet must be a multiple of the values in the table.

Table 18 RGB666 Packet Data Size Constraints

Pixels	Bytes	Bits
4	9	72

Bit order in transmission follows the general CSI-2 rule, LSB first. In RGB666 case the length of one data word is 18-bits, not eight bits. The word wise flip is done for 18-bit BGR words i.e. instead of flipping each byte (8-bits), each 18-bits pixel value is flipped. This is illustrated in Figure 81.

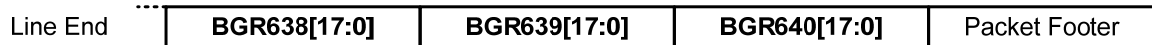


Figure 80 RGB666 Transmission with 18-bit BGR Words

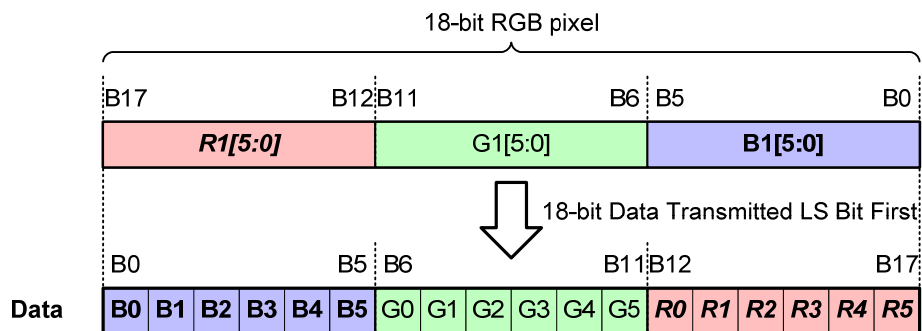


Figure 81 RGB666 Transmission on CSI-2 Bus Bitwise Illustration

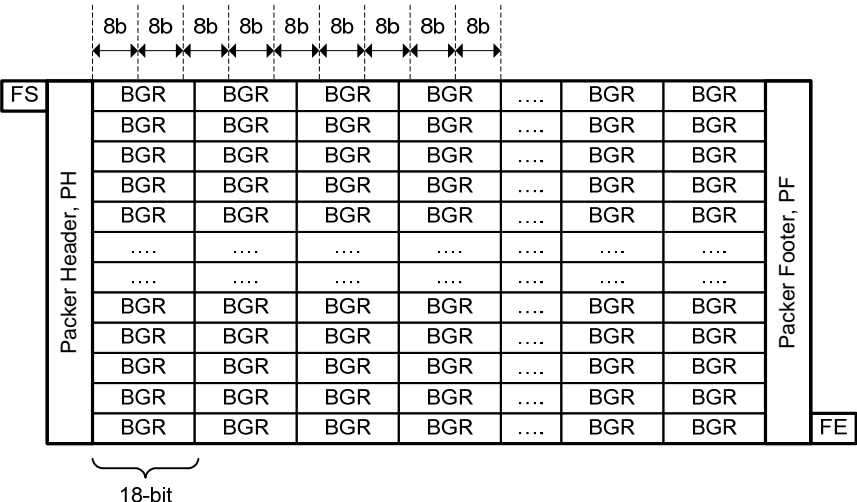


Figure 82 RGB666 Frame Format

11.3.3 RGB565

RGB565 data transmission is performed by transmitting B0...B4, G0...G5, R0...R4 in a 16-bit sequence. This sequence is illustrated in Figure 83. The frame format for RGB565 is presented in the Figure 85.

Table 19 specifies the packet size constraints for RGB565 packets. The length of each packet must be a multiple of the values in the table.

Table 19 RGB565 Packet Data Size Constraints

Pixels	Bytes	Bits
1	2	16

Bit order in transmission follows the general CSI-2 rule, LSB first. In RGB565 case the length of one data word is 16-bits, not eight bits. The word wise flip is done for 16-bit BGR words i.e. instead of flipping each byte (8-bits), each two bytes (16-bits) are flipped. This is illustrated in Figure 84.

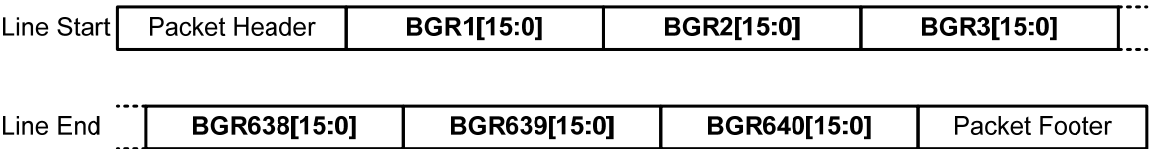


Figure 83 RGB565 Transmission with 16-bit BGR Words

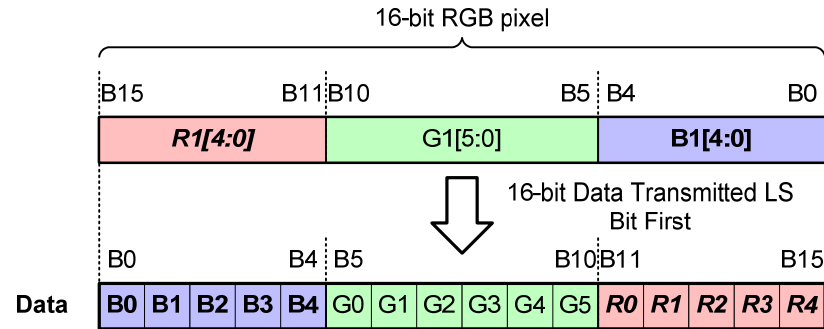


Figure 84 RGB565 Transmission on CSI-2 Bus Bitwise Illustration

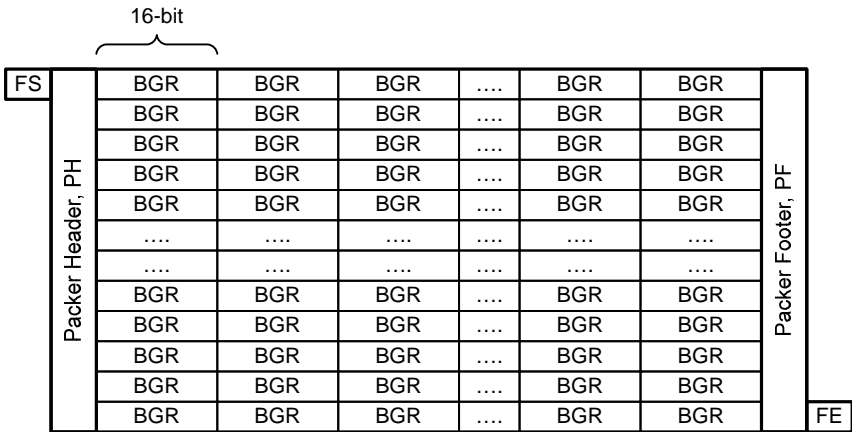


Figure 85 RGB565 Frame Format

11.3.4 RGB555

RGB555 data can be transmitted over a CSI-2 bus with some special arrangements. The RGB555 data should be made to look like RGB565 data. This can be accomplished by inserting padding bits to the LSBs of the green color component as illustrated in Figure 86.

Both the frame format and the package size constraints are the same as the RGB565 case.

Bit order in transmission follows the general CSI-2 rule, LSB first. In RGB555 case the length of one data word is 16-bits, not eight bits. The word wise flip is done for 16-bit BGR words i.e. instead of flipping each byte (8-bits), each two bytes (16-bits) are flipped. This is illustrated in Figure 86.

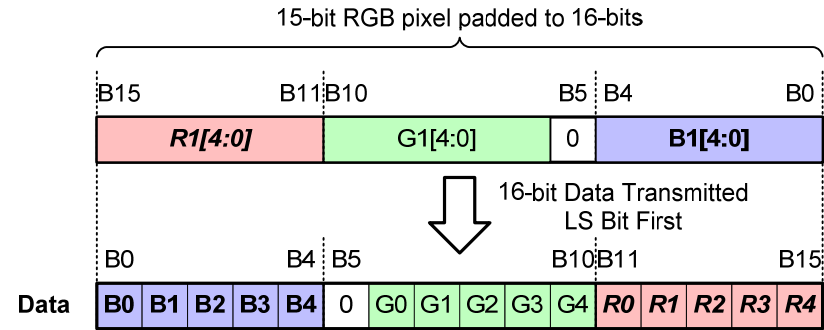


Figure 86 RGB555 Transmission on CSI-2 Bus Bitwise Illustration

11.3.5 RGB444

RGB444 data can be transmitted over a CSI-2 bus with some special arrangements. The RGB444 data should be made to look like RGB565 data. This can be accomplished by inserting padding bits to the LSBs of each color component as illustrated in Figure 87.

Both the frame format and the package size constraints are the same as the RGB565 case.

Bit order in transmission follows the general CSI-2 rule, LSB first. In RGB444 case the length of one data word is 16-bits, not eight bits. The word-wise flip is done for 16-bit BGR words i.e. instead of flipping each byte (8-bits), each two bytes (16-bits) are flipped. This is illustrated in Figure 87.

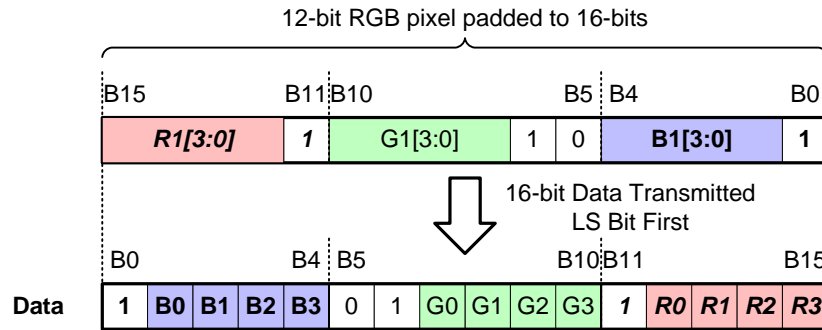


Figure 87 RGB444 Transmission on CSI-2 Bus Bitwise Illustration

11.4 RAW Image Data

The RAW 6/7/8/10/12/14 modes are used for transmitting Raw image data from the image sensor.

The intent is that Raw image data is unprocessed image data for example Raw Bayer data or complementary color data, but RAW image data is not limited to these data types.

It is possible to transmit e.g. light shielded pixels in addition to effective pixels. This leads to a situation where the line length is longer than sum of effective pixels per line. The line length, if not specified otherwise, has to be a multiple of word (32 bits).

Table 20 defines the data type codes for RAW data formats described in this section.

Table 20 RAW Image Data Types

Data Type	Description
0x28	RAW6
0x29	RAW7
0x2A	RAW8
0x2B	RAW10
0x2C	RAW12
0x2D	RAW14
0x2E	Reserved
0x2F	Reserved

11.4.1 RAW6

The 6-bit Raw data transmission is performed by transmitting the pixel data over CSI-2 bus. Each line is separated by line start / end synchronization codes. This sequence is illustrated in Figure 88 (VGA case). Table 21 specifies the packet size constraints for RAW6 packets. The length of each packet must be a multiple of the values in the table.

Table 21 RAW6 Packet Data Size Constraints

Pixels	Bytes	Bits
4	3	24

Each 6-bit pixel is sent LSB first. This is an exception to general CSI-2 rule byte wise LSB first.

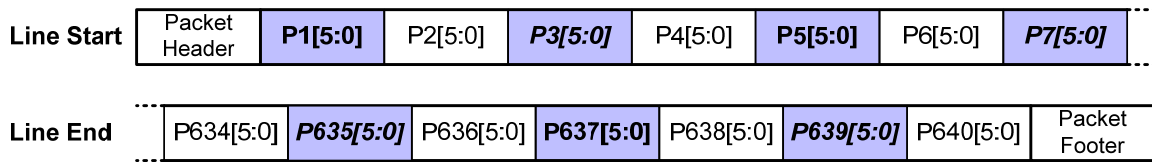


Figure 88 RAW6 Transmission

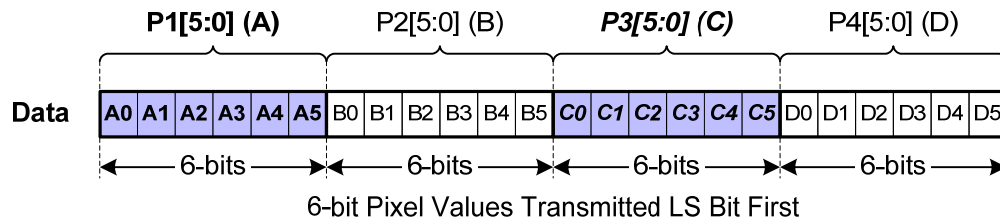


Figure 89 RAW6 Data Transmission on CSI-2 Bus Bitwise Illustration

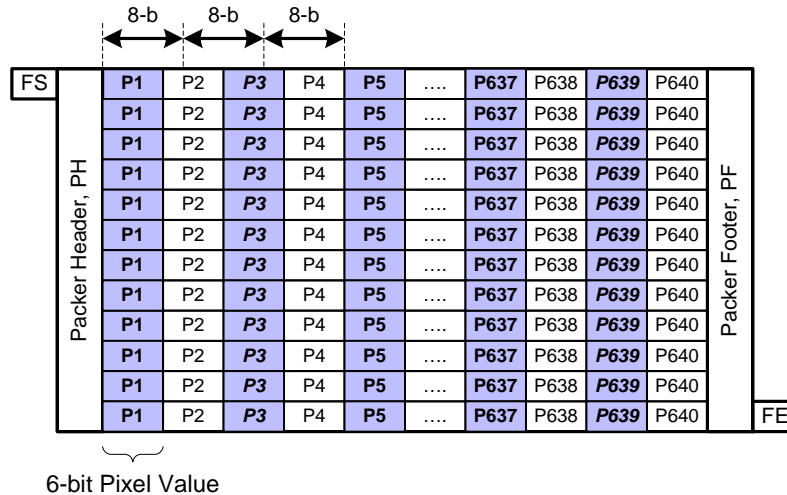


Figure 90 RAW6 Frame Format

11.4.2 RAW7

The 7-bit Raw data transmission is performed by transmitting the pixel data over CSI-2 bus. Each line is separated by line start / end synchronization codes. This sequence is illustrated in Figure 91 (VGA case).

1451 Table 22 specifies the packet size constraints for RAW7 packets. The length of each packet must be a
 1452 multiple of the values in the table.

1453 **Table 22 RAW7 Packet Data Size Constraints**

Pixels	Bytes	Bits
8	7	56

1454 Each 7-bit pixel is sent LSB first. This is an exception to general CSI-2 rule byte-wise LSB first.

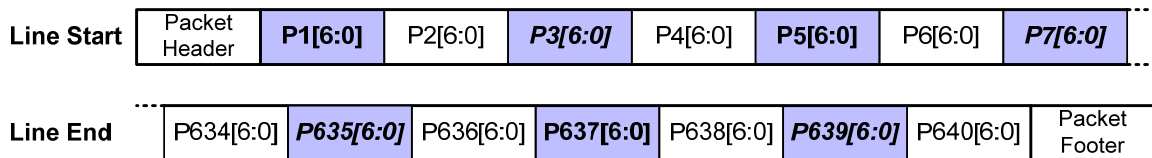


Figure 91 RAW7 Transmission

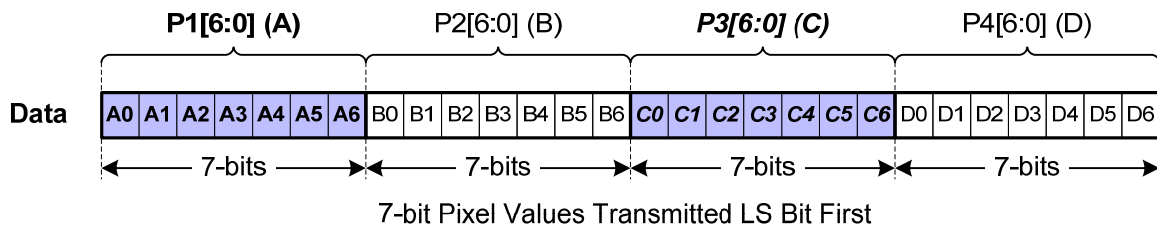


Figure 92 RAW7 Data Transmission on CSI-2 Bus Bitwise Illustration

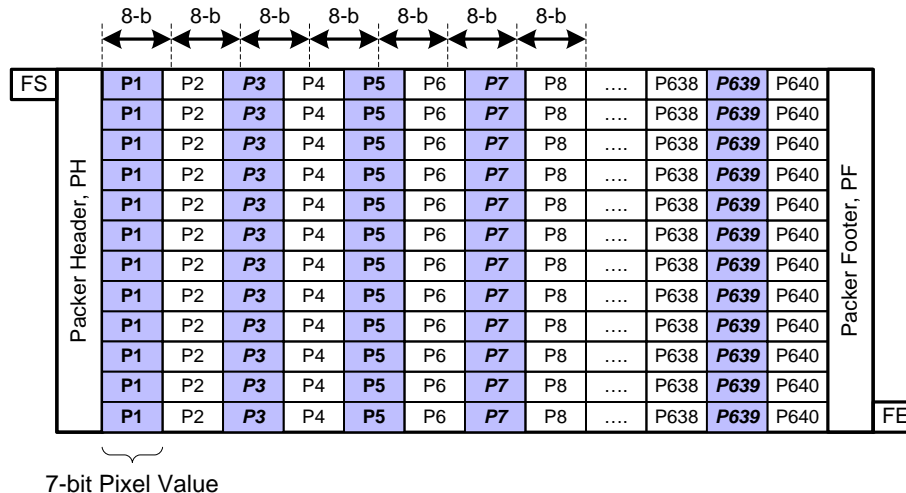


Figure 93 RAW7 Frame Format

11.4.3 RAW8

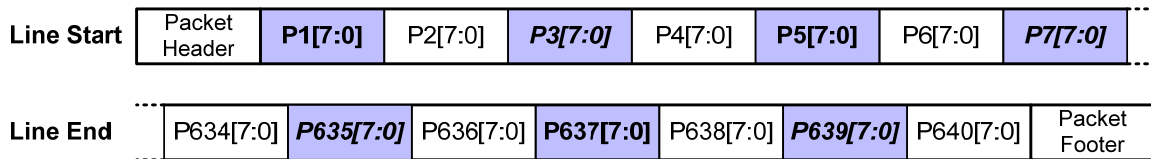
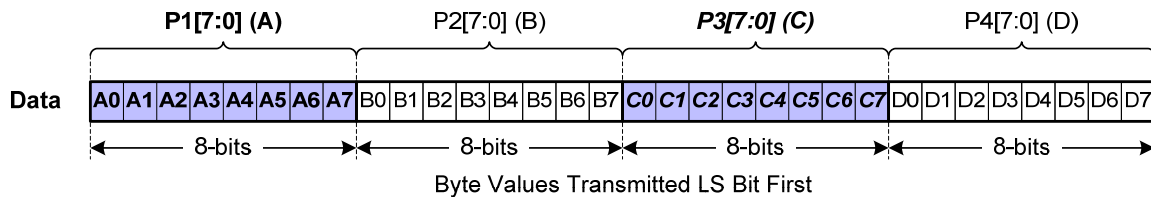
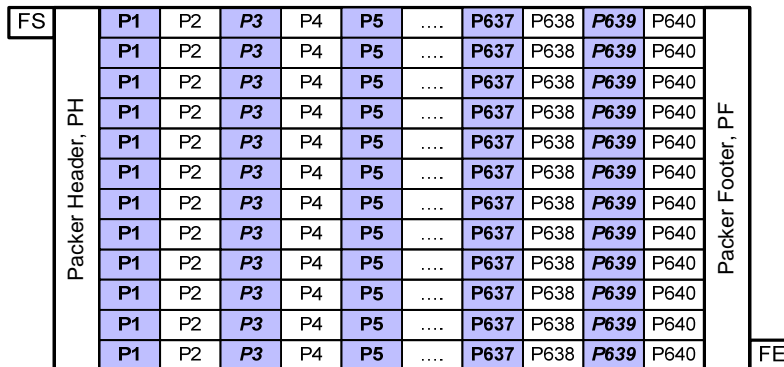
1463 The 8-bit Raw data transmission is performed by transmitting the pixel data over a CSI-2 bus. Table 23
 1464 specifies the packet size constraints for RAW8 packets. The length of each packet must be a multiple of the
 1465 values in the table.

Table 23 RAW8 Packet Data Size Constraints

Pixels	Bytes	Bits
1	1	8

This sequence is illustrated in Figure 94 (VGA case).

Bit order in transmission follows the general CSI-2 rule, LSB first.

**Figure 94 RAW8 Transmission****Figure 95 RAW8 Data Transmission on CSI-2 Bus Bitwise Illustration****Figure 96 RAW8 Frame Format**

11.4.4 RAW10

The transmission of 10-bit Raw data is accomplished by packing the 10-bit pixel data to look like 8-bit data format. Table 24 specifies the packet size constraints for RAW10 packets. The length of each packet must be a multiple of the values in the table.

Table 24 RAW10 Packet Data Size Constraints

Pixels	Bytes	Bits
4	5	40

This sequence is illustrated in Figure 97 (VGA case).

Bit order in transmission follows the general CSI-2 rule, LSB first.

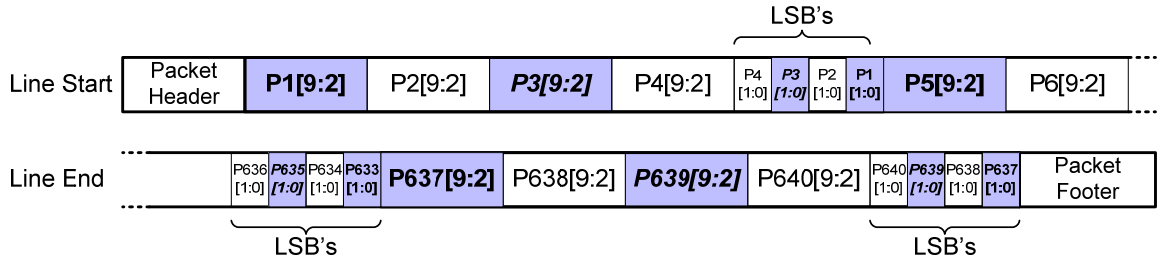


Figure 97 RAW10 Transmission

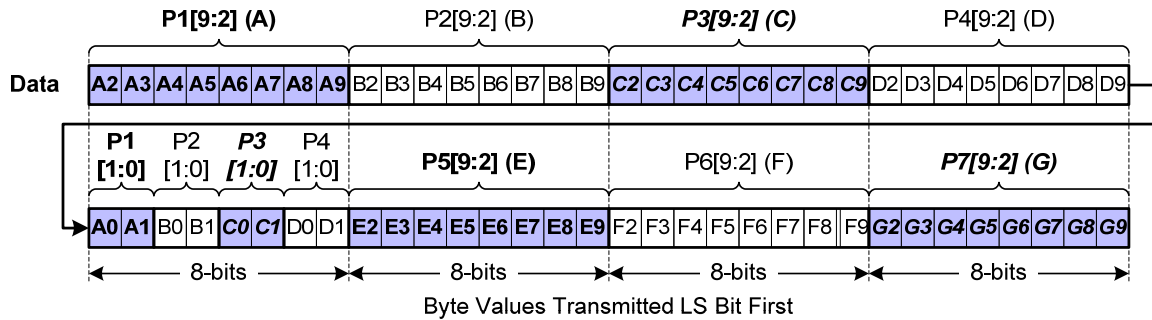


Figure 98 RAW10 Data Transmission on CSI-2 Bus Bitwise Illustration

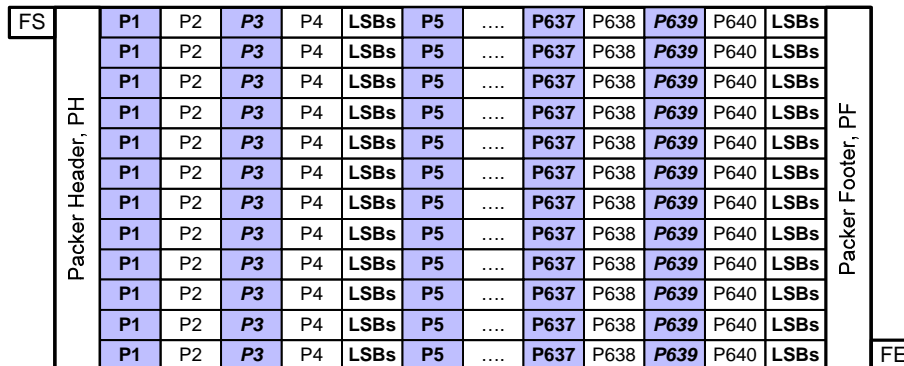


Figure 99 RAW10 Frame Format

11.4.5 RAW12

The transmission of 12-bit Raw data is also accomplished by packing the 12-bit pixel data to look like 8-bit data format. Table 25 specifies the packet size constraints for RAW12 packets. The length of each packet must be a multiple of the values in the table.

Table 25 RAW12 Packet Data Size Constraints

Pixels	Bytes	Bits
2	3	24

This sequence is illustrated in Figure 100 (VGA case).

Bit order in transmission follows the general CSI-2 rule, LSB first.

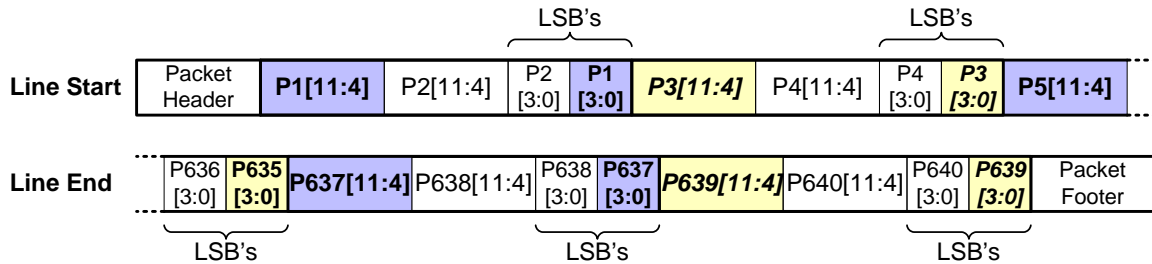


Figure 100 RAW12 Transmission

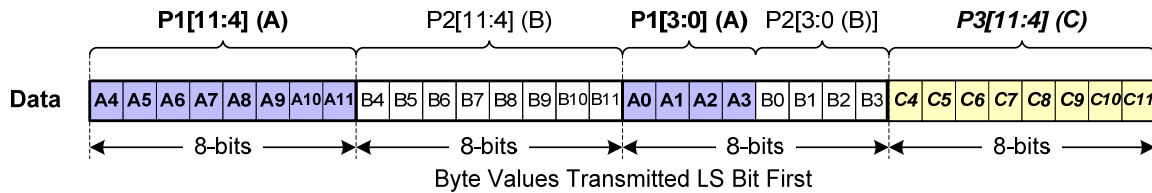


Figure 101 RAW12 Transmission on CSI-2 Bus Bitwise Illustration

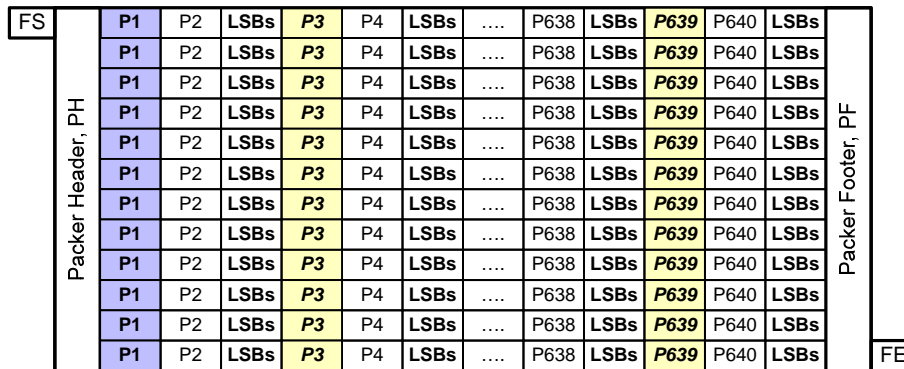


Figure 102 RAW12 Frame Format

11.4.6 RAW14

The transmission of 14-bit Raw data is accomplished by packing the 14-bit pixel data in 8-bit slices. For every four pixels, seven bytes of data is generated. Table 26 specifies the packet size constraints for RAW14 packets. The length of each packet must be a multiple of the values in the table.

Table 26 RAW14 Packet Data Size Constraints

Pixels	Bytes	Bits
4	7	56

The sequence is illustrated in Figure 103 (VGA case).

The LS bits for P1, P2, P3 and P4 are distributed in three bytes as shown in Figure 104. The same is true for the LS bits for P637, P638, P639 and P640. The bit order during transmission follows the general CSI-2 rule, i.e. LSB first.

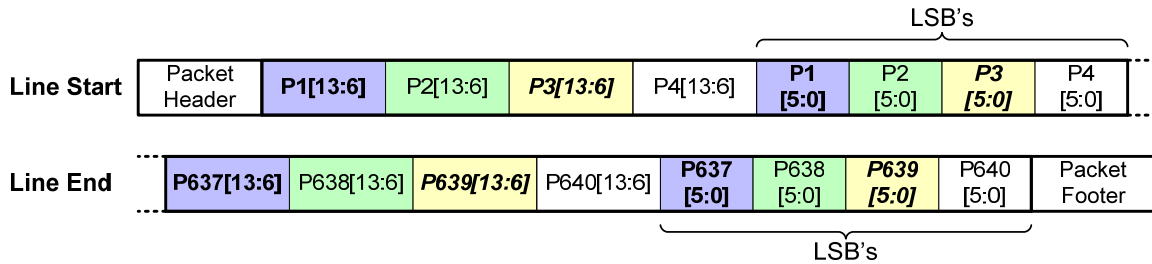


Figure 103 RAW14 Transmission

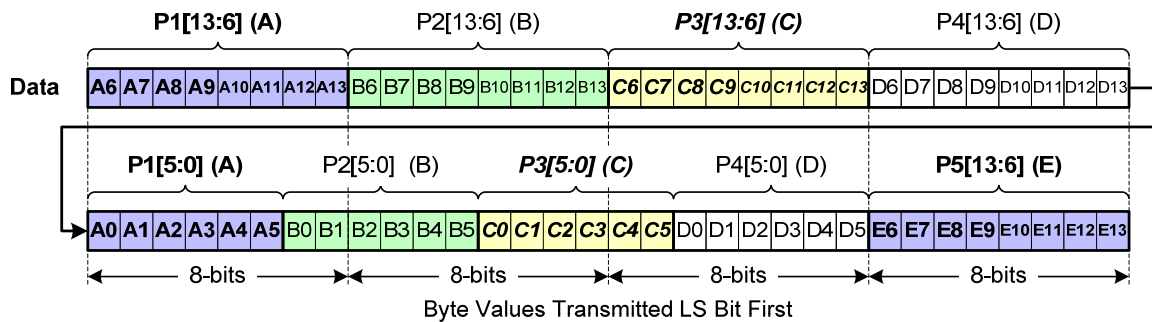


Figure 104 RAW14 Transmission on CSI-2 Bus Bitwise Illustration

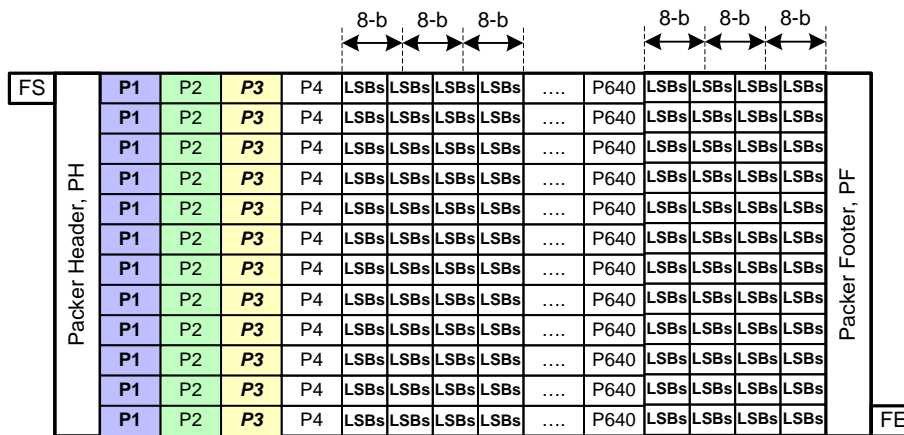


Figure 105 RAW14 Frame Format

11.5 User Defined Data Formats

The User Defined Data Type values shall be used to transmit arbitrary data, such as JPEG and MPEG4 data, over the CSI-2 bus. Data shall be packed so that the data length is divisible by eight bits. If data padding is required, the padding shall be added before data is presented to the CSI-2 protocol interface.

Bit order in transmission follows the general CSI-2 rule, LSB first.

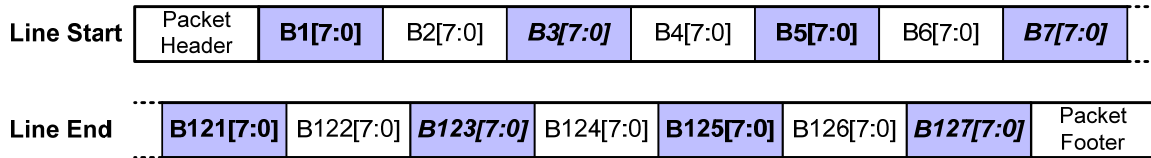


Figure 106 User Defined 8-bit Data (128 Byte Packet)

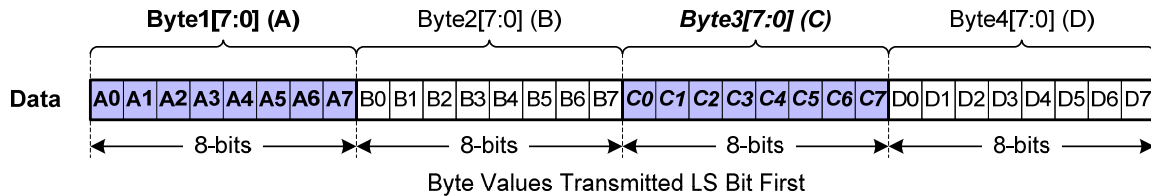


Figure 107 User Defined 8-bit Data Transmission on CSI-2 Bus Bitwise Illustration

The packet data size in bits shall be divisible by eight, i.e. a whole number of bytes shall be transmitted.

For User Defined data:

- The frame is transmitted as a sequence of arbitrary sized packets.
- The packet size may vary from packet to packet.
- The packet spacing may vary between packets.

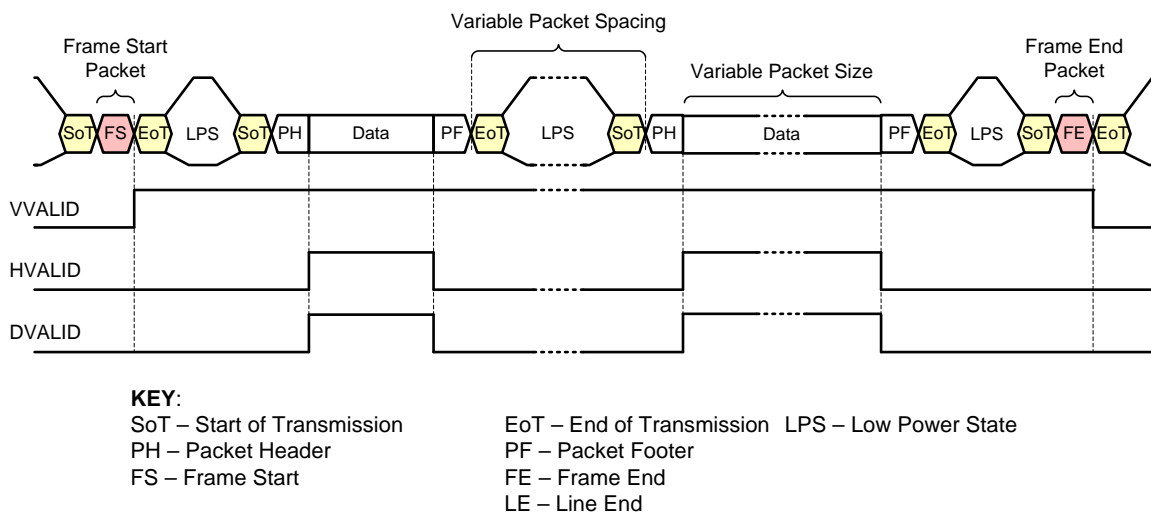


Figure 108 Transmission of User Defined 8-bit Data

Eight different User Defined data type codes are available as shown in Table 27.

Table 27 User Defined 8-bit Data Types

Data Type	Description
0x30	User Defined 8-bit Data Type 1
0x31	User Defined 8-bit Data Type 2

Data Type	Description
0x32	User Defined 8-bit Data Type 3
0x33	User Defined 8-bit Data Type 4
0x34	User Defined 8-bit Data Type 5
0x35	User Defined 8-bit Data Type 6
0x36	User Defined 8-bit Data Type 7
0x37	User Defined 8-bit Data Type 8

1540

1541

12 Recommended Memory Storage

This section is informative.

The CSI-2 data protocol requires certain behavior from the receiver connected to the CSI transmitter. The following sections describe how different data formats should be stored inside the receiver. While informative, this section is provided to ease application software development by suggesting a common data storage format among different receivers.

12.1 General/Arbitrary Data Reception

In the generic case and for arbitrary data the first byte of payload data transmitted maps the LS byte of the 32-bit memory word and the fourth byte of payload data transmitted maps to the MS byte of the 32-bit memory word.

The below is the generic CSI-2 byte to 32-bit memory word mapping rule.

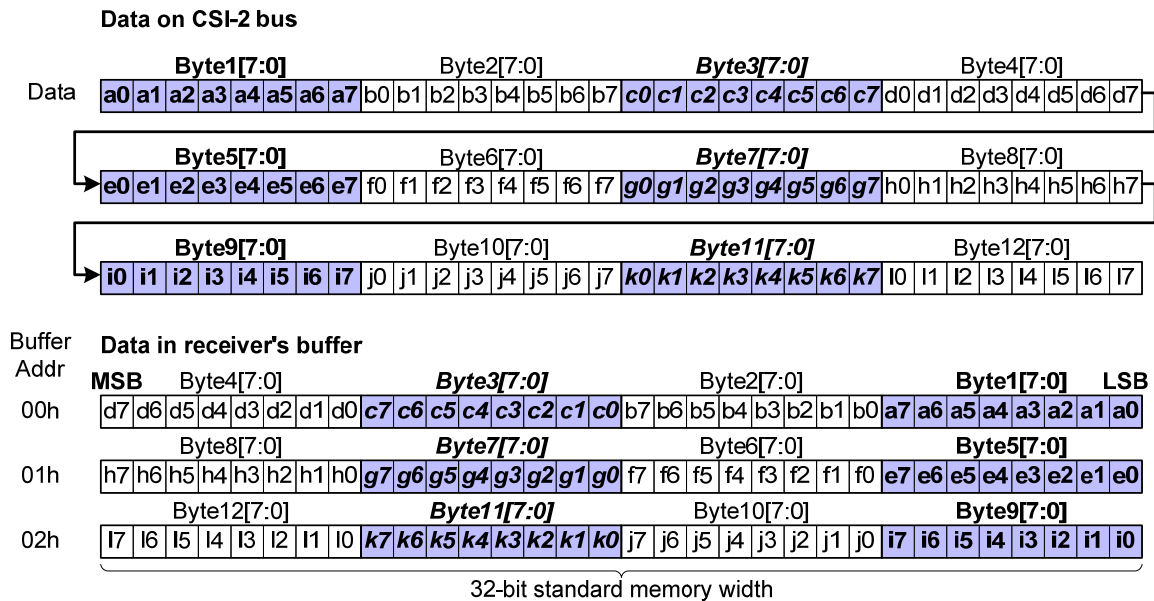


Figure 109 General/Arbitrary Data Reception

12.2 RGB888 Data Reception

The RGB888 data format byte to 32-bit memory word mapping follows the generic CSI-2 rule.

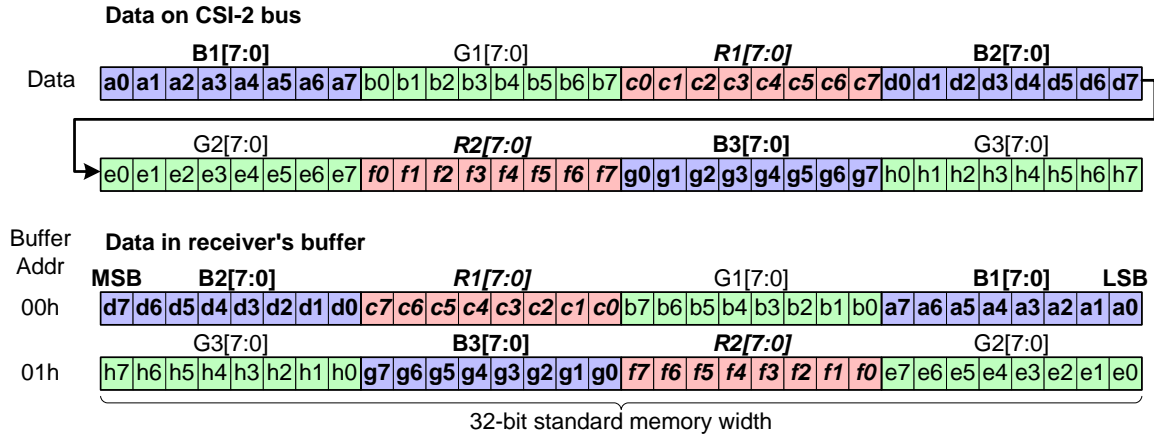


Figure 110 RGB888 Data Format Reception

12.3 RGB666 Data Reception

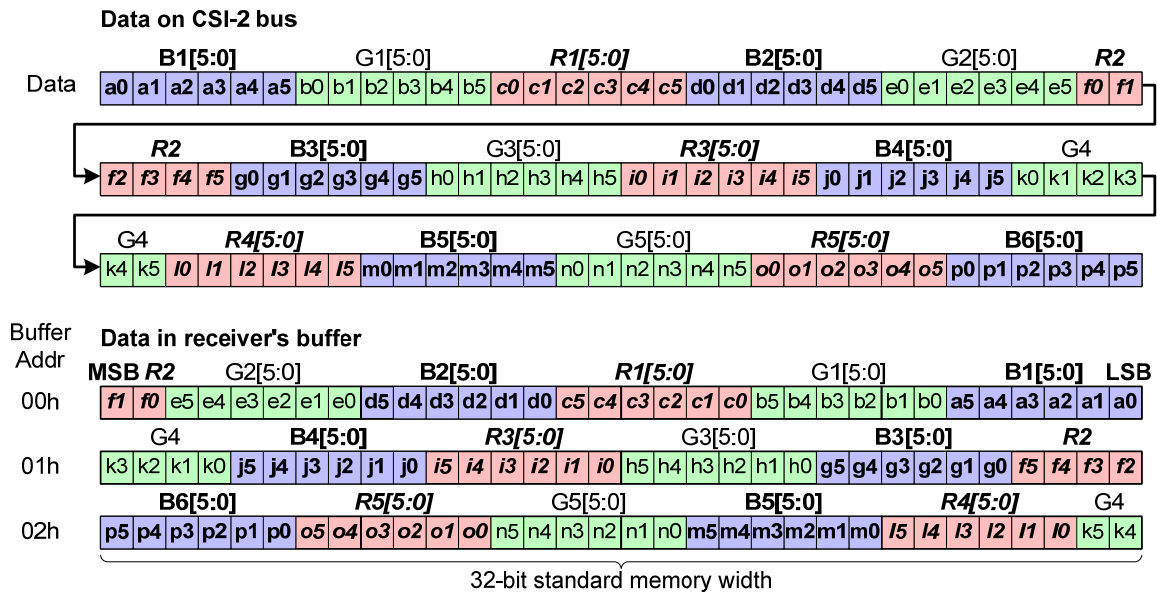
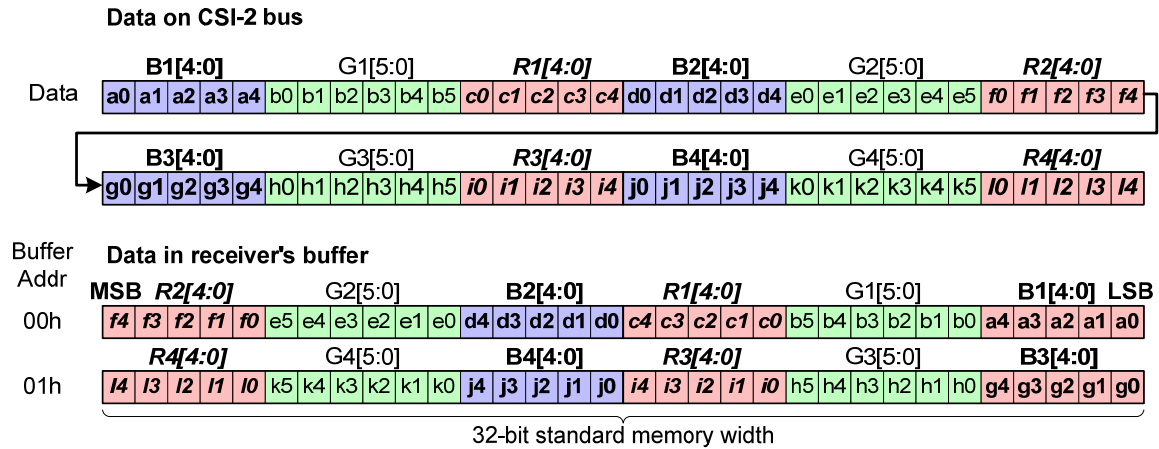
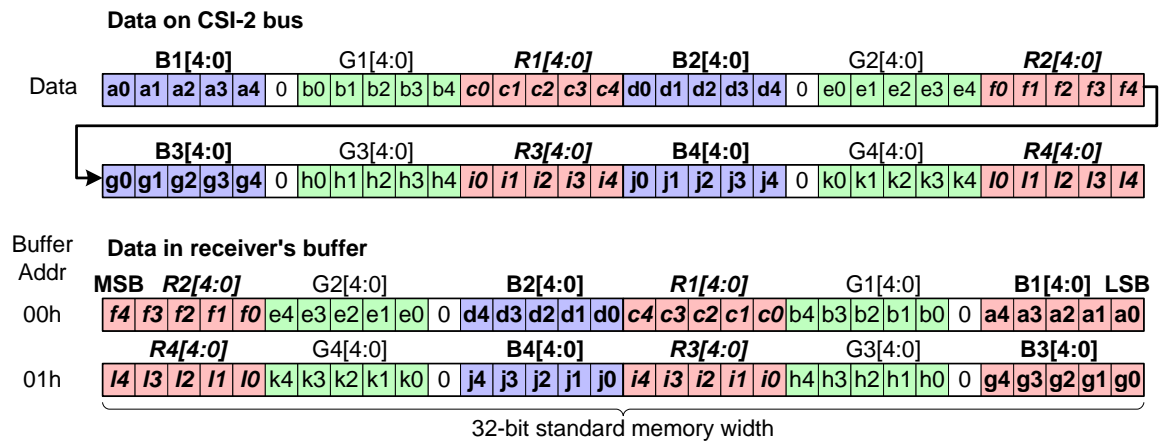


Figure 111 RGB666 Data Format Reception

12.4 RGB565 Data Reception



12.5 RGB555 Data Reception



12.6 RGB444 Data Reception

The RGB444 data format byte to 32-bit memory word mapping has a special transform as shown in Figure 114.

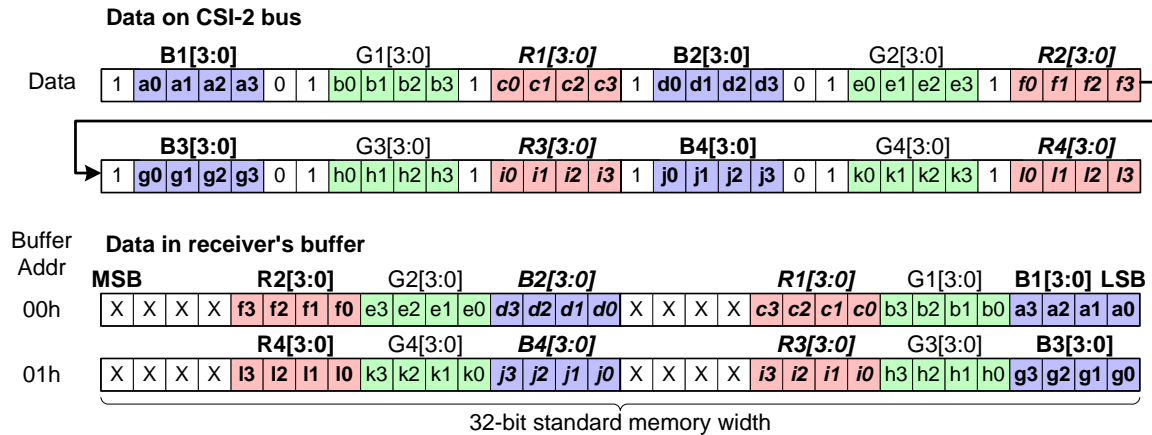


Figure 114 RGB444 Data Format Reception

12.7 YUV422 8-bit Data Reception

The YUV422 8-bit data format the byte to 32-bit memory word mapping does not follow the generic CSI-2 rule.

For YUV422 8-bit data format the first byte of payload data transmitted maps the MS byte of the 32-bit memory word and the fourth byte of payload data transmitted maps to the LS byte of the 32-bit memory word.

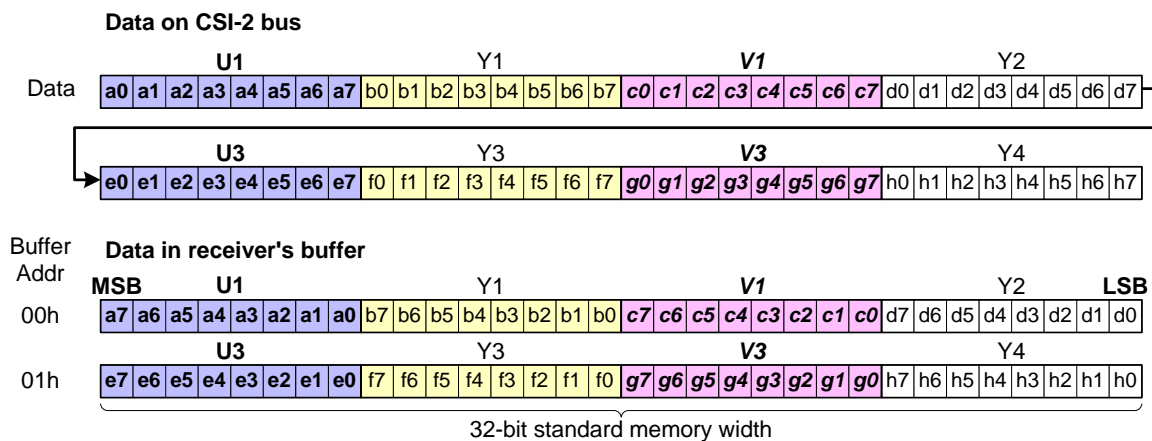


Figure 115 YUV422 8-bit Data Format Reception

12.8 YUV422 10-bit Data Reception

The YUV422 10-bit data format the byte to 32-bit memory word mapping follows the generic CSI-2 rule.

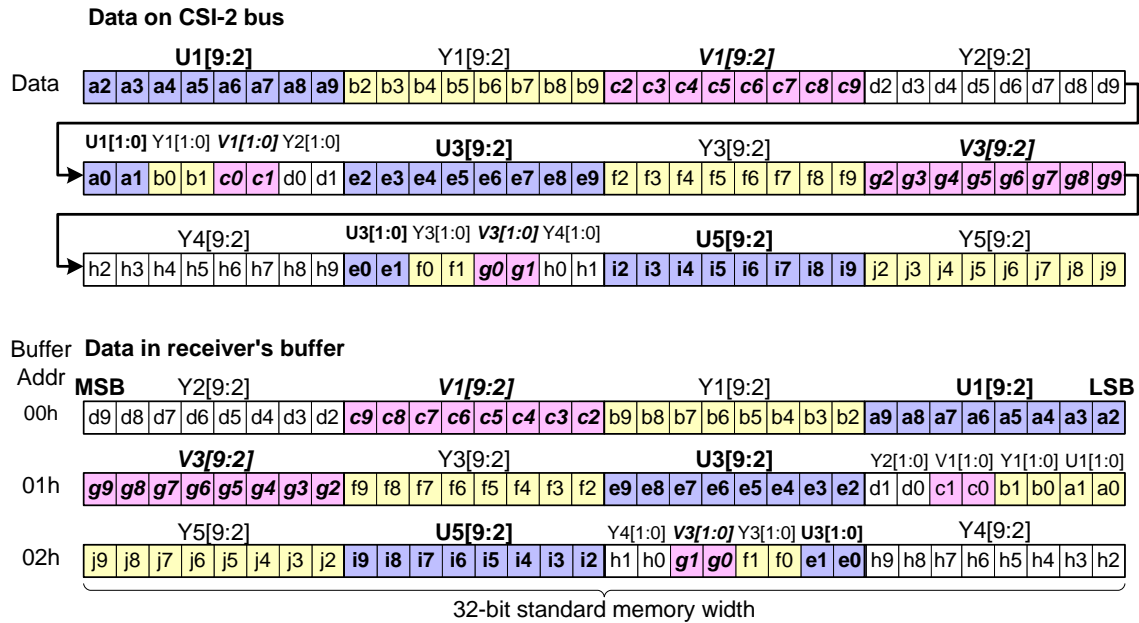


Figure 116 YUV422 10-bit Data Format Reception

12.9 YUV420 8-bit (Legacy) Data Reception

The YUV420 8-bit (legacy) data format the byte to 32-bit memory word mapping does not follow the generic CSI-2 rule.

For YUV422 8-bit (legacy) data format the first byte of payload data transmitted maps the MS byte of the 32-bit memory word and the fourth byte of payload data transmitted maps to the LS byte of the 32-bit memory word.

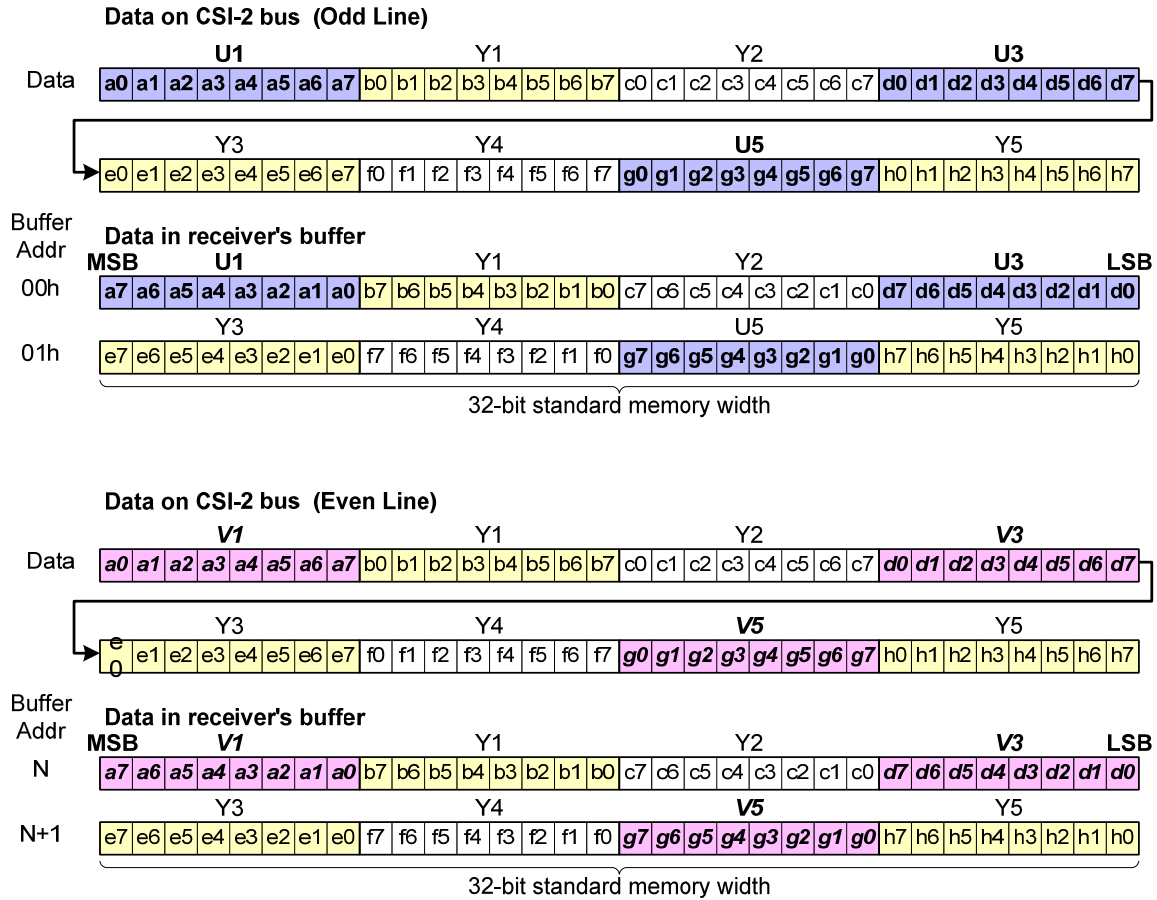


Figure 117 YUV420 8-bit Legacy Data Format Reception

12.10 YUV420 8-bit Data Reception

The YUV420 8-bit data format the byte to 32-bit memory word mapping follows the generic CSI-2 rule.

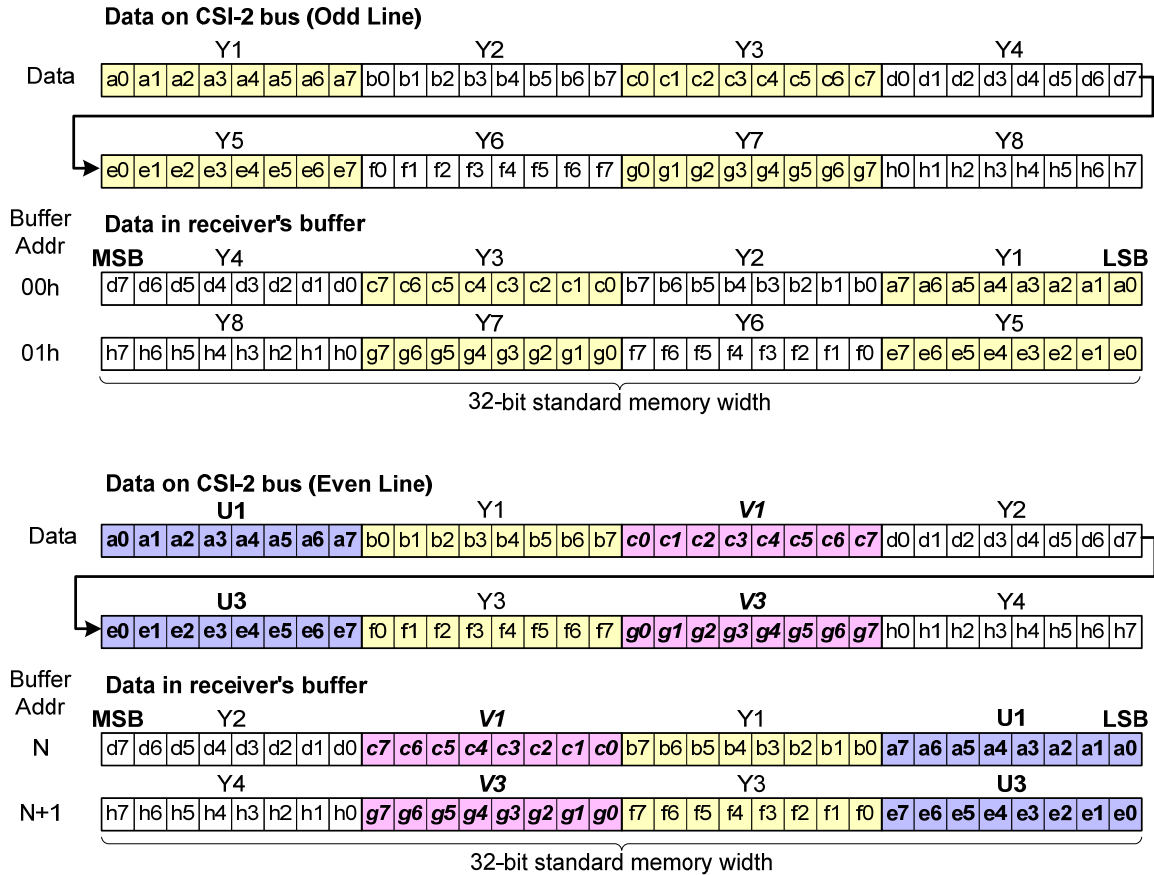


Figure 118 YUV420 8-bit Data Format Reception

12.11 YUV420 10-bit Data Reception

The YUV420 10-bit data format the byte to 32-bit memory word mapping follows the generic CSI-2 rule.

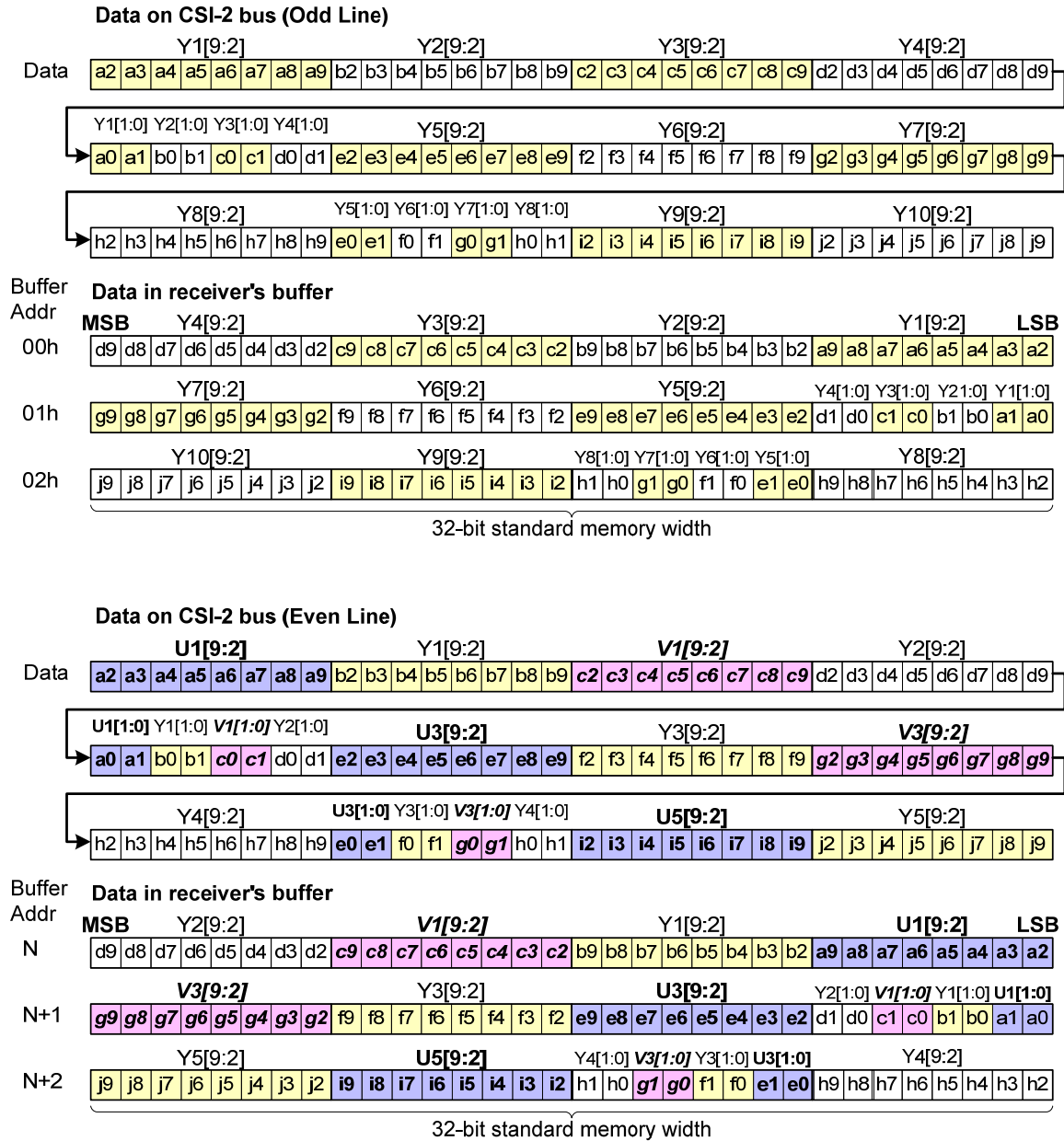


Figure 119 YUV420 10-bit Data Format Reception

12.12 RAW6 Data Reception

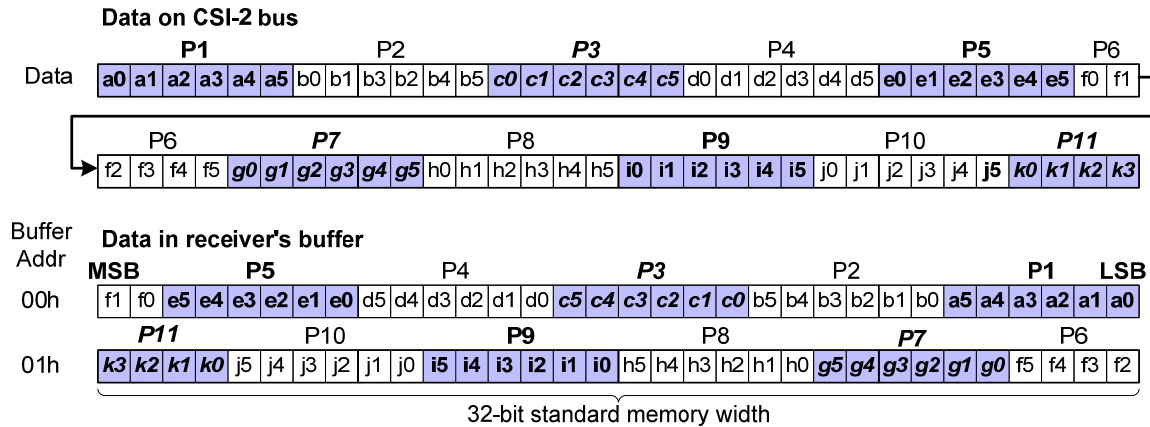


Figure 120 RAW6 Data Format Reception

12.13 RAW7 Data Reception

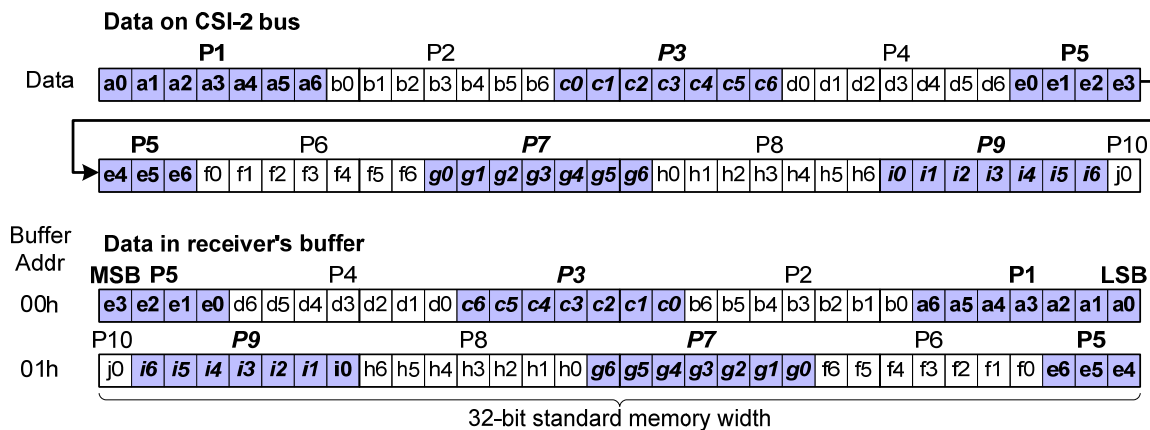


Figure 121 RAW7 Data Format Reception

12.14 RAW8 Data Reception

The RAW8 data format the byte to 32-bit memory word mapping follows the generic CSI-2 rule.

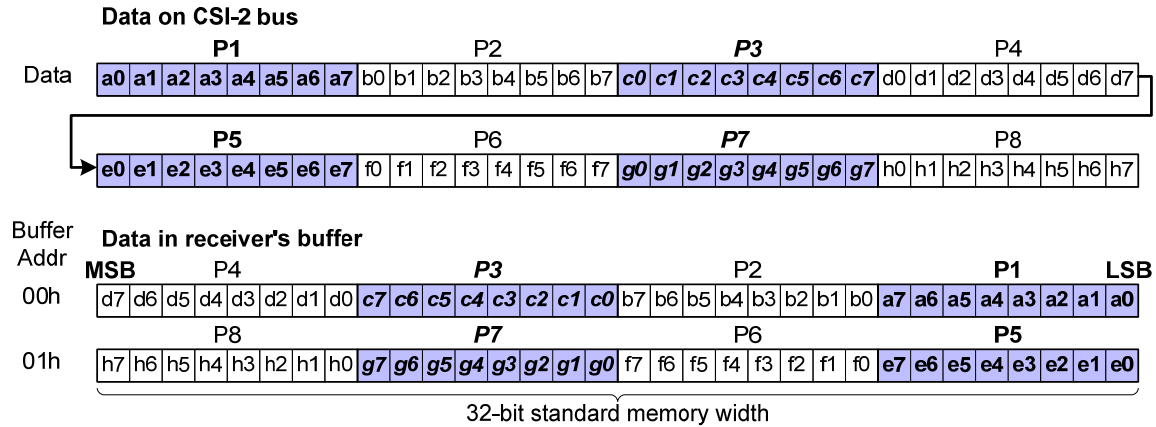


Figure 122 RAW8 Data Format Reception

12.15 RAW10 Data Reception

The RAW10 data format the byte to 32-bit memory word mapping follows the generic CSI-2 rule.

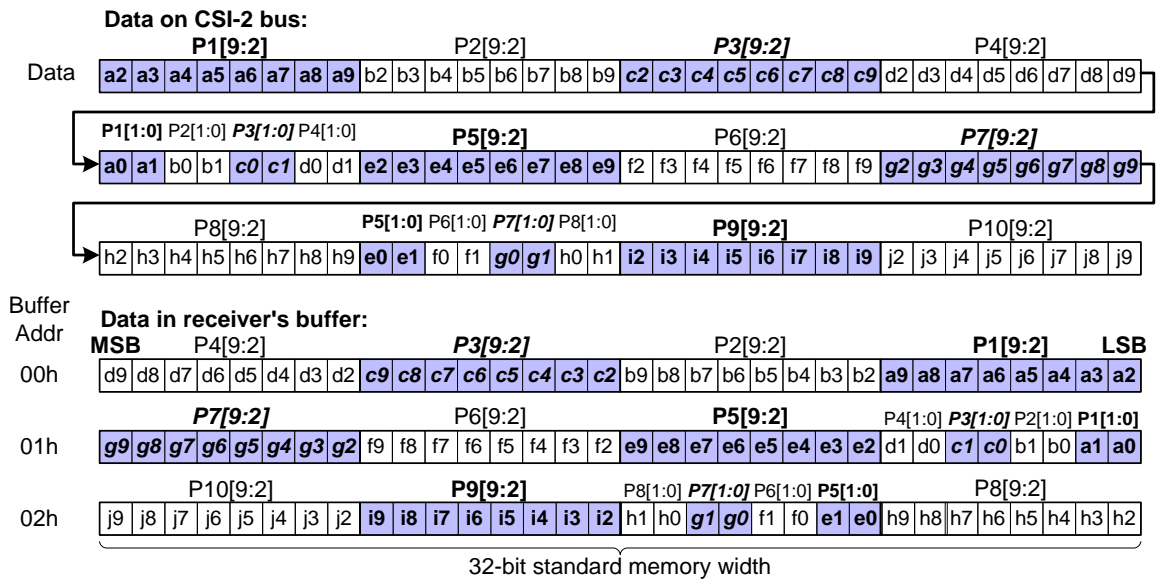


Figure 123 RAW10 Data Format Reception

12.16 RAW12 Data Reception

The RAW12 data format the byte to 32-bit memory word mapping follows the generic CSI-2 rule.

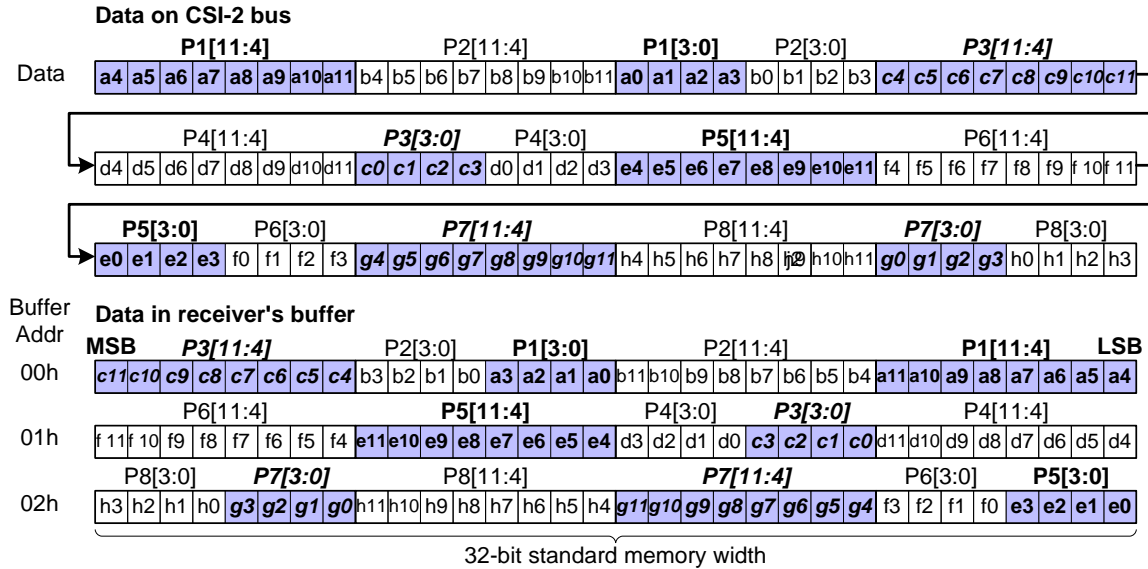


Figure 124 RAW12 Data Format Reception

12.17 RAW14 Data Reception

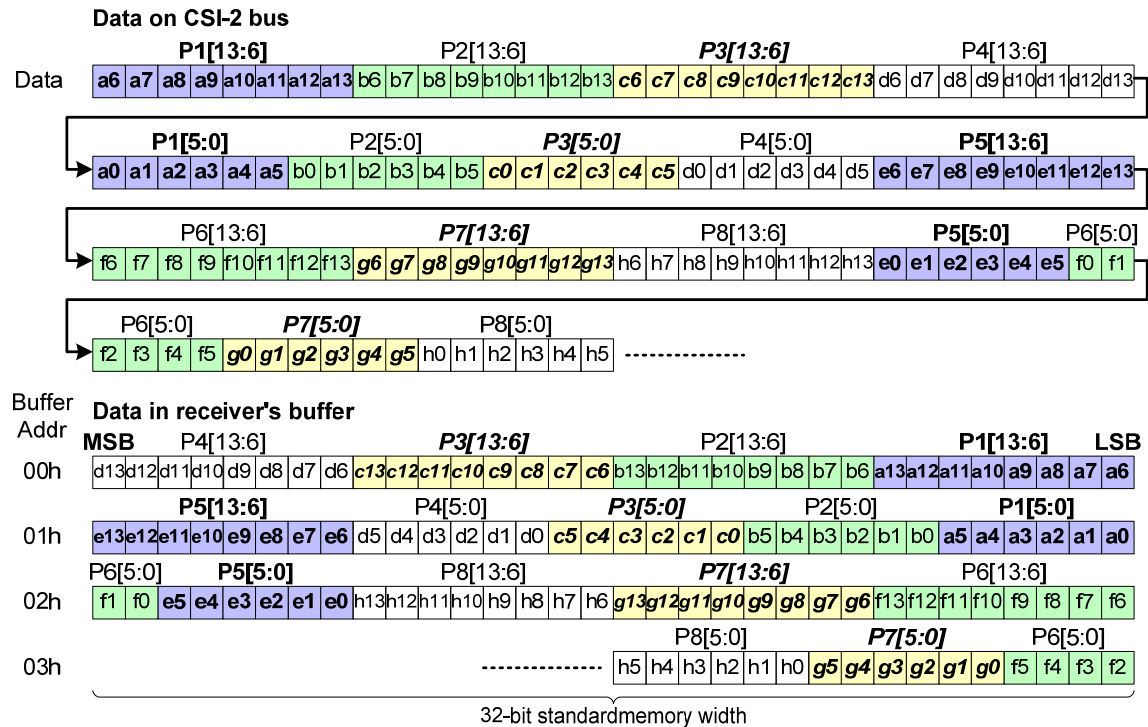


Figure 125 RAW 14 Data Format Reception

Annex A JPEG8 Data Format (informative)

A.1 Introduction

This Annex contains an informative example of the transmission of compressed image data format using the arbitrary Data Type values.

JPEG8 has two non-standard extensions:

- Status information (mandatory)
- Embedded Image information e.g. a thumbnail image (optional)

Any non-standard or additional data inside the baseline JPEG data structure has to be removed from JPEG8 data before it is compliant with e.g. standard JPEG image viewers in e.g. a personal computer.

The JPEG8 data flow is illustrated in the Figure 126 and Figure 127.

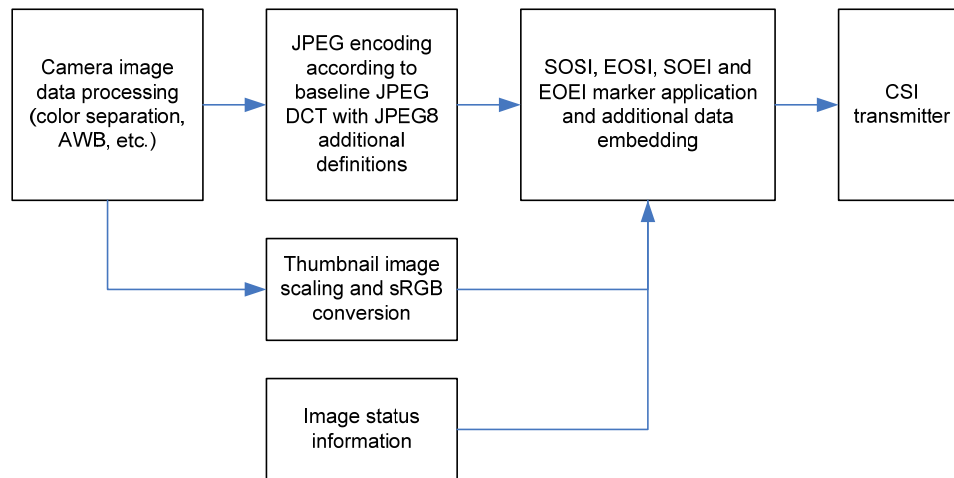


Figure 126 JPEG8 Data Flow in the Encoder

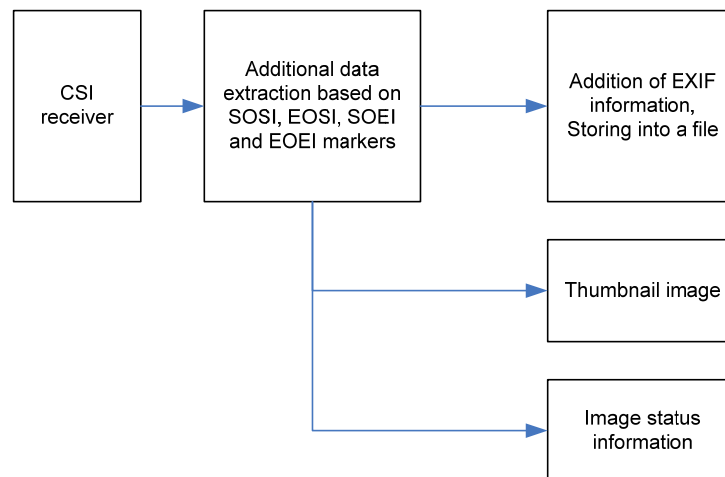


Figure 127 JPEG8 Data Flow in the Decoder

A.2 JPEG Data Definition

The JPEG data generated in camera module is baseline JPEG DCT format defined in ISO/IEC 10918-1, with following additional definitions or modifications:

- sRGB color space shall be used. The JPEG is generated from YcbCr format after sRGB to YcbCr conversion.
- The JPEG metadata has to be EXIF compatible, i.e. metadata within application segments has to be placed in beginning of file, in the order illustrated in Figure 128.
- A status line is added in the end of JPEG data as defined in section A.3.
- If needed, an embedded image is interlaced in order which is free of choice as defined in section A.4.
- Prior to storing into a file, the CSI-2 JPEG data is processed by the data separation process described in section A.1.

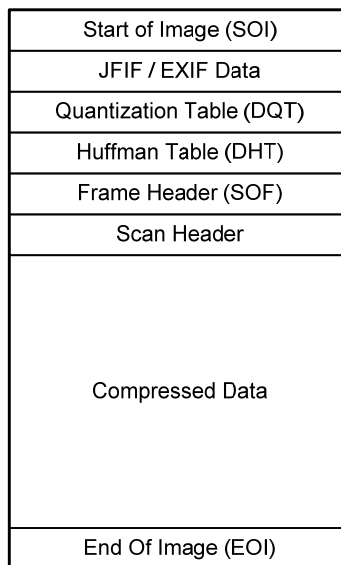


Figure 128 EXIF Compatible Baseline JPEG DCT Format

A.3 Image Status Information

Information of at least the following items has to be stored in the end of the JPEG sequence as illustrated in Figure 129:

- Image exposure time
- Analog & digital gains used
- White balancing gains for each color component
- Camera version number
- Camera register settings
- Image resolution and possible thumbnail resolution

The camera register settings may include a subset of camera's registers. The essential information needed for JPEG8 image is the information needed for converting the image back to linear space. This is necessary e.g. for printing service. An example of register settings is following:

- Sample frequency
- Exposure
- Analog and digital gain
- Gamma
- Color gamut conversion matrix
- Contrast
- Brightness
- Pre-gain

The status information content has to be defined in the product specification of each camera module containing the JPEG8 feature. The format and content is manufacturer specific.

The image status data should be arranged so that each byte is split into two 4-bit nibbles and “1010” padding sequence is added to MSB, as presented in the Table 28. This ensures that no JPEG escape sequences (0xFF 0x00) are present in the status data.

The SOSI and EOSI markers are defined in 14.5.

Table 28 Status Data Padding

Data Word	After Padding
D7D6D5D4 D3D2D1D0	1010D7D6D5D4 1010D3D2D1D0

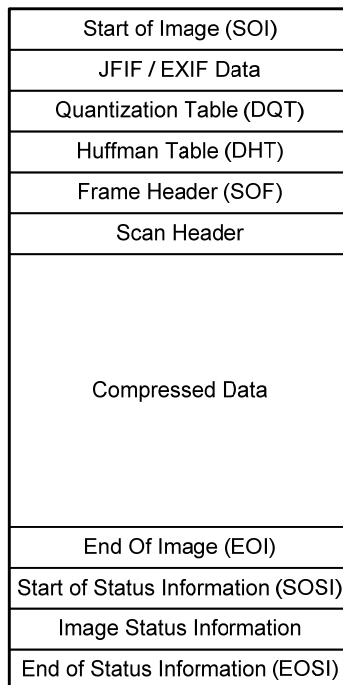


Figure 129 Status Information Field in the End of Baseline JPEG Frame

A.4 Embedded Images

An image may be embedded inside the JPEG data, if needed. The embedded image feature is not compulsory for each camera module containing the JPEG8 feature. An example of embedded data is a 24-bit RGB thumbnail image.

The philosophy of embedded / interleaved thumbnail additions is to minimize the needed frame memory. The EI (Embedded Image) data can be included in any part of the compressed image data segment and in as many pieces as needed. See Figure 130.

Embedded Image data is separated from compressed data by SOEI (Start Of Embedded Image) and EOEI (End Of Embedded Image) non-standard markers, which are defined in 14.5. The amount of fields separated by SOEI and EOEI is not limited.

The pixel to byte packing for image data within an EI data field should be as specified for the equivalent CSI-2 data format. However there is an additional restriction; the embedded image data must not generate any false JPEG marker sequences (0xFFXX).

The suggested method of preventing false JPEG marker codes from occurring within the embedded image data is to limit the data range for the pixel values. For example

- For RGB888 data the suggested way to solve the false synchronization code issue is to constrain the numerical range of R, G and B values from 1 to 254.
- For RGB565 data the suggested way to solve the false synchronization code issue is to constrain the numerical range of G component from 1-62 and R component from 1-30.

Each EI data field is separated by the SOEI / EOEI markers, has to contain an equal amount bytes and a complete number of pixels. An EI data field may contain multiple lines or a full frame of image data.

The embedded image data is decoded and removed apart from the JPEG compressed data prior to writing the JPEG into a file. In the process, EI data fields are appended one after each other, in order of occurrence in the received JPEG data.

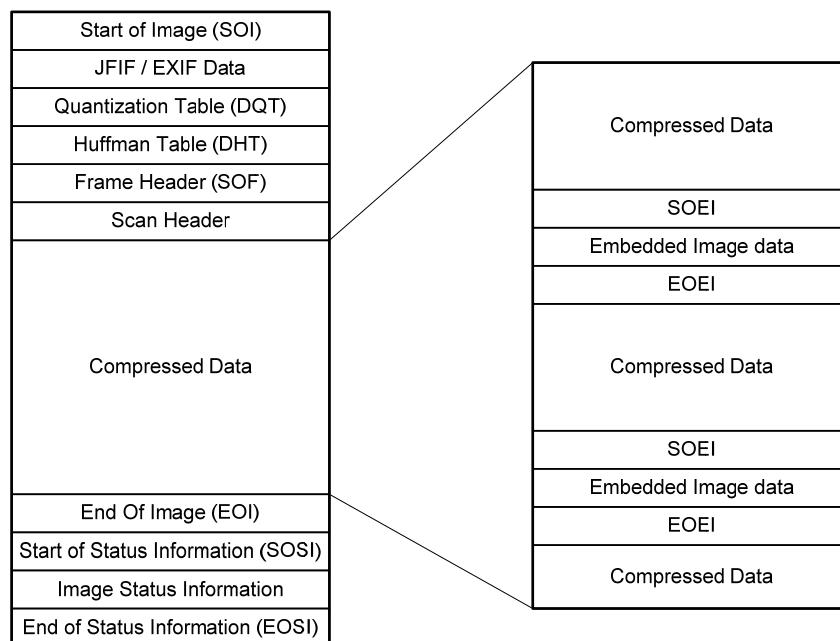


Figure 130 Example of TN Image Embedding Inside the Compressed JPEG Data Block

A.5 JPEG8 Non-standard Markers

JPEG8 uses the reserved JPEG data markers for special purposes, marking the additional segments inside the data file. These segments are not part of the JPEG, JFIF [0], EXIF [0] or any other specifications; instead their use is specified in this document in sections 14.3 and 14.4.

The use of the non-standard markers is always internal to a product containing the JPEG8 camera module, and these markers are always removed from the JPEG data before storing it into a file

Table 29 JPEG8 Additional Marker Codes Listing

Non-standard Marker Symbol	Marker Data Code
SOSI	0xFF 0xBC
EOSI	0xFF 0xBD
SOEI	0xFF 0xBE
EOEI	0xFF 0xBF

A.6 JPEG8 Data Reception

The compressed data format the byte to 32-bit memory word mapping follows the generic CSI-2 rule.

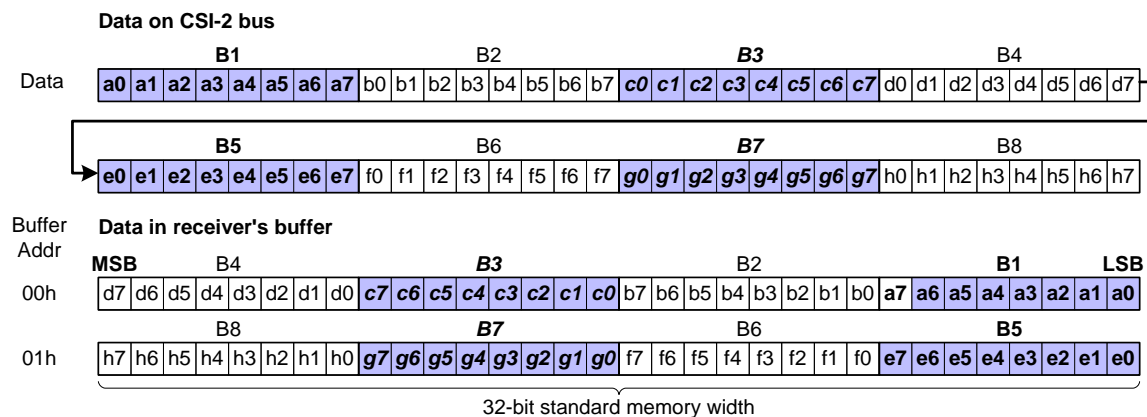


Figure 131 JPEG8 Data Format Reception

Annex B CSI-2 Implementation Example (informative)

B.1 Overview

The CSI-2 implementation example assumes that the interface comprises of D-PHY unidirectional Clock and Data, with forward escape mode functionality. The scope in this implementation example refers only to the unidirectional data link without any references to the CCI interface, as it can be seen in Figure 132. This implementation example varies from the informative PPI example in [MIP101].

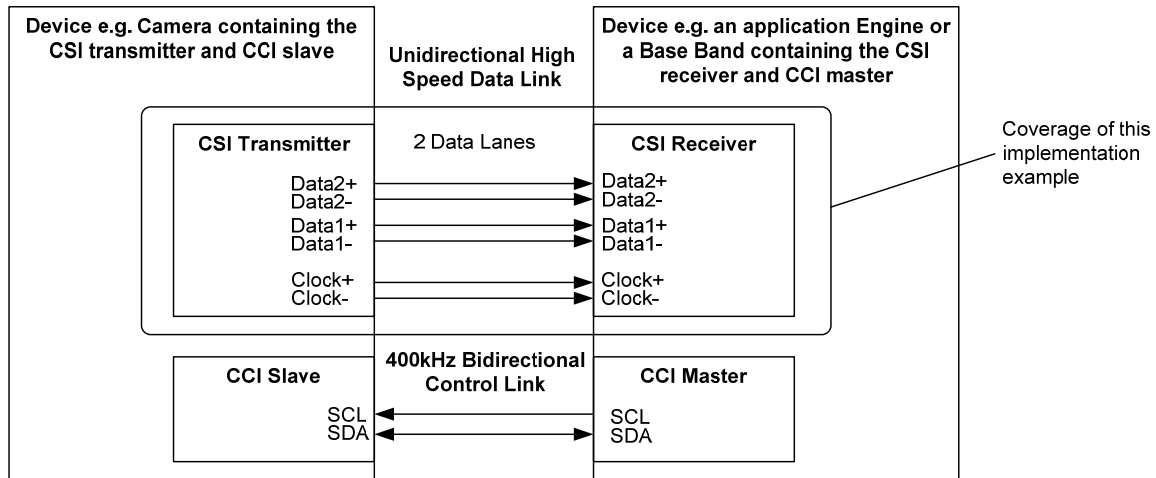


Figure 132 Implementation Example Block Diagram and Coverage

For this implementation example a layered structure is described with the following parts:

- D-PHY implementation details
- Multi lane merger details
- Protocol layer details

This implementation example refers to a RAW8 data type only; hence no packing/unpacking or byte clock/pixel clock timing will be referenced as for this type of implementation they are not needed.

No error recovery mechanism or error processing details will be presented, as the intent of the document is to present an implementation from the data flow perspective.

B.2 CSI-2 Transmitter Detailed Block Diagram

Using the layered structure described in the overview the CSI-2 transmitter could have the block diagram in Figure 133.

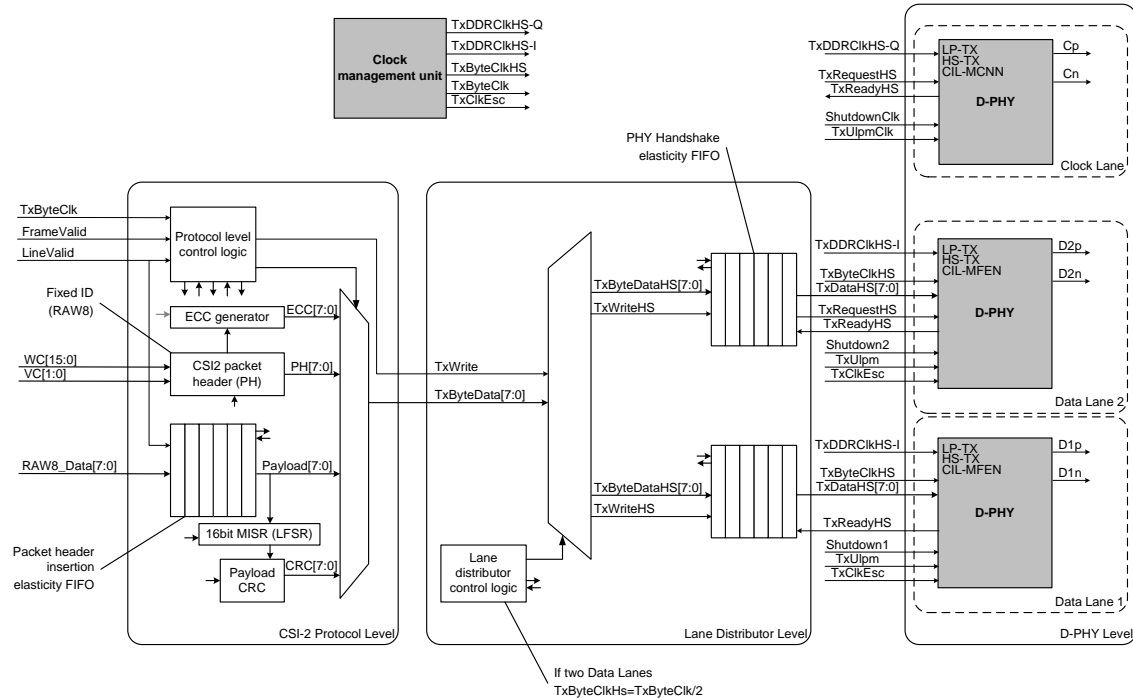


Figure 133 CSI-2 Transmitter Block Diagram

B.3 CSI-2 Receiver Detailed Block Diagram

Using the layered structure described in the overview, the CSI-2 receiver could have the block diagram in Figure 134.

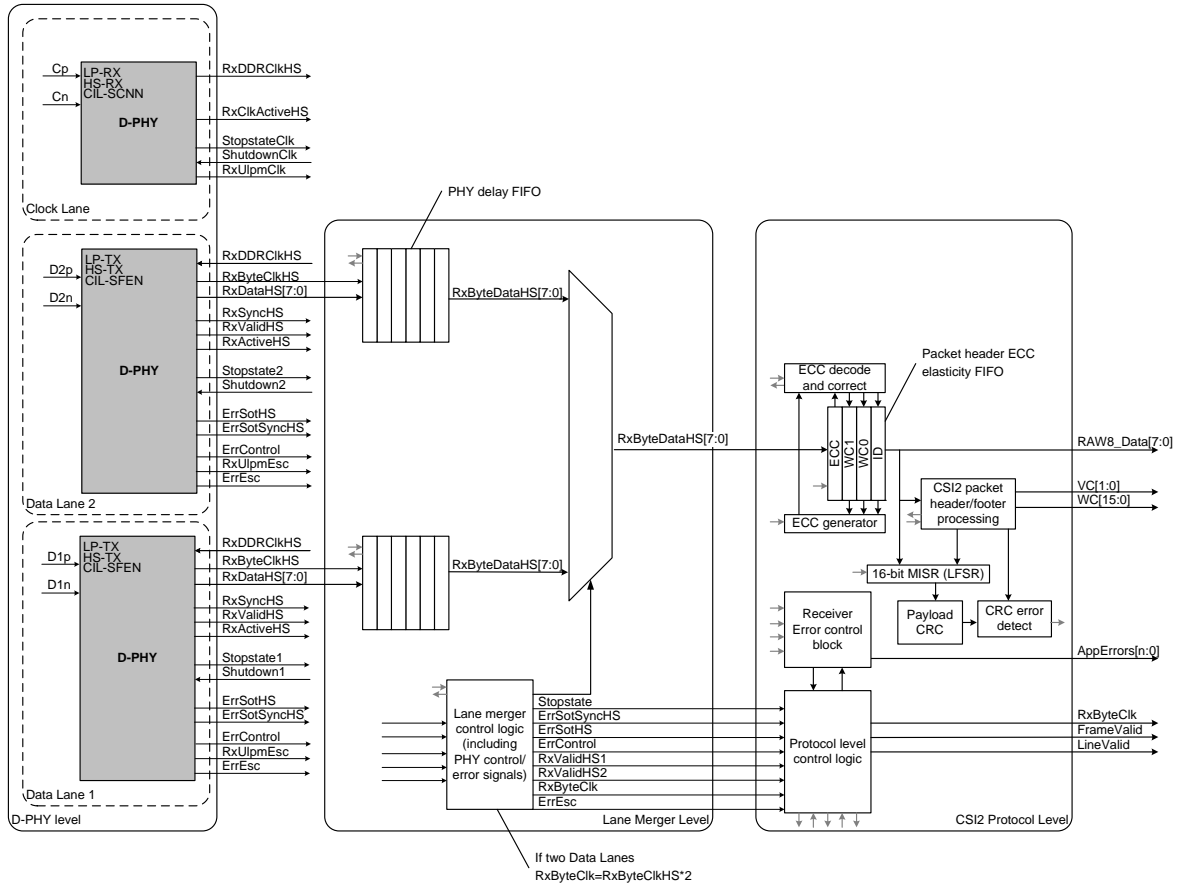


Figure 134 CSI-2 Receiver Block Diagram

B.4 Details on the D-PHY implementation

The PHY level of implementation has the top level structure as seen in Figure 135.

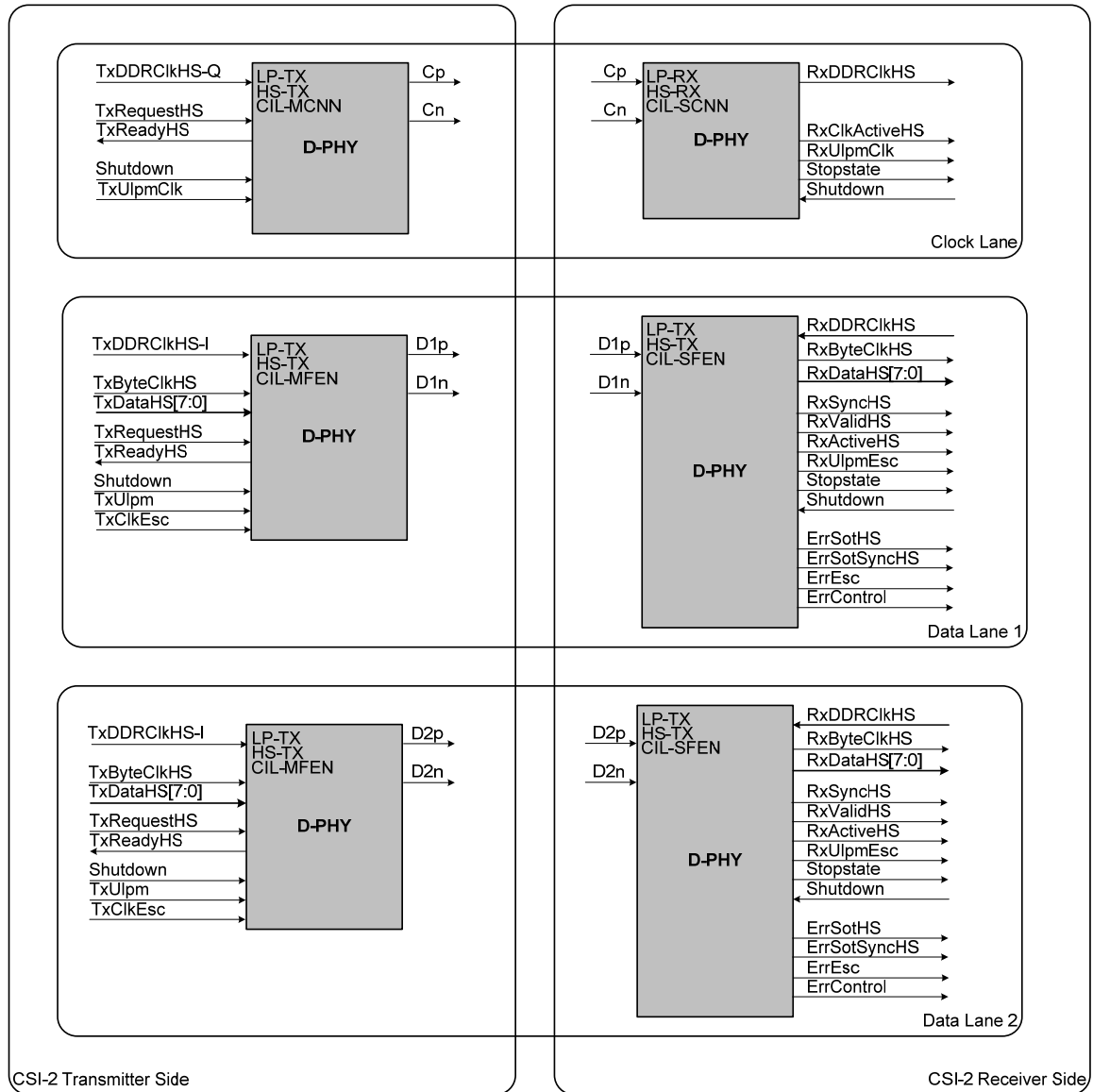


Figure 135 D-PHY Level Block Diagram

The components can be categorized as:

- CSI-2 Transmitter side:
 - Clock lane (Transmitter)
 - Data1 lane (Transmitter)
 - Data2 lane (Transmitter)
- CSI-2 Receiver side:
 - Clock lane (Receiver)
 - Data1 lane (Receiver)
 - Data2 lane (Receiver)

B.4.1 CSI-2 Clock Lane Transmitter

The suggested implementation can be seen in Figure 136.

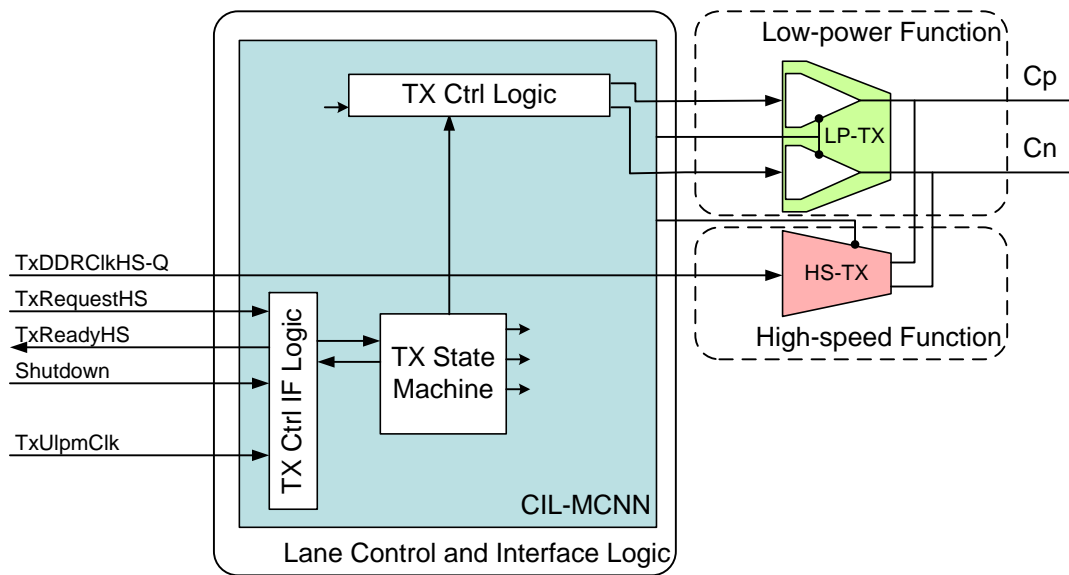


Figure 136 CSI-2 Clock Lane Transmitter

The modular D-PHY components used to build a CSI-2 clock lane transmitter are:

- **LP-TX** for the Low-power function
- **HS-TX** for the High-speed function
- **CIL-MCNCN** for the Lane control and interface logic

The PPI interface signals to the CSI-2 clock lane transmitter are:

- **TxDDRCIkHS-Q** (Input): High-Speed Transmit DDR Clock (Quadrature).
- **TxRequestHS** (Input): High-Speed Transmit Request. This active high signal causes the lane module to begin transmitting a high-speed clock.
- **TxReadyHS** (Output): High-Speed Transmit Ready. This active high signal indicates that the clock lane is transmitting HS clock.
- **Shutdown** (Input): Shutdown Lane Module. This active high signal forces the lane module into “shutdown”, disabling all activity. All line drivers, including terminators, are turned off when Shutdown is asserted. When Shutdown is high, all other PPI inputs are ignored and all PPI outputs are driven to the default inactive state. Shutdown is a level sensitive signal and does not depend on any clock.
- **TxUlpmClk** (Input): Transmit Ultra Low-Power mode on Clock Lane This active high signal is asserted to cause a Clock Lane module to enter the Ultra Low-Power mode. The lane module remains in this mode until TxUlpmClk is de-asserted.

B.4.2 CSI-2 Clock Lane Receiver

The suggested implementation can be seen in Figure 137.

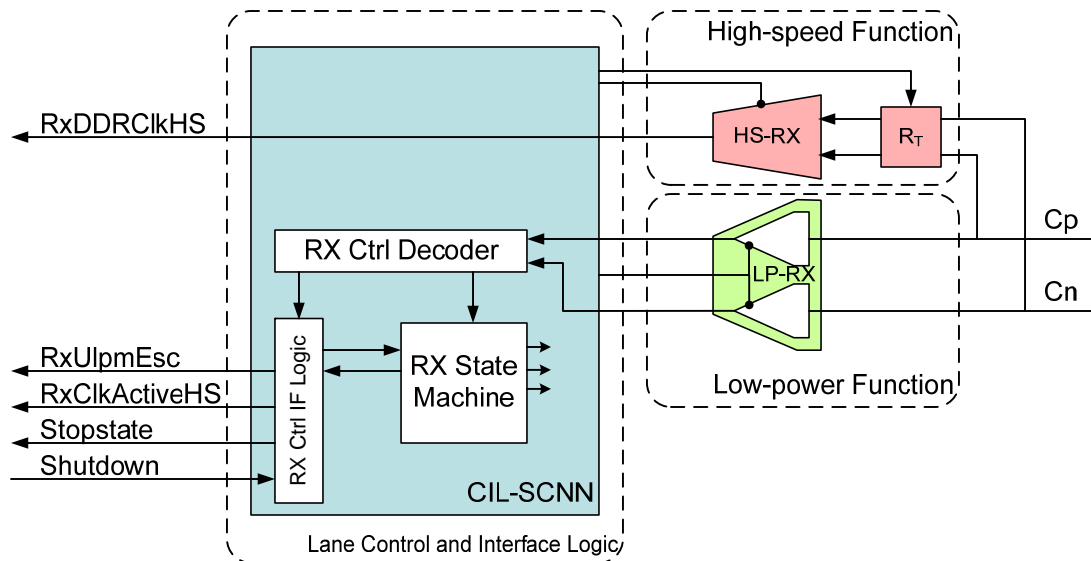


Figure 137 CSI-2 Clock Lane Receiver

The modular D-PHY components used to build a CSI-2 clock lane receiver are:

- **LP-RX** for the Low-power function
- **HS-RX** for the High-speed function
- **CIL-SCNN** for the Lane control and interface logic

The PPI interface signals to the CSI-2 clock lane receiver are:

- **RxDDRCIkHS** (Output): High-Speed Receive DDR Clock used to sample the data in all data lanes.
- **RxClkActiveHS** (Output): High-Speed Reception Active. This active high signal indicates that the clock lane is receiving valid clock. This signal is asynchronous.
- **Stopstate** (Output): Lane is in Stop state. This active high signal indicates that the lane module is currently in Stop state. This signal is asynchronous.
- **Shutdown** (Input): Shutdown Lane Module. This active high signal forces the lane module into “shutdown”, disabling all activity. All line drivers, including terminators, are turned off when Shutdown is asserted. When Shutdown is high, all PPI outputs are driven to the default inactive state. Shutdown is a level sensitive signal and does not depend on any clock.
- **RxUlpmEsc** (Output): Escape Ultra Low Power (Receive) mode. This active high signal is asserted to indicate that the lane module has entered the ultra low power mode. The lane module remains in this mode with RxUlpmEsc asserted until a Stop state is detected on the lane interconnect.

B.4.3 CSI-2 Data Lane Transmitter

The suggested implementation can be seen in Figure 138.

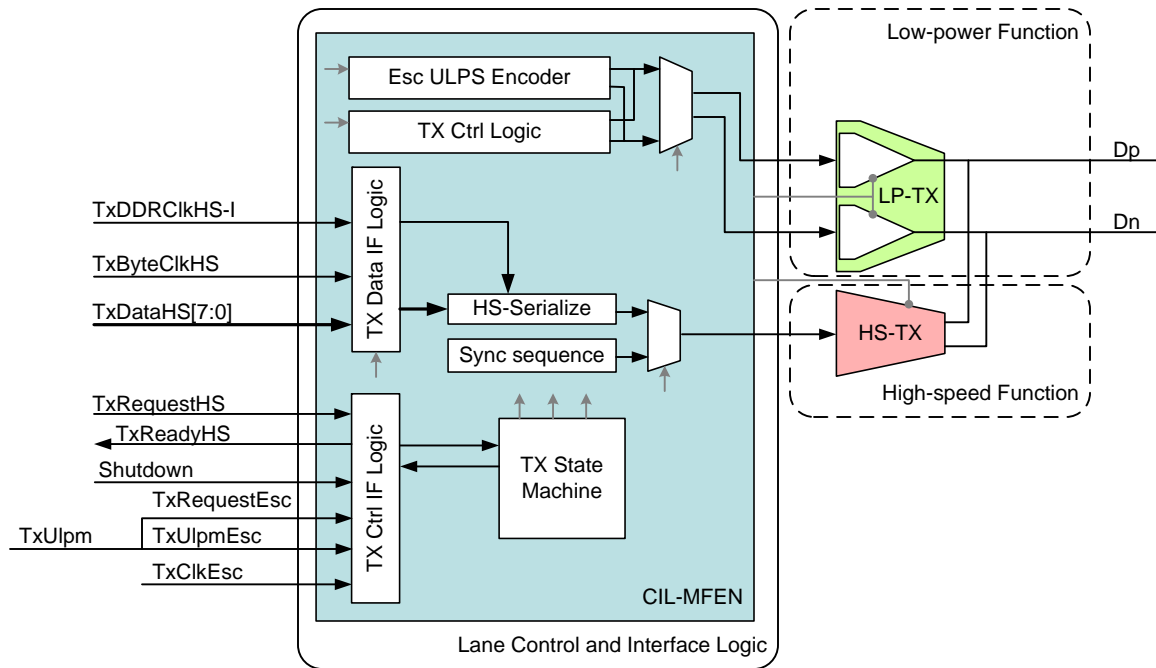


Figure 138 CSI-2 Data Lane Transmitter

The modular D-PHY components used to build a CSI-2 data lane transmitter are:

- **LP-TX** for the Low-power function
- **HS-TX** for the High-speed function
- **CIL-MFEN** for the Lane control and interface logic

The PPI interface signals to the CSI-2 data lane transmitter are:

- **TxDDRCIkHS-I** (Input): High-Speed Transmit DDR Clock (in-phase).
- **TxByteClkHS** (Input): High-Speed Transmit Byte Clock. This is used to synchronize PPI signals in the high-speed transmit clock domain. It is recommended that both transmitting data lane modules share one TxByteClkHS signal. The frequency of TxByteClkHS must be exactly 1/8 the high-speed bit rate.
- **TxDataHS[7:0]** (Input): High-Speed Transmit Data. Eight bit high-speed data to be transmitted. The signal connected to TxDataHS[0] is transmitted first. Data is registered on rising edges of TxByteClkHS.
- **TxRequestHS** (Input): High-Speed Transmit Request. A low-to-high transition on TxRequestHS causes the lane module to initiate a Start-of-Transmission sequence. A high-to-low transition on TxRequest causes the lane module to initiate an End-of-Transmission sequence. This active high signal also indicates that the protocol is driving valid data on TxByteDataHS to be transmitted. The lane module accepts the data when both TxRequestHS and TxReadyHS are active on the same rising TxByteClkHS clock edge. The protocol always provides valid transmit data when TxRequestHS is active. Once asserted, TxRequestHS should remain high until the all the data has been accepted.
- **TxReadyHS** (Output): High-Speed Transmit Ready. This active high signal indicates that TxDataHS is accepted by the lane module to be serially transmitted. TxReadyHS is valid on rising edges of TxByteClkHS. Valid data has to be provided for the whole duration of active TxReadyHS.

- **Shutdown** (Input): Shutdown Lane Module. This active high signal forces the lane module into “shutdown”, disabling all activity. All line drivers, including terminators, are turned off when Shutdown is asserted. When Shutdown is high, all other PPI inputs are ignored and all PPI outputs are driven to the default inactive state. Shutdown is a level sensitive signal and does not depend on any clock.
- **TxUlpmEsc** (Input): Escape mode Transmit Ultra Low Power. This active high signal is asserted with TxRequestEsc to cause the lane module to enter the ultra low power mode. The lane module remains in this mode until TxRequestEsc is de-asserted.
- **TxRequestEsc** (Input): This active high signal, asserted together with TxUlpmEsc is used to request entry into escape mode. Once in escape mode, the lane stays in escape mode until TxRequestEsc is de-asserted. TxRequestEsc is only asserted by the protocol while TxRequestHS is low.
- **TxCikEsc** (Input): Escape mode Transmit Clock. This clock is directly used to generate escape sequences. The period of this clock determines the symbol time for low power signals. It is therefore constrained by the normative part of the [MIPI01].

B.4.4 CSI-2 Data Lane Receiver

The suggested implementation can be seen in Figure 139.

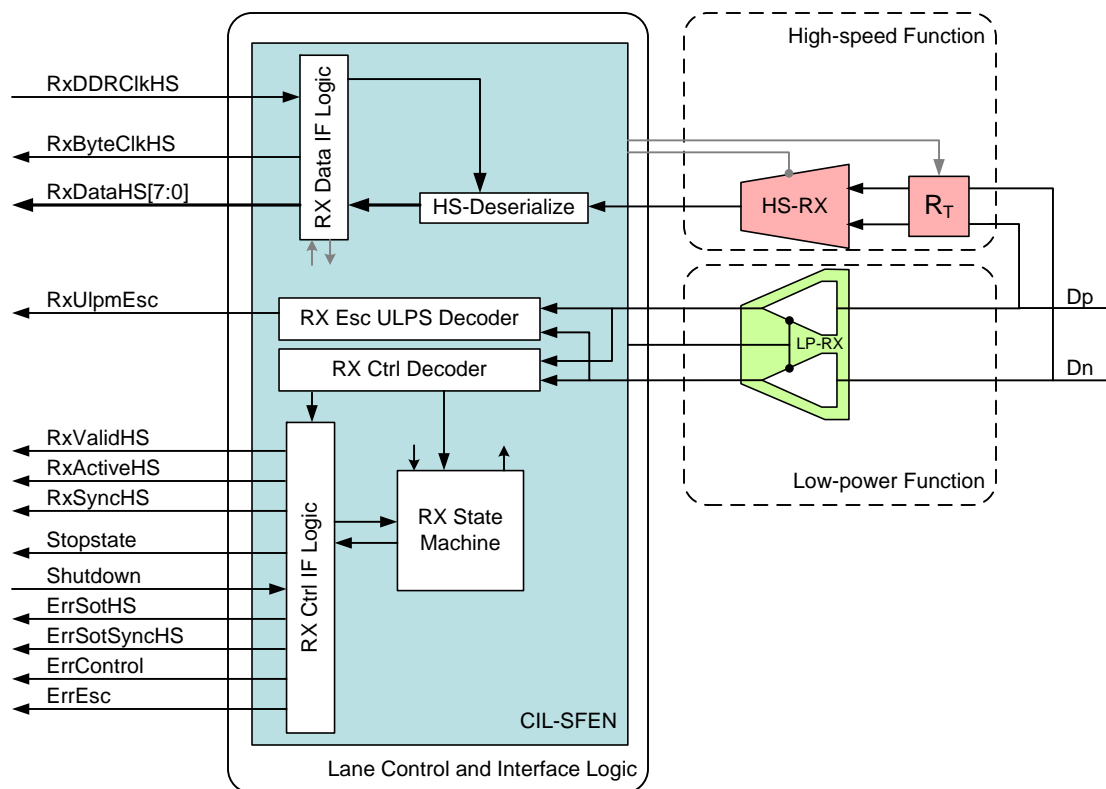


Figure 139 CSI-2 Data Lane Receiver

The modular D-PHY components used to build a CSI-2 data lane receiver are:

- **LP-RX** for the Low-power function
- **HS-RX** for the High-speed function

- **CIL-SFEN** for the Lane control and interface logic

The PPI interface signals to the CSI-2 data lane receiver are:

- **RxDDRCIkHS** (Input): High-Speed Receive DDR Clock used to sample the data in all data lanes. This signal is supplied by the CSI-2 clock lane receiver.
- **RxByteClkHS** (Output): High-Speed Receive Byte Clock. This signal is used to synchronize signals in the high-speed receive clock domain. The RxByteClkHS is generated by dividing the received RxDDRCIkHS.
- **RXDataHS[7:0]** (Output): High-Speed Receive Data. Eight bit high-speed data received by the lane module. The signal connected to RxDataHS[0] was received first. Data is transferred on rising edges of RxByteClkHS.
- **RxValidHS** (Output): High-Speed Receive Data Valid. This active high signal indicates that the lane module is driving valid data to the protocol on the RxDataHS output. There is no “RxReadyHS” signal, and the protocol is expected to capture RxDataHS on every rising edge of RxByteClkHS where RxValidHS is asserted. There is no provision for the protocol to slow down (“throttle”) the receive data.
- **RxActiveHS** (Output): High-Speed Reception Active. This active high signal indicates that the lane module is actively receiving a high-speed transmission from the lane interconnect.
- **RxSyncHS** (Output): Receiver Synchronization Observed. This active high signal indicates that the lane module has seen an appropriate synchronization event. In a typical high-speed transmission, RxSyncHS is high for one cycle of RxByteClkHS at the beginning of a high-speed transmission when RxActiveHS is first asserted. This signal missing is signaled using ErrSotSyncHS.
- **RxUlpmEsc** (Output): Escape Ultra Low Power (Receive) mode. This active high signal is asserted to indicate that the lane module has entered the ultra low power mode. The lane module remains in this mode with RxUlpmEsc asserted until a Stop state is detected on the lane interconnect.
- **Stopstate** (Output): Lane is in Stop state. This active high signal indicates that the lane module is currently in Stop state. This signal is asynchronous.
- **Shutdown** (Input): Shutdown Lane Module. This active high signal forces the lane module into “shutdown”, disabling all activity. All line drivers including terminators, are turned off when Shutdown is asserted. When Shutdown is high, all PPI outputs are driven to the default inactive state. Shutdown is a level sensitive signal and does not depend on any clock.
- **ErrSotHS** (Output): Start-of-Transmission (SoT) Error. If the high-speed SoT leader sequence is corrupted, but in such a way that proper synchronization can still be achieved, this error signal is asserted for one cycle of RxByteClkHS. This is considered to be a “soft error” in the leader sequence and confidence in the payload data is reduced.
- **ErrSotSyncHS** (Output): Start-of-Transmission Synchronization Error. If the high-speed SoT leader sequence is corrupted in a way that proper synchronization cannot be expected, this error is asserted for one cycle of RxByteClkHS.
- **ErrControl** (Output): Control Error. This signal is asserted when an incorrect line state sequence is detected.
- **ErrEsc** (Output): Escape Entry Error. If an unrecognized escape entry command is received, this signal is asserted and remains high until the next change in line state. The only escape entry command supported by the receiver is the ULPS.

Annex C CSI-2 Recommended Receiver Error Behavior (informative)

C.1 Overview

This section proposes one approach to handling error conditions at the receiving side of a CSI-2 Link. Although the section is informative and therefore does not affect compliance for CSI-2, the approach is offered by the MIPI Camera Working Group as a recommended approach. The CSI-2 receiver assumes the case of a CSI-2 Link comprised of unidirectional Lanes for D-PHY Clock and Data Lanes with Escape Mode functionality on the Data Lanes and a continuously running clock. This Annex does not discuss other cases, including those that differ widely in implementation, where the implementer should consider other potential error situations.

Because of the layered structure of a compliant CSI-2 receiver implementation, the error behavior is described in a similar way with several “levels” where errors could occur, each requiring some implementation at the appropriate functional layer of the design:

- *D-PHY Level errors*
Refers to any PHY related transmission error and is unrelated to the transmission’s contents:
 - *Start of Transmission (SoT) errors*, which can be:
 - Recoverable, if the PHY successfully identifies the Sync code but an error was detected.
 - Unrecoverable, if the PHY does not successfully identify the sync code but does detect a HS transmission.
 - *Control Error*, which signals that the PHY has detected a control sequence that should not be present in this implementation of the Link.
- *Packet Level errors*
This type of error refers strictly to data integrity of the received Packet Header and payload data:
 - *Packet Header errors*, signaled through the ECC code, that result in:
 - A single bit-error, which can be detected and corrected by the ECC code
 - Two bit-errors in the header, which can be detected but not corrected by the ECC code, resulting in a corrupt header
 - *Packet payload errors*, signaled through the CRC code
- *Protocol Decoding Level errors*
This type of error refers to errors present in the decoded Packet Header or errors resulting from an incomplete sequence of events:
 - *Frame Sync Error*, caused when a FS could not be successfully paired with a FE on a given virtual channel
 - *Unrecognized ID*, caused by the presence of an unimplemented or unrecognized ID in the header

The proposed methodology for handling errors is signal based, since it offers an easy path to a viable CSI-2 implementation that handles all three error levels. Even so, error handling at the Protocol Decoding Level should implement sequential behavior using a state machine for proper operation.

C.2 D-PHY Level Error

The recommended behavior for handling this error level covers only those errors generated by the Data Lane(s), since an implementation can assume that the Clock Lane is running reliably as provided by the expected BER of the Link, as discussed in [MIPI01]. Note that this error handling behavior assumes unidirectional Data Lanes without escape mode functionality. Considering this, and using the signal names and descriptions from the [MIPI01], PPI Annex, signal errors at the PHY-Protocol Interface (PPI) level consist of the following:

- **ErrSotHS:** Start-of-Transmission (SoT) Error. If the high-speed SoT leader sequence is corrupted, but in such a way that proper synchronization can still be achieved, this error signal is asserted for one cycle of RxByteClkHS. This is considered to be a “soft error” in the leader sequence and confidence in the payload data is reduced.
- **ErrSotSyncHS:** Start-of-Transmission Synchronization Error. If the high-speed SoT leader sequence is corrupted in a way that proper synchronization cannot be expected, this error signal is asserted for one cycle of RxByteClkHS.
- **ErrControl:** Control Error. This signal is asserted when an incorrect line state sequence is detected. For example, if a Turn-around request or Escape Mode request is immediately followed by a Stop state instead of the required Bridge state, this signal is asserted and remains high until the next change in line state.

The recommended receiver error behavior for this level is:

- **ErrSotHS** should be passed to the Application Layer. Even though the error was detected and corrected and the Sync mechanism was unaffected, confidence in the data integrity is reduced and the application should be informed. This signal should be referenced to the corresponding data packet.
- **ErrSotSyncHS** should be passed to the Protocol Decoding Level, since this is an unrecoverable error. An unrecoverable type of error should also be signaled to the Application Layer, since the whole transmission until the first D-PHY Stop state should be ignored if this type of error occurs.
- **ErrControl** should be passed to the Application Layer, since this type of error doesn’t normally occur if the interface is configured to be unidirectional. Even so, the application needs to be aware of the error and configure the interface accordingly through other, implementation specific means.

Also, it is recommended that the PPI StopState signal for each implemented Lane should be propagated to the Application Layer during configuration or initialization to indicate the Lane is ready.

C.3 Packet Level Error

The recommended behavior for this error level covers only errors recognized by decoding the Packet Header’s ECC byte and computing the CRC of the data payload.

Decoding and applying the ECC byte of the Packet Header should signal the following errors:

- **ErrEccDouble:** Asserted when an ECC syndrome was computed and two bit-errors are detected in the received Packet Header.
- **ErrEccCorrected:** Asserted when an ECC syndrome was computed and a single bit-error in the Packet Header was detected and corrected.
- **ErrEccNoError:** Asserted when an ECC syndrome was computed and the result is zero indicating a Packet Header that is considered to be without errors or has more than two bit-errors. CSI-2’s ECC mechanism cannot detect this type of error.

Also, computing the CRC code over the whole payload of the received packet could generate the following errors:

- **ErrCrc:** Asserted when the computed CRC code is different than the received CRC code.
- **ErrID:** Asserted when a Packet Header is decoded with an unrecognized or unimplemented data ID.

The recommended receiver error behavior for this level is:

- **ErrEccDouble** should be passed to the Application Layer since assertion of this signal proves that the Packet Header information is corrupt, and therefore the WC is not usable, and thus the packet end cannot be estimated. Commonly, this type of error will be accompanied with an ErrCrc. This type of error should also be passed to the Protocol Decoding Level, since the whole transmission until D-PHY Stop state should be ignored.
- **ErrEccCorrected** should be passed to the Application Layer since the application should be informed that an error had occurred but was corrected, so the received Packet Header was unaffected, although the confidence in the data integrity is reduced.
- **ErrEccNoError** can be passed to the Protocol Decoding Level to signal the validity of the current Packet Header.
- **ErrCrc** should be passed to the Protocol Decoding Level to indicate that the packet's payload data might be corrupt.
- **ErrID** should be passed to the Application Layer to indicate that the data packet is unidentified and cannot be unpacked by the receiver. This signal should be asserted after the ID has been identified and de-asserted on the first Frame End (FE) on same virtual channel.

C.4 Protocol Decoding Level Error

The recommended behavior for this error level covers errors caused by decoding the Packet Header information and detecting a sequence that is not allowed by the CSI-2 protocol or a sequence of detected errors by the previous layers. CSI-2 implementers will commonly choose to implement this level of error handling using a state machine that should be paired with the corresponding virtual channel. The state machine should generate at least the following error signals:

- **ErrFrameSync:** Asserted when a Frame End (FE) is not paired with a Frame Start (FS) on the same virtual channel. A ErrSotSyncHS should also generate this error signal.
- **ErrFrameData:** Asserted after a FE when the data payload received between FS and FE contains errors.

The recommended receiver error behavior for this level is:

- **ErrFrameSync** should be passed to the Application Layer with the corresponding virtual channel, since the frame could not be successfully identified. Several error cases on the same virtual channel can be identified for this type of error.
 - If a FS is followed by a second FS on the same virtual channel, the frame corresponding to the first FS is considered in error.
 - If a Packet Level ErrEccDouble was signaled from the Protocol Layer, the whole transmission until the first D-PHY Stop-state should be ignored since it contains no information that can be safely decoded and cannot be qualified with a data valid signal.
 - If a FE is followed by a second FE on the same virtual channel, the frame corresponding to the second FE is considered in error.

- 2026 • If an ErrSotSyncHS was signaled from the PHY Layer, the whole transmission until the first
2027 D-PHY Stop state should be ignored since it contains no information that can be safely
2028 decoded and cannot be qualified with a data valid signal.
- 2029 • **ErrFrameData:** should be passed to the Application Layer to indicate that the frame contains data
2030 errors. This signal should be asserted on any ErrCrc and de-asserted on the first FE.
- 2031

Annex D CSI-2 Sleep Mode (informative)

D.1 Overview

Since a camera in a mobile terminal spends most of its time in an inactive state, implementers need a way to put the CSI-2 Link into a low power mode that approaches, or may be as low as, the leakage level. This section proposes one approach for putting a CSI-2 Link in a “Sleep Mode” (SLM). Although the section is informative and therefore does not affect compliance for CSI-2, the approach is offered by the MIPI Camera Working Group as a recommended approach.

This approach relies on an aspect of a D-PHY transmitter’s behavior that permits regulators to be disabled safely when LP-00 (Space state) is on the Link. Accordingly, this will be the output state for a CSI-2 camera transmitter in SLM.

SLM can be thought of as a three-phase process:

1. SLM Command Phase. The ‘ENTER SLM’ command is issued to the TX side only, or to both sides of the Link.
2. SLM Entry Phase. The CSI-2 Link has entered, or is entering, the SLM in a controlled or synchronized manner. This phase is also part of the power-down process.
3. SLM Exit Phase. The CSI-2 Link has exited the SLM and the interface/device is operational. This phase is also part of the power-up process.

In general, when in SLM, both sides of the interface will be in ULPS, as defined in [MIPI01].

D.2 SLM Command Phase

For the first phase, initiation of SLM occurs by a mechanism outside the scope of CSI-2. Of the many mechanisms available, two examples would be:

1. An External SLEEP signal input to the CSI-2 transmitter and optionally also to the CSI-2 Receiver. When at logic 0, the CSI-2 Transmitter and, if connected, the CSI Receiver, will enter Sleep mode. When at logic 1, normal operation will take place.
2. A CCI control command, provided on the I2C control Link, is used to trigger ULPS.

D.3 SLM Entry Phase

For the second phase, consider one option:

Only the TX side enters SLM and propagates the ULPS to the RX side by sending a D-PHY ‘ULPS’ command on Clock Lane and on Data Lane(s). In the following picture only Data Lane ‘ULPS’ command is used as an example.

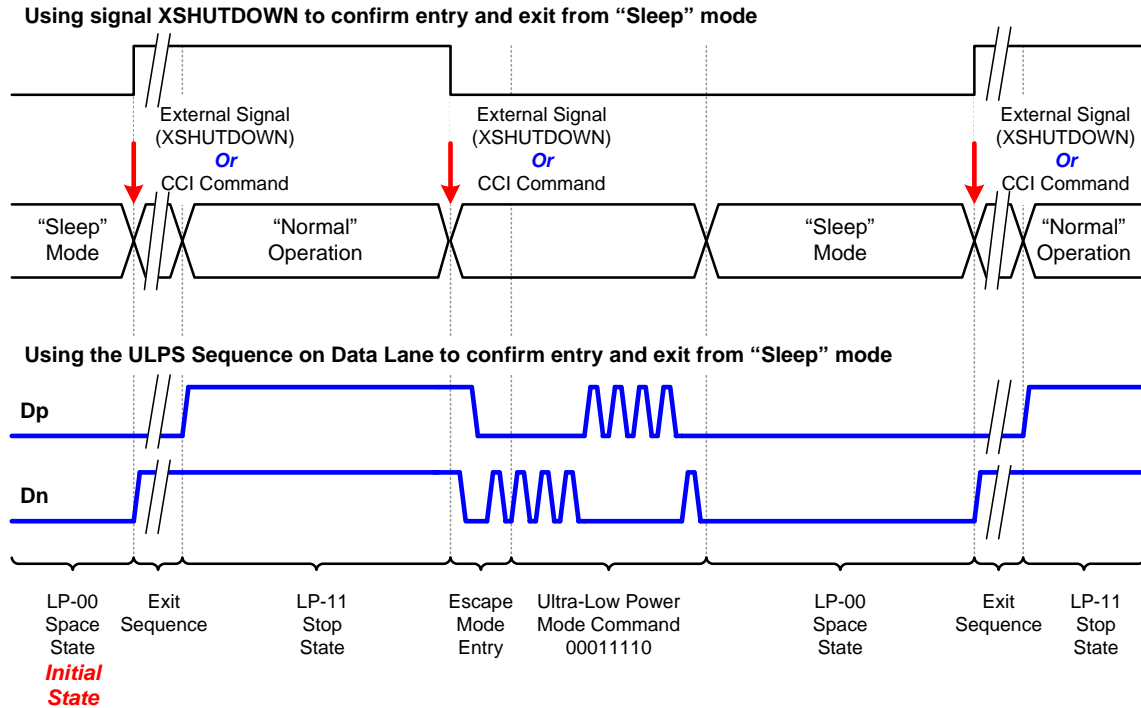


Figure 140 SLM Synchronization

D.4 SLM Exit Phase

For the third phase, three options are presented and assume the camera peripheral is in ULPS or Sleep mode at power-up:

1. Use a SLEEP signal to power-up both sides of the interface.
2. Detect any CCI activity on the I2C control Link, which have been in 00 state ({SCL, SDA}), after receiving the I2C instruction to enter ULPS command as per Section D.2, option 2. Any change on those lines should wake up the camera peripheral. The drawback of this method is that I2C lines are used exclusively for control of the camera.
3. Detect a wake-up sequence on the I2C lines. This sequence, which may vary by implementation, shall not disturb the I2C interface so that it can be used by other devices. One example sequence is: StopI2C-StartI2C-StopI2C. See section 6 for details on CCI.

A handshake using the 'ULPS' mechanism in the as described in [MIPI01] should be used for powering up the interface.

Annex E Data Compression for RAW Data Types (normative)

A CSI-2 implementation using RAW data types may support compression on the interface to reduce the data bandwidth requirements between the host processor and a camera module. Data compression is not mandated by this specification. However, if data compression is used, it shall be implemented as described in this annex.

Data compression schemes use an X–Y–Z naming convention where X is the number of bits per pixel in the original image, Y is the encoded (compressed) bits per pixel and Z is the decoded (uncompressed) bits per pixel.

The following data compression schemes are defined:

- 12–8–12
- 12–7–12
- 12–6–12
- 10–8–10
- 10–7–10
- 10–6–10

To identify the type of data on the CSI-2 interface, packets with compressed data shall have a User Defined Data Type value as indicated in Table 27. Note that User Defined data type codes are not reserved for compressed data types. Therefore, a CSI-2 device shall be able to communicate over the CCI the data compression scheme represented by a particular User Defined data type code for each scheme supported by the device. Note that the method to communicate the data compression scheme to Data Type code mapping is beyond the scope of this document.

The number of bits in a packet shall be a multiple of eight. Therefore, implementations with data compression schemes that result in each pixel having less than eight encoded bits per pixel shall transfer the encoded data in a packed pixel format. For example, the 12–7–12 data compression scheme uses a packed pixel format as described in section 11.4.2 except the Data Type value in the Packet Header is a User Defined data type code.

The data compression schemes in this annex are lossy and designed to encode each line independent of the other lines in the image.

The following definitions are used in the description of the data compression schemes:

- **Xorig** is the original pixel value
- **Xpred** is the predicted pixel value
- **Xdiff** is the difference value (**Xorig** - **Xpred**)
- **Xenco** is the encoded value
- **Xdeco** is the decoded pixel value

The data compression system consists of encoder, decoder and predictor blocks as shown in Figure 141.

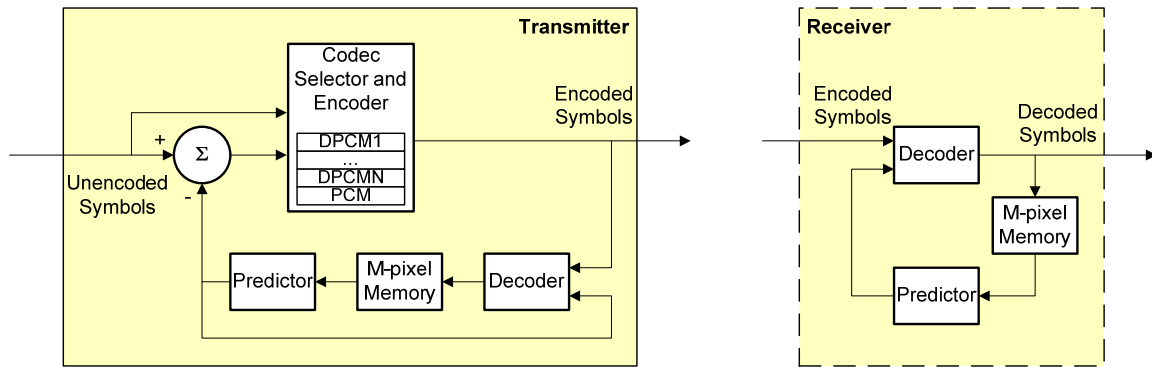


Figure 141 Data Compression System Block Diagram

The encoder uses a simple algorithm to encode the pixel values. A fixed number of pixel values at the beginning of each line are encoded without using prediction. These first few values are used to initialize the predictor block. The remaining pixel values on the line are encoded using prediction.

If the predicted value of the pixel, **Xpred**, is close enough to the original value of the pixel, **Xorig**, ($\text{abs}(\mathbf{Xorig} - \mathbf{Xpred}) < \text{difference limit}$) its difference value, **Xdiff**, is quantized using a DPCM codec. Otherwise, **Xorig** is quantized using a PCM codec. The quantized value is combined with a code word describing the codec used to quantize the pixel and the sign bit, if applicable, to create the encoded value, **Xenco**.

E.1 Predictors

In order to have meaningful data transfer, both the transmitter and the receiver need to use the same predictor block.

The order of pixels in a raw image is shown in Figure 142.

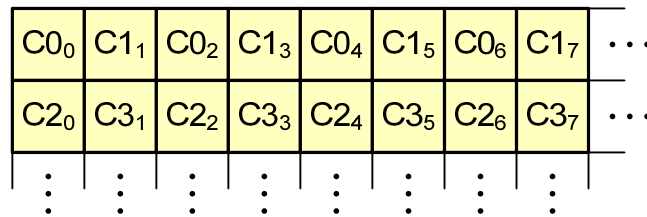


Figure 142 Pixel Order of the Original Image

Figure 143 shows an example of the pixel order with RGB data.

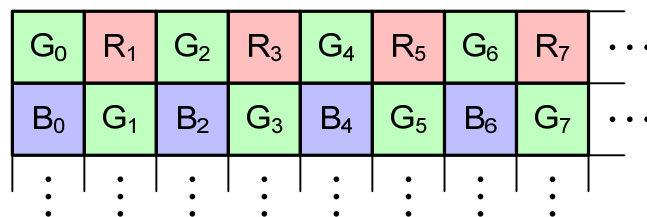


Figure 143 Example Pixel Order of the Original Image

Two predictors are defined for use in the data compression schemes.

Predictor1 uses a very simple algorithm and is intended to minimize processing power and memory size requirements. Typically, this predictor is used when the compression requirements are modest and the original image quality is high. Predictor1 should be used with 10–8–10, 10–7–10 and 12–8–12 data compression schemes.

The second predictor, Predictor2, is more complex than Predictor1. This predictor provides slightly better prediction than Predictor1 and therefore the decoded image quality can be improved compared to Predictor1. Predictor2 should be used with 10–6–10, 12–7–12, and 12–6–12 data compression schemes.

Both receiver and transmitter shall support Predictor1 for all data compression schemes.

2144 **E.1.1 Predictor1**

Predictor1 uses only the previous same color component value as the prediction value. Therefore, only a two-pixel deep memory is required.

The first two pixels ($C0_0$, $C1_1$ / $C2_0$, $C3_1$ or as in example G_0 , R_1 / B_0 , G_1) in a line are encoded without prediction.

The prediction values for the remaining pixels in the line are calculated using the previous same color decoded value, **Xdeco**. Therefore, the predictor equation can be written as follows:

$$2151 \quad \mathbf{Xpred(n)} = \mathbf{Xdeco(n-2)}$$

2152 **E.1.2 Predictor2**

Predictor2 uses the four previous pixel values, when the prediction value is evaluated. This means that also the other color component values are used, when the prediction value has been defined. The predictor equations can be written as below.

Predictor2 uses all color components of the four previous pixel values to create the prediction value. Therefore, a four-pixel deep memory is required.

The first pixel ($C0_0$ / $C2_0$, or as in example G_0 / B_0) in a line is coded without prediction.

The second pixel ($C1_1$ / $C3_1$ or as in example R_1 / G_1) in a line is predicted using the previous decoded different color value as a prediction value. The predictor equation for the second pixel is shown below:

$$2161 \quad \mathbf{Xpred(n)} = \mathbf{Xdeco(n-1)}$$

The third pixel ($C0_2$ / $C2_2$ or as in example G_2 / B_2) in a line is predicted using the previous decoded same color value as a prediction value. The predictor equation for the third pixel is shown below:

$$2164 \quad \mathbf{Xpred(n)} = \mathbf{Xdeco(n-2)}$$

The fourth pixel ($C1_3$ / $C3_3$ or as in example R_3 / G_3) in a line is predicted using the following equation:

```

2166     if ((Xdeco(n-1) <= Xdeco(n-2) AND Xdeco(n-2) <= Xdeco(n-3)) OR
2167         (Xdeco(n-1) >= Xdeco(n-2) AND Xdeco(n-2) >= Xdeco(n-3))) then
2168         Xpred(n) = Xdeco(n-1)
2169     else
2170         Xpred(n) = Xdeco(n-2)
2171     endif

```

2172 Other pixels in all lines are predicted using the equation:

```

2173     if ((Xdeco( n-1 ) <= Xdeco( n-2 ) AND Xdeco( n-2 ) <= Xdeco( n-3 )) OR
2174         (Xdeco( n-1 ) >= Xdeco( n-2 ) AND Xdeco( n-2 ) >= Xdeco( n-3 ))) then
2175         Xpred( n ) = Xdeco( n-1 )
2176     else if ((Xdeco( n-1 ) <= Xdeco( n-3 ) AND Xdeco( n-2 ) <= Xdeco( n-4 )) OR
2177         (Xdeco( n-1 ) >= Xdeco( n-3 ) AND Xdeco( n-2 ) >= Xdeco( n-4 ))) then
2178         Xpred( n ) = Xdeco( n-2 )
2179     else
2180         Xpred( n ) = (Xdeco( n-2 ) + Xdeco( n-4 ) + 1) / 2
2181     endif

```

2182 E.2 Encoders

2183 There are six different encoders available, one for each data compression scheme.

2184 For all encoders, the formula used for non-predicted pixels (beginning of lines) is different than the formula
2185 for predicted pixels.

2186 E.2.1 Coder for 10–8–10 Data Compression

2187 The 10–8–10 coder offers a 20% bit rate reduction with very high image quality.

2188 Pixels without prediction are encoded using the following formula:

2189
$$\mathbf{Xenco(n) = Xorig(n) / 4}$$

2190 To avoid a full-zero encoded value, the following check is performed:

```

2191     if (Xenco( n ) == 0) then
2192         Xenco( n ) = 1
2193     endif

```

2194 Pixels with prediction are encoded using the following formula:

```

2195     if (abs(Xdiff( n )) < 32) then
2196         use DPCM1
2197     else if (abs(Xdiff( n )) < 64) then
2198         use DPCM2
2199     else if (abs(Xdiff( n )) < 128) then
2200         use DPCM3
2201     else
2202         use PCM
2203     endif

```

2204 E.2.1.1 DPCM1 for 10–8–10 Coder

2205 **Xenco(n)** has the following format:

2206
$$\mathbf{Xenco(n) = "00 s xxxxx"}$$

2207 where,

2208 “00” is the code word

2209 “s” is the **sign** bit

2210 “xxxxx” is the five bit **value** field

2211 The coder equation is described as follows:

2212 if (**Xdiff**(n) <= 0) then

2213 **sign** = 1

2214 else

2215 **sign** = 0

2216 endif

2217 **value** = **abs**(**Xdiff**(n))

2218 Note: Zero code has been avoided (0 is sent as -0).

2219 **E.2.1.2 DPCM2 for 10–8–10 Coder**

2220 **Xenco**(n) has the following format:

2221 **Xenco**(n) = “010 s xxxx”

2222 where,

2223 “010” is the code word

2224 “s” is the **sign** bit

2225 “xxxx” is the four bit **value** field

2226 The coder equation is described as follows:

2227 if (**Xdiff**(n) < 0) then

2228 **sign** = 1

2229 else

2230 **sign** = 0

2231 endif

2232 **value** = (**abs**(**Xdiff**(n)) - 32) / 2

2233

2234 **E.2.1.3 DPCM3 for 10–8–10 Coder**

2235 **Xenco**(n) has the following format:

2236 **Xenco**(n) = “011 s xxxx”

2237 where,

2238 “010” is the code word

2239 “s” is the **sign** bit

2240 “xxxx” is the four bit **value** field

2241 The coder equation is described as follows:

```

2242     if (Xdiff( n ) < 0) then
2243         sign = 1
2244     else
2245         sign = 0
2246     endif
2247     value = (abs(Xdiff( n )) - 64) / 4

```

2248 **E.2.1.4 PCM for 10–8–10 Coder**

2249 **Xenco(n)** has the following format:

2250 **Xenco(n)** = “1 xxxxxxx”

2251 where,

```

2252     “1” is the code word
2253     the sign bit is not used
2254     “xxxxxxx” is the seven bit value field

```

2255 The coder equation is described as follows:

2256 **value** = **Xorig(n)** / 8

2257 **E.2.2 Coder for 10–7–10 Data Compression**

2258 The 10–7–10 coder offers 30% bit rate reduction with high image quality.

2259 Pixels without prediction are encoded using the following formula:

2260 **Xenco(n)** = **Xorig(n)** / 8

2261 To avoid a full-zero encoded value, the following check is performed:

```

2262     if (Xenco( n ) == 0) then
2263         Xenco( n ) = 1

```

2264 Pixels with prediction are encoded using the following formula:

```

2265     if (abs(Xdiff( n )) < 8) then
2266         use DPCM1
2267     else if (abs(Xdiff( n )) < 16) then
2268         use DPCM2
2269     else if (abs(Xdiff( n )) < 32) then
2270         use DPCM3
2271     else if (abs(Xdiff( n )) < 160) then
2272         use DPCM4
2273     else
2274         use PCM
2275     endif

```

2276 **E.2.2.1 DPCM1 for 10–7–10 Coder**

2277 **Xenco(n)** has the following format:

2278 **Xenco(n)** = “000 s xxx”

2279 where,

2280 “000” is the code word

2281 “s” is the **sign** bit

2282 “xxx” is the three bit **value** field

2283 The coder equation is described as follows:

2284 if (**Xdiff(n)** <= 0) then

2285 **sign** = 1

2286 else

2287 **sign** = 0

2288 endif

2289 **value** = abs(**Xdiff(n)**)

2290 Note: Zero code has been avoided (0 is sent as -0).

2291 **E.2.2.2 DPCM2 for 10–7–10 Coder**

2292 **Xenco(n)** has the following format:

2293 **Xenco(n)** = “0010 s xx”

2294 where,

2295 “0010” is the code word

2296 “s” is the **sign** bit

2297 “xx” is the two bit **value** field

2298 The coder equation is described as follows:

2299 if (**Xdiff(n)** < 0) then

2300 **sign** = 1

2301 else

2302 **sign** = 0

2303 endif

2304 **value** = (abs(**Xdiff(n)**) - 8) / 2

2305 **E.2.2.3 DPCM3 for 10–7–10 Coder**

2306 **Xenco(n)** has the following format:

2307 **Xenco(n)** = “0011 s xx”

2308 where,

2309 “0011” is the code word

2310 “s” is the **sign** bit

2311 “xx” is the two bit **value** field

2312 The coder equation is described as follows:

2313 if ($X_{diff}(n) < 0$) then

2314 **sign** = 1

2315 else

2316 **sign** = 0

2317 endif

2318 **value** = $(abs(X_{diff}(n)) - 16) / 4$

2319 **E.2.2.4 DPCM4 for 10–7–10 Coder**

2320 **Xenco**(*n*) has the following format:

2321 **Xenco**(*n*) = “01 s xxxx”

2322 where,

2323 “01” is the code word

2324 “s” is the **sign** bit

2325 “xxxx” is the four bit **value** field

2326 The coder equation is described as follows:

2327 if ($X_{diff}(n) < 0$) then

2328 **sign** = 1

2329 else

2330 **sign** = 0

2331 endif

2332 **value** = $(abs(X_{diff}(n)) - 32) / 8$

2333 **E.2.2.5 PCM for 10–7–10 Coder**

2334 **Xenco**(*n*) has the following format:

2335 **Xenco**(*n*) = “1 xxxxxx”

2336 where,

2337 “1” is the code word

2338 the **sign** bit is not used

2339 “xxxxxx” is the six bit **value** field

2340 The coder equation is described as follows:

2341 **value** = $X_{orig}(n) / 16$

E.2.3 Coder for 10–6–10 Data Compression

The 10–6–10 coder offers 40% bit rate reduction with acceptable image quality.

Pixels without prediction are encoded using the following formula:

$$\mathbf{Xenco}(n) = \mathbf{Xorig}(n) / 16$$

To avoid a full-zero encoded value, the following check is performed:

```

if ( $\mathbf{Xenco}(n) == 0$ ) then
     $\mathbf{Xenco}(n) = 1$ 
endif

```

Pixels with prediction are encoded using the following formula:

```

if ( $\text{abs}(\mathbf{Xdifff}(n)) < 1$ ) then
    use DPCM1
else if ( $\text{abs}(\mathbf{Xdifff}(n)) < 3$ ) then
    use DPCM2
else if ( $\text{abs}(\mathbf{Xdifff}(n)) < 11$ ) then
    use DPCM3
else if ( $\text{abs}(\mathbf{Xdifff}(n)) < 43$ ) then
    use DPCM4
else if ( $\text{abs}(\mathbf{Xdifff}(n)) < 171$ ) then
    use DPCM5
else
    use PCM
endif

```

E.2.3.1 DPCM1 for 10–6–10 Coder

$\mathbf{Xenco}(n)$ has the following format:

$$\mathbf{Xenco}(n) = \text{"00000 s"}$$

where,

"00000" is the code word
 "s" is the **sign** bit
 the **value** field is not used

The coder equation is described as follows:

$$\mathbf{sign} = 1$$

Note: Zero code has been avoided (0 is sent as -0).

E.2.3.2 DPCM2 for 10–6–10 Coder

$\mathbf{Xenco}(n)$ has the following format:

$$\mathbf{Xenco}(n) = \text{"00001 s"}$$

2377 where,
 2378 “00001” is the code word
 2379 “s” is the **sign** bit
 2380 the **value** field is not used

2381 The coder equation is described as follows:

2382 if ($X_{diff}(n) < 0$) then
 2383 **sign** = 1
 2384 else
 2385 **sign** = 0
 2386 endif

2387 **E.2.3.3 DPCM3 for 10–6–10 Coder**

2388 **Xenco(n)** has the following format:

2389 **Xenco(n)** = “0001 s x”

2390 where,

2391 “0001” is the code word
 2392 “s” is the **sign** bit
 2393 “x” is the one bit **value** field

2394 The coder equation is described as follows:

2395 if ($X_{diff}(n) < 0$) then
 2396 **sign** = 1
 2397 else
 2398 **sign** = 0
 2399 **value** = ($\text{abs}(X_{diff}(n)) - 3$) / 4
 2400 endif

2401 **E.2.3.4 DPCM4 for 10–6–10 Coder**

2402 **Xenco(n)** has the following format:

2403 **Xenco(n)** = “001 s xx”

2404 where,

2405 “001” is the code word
 2406 “s” is the **sign** bit
 2407 “xx” is the two bit **value** field

2408 The coder equation is described as follows:

2409 if ($X_{diff}(n) < 0$) then
 2410 **sign** = 1
 2411 else
 2412 **sign** = 0
 2413 endif

2414 **value** = (abs(**Xdiff**(**n**)) - 11) / 8

2415 **E.2.3.5 DPCM5 for 10–6–10 Coder**

2416 **Xenco**(**n**) has the following format:

2417 **Xenco**(**n**) = “01 s xxx”

2418 where,

2419 “01” is the code word

2420 “s” is the **sign** bit

2421 “xxx” is the three bit **value** field

2422 The coder equation is described as follows:

2423 if (**Xdiff**(**n**) < 0) then

2424 **sign** = 1

2425 else

2426 **sign** = 0

2427 endif

2428 **value** = (abs(**Xdiff**(**n**)) - 43) / 16

2429 **E.2.3.6 PCM for 10–6–10 Coder**

2430 **Xenco**(**n**) has the following format:

2431 **Xenco**(**n**) = “1 xxxxx”

2432 where,

2433 “1” is the code word

2434 the **sign** bit is not used

2435 “xxxxx” is the five bit **value** field

2436 The coder equation is described as follows:

2437 **value** = **Xorig**(**n**) / 32

2438 **E.2.4 Coder for 12–8–12 Data Compression**

2439 The 12–8–12 coder offers 33% bit rate reduction with very high image quality.

2440 Pixels without prediction are encoded using the following formula:

2441 **Xenco**(**n**) = **Xorig**(**n**) / 16

2442 To avoid a full-zero encoded value, the following check is performed:

2443 if (**Xenco**(**n**) == 0) then

2444 **Xenco**(**n**) = 1

2445 endif

2446 Pixels with prediction are encoded using the following formula:

```

2447     if (abs(Xdiff( n )) < 8) then
2448         use DPCM1
2449     else if (abs(Xdiff( n )) < 40) then
2450         use DPCM2
2451     else if (abs(Xdiff( n )) < 104) then
2452         use DPCM3
2453     else if (abs(Xdiff( n )) < 232) then
2454         use DPCM4
2455     else if (abs(Xdiff( n )) < 360) then
2456         use DPCM5
2457     else
2458         use PCM

```

2459 **E.2.4.1 DPCM1 for 12–8–12 Coder**

2460 **Xenco(n)** has the following format:

2461 **Xenco(n)** = “0000 s xxx”

2462 where,

```

2463     “0000” is the code word
2464     “s” is the sign bit
2465     “xxx” is the three bit value field

```

2466 The coder equation is described as follows:

```

2467     if (Xdiff( n ) <= 0) then
2468         sign = 1
2469     else
2470         sign = 0
2471     endif
2472     value = abs(Xdiff( n ))

```

2473 Note: Zero code has been avoided (0 is sent as -0).

2474 **E.2.4.2 DPCM2 for 12–8–12 Coder**

2475 **Xenco(n)** has the following format:

2476 **Xenco(n)** = “011 s xxxx”

2477 where,

```

2478     “011” is the code word
2479     “s” is the sign bit
2480     “xxxx” is the four bit value field

```

2481 The coder equation is described as follows:

```

2482     if (Xdiff( n ) < 0) then
2483         sign = 1
2484     else
2485         sign = 0
2486     endif
2487     value = (abs(Xdiff( n )) - 8) / 2

```

2488 **E.2.4.3 DPCM3 for 12–8–12 Coder**

2489 **Xenco**(n) has the following format:

2490 **Xenco**(n) = “010 s xxxx”

2491 where,

```

2492     “010” is the code word
2493     “s” is the sign bit
2494     “xxxx” is the four bit value field

```

2495 The coder equation is described as follows:

```

2496     if (Xdiff( n ) < 0) then
2497         sign = 1
2498     else
2499         sign = 0
2500     endif
2501     value = (abs(Xdiff( n )) - 40) / 4

```

2502 **E.2.4.4 DPCM4 for 12–8–12 Coder**

2503 **Xenco**(n) has the following format:

2504 **Xenco**(n) = “001 s xxxx”

2505 where,

```

2506     “001” is the code word
2507     “s” is the sign bit
2508     “xxxx” is the four bit value field

```

2509 The coder equation is described as follows:

```

2510     if (Xdiff( n ) < 0) then
2511         sign = 1
2512     else
2513         sign = 0
2514     endif
2515     value = (abs(Xdiff( n )) - 104) / 8

```

2516 **E.2.4.5 DPCM5 for 12–8–12 Coder**2517 **Xenco(n)** has the following format:2518 **Xenco(n)** = “0001 s xxx”

2519 where,

2520 “0001” is the code word

2521 “s” is the **sign** bit2522 “xxx” is the three bit **value** field

2523 The coder equation is described as follows:

2524 if (**Xdiff(n)** < 0) then2525 **sign** = 1

2526 else

2527 **sign** = 0

2528 endif

2529 **value** = (abs(**Xdiff(n)**) - 232) / 162530 **E.2.4.6 DPCM5 for 12–8–12 Coder**2531 **Xenco(n)** has the following format:2532 **Xenco(n)** = “1 xxxxxxx”

2533 where,

2534 “1” is the code word

2535 the **sign** bit is not used2536 “xxxxxxx” is the seven bit **value** field

2537 The coder equation is described as follows:

2538 **value** = **Xorig(n)** / 322539 **E.2.5 Coder for 12–7–12 Data Compression**

2540 The 12–7–12 coder offers 42% bit rate reduction with high image quality.

2541 Pixels without prediction are encoded using the following formula:

2542 **Xenco(n)** = **Xorig(n)** / 32

2543 To avoid a full-zero encoded value, the following check is performed:

2544 if (**Xenco(n)** == 0) then2545 **Xenco(n)** = 1

2546 endif

2547 Pixels with prediction are encoded using the following formula:

```

2548     if (abs(Xdiff( n )) < 4) then
2549         use DPCM1
2550     else if (abs(Xdiff( n )) < 12) then
2551         use DPCM2
2552     else if (abs(Xdiff( n )) < 28) then
2553         use DPCM3
2554     else if (abs(Xdiff( n )) < 92) then
2555         use DPCM4
2556     else if (abs(Xdiff( n )) < 220) then
2557         use DPCM5
2558     else if (abs(Xdiff( n )) < 348) then
2559         use DPCM6
2560     else
2561         use PCM
2562     endif

```

2563 **E.2.5.1 DPCM1 for 12–7–12 Coder**

2564 **Xenco**(n) has the following format:

2565 **Xenco**(n) = “0000 s xx”

2566 where,

2567 “0000” is the code word
 2568 “s” is the **sign** bit
 2569 “xx” is the two bit **value** field

2570 The coder equation is described as follows:

```

2571     if (Xdiff( n ) <= 0) then
2572         sign = 1
2573     else
2574         sign = 0
2575     endif
2576     value = abs(Xdiff( n ))

```

2577 Note: Zero code has been avoided (0 is sent as -0).

2578 **E.2.5.2 DPCM2 for 12–7–12 Coder**

2579 **Xenco**(n) has the following format:

2580 **Xenco**(n) = “0001 s xx”

2581 where,

2582 “0001” is the code word
 2583 “s” is the **sign** bit
 2584 “xx” is the two bit **value** field

2585 The coder equation is described as follows:

```

2586     if (Xdiff( n ) < 0) then
2587         sign = 1
2588     else
2589         sign = 0
2590     endif
2591     value = (abs(Xdiff( n )) - 4) / 2

```

2592 **E.2.5.3 DPCM3 for 12–7–12 Coder**

2593 **Xenco**(**n**) has the following format:

2594 **Xenco**(**n**) = “0010 s xx”

2595 where,

```

2596     “0010” is the code word
2597     “s” is the sign bit
2598     “xx” is the two bit value field

```

2599 The coder equation is described as follows:

```

2600     if (Xdiff( n ) < 0) then
2601         sign = 1
2602     else
2603         sign = 0
2604     endif
2605     value = (abs(Xdiff( n )) - 12) / 4

```

2606 **E.2.5.4 DPCM4 for 12–7–12 Coder**

2607 **Xenco**(**n**) has the following format:

2608 **Xenco**(**n**) = “010 s xxx”

2609 where,

```

2610     “010” is the code word
2611     “s” is the sign bit
2612     “xxx” is the three bit value field

```

2613 The coder equation is described as follows:

```

2614     if (Xdiff( n ) < 0) then
2615         sign = 1
2616     else
2617         sign = 0
2618     endif
2619     value = (abs(Xdiff( n )) - 28) / 8

```

2620 **E.2.5.5 DPCM5 for 12–7–12 Coder**

2621 **Xenco(n)** has the following format:

2622 **Xenco(n)** = “011 s xxx”

2623 where,

2624 “011” is the code word

2625 “s” is the **sign** bit

2626 “xxx” is the three bit **value** field

2627 The coder equation is described as follows:

2628 if (**Xdiff(n)** < 0) then

2629 **sign** = 1

2630 else

2631 **sign** = 0

2632 endif

2633 **value** = (abs(**Xdiff(n)**) - 92) / 16

2634 **E.2.5.6 DPCM6 for 12–7–12 Coder**

2635 **Xenco(n)** has the following format:

2636 **Xenco(n)** = “0011 s xx”

2637 where,

2638 “0011” is the code word

2639 “s” is the **sign** bit

2640 “xx” is the two bit **value** field

2641 The coder equation is described as follows:

2642 if (**Xdiff(n)** < 0) then

2643 **sign** = 1

2644 else

2645 **sign** = 0

2646 endif

2647 **value** = (abs(**Xdiff(n)**) - 220) / 32

2648 **E.2.5.7 PCM for 12–7–12 Coder**

2649 **Xenco(n)** has the following format:

2650 **Xenco(n)** = “1 xxxxxx”

2651 where,

2652 “1” is the code word

2653 the **sign** bit is not used

2654 “xxxxxx” is the six bit **value** field

2655 The coder equation is described as follows:

2656 **value** = **Xorig**(**n**) / 64

2657 **E.2.6 Coder for 12–6–12 Data Compression**

2658 The 12–6–12 coder offers 50% bit rate reduction with acceptable image quality.

2659 Pixels without prediction are encoded using the following formula:

2660 **Xenco**(**n**) = **Xorig**(**n**) / 64

2661 To avoid a full-zero encoded value, the following check is performed:

2662 if (**Xenco**(**n**) == 0) then

2663 **Xenco**(**n**) = 1

2664 endif

2665 Pixels with prediction are encoded using the following formula:

2666 if (abs(**Xdiff**(**n**)) < 2) then

2667 use **DPCM1**

2668 else if (abs(**Xdiff**(**n**)) < 10) then

2669 use **DPCM3**

2670 else if (abs(**Xdiff**(**n**)) < 42) then

2671 use **DPCM4**

2672 else if (abs(**Xdiff**(**n**)) < 74) then

2673 use **DPCM5**

2674 else if (abs(**Xdiff**(**n**)) < 202) then

2675 use **DPCM6**

2676 else if (abs(**Xdiff**(**n**)) < 330) then

2677 use **DPCM7**

2678 else

2679 use **PCM**

2680 endif

2681 Note: **DPCM2** is not used.

2682 **E.2.6.1 DPCM1 for 12–6–12 Coder**

2683 **Xenco**(**n**) has the following format:

2684 **Xenco**(**n**) = “0000 s x”

2685 where,

2686 “0000” is the code word

2687 “s” is the **sign** bit

2688 “x” is the one bit **value** field

2689 The coder equation is described as follows:

```

2690     if (Xdiff( n ) <= 0) then
2691         sign = 1
2692     else
2693         sign = 0
2694     endif
2695     value = abs(Xdiff( n ))

```

2696 Note: Zero code has been avoided (0 is sent as -0).

2697 **E.2.6.2 DPCM3 for 12–6–12 Coder**

2698 **Xenco(n)** has the following format:

2699 **Xenco(n)** = “0001 s x”

2700 where,

```

2701     “0001” is the code word
2702     “s” is the sign bit
2703     “x” is the one bit value field

```

2704 The coder equation is described as follows:

```

2705     if (Xdiff( n ) < 0) then
2706         sign = 1
2707     else
2708         sign = 0
2709     endif
2710     value = (abs(Xdiff( n )) - 2) / 4

```

2711 **E.2.6.3 DPCM4 for 12–6–12 Coder**

2712 **Xenco(n)** has the following format:

2713 **Xenco(n)** = “010 s xx”

2714 where,

```

2715     “010” is the code word
2716     “s” is the sign bit
2717     “xx” is the two bit value field

```

2718 The coder equation is described as follows:

```

2719     if (Xdiff( n ) < 0) then
2720         sign = 1
2721     else
2722         sign = 0
2723     endif
2724     value = (abs(Xdiff( n )) - 10) / 8

```

2725 **E.2.6.4 DPCM5 for 12–6–12 Coder**2726 **Xenco(n)** has the following format:2727 **Xenco(n)** = “0010 s x”

2728 where,

2729 “0010” is the code word

2730 “s” is the **sign** bit2731 “x” is the one bit **value** field

2732 The coder equation is described as follows:

2733 if (**Xdiff(n)** < 0) then2734 **sign** = 1

2735 else

2736 **sign** = 0

2737 endif

2738 **value** = (abs(**Xdiff(n)**) - 42) / 162739 **E.2.6.5 DPCM6 for 12–6–12 Coder**2740 **Xenco(n)** has the following format:2741 **Xenco(n)** = “011 s xx”

2742 where,

2743 “011” is the code word

2744 “s” is the **sign** bit2745 “xx” is the two bit **value** field

2746 The coder equation is described as follows:

2747 if (**Xdiff(n)** < 0) then2748 **sign** = 1

2749 else

2750 **sign** = 0

2751 endif

2752 **value** = (abs(**Xdiff(n)**) - 74) / 322753 **E.2.6.6 DPCM7 for 12–6–12 Coder**2754 **Xenco(n)** has the following format:2755 **Xenco(n)** = “0011 s x”

2756 where,

2757 “0011” is the code word

2758 “s” is the **sign** bit2759 “x” is the one bit **value** field

2760 The coder equation is described as follows:

```

2761     if (Xdiff( n ) < 0) then
2762         sign = 1
2763     else
2764         sign = 0
2765     endif
2766     value = (abs(Xdiff( n )) - 202) / 64

```

2767 **E.2.6.7 PCM for 12–6–12 Coder**

2768 **Xenco**(n) has the following format:

2769 **Xenco**(n) = “1 xxxxx”

2770 where,

```

2771     “1” is the code word
2772     the sign bit is not used
2773     “xxxxx” is the five bit value field

```

2774 The coder equation is described as follows:

2775 **value** = **Xorig**(n) / 128

2776 **E.3 Decoders**

2777 There are six different decoders available, one for each data compression scheme.

2778 For all decoders, the formula used for non-predicted pixels (beginning of lines) is different than the formula
 2779 for predicted pixels.

2780 **E.3.1 Decoder for 10–8–10 Data Compression**

2781 Pixels without prediction are decoded using the following formula:

2782 **Xdeco**(n) = 4 * **Xenco**(n) + 2

2783 Pixels with prediction are decoded using the following formula:

```

2784     if (Xenco( n ) & 0xc0 == 0x00) then
2785         use DPCM1
2786     else if (Xenco( n ) & 0xe0 == 0x40) then
2787         use DPCM2
2788     else if (Xenco( n ) & 0xe0 == 0x60) then
2789         use DPCM3
2790     else
2791         use PCM
2792     endif
2793

```

2794 **E.3.1.1 DPCM1 for 10–8–10 Decoder**2795 **Xenco(n)** has the following format:2796 **Xenco(n)** = “00 s xxxxx”

2797 where,

2798 “00” is the code word

2799 “s” is the **sign** bit2800 “xxxxx” is the five bit **value** field

2801 The decoder equation is described as follows:

2802 **sign** = **Xenco(n)** & 0x202803 **value** = **Xenco(n)** & 0x1f2804 if (**sign** > 0) then2805 **Xdeco(n)** = **Xpred(n)** - **value**

2806 else

2807 **Xdeco(n)** = **Xpred(n)** + **value**

2808 endif

2809 **E.3.1.2 DPCM2 for 10–8–10 Decoder**2810 **Xenco(n)** has the following format:2811 **Xenco(n)** = “010 s xxxx”

2812 where,

2813 “010” is the code word

2814 “s” is the **sign** bit2815 “xxxx” is the four bit **value** field

2816 The decoder equation is described as follows:

2817 **sign** = **Xenco(n)** & 0x102818 **value** = 2 * (**Xenco(n)** & 0xf) + 322819 if (**sign** > 0) then2820 **Xdeco(n)** = **Xpred(n)** - **value**

2821 else

2822 **Xdeco(n)** = **Xpred(n)** + **value**

2823 endif

2824 **E.3.1.3 DPCM3 for 10–8–10 Decoder**2825 **Xenco(n)** has the following format:2826 **Xenco(n)** = “011 s xxxx”

2827 where,

2828 “011” is the code word

2829 “s” is the **sign** bit

2830 “xxxx” is the four bit **value** field

2831 The decoder equation is described as follows:

```

2832       sign = Xenco( n ) & 0x10
2833       value = 4 * (Xenco( n ) & 0xf) + 64 + 1
2834       if (sign > 0) then
2835           Xdeco( n ) = Xpred( n ) - value
2836           if (Xdeco( n ) < 0) then
2837               Xdeco( n ) = 0
2838           endif
2839       else
2840           Xdeco( n ) = Xpred( n ) + value
2841           if (Xdeco( n ) > 1023) then
2842               Xdeco( n ) = 1023
2843           endif
2844       endif

```

2845 **E.3.1.4 PCM for 10–8–10 Decoder**

2846 **Xenco**(**n**) has the following format:

2847 **Xenco**(**n**) = “1 xxxxxxxx”

2848 where,

2849 “1” is the code word

2850 the **sign** bit is not used

2851 “xxxxxxx” is the seven bit **value** field

2852 The codec equation is described as follows:

```

2853       value = 8 * (Xenco( n ) & 0x7f)
2854       if (value > Xpred( n )) then
2855           Xdeco( n ) = value + 3
2856       endif
2857       else
2858           Xdeco( n ) = value + 4
2859       endif

```

2860 **E.3.2 Decoder for 10–7–10 Data Compression**

2861 Pixels without prediction are decoded using the following formula:

2862 **Xdeco**(**n**) = 8 * **Xenco**(**n**) + 4

2863 Pixels with prediction are decoded using the following formula:

```

2864     if (Xenco( n ) & 0x70 == 0x00) then
2865         use DPCM1
2866     else if (Xenco( n ) & 0x78 == 0x10) then
2867         use DPCM2
2868     else if (Xenco( n ) & 0x78 == 0x18) then
2869         use DPCM3
2870     else if (Xenco( n ) & 0x60 == 0x20) then
2871         use DPCM4
2872     else
2873         use PCM
2874     endif

```

2875 **E.3.2.1 DPCM1 for 10–7–10 Decoder**

2876 **Xenco**(n) has the following format:

2877 **Xenco**(n) = “000 s xxx”

2878 where,

2879 “000” is the code word
2880 “s” is the **sign** bit
2881 “xxx” is the three bit **value** field

2882 The codec equation is described as follows:

```

2883     sign = Xenco( n ) & 0x8
2884     value = Xenco( n ) & 0x7
2885     if (sign > 0) then
2886         Xdeco( n ) = Xpred( n ) - value
2887     else
2888         Xdeco( n ) = Xpred( n ) + value
2889     endif

```

2890 **E.3.2.2 DPCM2 for 10–7–10 Decoder**

2891 **Xenco**(n) has the following format:

2892 **Xenco**(n) = “0010 s xx”

2893 where,

2894 “0010” is the code word
2895 “s” is the **sign** bit
2896 “xx” is the two bit **value** field

2897 The codec equation is described as follows:

```

2898     sign = Xenco( n ) & 0x4
2899     value = 2 * (Xenco( n ) & 0x3) + 8

```

```

2900     if (sign > 0) then
2901         Xdeco( n ) = Xpred( n ) - value
2902     else
2903         Xdeco( n ) = Xpred( n ) + value
2904     endif

```

2905 E.3.2.3 DPCM3 for 10–7–10 Decoder

2906 **Xenco**(**n**) has the following format:

2907 **Xenco**(**n**) = “0011 s xx”

2908 where,

2909 “0011” is the code word
2910 “s” is the **sign** bit
2911 “xx” is the two bit **value** field

2912 The codec equation is described as follows:

```

2913     sign = Xenco( n ) & 0x4
2914     value = 4 * (Xenco( n ) & 0x3) + 16 + 1
2915     if (sign > 0) then
2916         Xdeco( n ) = Xpred( n ) - value
2917         if (Xdeco( n ) < 0) then
2918             Xdeco( n ) = 0
2919         endif
2920     else
2921         Xdeco( n ) = Xpred( n ) + value
2922         if (Xdeco( n ) > 1023) then
2923             Xdeco( n ) = 1023
2924         endif
2925     endif

```

2926 E.3.2.4 DPCM4 for 10–7–10 Decoder

2927 **Xenco**(**n**) has the following format:

2928 **Xenco**(**n**) = “01 s xxxx”

2929 where,

2930 “01” is the code word
2931 “s” is the **sign** bit
2932 “xxxx” is the four bit **value** field

2933 The codec equation is described as follows:

```

2934     sign = Xenco( n ) & 0x10
2935     value = 8 * (Xenco( n ) & 0xf) + 32 + 3

```



```

2936     if (sign > 0) then
2937         Xdeco( n ) = Xpred( n ) - value
2938         if (Xdeco( n ) < 0) then
2939             Xdeco( n ) = 0
2940         endif
2941     else
2942         Xdeco( n ) = Xpred( n ) + value
2943         if (Xdeco( n ) > 1023) then
2944             Xdeco( n ) = 1023
2945         endif
2946     endif

```

2947 **E.3.2.5 PCM for 10–7–10 Decoder**

2948 **Xenco**(**n**) has the following format:

2949 **Xenco**(**n**) = “1 xxxxxx”

2950 where,

2951 “1” is the code word
 2952 the **sign** bit is not used
 2953 “xxxxxx” is the six bit **value** field

2954 The codec equation is described as follows:

```

2955     value = 16 * (Xenco( n ) & 0x3f)
2956     if (value > Xpred( n )) then
2957         Xdeco( n ) = value + 7
2958     else
2959         Xdeco( n ) = value + 8
2960     endif

```

2961 **E.3.3 Decoder for 10–6–10 Data Compression**

2962 Pixels without prediction are decoded using the following formula:

2963 **Xdeco**(**n**) = 16 * **Xenco**(**n**) + 8

2964 Pixels with prediction are decoded using the following formula:

```

2965     if (Xenco( n ) & 0x3e == 0x00) then
2966         use DPCM1
2967     else if (Xenco( n ) & 0x3e == 0x02) then
2968         use DPCM2
2969     else if (Xenco( n ) & 0x3c == 0x04) then
2970         use DPCM3
2971     else if (Xenco( n ) & 0x38 == 0x08) then
2972         use DPCM4
2973     else if (Xenco( n ) & 0x30 == 0x10) then
2974         use DPCM5
2975     else
2976         use PCM
2977     endif

```

2978 **E.3.3.1 DPCM1 for 10–6–10 Decoder**2979 **Xenco(n)** has the following format:2980 **Xenco(n)** = “00000 s”

2981 where,

2982 “00000” is the code word

2983 “s” is the **sign** bit2984 the **value** field is not used

2985 The codec equation is described as follows:

2986 **Xdeco(n) = Xpred(n)**2987 **E.3.3.2 DPCM2 for 10–6–10 Decoder**2988 **Xenco(n)** has the following format:2989 **Xenco(n)** = “00001 s”

2990 where,

2991 “00001” is the code word

2992 “s” is the **sign** bit2993 the **value** field is not used

2994 The codec equation is described as follows:

2995 **sign = Xenco(n) & 0x1**2996 **value = 1**2997 if (**sign** > 0) then2998 **Xdeco(n) = Xpred(n) - value**

2999 else

3000 **Xdeco(n) = Xpred(n) + value**

3001 endif

3002 **E.3.3.3 DPCM3 for 10–6–10 Decoder**3003 **Xenco(n)** has the following format:3004 **Xenco(n)** = “0001 s x”

3005 where,

3006 “0001” is the code word

3007 “s” is the **sign** bit3008 “x” is the one bit **value** field

3009 The codec equation is described as follows:

3010 **sign = Xenco(n) & 0x2**3011 **value = 4 * (Xenco(n) & 0x1) + 3 + 1**

```

3012         if (sign > 0) then
3013             Xdeco( n ) = Xpred( n ) - value
3014             if (Xdeco( n ) < 0) then
3015                 Xdeco( n ) = 0
3016             endif
3017         else
3018             Xdeco( n ) = Xpred( n ) + value
3019             if (Xdeco( n ) > 1023) then
3020                 Xdeco( n ) = 1023
3021             endif
3022         endif

```

3023 **E.3.3.4 DPCM4 for 10–6–10 Decoder**

3024 **Xenco(n)** has the following format:

3025 **Xenco(n)** = “001 s xx”

3026 where,

3027 “001” is the code word
 3028 “s” is the **sign** bit
 3029 “xx” is the two bit **value** field

3030 The codec equation is described as follows:

```

3031     sign = Xenco( n ) & 0x4
3032     value = 8 * (Xenco( n ) & 0x3) + 11 + 3
3033     if (sign > 0) then
3034         Xdeco( n ) = Xpred( n ) - value
3035         if (Xdeco( n ) < 0) then
3036             Xdeco( n ) = 0
3037         endif
3038     else
3039         Xdeco( n ) = Xpred( n ) + value
3040         if (Xdeco( n ) > 1023) then
3041             Xdeco( n ) = 1023
3042         endif
3043     endif

```

3044 **E.3.3.5 DPCM5 for 10–6–10 Decoder**

3045 **Xenco(n)** has the following format:

3046 **Xenco(n)** = “01 s xxx”

3047 where,

3048 “01” is the code word
 3049 “s” is the **sign** bit
 3050 “xxx” is the three bit **value** field

3051 The codec equation is described as follows:

```

3052     sign = Xenco( n ) & 0x8
3053     value = 16 * (Xenco( n ) & 0x7) + 43 + 7
3054     if (sign > 0) then
3055         Xdeco( n ) = Xpred( n ) - value
3056         if (Xdeco( n ) < 0) then
3057             Xdeco( n ) = 0
3058         endif
3059     else
3060         Xdeco( n ) = Xpred( n ) + value
3061         if (Xdeco( n ) > 1023) then
3062             Xdeco( n ) = 1023
3063         endif
3064     endif

```

3065 E.3.3.6 PCM for 10–6–10 Decoder

3066 **Xenco**(**n**) has the following format:

3067 **Xenco**(**n**) = “1 xxxxx”

3068 where,

3069 “1” is the code word
3070 the **sign** bit is not used
3071 “xxxxx” is the five bit **value** field

3072 The codec equation is described as follows:

```

3073     value = 32 * (Xenco( n ) & 0x1f)
3074     if (value > Xpred( n )) then
3075         Xdeco( n ) = value + 15
3076     else
3077         Xdeco( n ) = value + 16
3078     endif

```

3079 E.3.4 Decoder for 12–8–12 Data Compression

3080 Pixels without prediction are decoded using the following formula:

3081 **Xdeco**(**n**) = 16 * **Xenco**(**n**) + 8

3082 Pixels with prediction are decoded using the following formula:

```

3083     if (Xenco( n ) & 0xf0 == 0x00) then
3084         use DPCM1
3085     else if (Xenco( n ) & 0xe0 == 0x60) then
3086         use DPCM2
3087     else if (Xenco( n ) & 0xe0 == 0x40) then
3088         use DPCM3
3089     else if (Xenco( n ) & 0xe0 == 0x20) then
3090         use DPCM4
3091     else if (Xenco( n ) & 0xf0 == 0x10) then

```

```

3092         use DPCM5
3093     else
3094         use PCM
3095     endif

```

3096 **E.3.4.1 DPCM1 for 12–8–12 Decoder**

3097 **Xenco(n)** has the following format:

3098 **Xenco(n)** = “0000 s xxx”

3099 where,

```

3100         “0000” is the code word
3101         “s” is the sign bit
3102         “xxx” is the three bit value field

```

3103 The codec equation is described as follows:

```

3104         sign = Xenco( n ) & 0x8
3105         value = Xenco( n ) & 0x7
3106         if (sign > 0) then
3107             Xdeco( n ) = Xpred( n ) - value
3108         else
3109             Xdeco( n ) = Xpred( n ) + value
3110         endif

```

3111 **E.3.4.2 DPCM2 for 12–8–12 Decoder**

3112 **Xenco(n)** has the following format:

3113 **Xenco(n)** = “011 s xxxx”

3114 where,

```

3115         “011” is the code word
3116         “s” is the sign bit
3117         “xxxx” is the four bit value field

```

3118 The codec equation is described as follows:

```

3119         sign = Xenco( n ) & 0x10
3120         value = 2 * (Xenco( n ) & 0xf) + 8
3121         if (sign > 0) then
3122             Xdeco( n ) = Xpred( n ) - value
3123         else
3124             Xdeco( n ) = Xpred( n ) + value
3125         endif

```

3126 **E.3.4.3 DPCM3 for 12–8–12 Decoder**3127 **Xenco(n)** has the following format:3128 **Xenco(n)** = “010 s xxxx”

3129 where,

3130 “010” is the code word

3131 “s” is the **sign** bit3132 “xxxx” is the four bit **value** field

3133 The codec equation is described as follows:

```

3134 sign = Xenco( n ) & 0x10
3135 value = 4 * (Xenco( n ) & 0xf) + 40 + 1
3136 if (sign > 0) then
3137     Xdeco( n ) = Xpred( n ) - value
3138     if (Xdeco( n ) < 0) then
3139         Xdeco( n ) = 0
3140     endif
3141 else
3142     Xdeco( n ) = Xpred( n ) + value
3143     if (Xdeco( n ) > 4095) then
3144         Xdeco( n ) = 4095
3145     endif
3146 endif

```

3147 **E.3.4.4 DPCM4 for 12–8–12 Decoder**3148 **Xenco(n)** has the following format:3149 **Xenco(n)** = “001 s xxxx”

3150 where,

3151 “001” is the code word

3152 “s” is the **sign** bit3153 “xxxx” is the four bit **value** field

3154 The codec equation is described as follows:

```

3155 sign = Xenco( n ) & 0x10
3156 value = 8 * (Xenco( n ) & 0xf) + 104 + 3
3157 if (sign > 0) then
3158     Xdeco( n ) = Xpred( n ) - value
3159     if (Xdeco( n ) < 0) then
3160         Xdeco( n ) = 0
3161     endif
3162 else
3163     Xdeco( n ) = Xpred( n ) + value
3164     if (Xdeco( n ) > 4095)
3165         Xdeco( n ) = 4095
3166     endif
3167 endif

```

3168 **E.3.4.5 DPCM5 for 12–8–12 Decoder**3169 **Xenco(n)** has the following format:3170 **Xenco(n)** = “0001 s xxx”

3171 where,

3172 “0001” is the code word

3173 “s” is the **sign** bit3174 “xxx” is the three bit **value** field

3175 The codec equation is described as follows:

```

3176 sign = Xenco( n ) & 0x8
3177 value = 16 * (Xenco( n ) & 0x7) + 232 + 7
3178 if (sign > 0) then
3179     Xdeco( n ) = Xpred( n ) - value
3180     if (Xdeco( n ) < 0) then
3181         Xdeco( n ) = 0
3182     endif
3183 else
3184     Xdeco( n ) = Xpred( n ) + value
3185     if (Xdeco( n ) > 4095) then
3186         Xdeco( n ) = 4095
3187     endif
3188 endif

```

3189 **E.3.4.6 PCM for 12–8–12 Decoder**3190 **Xenco(n)** has the following format:3191 **Xenco(n)** = “1 xxxxxxx”

3192 where,

3193 “1” is the code word

3194 the **sign** bit is not used3195 “xxxxxxx” is the seven bit **value** field

3196 The codec equation is described as follows:

```

3197 value = 32 * (Xenco( n ) & 0x7f)
3198 if (value > Xpred( n )) then
3199     Xdeco( n ) = value + 15
3200 else
3201     Xdeco( n ) = value + 16
3202 endif

```

3203 **E.3.5 Decoder for 12–7–12 Data Compression**

3204 Pixels without prediction are decoded using the following formula:

3205 **Xdeco(n)** = 32 * **Xenco(n)** + 16

3206 Pixels with prediction are decoded using the following formula:

```

3207     if (Xenco( n ) & 0x78 == 0x00) then
3208         use DPCM1
3209     else if (Xenco( n ) & 0x78 == 0x08) then
3210         use DPCM2
3211     else if (Xenco( n ) & 0x78 == 0x10) then
3212         use DPCM3
3213     else if (Xenco( n ) & 0x70 == 0x20) then
3214         use DPCM4
3215     else if (Xenco( n ) & 0x70 == 0x30) then
3216         use DPCM5
3217     else if (Xenco( n ) & 0x78 == 0x18) then
3218         use DPCM6
3219     else
3220         use PCM
3221     endif

```

3222 **E.3.5.1 DPCM1 for 12–7–12 Decoder**

3223 **Xenco**(n) has the following format:

3224 **Xenco**(n) = “0000 s xx”

3225 where,

3226 “0000” is the code word
3227 “s” is the **sign** bit
3228 “xx” is the two bit **value** field

3229 The codec equation is described as follows:

```

3230     sign = Xenco( n ) & 0x4
3231     value = Xenco( n ) & 0x3
3232     if (sign > 0) then
3233         Xdeco( n ) = Xpred( n ) - value
3234     else
3235         Xdeco( n ) = Xpred( n ) + value
3236     endif

```

3237 **E.3.5.2 DPCM2 for 12–7–12 Decoder**

3238 **Xenco**(n) has the following format:

3239 **Xenco**(n) = “0001 s xx”

3240 where,

3241 “0001” is the code word
3242 “s” is the **sign** bit
3243 “xx” is the two bit **value** field

3244 The codec equation is described as follows:

```

3245     sign = Xenco( n ) & 0x4
3246     value = 2 * (Xenco( n ) & 0x3) + 4
3247     if (sign > 0) then
3248         Xdeco( n ) = Xpred( n ) - value
3249     else
3250         Xdeco( n ) = Xpred( n ) + value
3251     endif

```

3252 E.3.5.3 DPCM3 for 12–7–12 Decoder

3253 **Xenco**(**n**) has the following format:

3254 **Xenco**(**n**) = “0010 s xx”

3255 where,

3256 “0010” is the code word
 3257 “s” is the **sign** bit
 3258 “xx” is the two bit **value** field

3259 The codec equation is described as follows:

```

3260     sign = Xenco( n ) & 0x4
3261     value = 4 * (Xenco( n ) & 0x3) + 12 + 1
3262     if (sign > 0) then
3263         Xdeco( n ) = Xpred( n ) - value
3264         if (Xdeco( n ) < 0) then
3265             Xdeco( n ) = 0
3266         endif
3267     else
3268         Xdeco( n ) = Xpred( n ) + value
3269         if (Xdeco( n ) > 4095) then
3270             Xdeco( n ) = 4095
3271         endif
3272     endif

```

3273 E.3.5.4 DPCM4 for 12–7–12 Decoder

3274 **Xenco**(**n**) has the following format:

3275 **Xenco**(**n**) = “010 s xxx”

3276 where,

3277 “010” is the code word
 3278 “s” is the **sign** bit
 3279 “xxx” is the three bit **value** field

3280 The codec equation is described as follows:

```

3281     sign = Xenco( n ) & 0x8
3282     value = 8 * (Xenco( n ) & 0x7) + 28 + 3

```

```

3283     if (sign > 0) then
3284         Xdeco( n ) = Xpred( n ) - value
3285         if (Xdeco( n ) < 0) then
3286             Xdeco( n ) = 0
3287         endif
3288     else
3289         Xdeco( n ) = Xpred( n ) + value
3290         if (Xdeco( n ) > 4095) then
3291             Xdeco( n ) = 4095
3292         endif
3293     endif

```

3294 **E.3.5.5 DPCM5 for 12–7–12 Decoder**

3295 **Xenco(n)** has the following format:

3296 **Xenco(n)** = “011 s xxx”

3297 where,

3298 “011” is the code word
3299 “s” is the **sign** bit
3300 “xxx” is the three bit **value** field

3301 The codec equation is described as follows:

```

3302     sign = Xenco( n ) & 0x8
3303     value = 16 * (Xenco( n ) & 0x7) + 92 + 7
3304     if (sign > 0) then
3305         Xdeco( n ) = Xpred( n ) - value
3306         if (Xdeco( n ) < 0) then
3307             Xdeco( n ) = 0
3308         endif
3309     else
3310         Xdeco( n ) = Xpred( n ) + value
3311         if (Xdeco( n ) > 4095) then
3312             Xdeco( n ) = 4095
3313         endif
3314     endif

```

3315 **E.3.5.6 DPCM6 for 12–7–12 Decoder**

3316 **Xenco(n)** has the following format:

3317 **Xenco(n)** = “0011 s xx”

3318 where,

3319 “0011” is the code word
3320 “s” is the **sign** bit
3321 “xx” is the two bit **value** field

3322 The codec equation is described as follows:

```

3323     sign = Xenco( n ) & 0x4
3324     value = 32 * (Xenco( n ) & 0x3) + 220 + 15
3325     if (sign > 0) then
3326         Xdeco( n ) = Xpred( n ) - value
3327         if (Xdeco( n ) < 0) then
3328             Xdeco( n ) = 0
3329         endif
3330     else
3331         Xdeco( n ) = Xpred( n ) + value
3332         if (Xdeco( n ) > 4095) then
3333             Xdeco( n ) = 4095
3334         endif
3335     endif

```

3336 E.3.5.7 PCM for 12–7–12 Decoder

3337 **Xenco**(**n**) has the following format:

3338 **Xenco**(**n**) = “1 xxxxxx”

3339 where,

3340 “1” is the code word
 3341 the **sign** bit is not used
 3342 “xxxxxx” is the six bit **value** field

3343 The codec equation is described as follows:

```

3344     value = 64 * (Xenco( n ) & 0x3f)
3345     if (value > Xpred( n )) then
3346         Xdeco( n ) = value + 31
3347     else
3348         Xdeco( n ) = value + 32
3349     endif

```

3350 E.3.6 Decoder for 12–6–12 Data Compression

3351 Pixels without prediction are decoded using the following formula:

3352 **Xdeco**(**n**) = 64 * **Xenco**(**n**) + 32

3353 Pixels with prediction are decoded using the following formula:

```

3354     if (Xenco( n ) & 0x3c == 0x00) then
3355         use DPCM1
3356     else if (Xenco( n ) & 0x3c == 0x04) then
3357         use DPCM3
3358     else if (Xenco( n ) & 0x38 == 0x10) then
3359         use DPCM4
3360     else if (Xenco( n ) & 0x3c == 0x08) then
3361         use DPCM5
3362     else if (Xenco( n ) & 0x38 == 0x18) then

```

```

3363         use DPCM6
3364     else if (Xenco( n ) & 0x3c == 0x0c) then
3365         use DPCM7
3366     else
3367         use PCM
3368     endif

```

3369 Note: **DPCM2** is not used.

3370 **E.3.6.1 DPCM1 for 12–6–12 Decoder**

3371 **Xenco**(n) has the following format:

3372 **Xenco**(n) = “0000 s x”

3373 where,

3374 “0000” is the code word
 3375 “s” is the **sign** bit
 3376 “x” is the one bit **value** field

3377 The codec equation is described as follows:

```

3378     sign = Xenco( n ) & 0x2
3379     value = Xenco( n ) & 0x1
3380     if (sign > 0) then
3381         Xdeco( n ) = Xpred( n ) - value
3382     else
3383         Xdeco( n ) = Xpred( n ) + value
3384     endif

```

3385 **E.3.6.2 DPCM3 for 12–6–12 Decoder**

3386 **Xenco**(n) has the following format:

3387 **Xenco**(n) = “0001 s x”

3388 where,

3389 “0001” is the code word
 3390 “s” is the **sign** bit
 3391 “x” is the one bit **value** field

3392 The codec equation is described as follows:

```

3393     sign = Xenco( n ) & 0x2
3394     value = 4 * (Xenco( n ) & 0x1) + 2 + 1
3395     if (sign > 0) then
3396         Xdeco( n ) = Xpred( n ) - value
3397         if (Xdeco( n ) < 0) then
3398             Xdeco( n ) = 0
3399         endif
3400     else
3401         Xdeco( n ) = Xpred( n ) + value

```

```

3402         if (Xdeco( n ) > 4095) then
3403             Xdeco( n ) = 4095
3404         endif
3405     endif

```

3406 E.3.6.3 DPCM4 for 12–6–12 Decoder

3407 **Xenco(n)** has the following format:

3408 **Xenco(n)** = “010 s xx”

3409 where,

3410 “010” is the code word
 3411 “s” is the **sign** bit
 3412 “xx” is the two bit **value** field

3413 The codec equation is described as follows:

```

3414     sign = Xenco( n ) & 0x4
3415     value = 8 * (Xenco( n ) & 0x3) + 10 + 3
3416     if (sign > 0) then
3417         Xdeco( n ) = Xpred( n ) - value
3418         if (Xdeco( n ) < 0) then
3419             Xdeco( n ) = 0
3420         endif
3421     else
3422         Xdeco( n ) = Xpred( n ) + value
3423         if (Xdeco( n ) > 4095) then
3424             Xdeco( n ) = 4095
3425         endif
3426     endif

```

3427 E.3.6.4 DPCM5 for 12–6–12 Decoder

3428 **Xenco(n)** has the following format:

3429 **Xenco(n)** = “0010 s x”

3430 where,

3431 “0010” is the code word
 3432 “s” is the **sign** bit
 3433 “x” is the one bit **value** field

3434 The codec equation is described as follows:

```

3435     sign = Xenco( n ) & 0x2
3436     value = 16 * (Xenco( n ) & 0x1) + 42 + 7
3437     if (sign > 0) then
3438         Xdeco( n ) = Xpred( n ) - value
3439         if (Xdeco( n ) < 0) then
3440             Xdeco( n ) = 0
3441         endif

```

```

3442     else
3443         Xdeco( n ) = Xpred( n ) + value
3444         if (Xdeco( n ) > 4095) then
3445             Xdeco( n ) = 4095
3446         endif
3447     endif

```

3448 **E.3.6.5 DPCM6 for 12–6–12 Decoder**

3449 **Xenco(n)** has the following format:

3450 **Xenco(n)** = “011 s xx”

3451 where,

3452 “011” is the code word
 3453 “s” is the **sign** bit
 3454 “xx” is the two bit **value** field

3455 The codec equation is described as follows:

```

3456     sign = Xenco( n ) & 0x4
3457     value = 32 * (Xenco( n ) & 0x3) + 74 + 15
3458     if (sign > 0) then
3459         Xdeco( n ) = Xpred( n ) - value
3460         if (Xdeco( n ) < 0) then
3461             Xdeco( n ) = 0
3462         endif
3463     else
3464         Xdeco( n ) = Xpred( n ) + value
3465         if (Xdeco( n ) > 4095) then
3466             Xdeco( n ) = 4095
3467         endif
3468     endif

```

3469 **E.3.6.6 DPCM7 for 12–6–12 Decoder**

3470 **Xenco(n)** has the following format:

3471 **Xenco(n)** = “0011 s x”

3472 where,

3473 “0011” is the code word
 3474 “s” is the **sign** bit
 3475 “x” is the one bit **value** field

3476 The codec equation is described as follows:

```

3477     sign = Xenco( n ) & 0x2
3478     value = 64 * (Xenco( n ) & 0x1) + 202 + 31
3479     if (sign > 0) then
3480         Xdeco( n ) = Xpred( n ) - value
3481         if (Xdeco( n ) < 0) then

```

```

3482         Xdeco( n ) = 0
3483     endif
3484     else
3485         Xdeco( n ) = Xpred( n ) + value
3486         if (Xdeco( n ) > 4095) then
3487             Xdeco( n ) = 4095
3488         endif
3489     endif

```

3490 **E.3.6.7 PCM for 12–6–12 Decoder**

3491 **Xenco(n)** has the following format:

3492 **Xenco(n) = “1 xxxxx”**

3493 where,

3494 “1” is the code word
 3495 the **sign** bit is not used
 3496 “xxxxx” is the five bit **value** field

3497 The codec equation is described as follows:

```

3498     value = 128 * (Xenco( n ) & 0x1f)
3499     if (value > Xpred( n )) then
3500         Xdeco( n ) = value + 63
3501     else
3502         Xdeco( n ) = value + 64
3503     endif

```

3504

Annex F JPEG Interleaving (informative)

This annex illustrates how the standard features of the CSI-2 protocol should be used to interleave (multiplex) JPEG image data with other types of image data, e.g. RGB565 or YUV422, without requiring a custom JPEG format such as JPEG8.

The Virtual Channel Identifier and Data Type value in the CSI-2 Packet Header provide simple methods of interleaving multiple data streams or image data types at the packet level. Interleaving at the packet level minimizes the amount of buffering required in the system.

The Data Type value in the CSI-2 Packet Header should be used to multiplex different image data types at the CSI-2 transmitter and de-multiplex the data types at the CSI-2 receiver.

The Virtual Channel Identifier in the CSI-2 Packet Header should be used to multiplex different data streams (channels) at the CSI-2 transmitter and de-multiplex the streams at the CSI-2 receiver.

The main difference between the two interleaving methods is that images with different Data Type values within the same Virtual Channel use the same frame and line synchronization information, whereas multiple Virtual Channels (data streams) each have their own independent frame and line synchronization information and thus potentially each channel may have different frame rates.

Since the predefined Data Type values represent only YUV, RGB and RAW data types, one of the User Defined Data Type values should be used to represent JPEG image data.

Figure 144 illustrates interleaving JPEG image data with YUV422 image data using Data Type values.

Figure 145 illustrates interleaving JPEG image data with YUV422 image data using both Data Type values and Virtual Channel Identifiers.

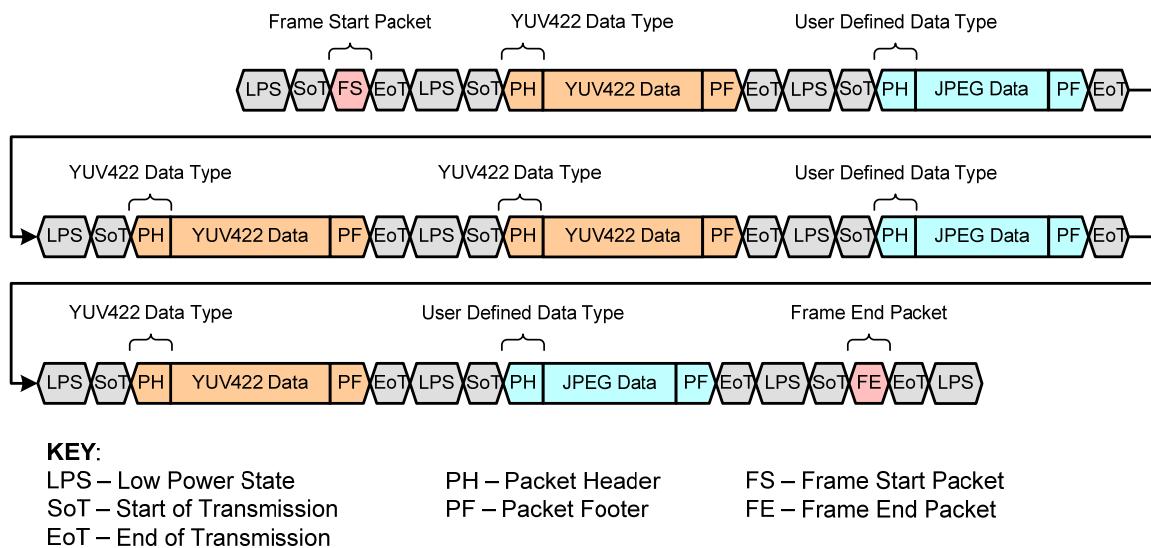


Figure 144 Data Type Interleaving: Concurrent JPEG and YUV Image Data

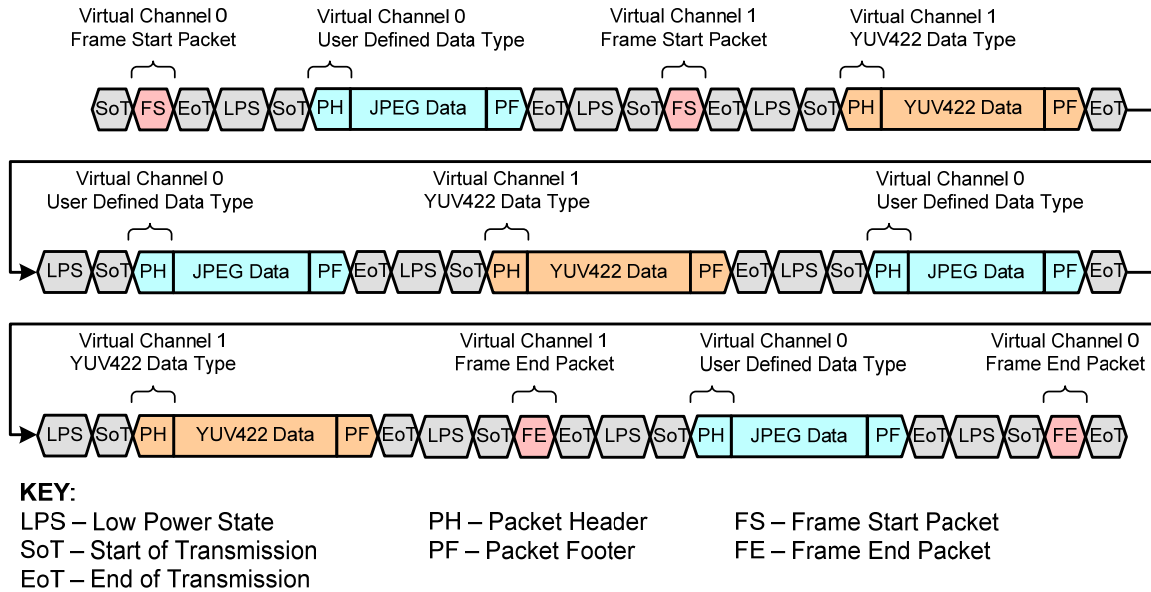


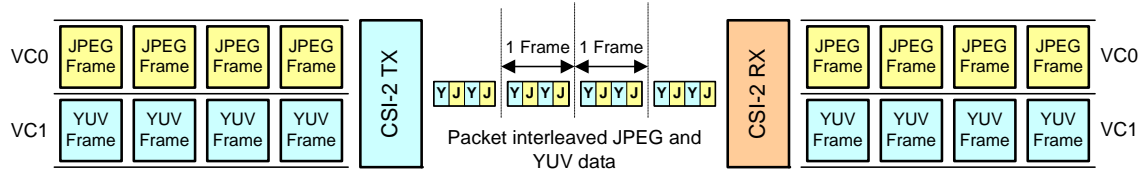
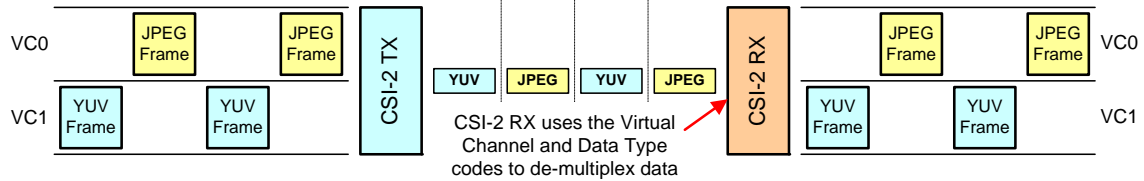
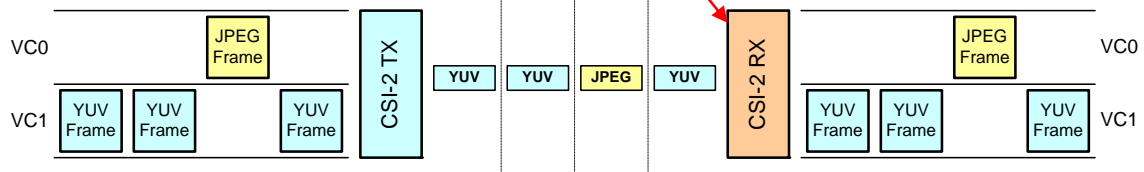
Figure 145 Virtual Channel Interleaving: Concurrent JPEG and YUV Image Data

Both Figure 144 and Figure 145 can be similarly extended to the interleaving of JPEG image data with any other type of image data, e.g. RGB565.

Figure 146 illustrates the use of Virtual Channels to support three different JPEG interleaving usage cases:

- Concurrent JPEG and YUV422 image data.
- Alternating JPEG and YUV422 output - one frame JPEG, then one frame YUV
- Streaming YUV22 with occasional JPEG for still capture

Again, these examples could also represent interleaving JPEG data with any other image data type.

Use Case 1: Concurrent JPEG output with YUV data**Use Case 2: Alternating JPEG and YUV output – one frame JPEG, then one frame YUV****Use Case 3: Streaming YUV with occasional JPEG still capture****Figure 146 Example JPEG and YUV Interleaving Use Cases**