EUROPEAN CENTRAL BANK

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Common Detector Interface 2 (CDI2)

Specifications

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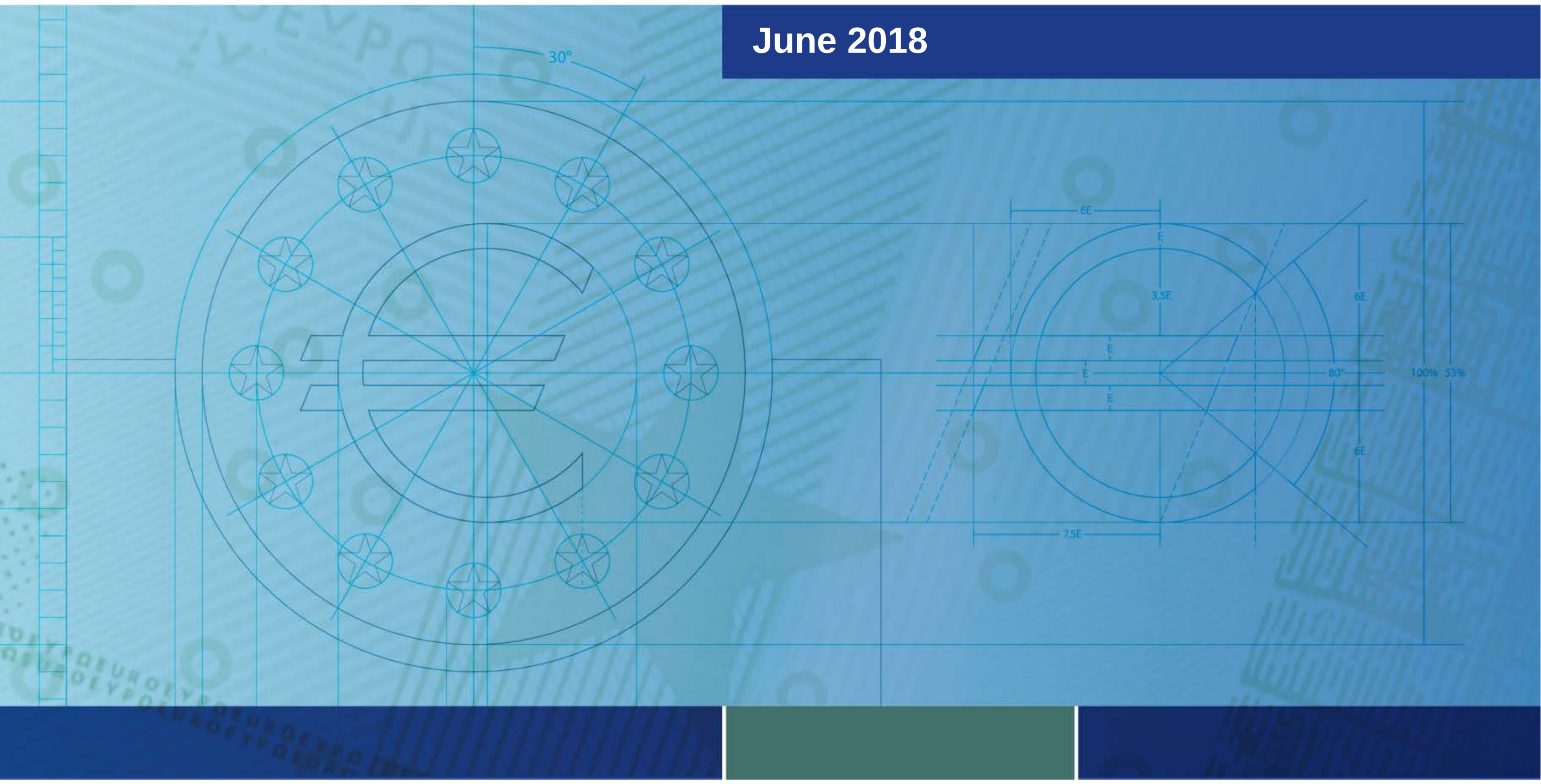

June 2018

Abstract

This document specifies the common detector interface 2 (CDI2) for banknote sorting machines (BSMs) and the detectors and camera systems installed thereon for inspecting banknotes.

Revision History

Interface Revision	Document Revision	Comment	Date
2.0	A	Final release	29 January 2016
2.0	B	Editorial revisions and clarifications	28 August 2016
2.1	A	First revision after CDI2 conference	03 November 2016
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1 Aim

The Common Detector Interface 2 (CDI2) aims to extend the existing CDI1 specifications creating the possibility to integrate a 3rd party camera system (with optional fitness sensor) into a central-bank used-banknote sorting machine (BSM) as well as defining sensor-fusion capabilities to the BSM to merge the data and results from different sensors of different manufacturers. This specification covers the definition of the electronic interface, the mechanical belt-free transport system and the sensor-fusion capabilities, as well as defining connectivity to external databases.

N.B.: Irrespective of the specifications contained in this document, the buyer of a sorting machine has the right to make the final decision about features and scope of all components and in what form/extent they should comply with the CDI2 standard. This applies especially to the optional CDI2 components (see chapter 2.8).

2 Definitions

2.1 Definitions and Abbreviations

2.1.1 Definitions

Aggregated Data	Data-set for one banknote comprising judgements and Supplemental Data of all CDI1, CDI2 and non-CDI Detectors.
Aggregation Unit	A dedicated unit in the BSM that collects all judgements and Supplemental Data from all connected Detectors (CDI1, CDI2 and non-CDI). The AU can combine this data and apply rules to generate virtual decisions.
Banknote Edge, Leading	Edge of the banknote, first in transport direction.
Banknote Edge, Trailing	Edge of the banknote, last in transport direction.
Banknote ID	Unique number assigned to a banknote by the BSM software. It identifies the banknote while present in the BSM, during the time it is processed and when check results are stored in a database.
Banknote Present	Dedicated TTS interface line representing the position of the banknote on the transport path. It aligns the inspection process at the Detector and synchronises the banknote, its Banknote ID and the Detector result.
Banknote Sorting Machine	Machine used for processing banknotes that is capable of sorting banknotes according to the results of the Detector(s).
Belt-Free-Area	Co-located Casing Positions within the banknote transport of a BSM providing two CS Casings belt-free access to both sides of the banknote at the same time (see 7.2).
Camera System	An arrangement consisting of multiple cameras, the CDI2 connections and an optional IEU.
Casing	Physical housing of a Detector or Camera System (see section 7.3 for content).
Casing Position	Physical mounting position of a Detector or Camera System, defined by a reference pin.

CDI2 Device	A CDI2 Device has a DMB connector. It can be a Detector, an IEU or a CS. Each CDI2 Device is a Controlled Node on the POWERLINK network of the DMB (see a more detailed description in 2.1.3).
Computational Detector	A Computational Detector is part of the AU and can combine the measurement results (judgements and Supplemental Data) of all physical detectors to build its own decision. Outputs of Computational Detectors are inputs for the final sorting decision and can be used as filters to control the storage of Aggregated Data and images (see 8.1).
Controlled Node	A Controlled Node in the POWERLINK network is polled cyclically by the Managing Node (MN).
Detector	A device for inspecting banknotes for authentication or fitness on a BSM. Either a Detector can be a device in a single housing as specified, or, alternatively, it can consist of a measurement head (conforming to the Detector housing specifications) and an External Evaluation Unit (see a more detailed description in 2.1.3).
Detector Machine Bus	A dedicated 100 Mbit Ethernet connection, connecting all CDI2 devices. It handles the control communication using POWERLINK as network protocol.
Evaluation Unit	The Evaluation Unit processes data captured by the MU and applies specific algorithms to the data in order to perform a judgement decision on the properties of the banknote and/or in order to extract specific properties.
External Evaluation Unit	Any kind of hardware conducting interim data processing tasks and providing a CDI2 compatible connection to the BSM. The External Evaluation Unit is mounted in the dedicated storage rack (see 7.7). It could be any kind of dedicated computer hardware or a standard PC.
External service port	External service port used to connect a PC directly to the Detector.
GigE Vision	Machine vision interface standard administered by the Automated Imaging Association (AIA) based on 1 or 10 GBit Ethernet.
Image Data Bus	Dedicated 10 GBit Ethernet connection distributing the banknote images from the Camera System to the BSM.
Image Evaluation Unit	A device evaluating images delivered from the cameras of the Camera System. Such a device may be integrated in the Camera System itself or can collect images from the IDB. In the latter case, the Image Evaluation Unit is a separate CDI2 Device located in the storage rack (see 7.7).
Managing Node	A Managing Node (MN) acts as the master in the POWERLINK network, it polls the Controlled Nodes (CN) cyclically. In CDI2 the BSM acts as the MN.
Measurement Unit	The Measurement Unit performs the measurement of physical properties of a banknote that passes it.
Nominal Casing Position	Position of the Central CDI mounting pin.
Non-CDI Detector	A proprietary detector not complying to the CDI specification.
POWERLINK	A real-time Ethernet protocol used for the DMB. See http://www.ethernet-powerlink.org

Raw Data	Data collected by the Detector for inspection of a feature (e.g. detailed line-scan data of a feature on a banknote).
READY	Dedicated TTS interface line from the Detector to the BSM to indicate that the Detector is ready for receiving commands.
RESET	Dedicated TTS interface line from the BSM to the Detector to carry out a hardware reset of the Detector.
Sensor	A Sensor is a physical device being mounted in the transport path and detecting a property of a banknote. A Sensor can be a camera or a multi-camera assembly but can be a thickness or magnetism measurement unit as well (see a more detailed description in 2.1.3).
Supplemental Data	A set of measurement data provided by the Detector describing specific properties of the measured feature, e.g. the intensity.
Timed Air Pulses	A method to stabilise banknotes in the BFA (see Appendix C).
Transport Clock	Dedicated TTS interface line. A square wave clock signal from the BSM to the Detector to synchronise the transport speed with the inspection rate of the Detector.
Transport Timing Signals	A collection of dedicated hardware lines providing trigger and clock signals from the BSM to the Detector and a READY signal in the other direction. Signals are Banknote Present (BP), Transport Clock (TC), RESET and READY.

2.1.2 Abbreviations

AU	Aggregation Unit
BFA	Belt-Free-Area
BN	Banknote
BNID	Banknote ID
BP	Banknote Present
BSM	Banknote Sorting Machine
BSMS	BSM Simulator
CLE	Colour Linearity Error
CN	Controlled Node
CS	Camera System
DET	Detector
DMB	Detector Machine Bus
DN	Digital numbers
DN rms	DN root mean square
DR	Data Range
DSNU	Dark Signal Non-Uniformity
ESP	External service port
EU	Evaluation Unit
FS	Full Scale
GEV	GigE Vision
GVSP	GigE Vision Stream Protocol
IDB	Image Data Bus
IEU	Image Evaluation Unit
IR	Infrared
LP	Line Pairs
MN	Managing Node
MTF	Modulation Transfer Function
MU	Measurement Unit
PL	POWERLINK
PRNU	Photo Response Non-Uniformity
RGB	Red, Green, Blue
SNR	Signal to Noise Ratio
TAP	Timed Air Pulses
TC	Transport Clock
TS	Transport Simulator
TTS	Transport Timing Signals

2.1.3 Supplementary definitions

Detector

A Detector is a logical unit that can take measurements on physical properties of a banknote, performs processing of the acquired data and delivers comprised results. Results consist of judgement decisions on fitness parameters and/or Supplemental Data.

Thus, a Detector consists of a Measurement Unit (MU) and an Evaluation Unit (EU). The MU performs the measurement of physical properties of a banknote that passes the casing position in the transport path of the sorting machine. The acquired data depends on the type of MU and can be any physical quantity, e.g. a detector for magnetic features would capture magnetic properties, whereas a detector for image features would capture a visible image of the banknote.

Generally, the MU delivers the acquired data to the EU. Then the EU applies specific algorithms to the data, in order to perform a judgement decision on the properties of the banknote and/or in order to extract specific properties, e.g. the soil level.

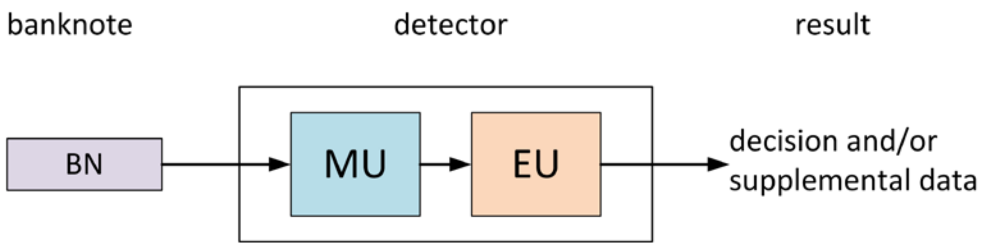


Figure 1: Detector definition

A Detector, as a logical unit, can be housed in a single physical casing or it can be composed of several separated physical units. The MU and the EU of a Detector might be enclosed in separate distinct physical units with proprietary interconnection between them. CDI2 also allows that the same image captured by the CS (acting as a MU) is shared by different EUs, denoted as Image Evaluation Units. In this case the IDB builds the interconnection between the MU und the EUs.

Please note that measurement of the physical quantities of a banknote is done by the MU. Thus, the MU is assigned to a specific casing position (mechanical slot) on the transport path of a BSM, as it needs to trigger its measurement when a banknote passes.

Sensor

In the context of this document a device containing at least one MU and which has a casing position (mechanical slot) on the transport path of the BSM is also denoted as a Sensor. Therefore, a Detector having MU and EU in a single casing can be denoted as Sensor as well.

CDI2 Device

A CDI2 Device has always one DMB interface port. Thus, each CDI2 Device has its own POWERLINK Node ID on the DMB. Additionally, it may have a TTS and IDB ports.

A CDI2 Device may consists of possible MUs and in any case EUs. A CDI2 Device that consists of an MU and an EU will be a complete Detector by itself, designated as a CDI2 Detector. It is mounted on a dedicated casing position on the transport path of a BSM, takes its own measurements and delivers results.

A CDI2 Camera System consists of one or more MUs, specifically it consists of several cameras for capturing images of the banknote. It makes the captured images available on the IDB. For note recognition and serial number detection, a CDI2 Camera System includes an optional Image Evaluation Unit (IEU) as well.

A CDI2 Image Evaluation Unit consists of an EU that can process images taken by the CS. Thereby a complete Detector is setup by the combination of an MU in the CS and an EU located in the CDI2 Image Evaluation Unit. Different Detectors can be setup by the combination of MUs and EUs.

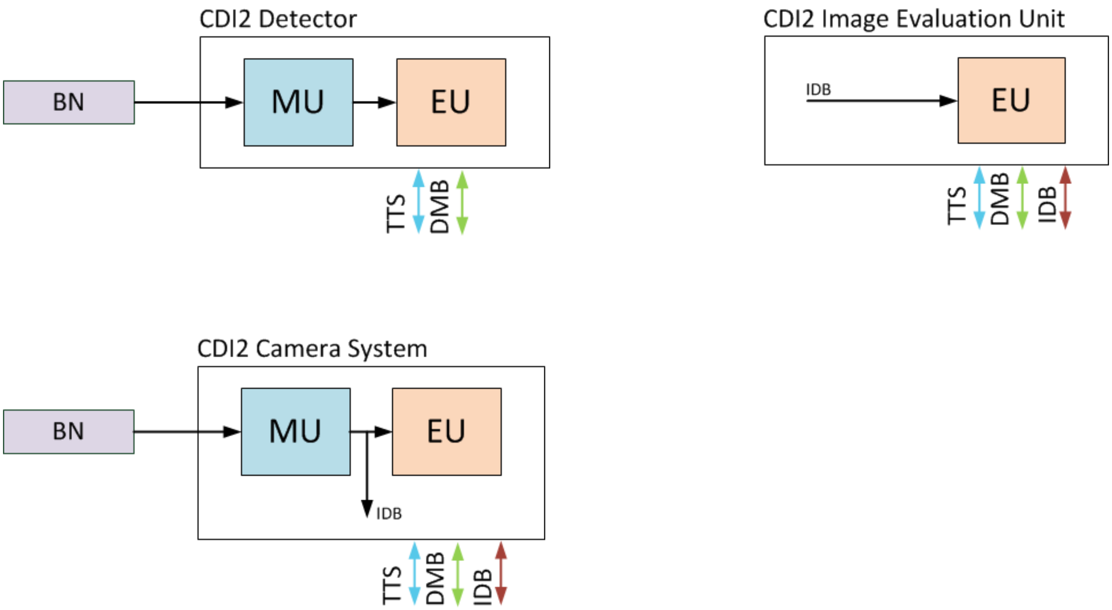


Figure 2: Three different kinds of CDI2 Devices

Device class	Description
0	Thickness detector
1	Authenticity Level1 feature
2	Authenticity Level2 feature
3	Authenticity Level3 feature
4	Fitness sensor (Camera System + IEU)
5	Other
6	Camera System without IEU
7	Image Evaluation unit without CS
8	BSM

Table 1: CDI2 device classes

2.2 CDI2 Block Diagram

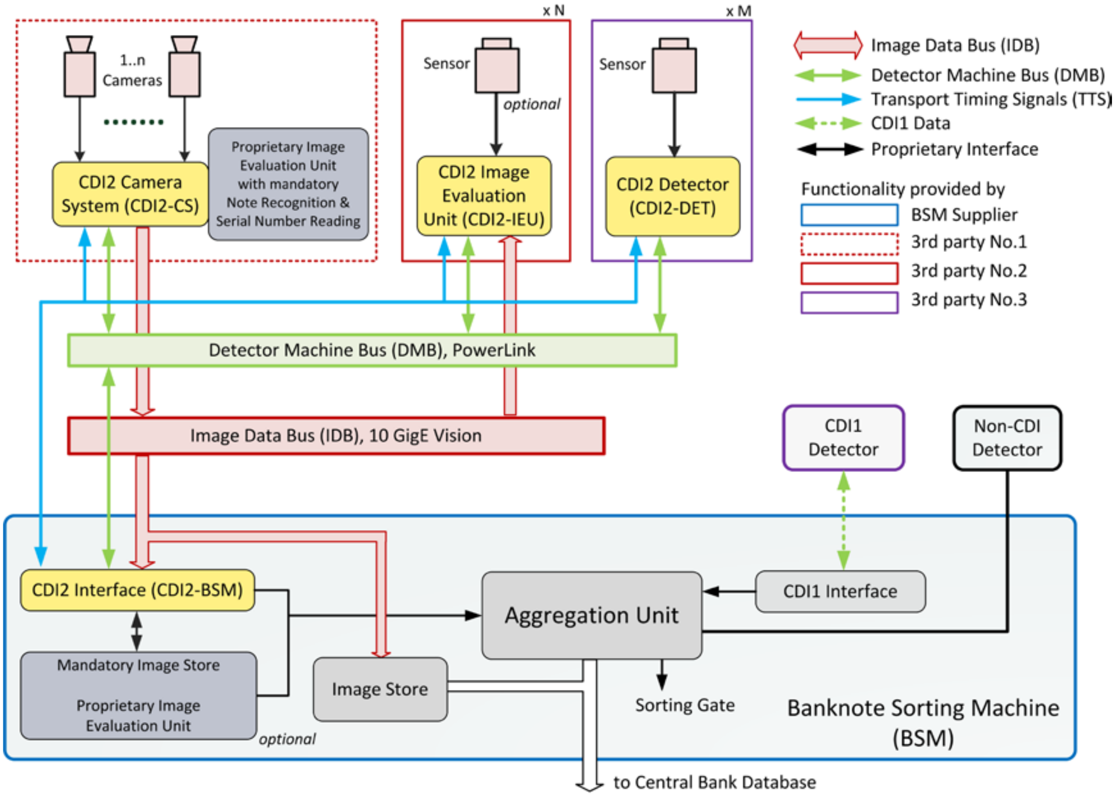


Figure 3: CDI2 block diagram

The colours in Figure 3 are used throughout the whole specification to clearly separate the three bus systems of CDI2.

Colour	Connection	Type
Blue	Transport Timing Signals (TTS)	Digital Signals
Red	Image Data Bus (IDB)	10 GBit Ethernet
Green	Detector Machine Bus (DMB)	100 Mbit POWERLINK connection

2.3 Components and basic specifications

All devices shall be based on a concept that supports BSM speeds from 1.0 m/s up to 12.5 m/s and banknote rates up to 50 BN/s.

2.3.1 CDI2 Sorting Machine

An example of a CDI2 compliant BSM is depicted in Appendix D

2.3.2 BSM transport system

- Has at least one Belt Free Area (BFA) for the CS
- Allows the optional installation of a second BFA with reasonable effort
- Allow robust transport to avoid jams due to low quality notes like: limp notes, taped notes, folded notes, notes with large tears and dog-ears
- Must allow the sorting of test charts (and, in this mode of operation, override the Banknote Series and Denomination codes received from the CS by setting the appropriate values in its BSMINFO message itself, see 6.7.4.2)
- Conforms to maximum tolerances for distance variation, slide, skew
- Shall be capable of transporting test charts with a size of 85 mm x 160 mm
- Conforms to dust, light and electric field specifications as defined in 7.8
- Provides compressed air to CDI2 device (see 7.4.6 for details)
- Provides cooling airflow for detectors
- Supports the following number of CDI1/2 detectors:
  - For aggregated data at the AU: 16
  - Mechanical, for CDI1/CDI2 Detectors: minimum 8 in total
    - At least 6 of these casing positions must allow the mounting of detector casing on both sides of the banknote transport as described in 7.3.
- Provides the switch for the IDB as described in 4.5.1
- Provides the hub for the DMB as described in 6.10

2.3.3 BSM Proprietary optional Image Evaluation Unit

- Get note images via the IDB to fulfil optional tasks of note recognition and handling
- May incorporate an optional fitness sensor

2.3.4 CDI1 Interface

- Acts to the CDI1 Detector like a normal CDI1 BSM in all aspects
- Makes CDI1 Supplemental Data available to the Aggregation Unit
- Supports mechanically and electrically minimum 8 CDI1 slots
- Shall support new, improved connectors as defined in 5.3

2.3.5 Non-CDI Detector

- the BSM may implement Detectors not conforming to CDI1 or CDI2 as non-CDI Detector
- the BSM needs to make sure that the judgement is available at the Aggregation Unit in time for the final judgement

2.3.6 Aggregation Unit

- Gives access to CDI1 supplemental data, CDI2 data from the DMB and at least the judgement of non-CDI sensors
- Provides tools for the combination of any of these parameters by mathematical parameters and setting of thresholds for final judgement
- Is accessible without the BSM supplier by authorised central bank staff
- Allows the transfer of settings from one machine to another
- Supports at least 500 aggregation rules (Computational Detectors) per denomination
- Supports different access levels to change parameter settings (for e.g. operator and administrator)

2.3.7 Data Storage

- Allows the configuration possibility to select which data is to be stored on a BSM and which one is to be transferred to a central database

- Provides a minimum of 4TB of storage for image and aggregated data at the BSM
- Transfers the stored data to a central bank provided sFTP server at shift end

2.4 CDI2 Camera System

- Provides the note images via the IDB to image evaluation units (IEUs) for fitness detection and to the BSM for its optional task of note recognition and handling
- Incorporates the recognition of series, denomination and orientation and provides this information to the BSM via the BNRECOGNITION
- Is connected to the BSM via the DMB and optionally IDB and/or TTS
- Conforms to the specifications regarding depth of view and BSM tolerances
- Conforms to the image quality tests specified in 4.2
- Provides images with a standard resolution to IDB of 0.2 mm (127 dpi), 8 bit per pixel
- Provides as a minimum front and back RGB and IR reflection both sides images (i.e. 8 ‘cameras’)
- Includes the necessary illumination to achieve the minimum image quality
- Complies to the mechanical requirements defined in 7.3
- Supports remote diagnosis via the DMB
- Conforms to dust, light and electric field specifications as defined in 7.8
- Provides the note recognition result
- Must read serial numbers and may implement a fitness sensor
- Shall use only one BFA for front and reverse imaging
- With every CDI2 device a user manual has to be delivered, which includes
    - a listing of the Supplemental Data provided (including names and data types)
    - error codes and their descriptions (see also "6.7.8.1 Error report" and "6.8 CDI2 Error Handling")
- With every CDI2 device a Device Information XML file ("device_info.xml") shall be provided as extra item

N.B.: CDI2 allows only a single CS in the BSM. Optional image data streams may be added at the IDB, but they must be provided by the same CS.

2.5 CDI2 Image Evaluation Unit

- Evaluates the note image delivered by the CS
- May either be integrated inside the CS itself or be part of the storage rack collecting the data from IDB
- With every CDI2 device a user manual has to be delivered, which includes
    - a listing of the Supplemental Data provided (including names and data types)
    - error codes and their descriptions (see also "6.7.8.1 Error report" and "6.8 CDI2 Error Handling")
- With every CDI2 device a Device Information XML file ("device_info.xml") shall be provided as extra item

2.6 CDI2 Detector

- Complies to the mechanical requirements defined in 7
- Shares mechanical slots with CDI1 Detectors (8 minimum in total CDI1 + CDI2) via adaptor plates, if necessary
- Can make use of a double-sided casing but both co-located detector casings must act as a single logical detector (single node on the DMB)
- Is connected to the BSM via the DMB and optionally TTS
- Supports remote diagnosis via the DMB
- Conforms to dust, light and electric field specifications as defined in 7.8
- With every CDI2 device a user manual has to be delivered, which includes
    - a listing of the Supplemental Data provided (including names and data types)
    - error codes and their descriptions (see also "6.7.8.1 Error report" and "6.8 CDI2 Error Handling")

- With every CDI2 device a Device Information XML file ("device_info.xml") shall be provided as extra item

2.7 CDI2 Interfaces

2.7.1 Image Data Bus (IDB, red line in Figure 3)

- Is a dedicated 10Gb Ethernet network with the CS streaming image data to all other nodes
- Does not use image compression for mandatory image data
- Uses a protocol allowing image streaming during image acquisition
- Provides the images from the various cameras to other interested Image Evaluation Units which then deliver results as Aggregated Data to BSM
- Is rugged and suitable for an industrial environment

2.7.2 Detector Machine Bus (DMB, green line in Figure 3)

- Is based on a 100Mbit Ethernet network implementing the Ethernet POWERLINK protocol to avoid data collision
- Allows 1.4 kB (up to 5.6kB in segmented mode) of data per note to be transmitted from each CDI2 Device to the BSM
- Allows remote diagnosis and software update of CDI2 Devices
- Is rugged and suitable for an industrial environment

2.7.3 Transport Timing Signals (TTS, blue line in Figure 3)

- Provides trigger, transport clock, reset and READY line to the Detectors via dedicated hardware lines in a dedicated additional connector
- Is rugged and suitable for an industrial environment

2.8 Summary of mandatory and optional Requirements for CDI2 Suppliers

The following Table 2 gives an (not necessarily complete) overview of the mandatory and optional requirements for all CDI2 components:

Supplier of CDI2-	Functionality	Chapter reference	[M]andatory or [O]ptional
BSM	Fulfil optional tasks of note recognition (includes series, denomination and orientation) and handling	2.4	O
	CDI1 support	7	M
	The mounting positions and order of the CDI2 detector along the transport path	3.2	M
	Must guarantee that the BNINFO arrives early enough	3.2	M
	Must allow the sorting of test charts	4.1	M
	Offer eight mechanical detector slots	5.1	M
	At least one BFA with the option of adding a 2nd BFA later	7.2	M
	Free to develop own BFA solution - as long as the requirements are met	7.2	O M
	Easily clean sensor positions	7.4.2	M
	Cables for all available CDI components (length, specification, CDI1 compatible, …)	4.6 5.3 6.10	M
	Aggregation unit requirements	8	M
	Store aggregated and Image Data	9	M
	IDB input	3	M
	DMB managing node	3	M
	9 TTS Plugs	5.3	M

Supplier of CDI2-	Functionality	Chapter reference	[M]andatory or [O]ptional
	IDB network switch in storage rack	4.5.1	M
	DMB network hub in storage rack	6.10	M
	POWERLINK gateway	3.3	M
	Browser for HTTP Port for Service and Maintenance	3.3	M
	Must dissipate the heat generated by all CDI Devices	7.13	M
	Allow access to CDI2 devices during Feed Off state	3.1.2	M
	Must fulfil all timing conditions	3.2	M
	Unique MAC address on DMB	6.2	M
	Store POWERLINK Node ID permanently	6.6.1	M
	Store logs persistently	6.8.1	M
	Maintain real-time master clock	6.8.6	M
	Comply with general operational specifications (safety, EMC, ESD, temperature, waterproof, dustproof, etc.)	7.8	M
	May incorporate an optional fitness sensor	2.3.3	O
	May send device specific parameters to CDI2 Devices	3.1.1	O
	Keep aggregated and Image Data after power-cycle	9	O
	Select compression level and image format	9.1.2	O
CS	image data consists of R, G, B and IR images from each side of the BN	4.1	M
	IDB utilises not more than 80% of the maximum bandwidth	4	M
	IDB output	4.1	M
	DMB controlled node	4.1	M
	Camera unit fits mounting spec of BFA slot	7.4.1	M
	Casing must be dust-proof	7.4.1	M
	Opposite side of the CS must have a uniform surface	7.2	M
	Max storage rack dimensions of 3U	7.4.1	M
	Max power ratings of 2*2*150 W	7.4.1	M
	Image of BN must be represented in orientation 1 on IDB	4.1 Table 33	M
	Needs to guarantee maximum latency	4.3	M
	Image data must be sent with multicasting	4.3.3	M
	Must be able to generate test images	4.4	M
	Unique MAC address on DMB	6.2	M
	Store POWERLINK Node ID permanently	6.6.1	M
	Deliver judgement and result code	6.7.4.4	M
	Deliver note recognition result	6.7.4.4	M
	Serial number reading	2.4	M
	Store logs persistently	6.8.1	M
	Comply with general operational specifications (safety, EMC, ESD, temperature, waterproof, dustproof, etc.)	7.8	M
	Must dissipate the heat generated	7.12	M
	Non TTS operation	5.4	O
	TTS plug	5.3	O
	May provide means for remote software update	3.4	O

Supplier of CDI2-	Functionality	Chapter reference	[M]andatory or [O]ptional
	Occupy 2nd BFA slot	7.2	O
	Electronics located in storage rack	7.4.1	O
	Series, denomination and orientation can be detected	3.1.3	O
	May incorporate a proprietary Image Evaluation Unit	2.4	O
	Special image data is allowed	4.1	O
	Image acquisition must also be possible with the lights turned off	4.2	M
IEU	Mechanical dimensions of 1U to fit into storage rack	7.7	M
	Max power rating of 150 W	7.9	M
	IDB input	2.1	M
	DMB controlled node	6	M
	Unique MAC address on DMB	6.2	M
	Store POWERLINK Node ID permanently	6.6.1	M
	Deliver judgement and result code	6.7.4.4	M
	Store logs persistently	6.8.1	M
	Comply with general operational specifications (safety, EMC, ESD, temperature, waterproof, dustproof, etc.)	7.8	M
	Must dissipate the heat generated	7.12	M
	May provide means for remote software update	3.4	O
	Non TTS operation	5.4	O
Detector	Connection between two parts of a detector	5.3	M
	Fit into BSM mounting slot using CDI2 Casing	7.4.3	M
	Max dimension of extra electronics of 1U	7.7	M
	Max power rating of 150 Watt	7.9	M
	DMB controlled node	6	M
	Unique MAC address on DMB	6.2	M
	Store POWERLINK Node ID permanently	6.6.1	M
	Deliver judgement and result code	6.7.4.4	M
	Store logs persistently	6.8.1	M
	Comply with general operational specifications (safety, EMC, ESD, temperature, waterproof, dustproof, etc.)	7.8	M
	Must dissipate the heat generated	7.12	M
	Non TTS operation	5.4	O
	TTS plug	5.3	
	May provide means for remote software update	3.4	O
	Extra electronics in storage rack with proprietary interconnection	2.1 7.7	O

Table 2: Summary of mandatory and optional Requirements for CDI2 Suppliers

For additional information on how the ECB and FRB are supporting developers of CDI2 components with Tools, Simulators, Analysers, Hardware and Software see chapter 10.

3 Communication Workflow Overview

An overview of a CDI2 Banknote Sorting Machine (BSM) is shown in Figure 3. The CDI2 interface of the BSM consists of three communication ports, the Image Data Bus (IDB), the Detector Machine Bus (DMB) und the Transport Timing Signals (TTS).

The Detector Machine Bus (see chapter 6) connects the BSM with its CDI2 devices, like Camera System, Image Evaluation Units and Detectors. During all phases of machine operation, the DMB acts as the main communication path for exchanging control information between the BSM and CDI2 Devices. The DMB utilises POWERLINK, a 100 Mbit/s real-time Ethernet field bus system, to ensure real-time response during the active sorting phase of the machine.

The Image Data Bus (see chapter 4) carries banknote images captured by the Camera System to the BSM and to Image Evaluation Units. The IDB uses a small subset of the GigE Vision interface standard, based on a 10GBit/s network (10 GigE).

The BSM provides Transport Timing Signals (see chapter 5) to all physical casing positions. For each position, the TTS port provides three output signals consisting of a hardware reset (RESET), a Banknote Present (BP) and Transport Clock (TC). BP and TC provide exact trigger timing to capture a banknote that passes the casing position. A READY input is used to indicate the device status to the BSM.

This chapter gives an overview about the basic operational sequences, involving DMB, IDB and TTS.

3.1 Overview of Communication Sequences

During startup and operation, the BSM acts as a master for the CDI2 System. It communicates mainly via the DMB with its CDI2 devices.

The major states of operation of the CDI2 System are:

1. INITIALISATION
2. FEED_OFF
3. SORTING

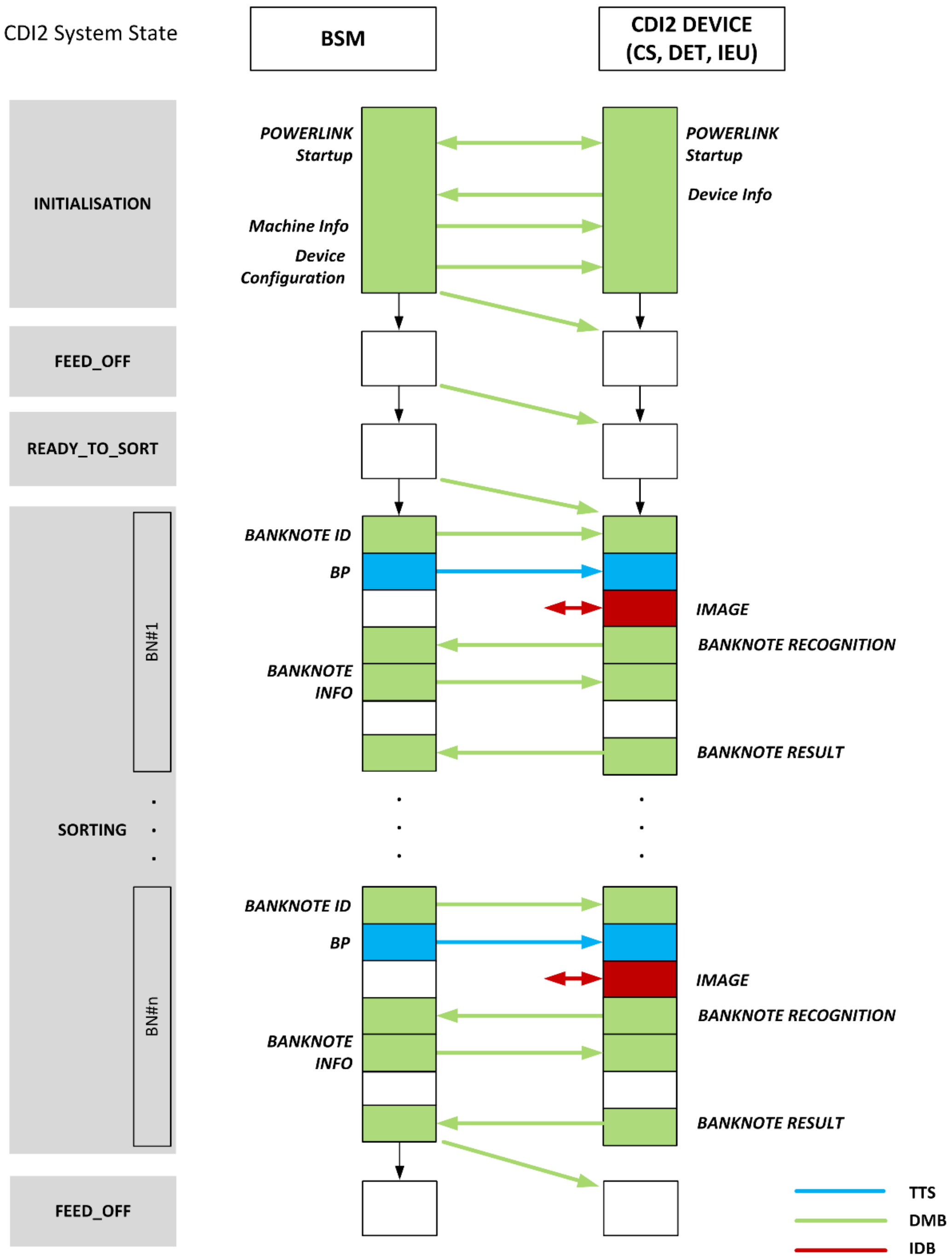


Figure 4: CDI2 startup and operational sequence

Communication and synchronisation between BSM and the CDI2 devices are accomplished via the Detector Machine Bus (DMB) using the POWERLINK real-time Ethernet protocol. Additional signals on the TTS support low-level startup and real-time clocking during sorting.

A typical startup and operational sequence is depicted in Figure 4. Please note that this is just an example and not all states are shown. Refer to chapter 6.7.2 for detailed state and command definitions.

3.1.1 INITIALISATION

As POWERLINK is the fundamental communication path, basic POWERLINK initialisation and configuration is performed in the setup processes very early.

As a prerequisite for POWERLINK, each node must have a unique Node ID assigned to it (see chapter 6.6.1).

After power-up (or system restart), the CDI2 System starts into the Initialisation Phase. During this phase, the BSM accesses the actual CDI2 configuration and starts the initialisation of the CDI2 components (see chapter 6.7.7).

Now the BSM can verify if the system is configured properly and if all required CDI2 components are present. In a final step, the BSM may send device specific parameters to the CDI2 Devices. This might include IDB/GigE Vision parameters as well.

3.1.2 FEED_OFF

At this state, the CDI2 System is ready for operation and can enter the SORTING state via READY_TO_SORT. As during FEED_OFF the transport system is off, no real-time operations are required on the DMB. Thus, access to CDI2 Devices is not restricted and maintenance operations (like download of raw data) are allowed.

3.1.3 SORTING

During this phase, the transport system is on and banknotes are processed. The DMB operates in real-time mode to ensure timing conditions required for the sorting and decision process are met. The BSM assigns a unique Banknote ID to each banknote entering the transport system. Each CDI2 Device receives the proper Banknote ID in conjunction with a Banknote Present (BP) signal, so that a banknote passing the Sensor is clearly identified. Banknote images captured by the Camera System are provided on the IDB for further processing. Series, denomination and orientation are determined by the Camera System and provided to the BSM via the BNRECOGNITION information as a mandatory feature. The BSM will subsequently broadcast this information via the DMB using a BSMINFO message. Alternatively, the BSM may determine series, denomination and orientation on its own and distribute it in the same manner. Which of the two options is used, is a matter of the BSM configuration. The BSMINFO message needs to be provided within a certain amount of time. Once a CDI2 Device has completed its processing, the result is sent to the BSM for aggregation and decision-making using a BNRESULT message.

A typical banknote checking sequence is shown in Figure 5. During sorting, the Camera System (CS) receives the Transport Clock (TC) and Banknote Present (BP) signals from the BSM via the TTS link.

The BSM sends a unique Banknote ID in advance via the DMB (step 1), so that the Banknote ID is available at the Camera System when the capturing of a banknote is triggered by the rising edge of the BP signal. Once triggered, the Camera System starts to acquire the image and typically streams the image data of the banknote via the IDB (step 2). The data stream sent over the IDB consists of a header followed by the image data payload. The header contains descriptive image parameters (image size, format) and the Banknote ID (see 4.1). The latency that the Camera System may introduce to the image data stream is limited (see chapter 3.2 for detailed latency specification).

In the next step, the CS will determine the banknote series, denomination and orientation of the captured banknote. The determined information will be sent to the BSM via the BNRECOGNITION information (step 3). The BSM combines this information as BNINFO and sends it via the DMB to all CDI2 nodes as part of a BSMINFO message (step 4).

The IEUs take the captured image, along with BNINFO, for banknote fitness/authenticity checking and provide their results to the BSM via the DMB by means of banknote result (BNRESULT) messages (step 5).

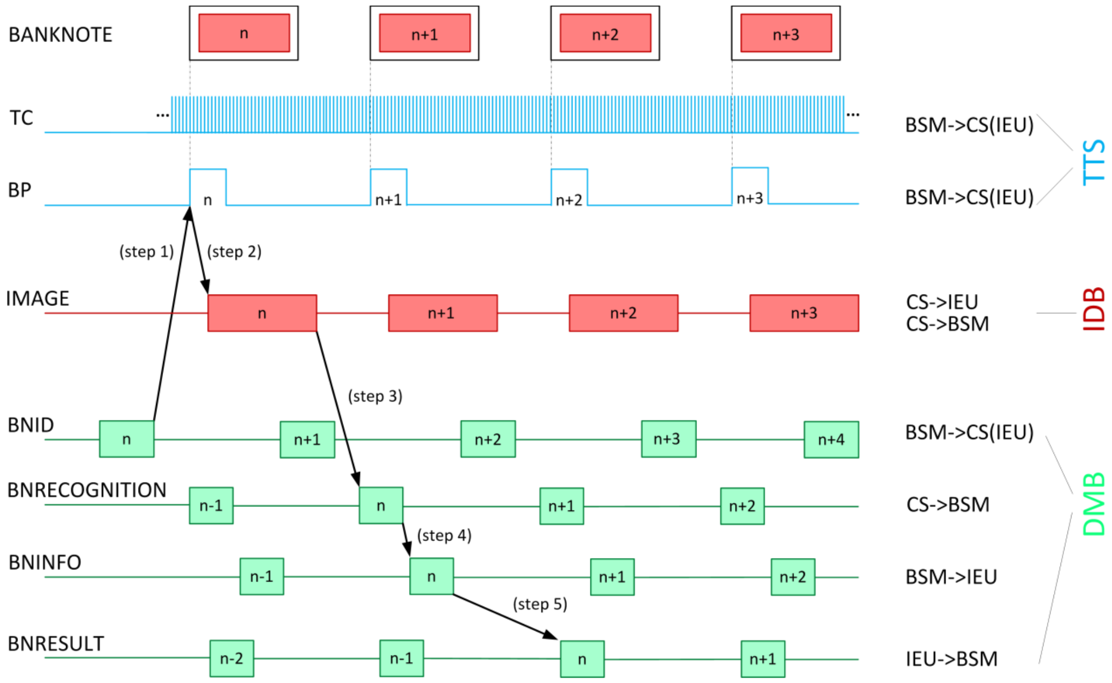


Figure 5: Communication sequence during banknote checking
(with camera image from CS)

In case of a CDI2 Detector, which does not require a banknote image from the IDB, the sequence is similar, except no IDB transfers are involved (see Figure 6). The BNINFO of a banknote arrives at the Detector before the appropriate banknote passes the casing position (step 1). Thus, the CDI2 Detector has to respect this situation and store the BNINFO to have it available when the banknote is processed. A CDI2 Detector must be capable to store 20 BNINFO messages at minimum. The other steps for triggering the banknote capturing, with BSM providing the BNID (step 2) and delivering the BNRESULT to the BSM after processing (step 3), remain unchanged.

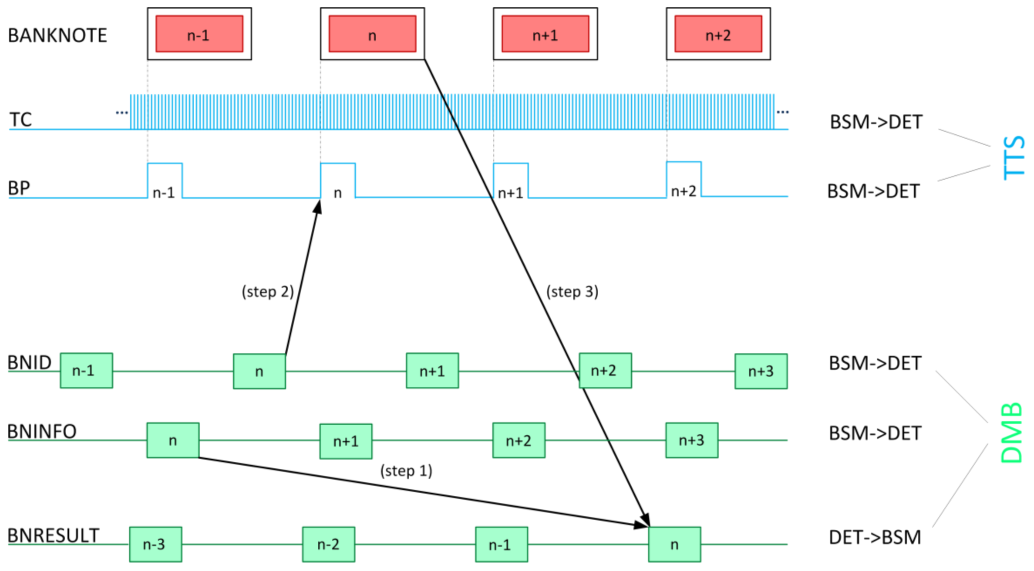


Figure 6: Communication sequence during banknote checking
(without using a camera Image from CS)

Note: An Image Evaluation Unit, having no sensors of its own, will just require DMB and IDB connections.

3.2 Timing Considerations

The processing of the banknote, from entry until the final sorting gate, has to be accomplished within a specific timeframe. For a Device to be CDI2 compliant, it has to perform its tasks within the timing requirements given in this chapter. A CDI2 compliant BSM has to provide a transport path where the physical distances are sufficient that, even with the highest transport speed of that BSM and in a worst-case situation, a banknote can be processed in time.

In this chapter, the following notation is used:

ṫ…Notation for a point in time
t…Notation for a time duration

The following table defines some terms that will be used to specify the timing requirements:

ṫBP	Point in time when the capture of a BN is triggered (either with the TTS BP line or with TC_TRIGn on the DMB)
ṫBNINFO	Point in time when the BNINFO for a BN has been received from the BSM. Note that at this point in time an IEU will have received all mandatory images from the CS, too.
ṫIMAGE	Point in time when all images (mandatory and optional) have been received from the CS. Note that optional images may be acquired at BFA#2 and, hence, may arrive later than the mandatory images captured at BFA#1.
lenMaxBN	Assumed maximum capture length of a BN. For the timing considerations in this chapter, lenMaxBN is defined to be 220.0 mm.
tMaxBN	Assumed maximum capture time of a BN. It depends on the transport speed vBN and on lenMaxBN, the assumed maximum capture length of a BN (see above). Hence, tMaxBN = lenMaxBN / vBN = 220.0 / vBN.

Table 3: Definition of terms used for timing requirements

The following table gives two examples for the maximum capture time of a BN tMaxBN depending on the transport speed vBN:

vBN (m/s)	tMaxBN (ms)
12.5	17.6
1.0	220.0

Table 4: Maximum capture time of a BN depending on transport speed

The timing requirements that a CDI2 Device (CS, IEU, Detector) has to fulfil to be CDI2 compliant are summarised in the following table:

Requirement	Description
ṫRCG_CS ≤ ṫBP_BFA#1 + tMaxBN + 3 ms	Point in time when the CS must be ready to send its BNRECOGNITION. Thus, from the trigger ṫBP_BFA#1 starting the capture of the BN at BFA#1, the available time duration to compute the denomination, series and orientation of a BN is the maximum capture time tMaxBN plus 3 ms.
ṫIMAGE_BFA ≤ ṫBP_BFA + tMaxBN + 5 ms	Point in time when the CS must have sent the image data acquired at BFA#1 or BFA#2, respectively, on the IDB. Thus, from the trigger ṫBP_BFA starting the capture of the BN at that BFA, the available time for sending the image data is the maximum capture time tMaxBN plus 5 ms. Note that all mandatory image data is acquired at BFA#1, which is the first position in the transport path. Optional image data may be acquired at both BFA#1 or BFA#2, hence the optional image data for a BN may arrive later than the mandatory image data.
ṫRES_IEU ≤ max (ṫBNINFO, ṫIMAGE) + 45 ms	Point in time when the CS or an IEU without an optional sensor must be ready to send its BNRESULT. Thus, from the point in time when all required inputs (BNINFO and images) for a BN are received, i.e. from ṫBNINFO or ṫIMAGE, whichever is later, the available time duration for processing the BN is 45 ms.
ṫRES_DET ≤ max (ṫBNINFO, ṫBP) + tMaxBN + 20 ms	Point in time when a Detector must be ready to send its BNRESULT. Thus, from either ṫBNINFO or the trigger ṫBP starting the capture of the BN, whichever is later, the available time duration for processing the BN is the maximum capture time tMaxBN plus 20 ms. Note that a detector that is mounted in one of the detector positions DET#1 to DET#8 can rely on the fact that the BNINFO will have arrived before a banknote is triggered. However, this is not necessarily the case for a detector mounted in BFA#2: If the BFA#2 is positioned before DET#1, the trigger may be earlier than the arrival of BNINFO
ṫRES_IEU_SEN ≤ max (ṫRES_IEU, ṫRES_DET)	Point in time when an IEU with an optional sensor must be ready to send its BNRESULT. For this, the IEU with optional sensor is supposed to consist of two independent components: An IEU without optional sensor and a Detector in the position of the optional sensor. The point in time when the BNRESULT has to be ready is the latest allowed time of the two components.
tA6 ≤ 2 ms	Setup time of a Detector or an IEU with an optional sensor for the capture of the BN (see Figure 8).

Table 5: Timing requirements for CDI2 Devices (CS, IEU, Detector)

From the timing requirements for the CDI2 Devices, the distance requirements for the transport path of a BSM can be derived. An example of how the casing positions are arranged on the transport path of a BSM is shown in Figure 7.

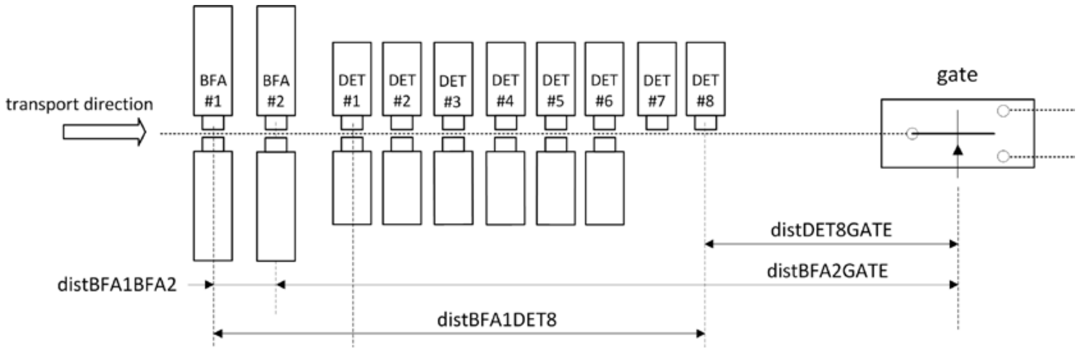


Figure 7: Exemplary casing positions on the transport path

Critical distances for the transport path of a BSM are the distance from BFA#1 to the first detector position DET#1 (distBFA1DET1) and either the distance from the last detector position DET#8 to the sorting gate (distDET8GATE) or the distance from BFA#2 to the sorting gate (distBFA2GATE). distBFA1DET1 has to be large enough that the detector in the first position receives the BNINFO with the denomination, series and orientation information early enough to set up its capture of the BN accordingly. distDET8GATE and distBFA2GATE have to be large enough that the BSM receives the result of the last detector or an IEU, respectively, early enough to carry out its aggregation and decision process and set up its sorting gate. Below in the explanations to Figure 8, Figure 9, and Figure 10, it will be shown how a BSM manufacturer can determine the minimum lengths for these distances. Note that distBFA1DET1, distDET8GATE and distBFA2GATE depend on the anticipated transport speed and will be the larger the higher the maximum transport speed will be.

On the other hand, CDI2 also requires a restriction of the maximum length of the BSM transport path: At a maximum, 20 BN may be in the transport path between BFA#1 and the sorting gate. For example, if the BNs are transported with a distance of 250.0 mm, this means that the maximum distance from BFA#1 to the sorting gate would be 5 m. Therefore, if a CDI2 Device has to buffer some data, e.g. the BNINFO for a BN or, in the case of an IEU with an optional sensor, images captured at BFA#1 or BFA#2, it will be sufficient to provide 20 buffers.

A special case is the BFA#2. The BSM manufacturer may choose the position of the BFA#2 to be anywhere on the transport path behind BFA#1. In the BFA#2, either the second image acquisition unit of a CS or a stand-alone detector is mounted.

If a second image acquisition unit of a CS is mounted in BFA#2, the distance distBFA2GATE from BFA#2 to the sorting gate must be large enough that the result of an IEU processing optional images acquired at BFA#2 can be handled (see Table 8).

For a stand-alone detector in BFA#2, the same timing requirements apply as for normal detectors mounted in DET#1 to DET#8. Note, however, a difference to normal detectors: Since the distance from BFA#1 to BFA#2 may be rather short (specifically shorter than distBFA1DET1), a detector mounted in BFA#2 must not rely on the fact that it will receive the BNINFO from the BSM before the trigger to capture the BN.

Figure 8 shows the sequence from the trigger at BFA#1 to the trigger at the first detector position DET#1. First, the image is captured at the CS mounted in BFA#1 (tA1). Then, the banknote orientation, series and orientation is determined by the CS (tA2) and delivered to the BSM via BNRECOGNITION (tA3). Based on this, the BSM will prepare a BNINFO for this banknote (tA4) and transmit it using a BSMINFO message (tA5). When a Device receives the BNINFO, it has now the opportunity to set up its capture unit (tA6) accounting for the received banknote orientation, series and orientation.

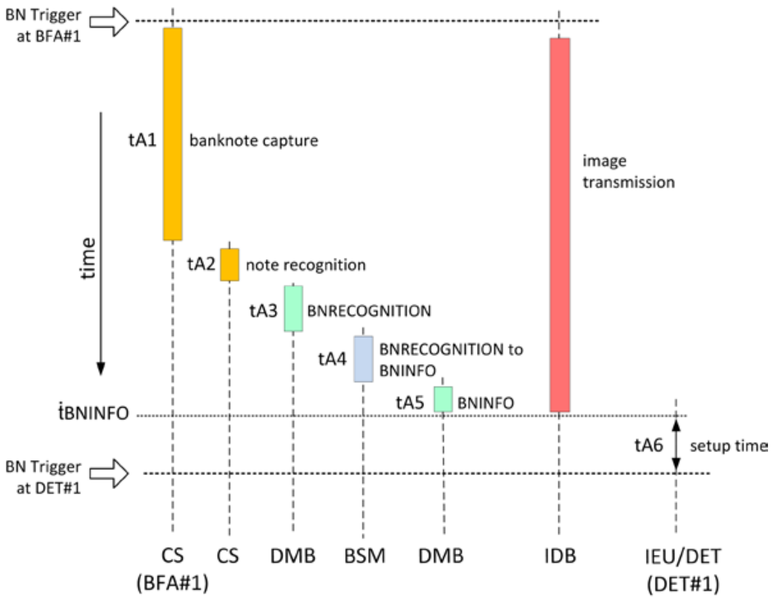


Figure 8: Timing sequence from trigger at BFA#1 to trigger at DET#1

The following table lists the times of Figure 8 and gives their worst-case values.

Time	***Description***	***Worst Case***
tA1	Banknote capture time	
tA2	Time for denomination, series and orientation calculation	tA1 + tA2 = 220.0 mm / vBN + 3 ms
tA3	BNRECOGNITION transmission time	tA3 = 4 ms
tA4	BSM internal delay from the reception of BNRECOGNITION until it is ready to transmit its BNINFO	(BSM dependent)
tA5	BNINFO transmission time	tA5 = 1 ms
tA6	Setup time for the capture of a BN	tA6 = 2 ms

Table 6: Worst-case timing calculation from BFA#1 (CS) to first detector position DET#1

Note that tA3, the time to transmit BNRECOGNITION, can be 1, 2, 3, or 4 ms. Since the period of the isochronous cycle is 1 ms, but the CS can be requested by the BSM with PReq only every 4th cycle, tA3 depends on how many cycles it takes from the point in time when the denomination, series and orientation calculation is finished until it is the turn to query the CS. For the worst-case computation in Table 6, the maximum of 4 ms is assumed.

The minimum distance between BFA#1 and DET#1 distBFA1DET1 can then be computed as

distBFA1DET1 = tBFA1DET1 * vBN

where tBFA1DET1 is the sum of all times from BFA#1 to DET#1

tBFA1DET1 = tA1 + tA2 + tA3 + tA4 + tA5 + tA6

Figure 9 depicts the sequence from the trigger at the last detector position DET#8 to the sorting gate. Starting with the trigger, the banknote is captured (tB1), processed (tB2D) and its result is transmitted to the BSM (tB3). When the BSM has received the results of all Devices, it carries out its aggregation and decision processing (tB4). Based on the result, it will set up its sorting gates (tB5) to direct the banknote into the proper stacker.

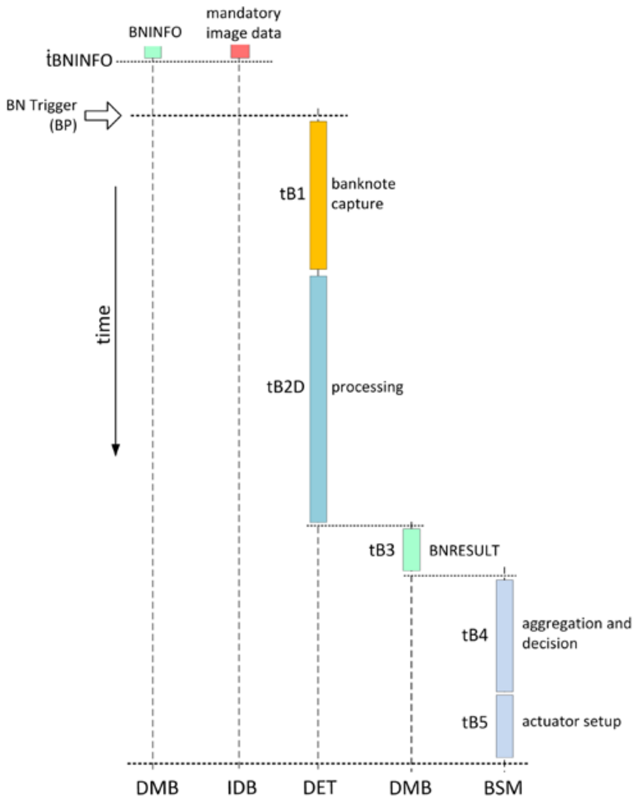


Figure 9: Timing sequence from trigger at the last detector position DET#8 to sorting gate

For the computation of the minimum distance from DET#8 to the sorting gate, the following table lists the times of Figure 9 and gives their worst-case values.

Time	***Description***	***Time duration***
tB1	Banknote capture time (= tMaxBN)	
tB2D	Time for processing	tB1 + tB2D = 220.0 mm / vBN + 20 ms
tB3	BNRESULT transmission time	tB3 = 4 ms
tB4	BSM aggregation and decision time	(BSM dependent)
tB5	BSM sorting gate actuator setup time	(BSM dependent)

Table 7: Worst-case timing calculation for a Detector (last position DET#8 to sorting gate)

Note that tB3 could increase to 16.0 ms, instead of 4.0 ms, if segmented transmission of BNRESULT is used (see 6.7.4.4). In this case, the time budget of the detector for the processing (tB2) has to be reduced accordingly.

As above, the minimum distance between DET#8 and the sorting gate distDET8GATE can be computed as

distDET8GATE = tDET8GATE * vBN

where tDET8GATE is the sum of all times from DET#8 to the sorting gate

tDET8GATE = tB1 + tB2D + tB3 + tB4 + tB5

As an additional case, the timing for an IEU without optional sensor is given in Figure 10. The IEU has all the input for its processing once it has received all image data from the CS as well as the BNINFO from the BSM. As soon as both have arrived, the IEU can carry out its processing (tB2I). The remainder of the timing sequence is identical to a detector (tB3, tB4, tB5, see Figure 9).

At an IEU, the order of BNINFO and all image data is arbitrary. However, if the BNINFO arrives later than all image data, it can be shown that the worst-case time at which this IEU sends its result is in any case earlier than the worst-case time at which the detector in DET#8 sends its result. This is due to the minimum distance between DET#1 (where the BNINFO must already be available before the trigger) and DET#8. This means that this case can be ignored when calculating the minimum distances in a BSM. In the following, therefore, only the case is considered in which the image data arrive later than the BNINFO.

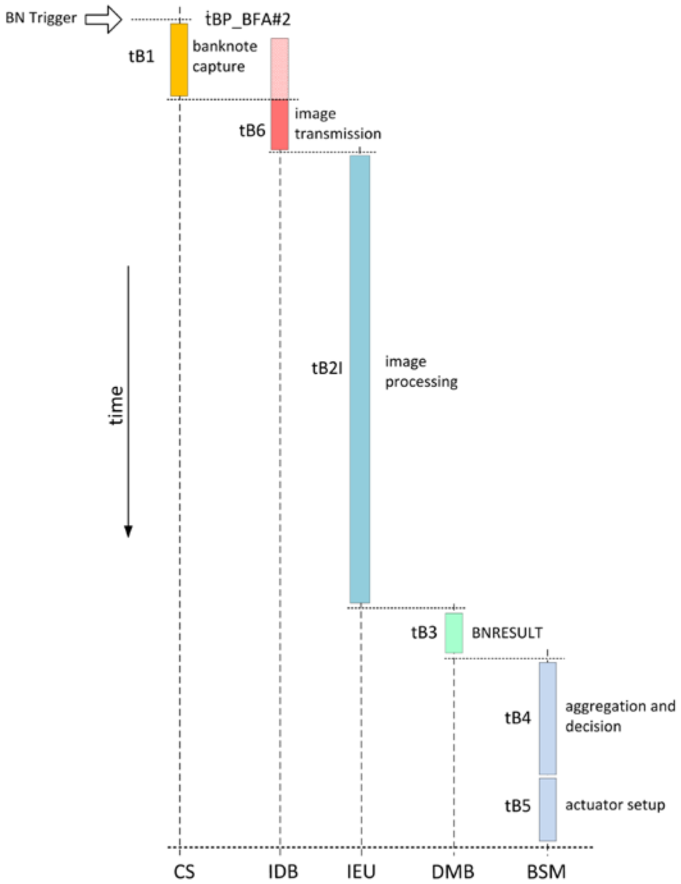


Figure 10: Timing sequence for an IEU from ṫBP_BFA#2 to sorting gate

For the computation of the minimum distance from BFA#2 to the sorting gate, the following table lists the times of Figure 10 and gives their worst-case values.

Time	***Description***	***Time duration***
tB1	Banknote capture time (= tMaxBN)	
tB6	Image transmission time	tB1 + tB6 = 220.0 mm / vBN + 5 ms
tB2I	Time for processing	tB2I = 45 ms
tB3	BNRESULT transmission time	tB3 = 4 ms
tB4	BSM aggregation and decision time	(BSM dependent)
tB5	BSM sorting gate actuator setup time	(BSM dependent)

Table 8: Worst-case timing calculation for an IEU (BFA#2 to sorting gate)

Note that, as above, tB3 could increase to 16.0 ms, instead of 4.0 ms, if segmented transmission of BNRESULT is used (see 6.7.4.4). As above, the time budget of the IEU for the processing (tB2) has then to be reduced accordingly.

With the help of Table 8, the minimum distance between BFA#2 and the sorting gate distBFA2GATE can be computed as

distBFA2GATE = tBFA2GATE * vBN

where tBFA2GATE is the sum of all times from BFA#2 to the sorting gate

tBFA2GATE = tB1 + tB6 + tB2I + tB3 + tB4 + tB5

A special case is an IEU with an optional sensor: Regarding the timing considerations, an IEU with optional sensor is treated as if it were an IEU without optional sensor plus a Detector in the position of the optional sensor. Thus, two timing sequences apply on when the BNRESULT has to be ready. Of the two, the later point in time has to be met by the IEU with optional sensor (see also Table 5).

To conclude this chapter, we give an example for the computation of the minimum distances from BFA#1 to DET#1, from DET#8 to the sorting gate, and from BFA#2 to the sorting gate. For this example, we assume the BSM dependent times to be as follows:

tA4 = 2 ms (delay from BNRECOGNITION to BNINFO)

tB4 = 5 ms (aggregation and decision)

tB5 = 2 ms (sorting gate setup)

With these assumptions, the following worst-case times and minimum distances result depending on the transport speed:

	BFA1DET1		**DET8GATE**		**BFA2GATE**	
vBN (m/sec)	**t (ms)**	**dist (mm)**	**t (ms)**	**dist (mm)**	**t (ms)**	**dist (mm)**
12.5	29.6	370.0	48.6	607.5	78.6	982.5
1.0	232.0	232.0	251.0	251.0	281.0	281.0

Table 9: Worst-case times and minimum distances depending on transport speed

3.3 HTTP Port for Service and Maintenance

Each CDI2 Device shall provide a remote access via the DMB for service and maintenance purposes. For this, a CDI2 Device shall provide a HTTP web server providing a user dialog.

The HTTP communication uses the Internet Protocol (IP) in the asynchronous phase as described in chapter 5.1 of [Ref 3.].

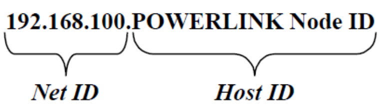
The IP traffic is transported with low priority and does not interfere with the real-time traffic in the POWERLINK synchronous phase. Thus, IP over POWERLINK is available even in the Sorting state of the machine. However, although technically possible on the POWERLINK network, a CDI2 Device does not need to respond to HTTP requests during the Sorting state.

The content of the HTTP server shall comply with the W3C HTML 4.0 standard and shall not rely on specific plugins installed on the web browser.

Basically, the HTTP ports can be accessed by any network device on the TCP/IP network with an internet web browser. As a minimum requirement, the BSM should have such a TCP/IP connection and should provide a web browser, with input devices like mouse and keyboard and supporting a minimum screen resolution of 1024x768 pixels, allowing the operator to access service and maintenance functions of the CDI2 Detectors without the need for any separate equipment like a PC or Laptop. Additionally, the BSM shall provide a network connector for an external computer to access the TCP/IP network as well.

The BSM may implement a network router to allow IP communication between an external network and the POWERLINK network via the external service port. The router shall use the IP address 192.168.100.254. The BSM may use a bridge with layer 2 switch functionality to interface the POWERLINK network to the network router (or directly to the network connector for an external computer).

Any CDI2 device has to support IP communication and use IP addressing as described in chapter 5.1.2 of [Ref 3.]. Specifically, it shall set its Default Gateway to IP address 192.168.100.254 and construct its static IP address depending on the Node ID according to the described scheme as 192.168.100.<POWERLINK Node ID>.



Self-Test, calibration and data up/download are examples for functions to be activated via the HTTP port.

Chapter 6.7.5 gives further information on service and maintenance operations.

3.4 Self-monitoring and Self-test

Each CDI device is expected to monitor itself and report its condition via the Error State in case of internal errors or via the Maintenance state if maintenance actions need to be initiated but do not require an immediate stop of the machine. (See 6.7.4.4 for more details)

The CDI2 device shall carry out more time consuming self-tests, namely an Intensive Self-Test or a Short Self-Test, on the transition to DS_FEED_OFF or DS_READY_TO_SORT, respectively. Chapter 6.7.2 defines maximum durations for these tests. CDI2 devices are required to perform these self-tests within the given time and to update their Maintenance or Error state, respectively.

Furthermore, a CDI2 device can request a self-test via the Maintenance state.

3.5 Software Update

This feature is optional for all CDI2 compliant devices. Any CDI2 device may provide means for remote software update.

A special user (service technician or cash office supervisor) would need to initiate software updates. The update files can be loaded from a USB, SD-Card or even network connection. The validity of the update process shall be verified by the BSM.

See chapter 6.7.6 for more details.

3.6 CDI Version Information

The revision code of the Common Detector Interface 2 (CDI2) Specifications contains two fields, the interface revision and the document revision.

<revision code> := <interface revision><document revision> (e.g. 2.5A)

The interface revision consist of a major and a minor version number

<interface revision> := <major>.<minor> (e.g. 2.5)

The CDIVersion relates to the interface revision with major and minor number.

Incompatible changes are reflected in the minor version number, compatible changes are just reflected in the document revision.

The CDIVersion version number in an xml file has to match the interface version number of the specification document. Each device should report a warning (in the error log) in case it cannot assure to support the CDIVersion version number in the machine info. It shall report an error and enter the error state if it does not support the specific version explicitly.

4 Image Data Bus (IDB)

The Image Data Bus (IDB) provides the images of the various cameras to the BSM and to interested units like an IEU for processing the image and delivering results as aggregated data to BSM. For this the IDB uses a small subset of the so-called GigE Vision interface standard (see [Ref 1.]), which means that IDB devices do not need to be fully compliant with GigE Vision devices.

"The GigE Vision interface standard was launched in 2006 and is administered by the Automated Imaging Association (AIA). AIA is the world's largest machine vision trade group and has more than 330 members from 32 countries, including system integrators, camera, lighting and other vision components manufacturers, vision software providers, OEMs and distributors. As the name GigE Vision implies, it is based on the internet protocol standard. In 2011 GigE Vision 2.0 was launched which included support for a 10 Gbps physical layer. GigE Vision over 10 GigE, often called 10 GigE Vision, is the next generation of the GigE Vision interface standard. It offers higher speed data rate transfer - 10 Gbps per single cable. 10 GigE Vision uses Ethernet-based connection infrastructure and supports long cable lengths and concurrent image streaming during image acquisition.
10 GigE is an industry standard, which has been around for years and is managed/produced by the IEEE 802.3 working group. The standard is used in applications such as telecom, data communications, industrial, military, etc. and now we leverage the benefits of this globally accepted cross-industry technology for machine vision applications."

A GigE Vision accessory program titled “Certified to Use in GigE Vision Systems” exists to allow the registration of products that have been designed to supplement GigE Vision products, but are not implementing the full GigE Vision standard.

The maximum bandwidth available for 10 GigE is 10 Gbps or 1,250 Mbytes/s. The usable bandwidth is around 9.5 Gbps or 1,180 Mbytes/s.

The CS must ensure that the IDB utilises no more than 80% of the maximum bandwidth.

4.1 Image data

The CS is responsible to set all parameters of the mandatory and special image data correctly. These parameters are set during the initialisation phase over the DMB.

The image data needs to be linked to a BNID to allow the alignment of subsequent results to the correct BN. The CS is triggered by the BSM (using the BP signal of the TTS or the DIST information of the DMB) along with a unique BNID sent to the CS via the DMB. This BNID needs to be administrated by the BSM as it shall be the same as used for CDI1 and other detectors.

One image data set consists of a group of up to 256 images for each banknote and cannot exceed the GigE bandwidth. Each image data set is sent together with the BNID previously received from the transport system via the DMB.

The mandatory image data consists of R, G, B and IR images from each side of the BN. The horizontal and vertical resolution is 0.2 mm and the pixel format is 8 Bit. The R, G, B and IR camera images must be grabbed at least at 0.2 mm in full resolution (if colour filter arrays like Bayer mosaic are used, a higher resolution than 0.2 mm will be required).

The size of a mandatory image must be sufficient to contain the entire banknote, including a margin required for processing the image. This margin shall be 1 mm on each side of the image (top, bottom, left, right). For the image width, the area in which the entire banknote will appear is given in chapter 7.5, resulting in a minimum width of 97 mm (= 95 + 1 + 1). For the image height, a banknote with a length of 160 mm shall be captured, taking into account all tolerances and the above margin. Considering the jitter of the BP signal (+/- 2 mm) and assuming a maximum skew of the small banknote side of 8 mm for a maximum rotation of 5°, this results in a minimum image height of 174 mm (= 160 + 4 + 8 + 1 + 1). The maximum size of the mandatory images shall be 102.4 x 204.8 mm (= 512 x 1024 pixels).

If the image pre-processing algorithms inside the CS need a calibration procedure to fulfil the image quality parameters (see Table 11) it must be provided by the CS (see section 6.7). The BSM shall allow the sorting of test charts to support such a calibration procedure.

The CS is not allowed to apply any image processing algorithms on the mandatory images provided to the IDB, which would have a negative impact, so that the image quality gets worse than the current state of the art.

The mandatory image data is always transferred uncompressed over the IDB (payload type = 0x001). Special image data is allowed to use all payload types defined in GigE Vision.

For mandatory images with a line width of up to 512 pixels, the data payload of one line has a maximum of 512 bytes. The image sender shall collect 16 lines of image data and pack the payload into one UDP packet, with the exception for residual lines at the end of an image. In this case the UDP packet may contain less than 16 lines.

The IDB network shall allow jumbo frames with an MTU (Maximum Transmission Unit) size of 9000 bytes. Thus, the 10 GigE Switch has to support such jumbo frames >= 9000 bytes as well. For details on the GigE Vision packet format, see 4.3.1.

The orientation of the images sent on the IDB depends on a number of factors. First, since the CS uses line scan cameras, a banknote will appear in portrait rather than in landscape mode in the image streams on the IDB. Furthermore, the appearance depends on the direction the banknotes are fed, i.e. if they are fed into the transport to the right or to the left. The following figure shows this for a banknote seen by the operator with Orientation=1 (front side, face forward, see Table 33).

Figure 11: Feeding directions of banknotes

The following table shows which casing of the CS sees which side of the banknote and with which orientation, depending on the Operator View (see Table 33) and the feeding direction.

Orientation	Operator View	Image on IDB			
		Feeding to the right		Feeding to the left	
		left casing	right casing	left casing	right casing
1					
2					
3					
4					

Table 10: Image orientation on IDB for left and right casing of a CS depending on Operator View and feeding direction

Note that the CS has to ensure that the images on the IDB display a banknote only rotated, but not mirrored horizontally. The feeding direction is known to a CDI2 Device (see Machine Info, chapter 6.7.3.1), and the Orientation code for an inspected banknote is provided in the BNRECOGNITION information. With this information an IEU knows which side of the banknote is seen in which orientation in the left and right casings of the CS (see table above) and must adjust its processing accordingly.

4.2 Image Quality

The following minimum requirements for the mandatory image data quality must be complied to by the CS. The limits are based on a spatial resolution of 0.2 mm in the object plane and 8-bit digital resolution of image data. Full scale (FS) is assumed as 255 digital numbers (DN). All parameters have to be reached taking a flutter of 0…2 mm into account, as specified in chapter 7.2

For measurement purposes, it is necessary to acquire specific test charts. These test charts are provided by the ECB and the FRB for verifying CDI2 compatibility. Images of the test charts are acquired either with the conveyor belt in motion (moving) or with stopped conveyor belt (stopped). As a prerequisite, the system under test has to be already calibrated.

For some acquisitions, the CS must provide an operating mode which allows image acquisition with lights turned off. The activation of this mode shall be possible via the HTTP Port for Service and Maintenance (see 3.3).

CDI2 specific test charts can be found in chapter 4.2.2.

4.2.1 Minimum Requirements

The Modulation Transfer Function (MTF) is specified in line pairs per millimetre (LP/mm) in the object plane. Note that for 0.2 mm spatial resolution, the Nyquist frequency is equal to 2.5 LP/mm.

To test the robustness of the CS against Moiré effects, which are understood as sampling artefacts or aliasing effects, a test with a zone plate pattern is defined. The zone plate pattern consists of concentric black/white ring structures with increasing line frequency and is part of test chart A. This pattern contains a continuous spectrum of line frequencies and line directions with the intention to cover the set of possible stripe patterns occurring on bank notes as good as possible. The criterion is that during a visual check of the image of the acquired zone plate pattern on a computer monitor with high enough zoom factor, Moiré artefacts must not disturb.

Colour linearity error (CLE) of the CS is tested with a calibrated IT8.7/2 colour test chart, i.e. reference colour values for all colour patches are available and are individual per test chart. On each test chart a test chart ID is printed as reference (per test chart or per test chart lot). The term “colour linearity” stresses that in the context of fitness checking of banknotes, linearity is more important than colour accuracy in the sense of some colour metric. I.e. – within certain limits - the multiplication of the sensor output signal with a 3x3 colour transformation matrix is allowed and shall not influence the definition of colour linearity. The CLE is defined as residual error when least square fitting the vector of measured colour values to the vector of reference colour values by allowing the multiplication with a 3x3 matrix as degrees of freedom for the fitting, but with the constraint that the 3x3 matrix preserves white or grey colour values as white or grey (9 matrix coefficients cannot be chosen arbitrarily because the sum of the coefficients of each row of the matrix must be 1. I.e. 6 degrees of freedom). For details refer to section 4.2.3.

To ensure proper weighting of the light incident to the camera, the spectral response of the camera output (R, G, B, IR) in the range of 400 nm to 1000 nm has to satisfy some requirements. The intention is, to limit VIS-IR cross-talk and to ensure that there is no permutation in the ordering of colour channels. For wavelength interval 400 … 1000 nm the following limits for the spectral responses of red-, green-, and blue-sensitive pixels are defined:

In the test images of test chart C, the average signals of the red, green and blue colour patches L17, L18, and L19 are calculated. In patch L17, the red colour channel has to be dominant (largest value), in patch L18 the green colour channel has to be dominant and in patch L19 the blue channel has to be dominant. Leaking between R, G, B channels is checked by the colour linearity criterion. Finally leaking between IR and RGB signal has to be checked by using a special reflective test chart D with patches filtering out the visible or the infrared spectral band or both. As currently no such test chart D is available, the properties of the CS can be tested by an equivalent test method, e.g. with an external white and IR test illumination that can be switched on alternatively or using a white paper in conjunction with long-pass and short pass filters. Which test method fits best depends on the type of illumination and image sensor of the CS. The decision is up to the manufacturer of the CS.

The hypothetical VIS-IR-cross-talk test chart D consists of four patches. The first patch is made of white material reflective for visible and infrared light. The second patch is additionally coated with a 750 nm short-pass filter (only visible spectral band is reflected). The third patch is coated with an 800 nm long-pass filter (only IR spectral band is reflected). The fourth patch is coated with both filters and is used to check the test chart itself: IR reflectance of the fourth patch must match that of the third (long-pass) patch to within 0.1%, and the visible reflectance of the fourth patch must match that of the second (short-pass) patch to within 0.1%. Overall reflectance of the fourth patch must be less than 10%.

Then for a calibrated CS (brightness criterion for RGB and IR image of first patch is important), VIS-IR-cross-talk has to be less than 0.5% of the signal (less than 1 DN). This means that the RGB images of the third and fourth patches must differ by less than 1 DN, and the IR images of the second and fourth patches must also differ by less than 1 DN.

Distortion test addresses the absolute distance measurement accuracy. Note that the quality of line trigger signal generated by the BSM and CS imprecision must be checked in advance. This is necessary because the defined y-distortion summarises line trigger inaccuracy of BSM, imprecision of the CS and mechanical transport inaccuracy of BSM. The intention is to ensure that the CS is not less accurate than the BSM. Details are specified below with the description of the dot pattern of test chart A.

Non-Uniformity comprises Dark Signal Non-Uniformity (DSNU), Photo Response Non-Uniformity (PRNU) and shading effects. Ideally, the image of an ideally homogeneous white paper should have homogeneous brightness. The evaluation is done in the sense of EMVA1288 Working Group, "EMVA1288 Standard – Standard for Characterisation of Image Sensors and Cameras," rel. 3.0, European Machine Vision Association (2010). http://www.emva.org
Non-uniformity is calculated based on acquired image of the white part of test chart B, when light is turned off. Column-wise averaging of pixel values averages out the temporal noise and the structure of the white part of test chart B (slight variations in reflectivity). Thus, DSNR and PRNU describe pixel to pixel variations of the column-wise averaged dark and white images.

Signal to Noise Ratio (SNR): The ratio of the camera signal of the acquired white test chart to the temporal noise of the acquired white test chart is evaluated in the sensor of EMVA1288 Working Group, "EMVA1288 Standard – Standard for Characterisation of Image Sensors and Cameras," rel. 3.0, European Machine Vision Association (2010). http://www.emva.org
To suppress the influence of the slight non-uniformity of reflectivity of the white test chart, the white test chart is acquired stationary, i.e. belts of BSM stopped. Then line-to-line fluctuations in the camera signal describe the temporal noise while the mean of the camera signal describes the signal value. According to EMVA1288 specification, two images, A and B, have to be acquired within few seconds. The signal S(white reference) is calculated as the arithmetic mean over all pixels of A with unit DN, the noise variance is half of the variance of the pixel-wise difference image A-B. The root mean square noise N(white reference) with unit [DN rms] is calculated as square root of the variance. Finally, the SNR_{max} is calculated by the following formula (the index “max” stresses that due to the shot noise term included in the above definition of noise, in real images of banknote parts with reflectivity less than the white test chart local SNR values can be significantly lower).

$$\mathrm{SNR}_{\mathrm{max}}[dB] = 20\log\left(\frac{S(\text{white reference})}{N(\text{white reference})}\right)$$

Equivalently, the dynamic range, DR, is defined as ratio of white signal, S(white reference) in [DN], and dark temporal noise, N(lights off) in [DN rms], as follows:

$$DR[dB] = 20\log\left(\frac{S(\text{white reference})}{N(\text{lights off})}\right)$$

Darkness test measures the absolute black level, when illumination of the CS is turned off.

The influence of stray light in the CS is tested by measuring the differences in black level between black parts of the test chart B and the black level measured with darkness test, when light is turned off.

Stray-light is tested using test chart B. The influence of stray light on the camera signal in the black regions of test chart B (Stray Light 1) and outside test chart B (Stray Light 2) is evaluated. Stray light can have many causes, important examples are: reflection of light by machine parts (direct light from illumination or reflected light from banknote depending on reflectivity pattern on banknote), imperfect anti-reflective coating of lenses, dust in the optical path. Note that dust is a separate issue. For dust conformity, please refer to the respective parts of the specification (see 7.8.6).

Brightness test measures absolute accuracy of brightness values using the white parts of test chart B as white reference. Limits in table 11 are preliminary and may be adjusted (depends on reflectivity of white reference relative to the whitest possible banknote). Note that the brightness limits specify CDI2 compatibility for an acceptance test. The accuracy of fitness checking will be far better due to frequent calibration of the system.

Parameter	Min.	Max.	Test chart	Remarks
Linearity		+/- 0.5 % FS	Special test equipment with calibrated photodiode	Provide Camera datasheet
MTF(1 LP/mm)	0.7		A, moving	
MTF(2 LP/mm)	0.4		A, moving	
Moiré		do not disturb visual impression	A, moving	Visual check of image of acquired zone plate pattern with high enough zoom factor
Colour Linearity Error (CLE)	0	25 DN	C, moving	See definition of CLE in the text below
Colour Order			C, moving	In image of colour patches L17, L18, L19 the correct colour channel must be dominant
VIS-IR Cross-Talk		1 DN	Test equivalent to a hypothetical test chart D	
Spectral Responsivity	Refer to text	Refer to text	test equipment with tuneable monochromatic light source	Provide Camera data sheet with spectral responsivity curves in range 400 nm-1000 nm
x-Distortion (line direction)	0	0.5 mm	A, moving	Important for length measurements
y-Distortion (transport direction)	0	0.5 mm	A, moving	Important for length measurements
Non-uniformity		+/- 0.5 % FS	B, moving	
Signal to Noise (SNRmax)	40 dB		B, stopped	Ratio signal to temporal noise in bright image parts
Dynamic Range (DR)	50 dB		B, stopped and light turned off	Ratio signal in bright image parts to temporal dark noise
Darkness	1 DN	5 DN	B, stopped or moving, light turned off	Measurement of dark signal level
Stray Light 1	0	20 DN	B, moving	Signal for black regions of test chart B
Stray Light 2	0	10 DN	B, moving	signal outside test chart B
Brightness	195 DN	205 DN	B, moving	

Table 11: Image quality parameters

Test chart A: reflective test chart comprising dot pattern, zone plate pattern and black/white stripe patterns with different line frequencies and line orientations (one-sided, structures are functional also with IR light)

Test chart B: black/white reference paper serving as white reference and for stray light test (one-sided, structures are functional also with IR light)

Test chart C: IT8.7/2 calibrated reflective colour test chart, e.g. vendor LaserSoft Imaging AG, Luisenweg 6-8, 24105 Kiel, Germany, http://www.silverfast.com/show/it8-targets/de.html.

4.2.2 Test charts

Test chart A is composed of the four components: Dot pattern, black-and-white stripe patterns with different line frequencies and orientations, black-and-white reference patches p10, p20 and a zone plate pattern (a concentric black-and-white ring structure with increasing line frequency). The dot pattern is used to check distance inaccuracy and distortions by comparing dot positions in the acquired image with reference dot positions. Reference dot positions are known from definition of test chart A. Measured dot positions are extracted as centre of gravity of the dots. After least square fitting the reference dot pattern into the measured dot pattern by allowing geometrical shift and rotation operations, the residual position errors of the dots are used to define a measure of distortion. The x-distortion is defined as 95% quantile of residual position errors in line direction. The y-distortion is defined as 95% quantile of residual position errors in transport direction. For example, an x-Distortion of 0.5 mm means that 95% of the measured dots have a residual error in line direction less than +/- 0.5 mm.

With the dot patterns, also the mutual alignment of the four mandatory channels R, G, B and IR can be checked.

The black/white stripe patterns are used to check MTF and Moiré properties. There are stripes oriented in transport direction and stripes oriented in line direction with spatial frequencies 0.5, 0.7, 1.0, 1.4, 2.0, 2.8 and 4.0 LP/mm. Contrast can be measured using the formula MTF = $(I_{max} – I_{min}) / (I_{white} – I_{black})$ with I_{max} and I_{min} denoting the maximum and minimum brightness within a colour patch, and I_{black}, I_{white} denoting the brightness of black and white reference patches p10 and p20. Note that the above MTF definition is robust against changes in print contrast ratio of black and white structures because of normalising to brightness difference between the large black and white patches p10 and p20.

Test chart A is used with visible and near infrared (IR) light. Spectral range of IR is understood as near infrared with 800 – 1000 nm wavelength. For IR case, the black and white structures are used. Therefore, stripe patterns, dot patterns, black, grey and white patches and Test chart ID have to be functional also in IR. Black and white patches have also to be calibrated in IR.

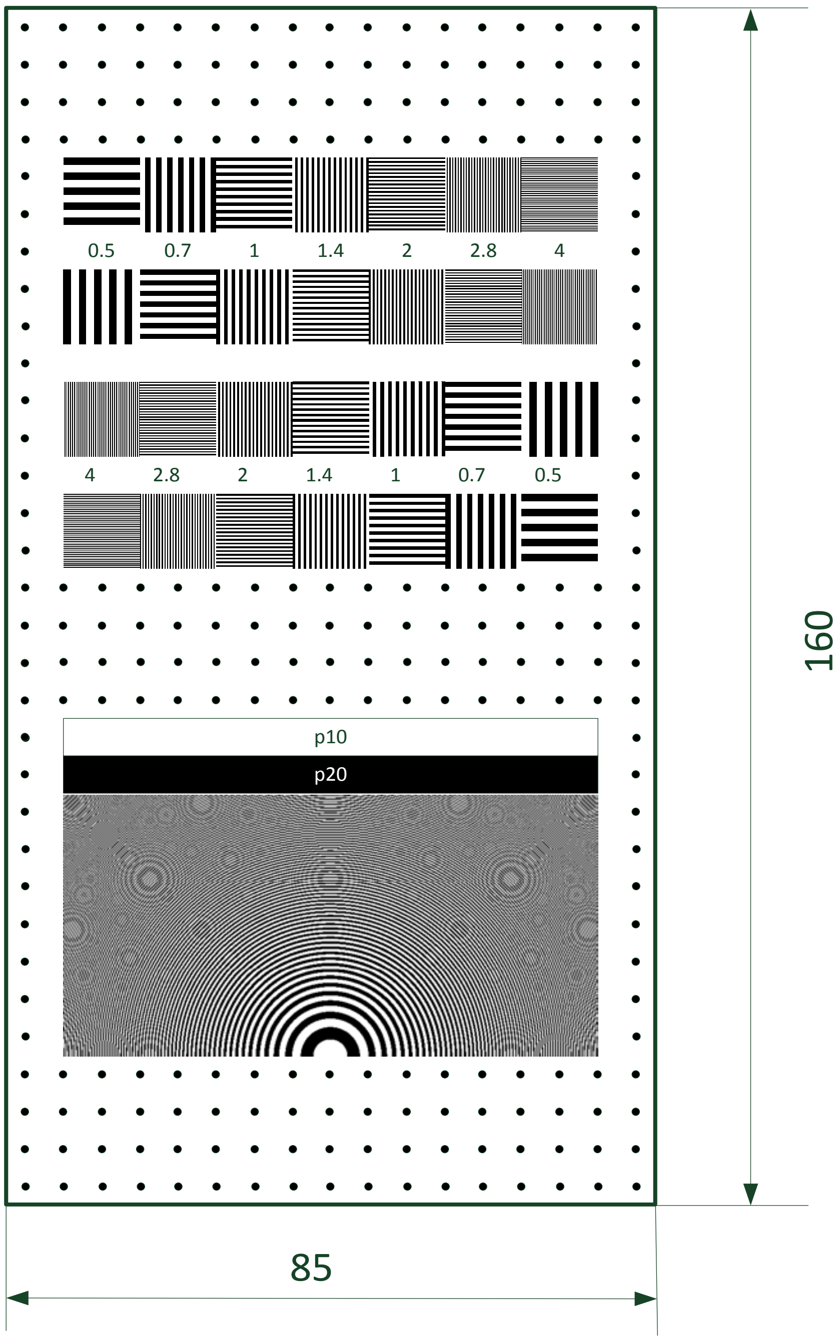


Figure 12: Test chart A to check MTF, Moiré, and Distortion. Not in scale. 70 mm x 35 mm Ring pattern (zone plate pattern) may not be correctly reproduced in this document due to artefacts of monitor or printing. Frequencies of ring pattern rising with 0.2 LP/mm per mm distance from centre (thus 7 LP/mm at distance 35 mm). Dimensions in mm. Dots are circles with 1 mm diameter. Centre to centre distance 5 mm. Dot centre distance to boundary 2.5 mm. Numbers in colour patches are not printed and serve as reference. Dot patterns, line patterns and black patches have to be absorbing also with IR light.

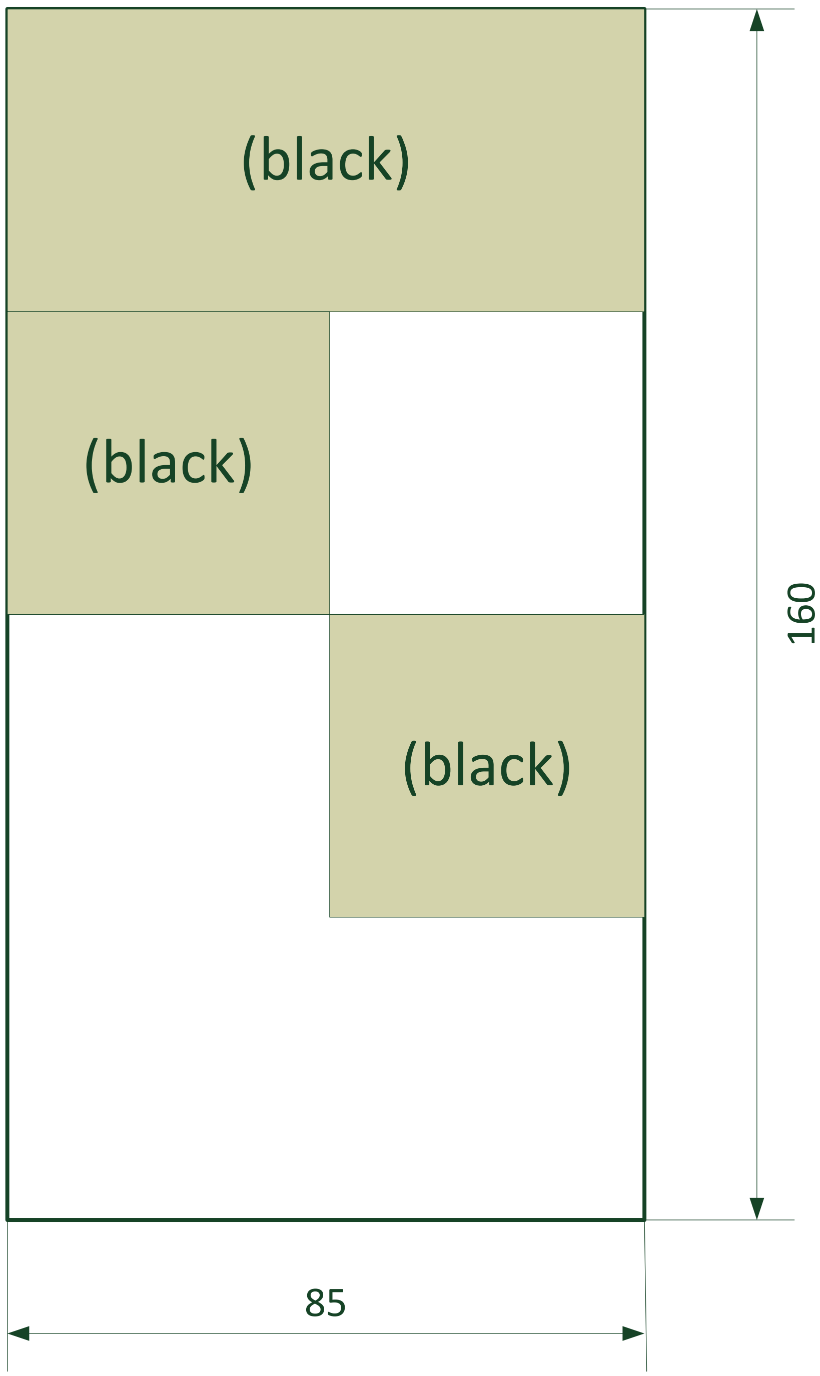


Figure 13: Test chart B - Black / White Reference Paper. Dimensions in mm.

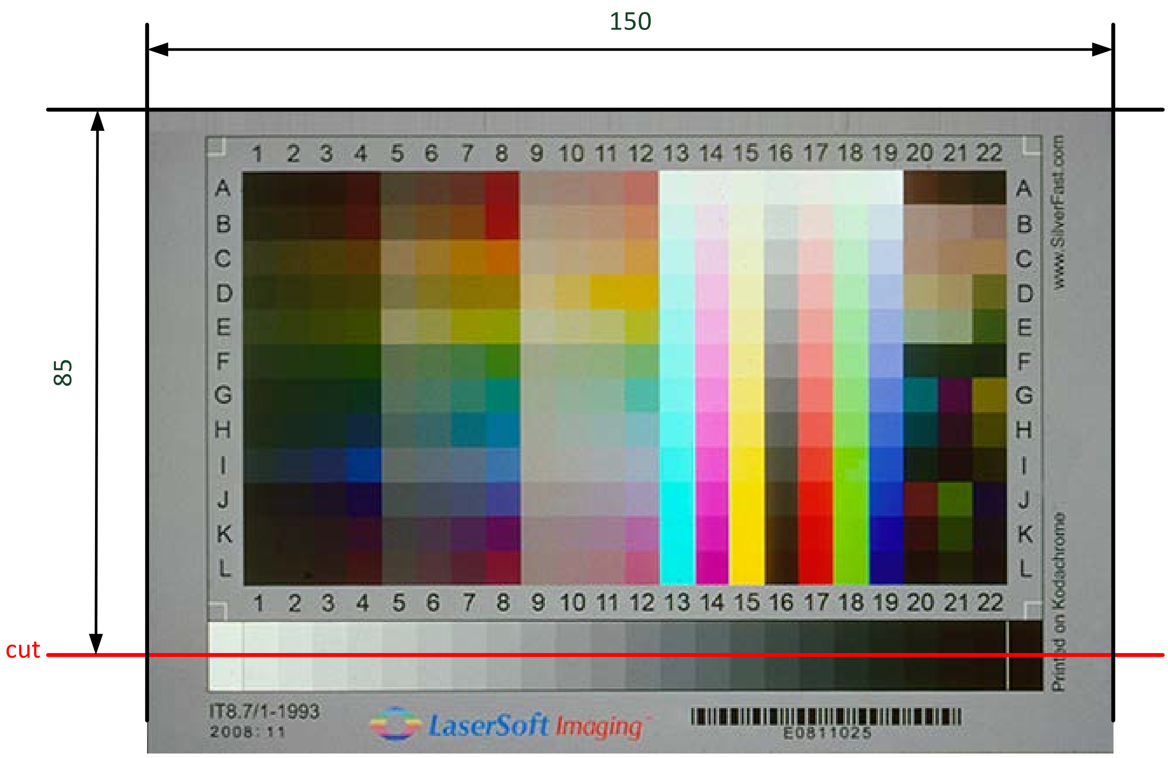


Figure 14: Test chart C: IT8.7/2 reflective test chart for colour calibration and test of colour linearity error, format 150 x 100 mm, cut to 150 x 85 mm.

Important note for cutting the test chart C: Since the batch number (the number under the barcode at the bottom right) is cut away, it must be written down on the right edge of the trimmed test chart. The calibration data is only valid for the respective charge.

4.2.3 Calculation of Colour Linearity Error (CLE)

The calculation of the CLE requires the acquired test image of the IT8.7 test chart C together with reference colour values of the colour patches of the test chart. For commercially available IT8.7 charts, reference colour values are provided by the colour chart vendor for the n colour patches, comprising also the grey scale patches. In this context, camera signal means the camera output signal after subtraction of the dark offset.

With S_{meas} denoting an $n \times 3$ matrix of the n measured camera signal vectors $(X_{i,\text{meas}}, Y_{i,\text{meas}}, Z_{i,\text{meas}})$, with $i = 1 \dots n$ and S_{ref} denoting an $n \times 3$ matrix of the n reference colour values$(X_{i,\text{ref}}, Y_{i,\text{ref}}, Z_{i,\text{ref}})$, a least square fit minimises the quadratic sum of the elements of the residual matrix

$$RES = S_{\text{meas}} M^T - S_{\text{ref}}$$

In other words, the expression

$$\text{CLE} = \sqrt{\frac{1}{3n} \sum_{(i,j)=(1,1)}^{(n,3)} \left(RES_{i,j}\right)^2}$$

has to be minimised. The 9 coefficients of the 3×3 matrix M are the optimisation parameters of the least square fit minimising CLE. In this sense, the matrix M is the optimum colour transformation mapping of the measured colour values into the reference colour values.

Finally, the residual error, CLE defines a measure of the colour linearity error in units DN.

4.3 Software Protocol

GigE Vision has four main elements:

- GigE Vision Stream Protocol (GVSP)
  - o Only this streaming part of GigE Vision is used in CDI2.
- GigE Vision Control Protocol (GVCP)
  - o Not used in CDI2 because all information is transferred via the DMB.
- GigE Device Discovery Mechanism
  - o Not used in CDI2 because all configuration is done via the DMB.
- Machine Vision Association's GenICam standard
  - o Not used in CDI2 because the CS has strict recommendations given by CDI2.

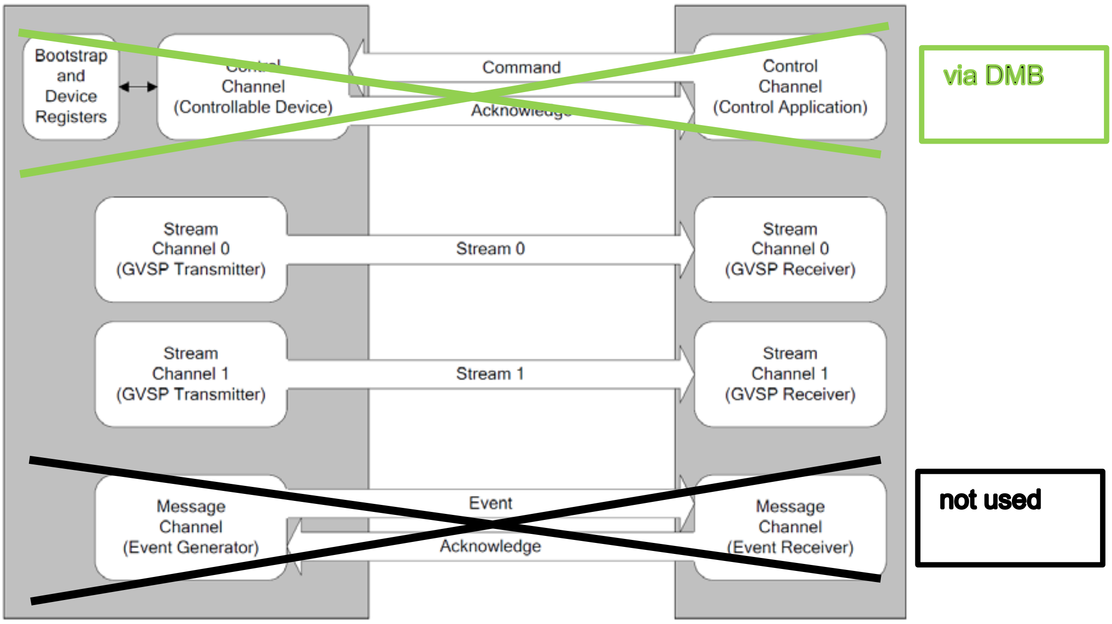


Figure 15: Use of GigE Vision channels

The real-time critical parts of CDI2 are being sent over TTS (triggers and transport clock) and DMB (BNID, BNINFO, BNRESULT). The IDB only needs to guarantee a maximum latency. To simplify the hardware IDB does therefore not make use of IEEE 1588 part of GigE Vision.

For reference, see GigE Vision specification [Ref 1.].

4.3.1 GigE Vision Stream Protocol (GVSP)

The GigE Vision standard uses UDP packets to stream image data of all cameras from the CDI2 Camera System to the CDI2 IEUs and the BSM. Figure 16 depicts a UDP packet with GVSP payload. The packet consists of an Ethernet Header followed by IP Header, UDP Header, UDP payload and Ethernet CRC as last item. The UDP payload carries the actual GVSP data, which can be either a Data Leader, a Data Payload or a Data Trailer packet.

For reference, see Part 3 of GigE Vision specification [Ref 1.].

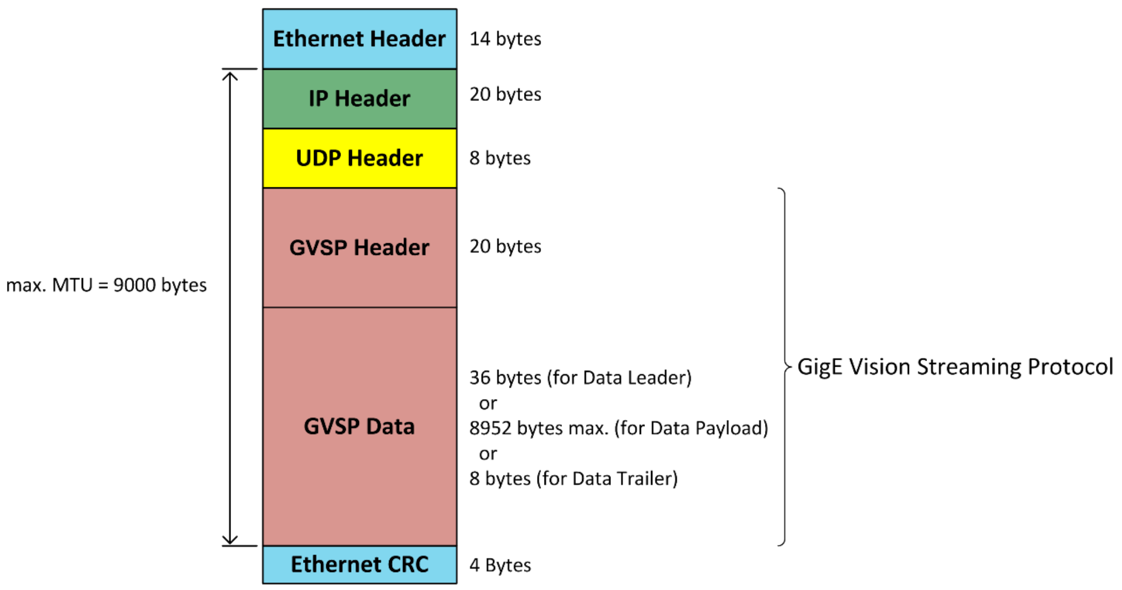


Figure 16: A GVSP UDP packet

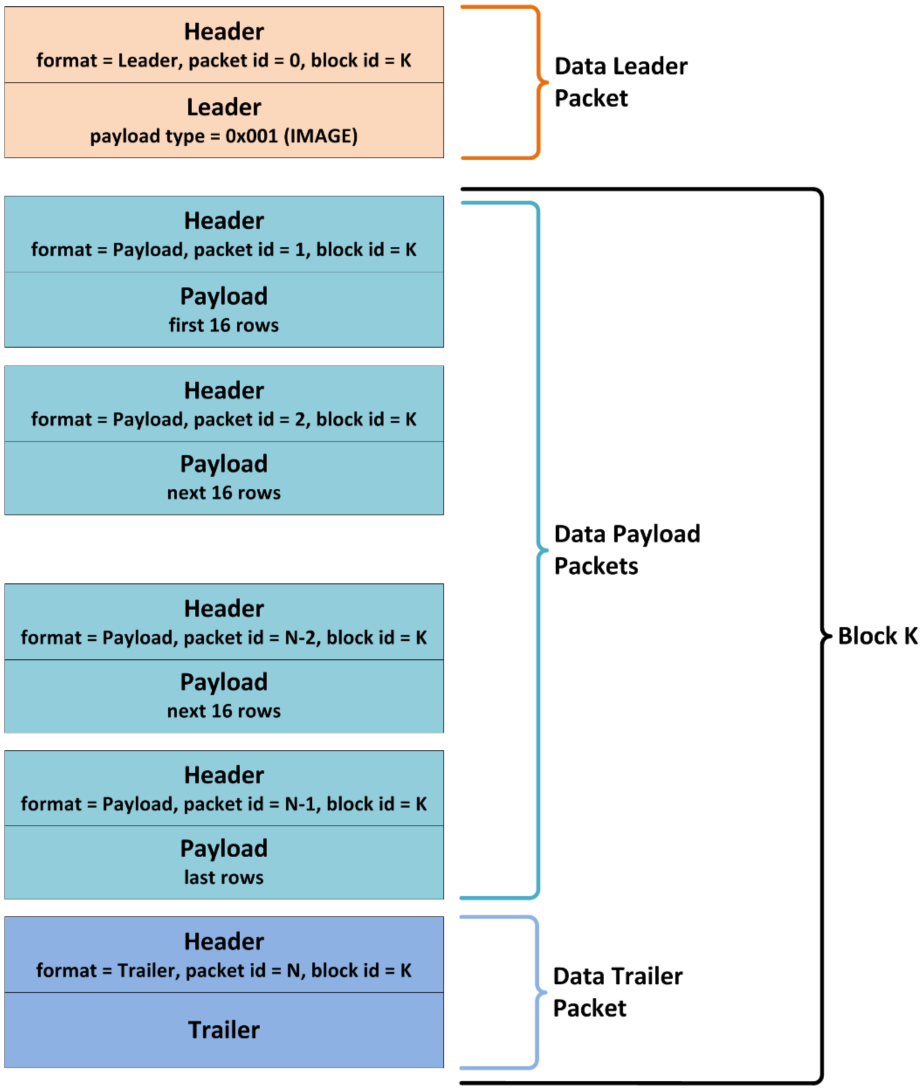


Figure 17: GVSP packetise and transmit data

Figure 17 depicts how GVSP is used to pack mandatory image data into a series of UDP frames to be transmitted on the network. All data of one image is encapsulated into a so-called block, with a block number assigned to it. The sequence starts with a Data Leader which defines the payload type (= 0x001) and the size of the image to be transmitted. The Data Leader is followed by a series of Data Payload packets, each having a unique packet id which is incremented for each packet. For mandatory images the payload shall hold 16 lines. Just the last payload packet can carry less lines, to transmit the residual lines at the end of the image. Finally, the block is terminated by a Data Trailer packet.

4.3.2 Packet loss and resends

Since image data packets are streamed using the UDP protocol, there is no protocol level handshaking to guarantee packet delivery. Therefore, the GigE Vision standard implements a packet recovery process to ensure that images have no missing data. This packet recovery implementation is not used in CDI2.

Out of order frames are not allowed on IDB.

The GigE Vision header, which is part of the UDP packet, contains the image number, packet number, and timestamp. If any IEU detects a missing packet, the IEU has to send a specific Result Code in the BNRESULT message over the DMB to the BSM. The BSM itself has to reject this banknote. Because of the very high data rates in 10 GigE, the expected number of missing packets is up to two packets in 24 hours when using the maximum bandwidth.

4.3.3 Multicasting and Unconditional Streaming

The mandatory and special image data shall be sent to one or multiple IEUs using IP multicast addressing, with the multicast group set to 239.205.18.1.

All streams are unconditional to make sure that all simultaneous IEUs can continue receiving image data no matter what happens to other Detector(s) or with the state of the network (e.g. ICMP destination unreachable). That means, all image channels from the CS will continue streaming as long as dictated by the BSM.

4.3.4 CDI2 GVSP Packet Headers

All GVSP packets share the same header. Because the GVSP protocol does not include a length field, the receivers must use the UDP length information to determine the packet size.

0		7	8	15	16	23	24	31
Status					reserved		channel number	
EI=1	res	format	reserved					
0								
BNID								
packet_id32								
…								

Table 12: Generic CDI2 GVSP header

As defined in Part 3 of GigE Vision specification [Ref 1.], chapter 24.2. “Data Block Packet Header”, the Extended ID is always set to 1. So, the generic GVSP header for CDI2 looks like:

CDI2 GVSP PACKET HEADER		
status	16 bits	Status of streaming operation
channel number	8 bits	Stream channel number (device specific in GigE Vision specification)
EI	1 bit	Mandatory set to 1
format	4 bits	1: DATA_LEADER_FORMAT 2: DATA_TRAILER_FORMAT 3: DATA_PAYLOAD_FORMAT 4: ALL_IN_FORMAT (not allowed for mandatory image data) 5: H.264 (not allowed for mandatory image data) 6: Multi-zone Image (not allowed for mandatory image data) all others: reserved
BNID	32 bits	unique BNID number (N.B.: this is different to the GigE Vision specification which specifies a block_id here)
packet_id	32 bits	ID of packet in the block. Reset to 0 at start of each block.

Table 13: Bits of generic GVSP header

4.3.5 Setup and streams

The CS acts as the GVSP transmitter and all IEUs act as GVSP receivers. For each image type, the CS opens a stream channel. Because IDB does not make use of the control and message channel, the BSM is responsible to provide proper configuration information via the DMB at the CDI2 configuration phase (see 6.6.3). The device configuration of a CS or IEU contains properties for IP Address, resolution, image size and IDB stream number (see 6.7.3.2 and 6.7.3.4), so that the CS can initialise all its IDB streaming channels and an IEU can setup its receiver. Once a CS has initialised its stream channels it is ready to capture images. An actual image capture is triggered after the CDI2 System enters the SORTING state and the BP signal or the BNID information of the BSMINFO message indicates a banknote passing the CS camera (see 3.1.3).

The streaming channels for the mandatory image data are set to numbers 0 to 7. Each special image data streaming channel must use the next free incremented number.

Stream Channel #	UDP Port(s)	Image Type	Pixel format	Remarks
0	49152	R left	MONO 8	mandatory
1	49153	G left	MONO 8	mandatory
2	49154	B left	MONO 8	mandatory
3	49155	IR left	MONO 8	mandatory
4	49156	R right	MONO 8	mandatory
5	49157	G right	MONO 8	mandatory
6	49158	B right	MONO 8	mandatory
7	49159	IR right	MONO 8	mandatory
8-255	49160-49407	special image	device specific	optional

Table 14: Stream channels

Channels	#	8 (R_{left} G_{left} B_{left} IR_{left} R_{right} G_{right} B_{right} IR_{right})
Width	mm	96
Length	mm	186
Resolution	mm	0.2
Width	# Pixel	480
Length	# Pixel	930
Pixels / Channel	# Pixel	446,400
Bits / Pixel	#	8
Data / BN	Kbyte	3,487.5
Data / s (at 50 BN/s)	Mbyte / s	170.29
Data / 1 Mio BN	Mbyte	3,405,761
Free for special image data	Mbyte / s	~1000

Table 15: Example IDB data rates of mandatory image data

		HiRes Window	Hi-Dynamic	HiDyn. LowRes	StdRes 0.2 mm	HiRes 0.15 mm	HiRes 0.1 mm
Resolution	mm	0.1	0.2	0.5	0.2	0.15	0.1
Width	mm	20	96	96	96	96	96
Length	mm	60	186	186	186	186	186
Pixels	# Pixel	120,000	446,400	71,424	446,400	793,600	1,785,600
Bits/Pixel	#	8	16	16	8	8	8
Data/BN	Kbyte	117.2	871.9	139.5	435.9	775.0	1743.8
Data/s (at 50BN/s)	Mbyte/s	5.72	42.57	6.81	21.29	37.84	85.14
Data / 1Mio BN	Mbyte	114,441	851,440	136,230	425,720	756,836	1,702,881

Table 16: Example IDB data rates of different special image data

4.3.6 IP Address

The IP address must use the subnet (192.168.101.xxx) and it must use the POWERLINK Node ID for the host address as shown in the following example:

192.168.101.<POWERLINK Node ID>

4.4 Debug Features

A CS shall provide features for testing and debugging of the IDB. For this purpose, the CS must be able to generate test images. The images shall have the same size and format as the real captured ones. The image data for 10 test images per stream shall be preloaded to the CS via the HTTP service port. Further parametrisation and control of the test modes shall happen through the HTTP service port as well. The detailed implementation of the specific dialogs is up to the manufacturer of the CS. In the test mode, the CS shall stream the 10 images to the IDB one after the other and then repeat the sequence in a loop. The number of loop iterations shall be configurable.

4.5 Electronics

4.5.1 10 GigE Switch

One 10 GigE Switch is part of the BSM. So, it has to be built-in inside and powered by the BSM. Resetting the switch (via hardware or software) is not allowed during BSM operation.

The IDB switch shall be in a dust protected area. Therefore, standard RJ-45 connectors can be used.

Name	Requirement
Protocol	IEEE 802.3 MAC Layer
Physical Transmission	IEEE 802.3i 10GBASE-T IEEE 802.3ae 10-Gigabit Ethernet
Bitrate of each port	10 Gbit/sec
Number of free RJ-45 Ports	min. 8
Line Reach of RJ-45 Ports	min. 15 m
Number of SFP+ Ports	optional, preferred for long distance IEUs with >100m
Line Reach of SFP+ Ports	min. 200m
Jumbo frame support	mandatory, min. 9K packet size
Link Aggregation	optional, preferred for future speed enhancements

Table 17: Requirements of 10 GigE switch

Example of a compliant switch:

Figure 18: Netgear ProSAFE XS712T

4.6 Connectors/Cables

The connectors and cables must be rugged and suitable for an industrial environment. There is a range of 10 GigE interconnect options, including 10GBASE-SR (short-reach fibre optic), enhanced small form factor pluggable (SFP+), direct-attach copper (DAC), and 10GBASE-T. Out of these options only 10GBASE-T fulfils the industrial requirements and components (e.g. Ethernet switches) are widely available.

Defined by IEEE 802.3, an 10GBASE-T is the most recent version of the BASE-T (commonly referred to as “twisted-pair” Ethernet) networking standard. 10GBASE-T uses Cat-6_A or higher balanced twisted-pair copper cabling for a maximum reach of 100 meters. The connectors and cables must conform to the ISO/IEC-standard 11801:2002 Amendment 2 (components: Cat-6_A, channel: Class E_A) and use shielding (U/FTP or F/UTP).

In non-industrial applications, 10GBASE-T uses the same RJ-45 physical interface found in all existing BASE-T networks for backward compatibility.

M12 X-coded is the de facto standard for industrial 10 GigE and will be used as IDB connector at the sensor side as long as the Camera System Casing is directly connected to the IDB. If the IDB connection is established within the “Storage Rack for External Evaluation Units” (see chapter 7.7) standard RJ-45 connectors can be used.

All IDB cables must be performance certified as specified in the ANSI/TIA/EIA-568-B.1 and the ISO/IEC 11801 standard. The installation of all IDB cables must conform to TSB-155 and ISO/IEC 24750. This is within the responsibility of the BSM manufacturer.

The BSM manufacturer must provide a minimum of two IDB cables with a maximum length of 20m.

Figure 19: IDB connector

Examples:

M12 X-Coded network cable (Phoenix Contact)

Network cable - VS-M12MSS-IP20-94F/ 0,5/10G – 1440591

https://www.phoenixcontact.com/online/portal/us?uri=pxc-oc-itemdetail:pid=1440591&library=usen&pcck=P-10-01-01&tab=1

Figure 20: Example of an IDB cable

References:

http://www.siemon.com/de/white_papers/12-03-01-state-of-network-10gbaset-copper.asp

http://www.ieee802.org/3/10GBT/public/nov03/10GBASE-T_tutorial.pdf

http://www.ethernetalliance.org/wp-content/uploads/2011/10/static_page_files_127_10GBASE_T2.pdf

5 Transport Timing Signals (TTS)

5.1 General

The TTS interface provides trigger(BP), transport clock(TC) and reset signals (RESET) from BSM to CDI2 devices, like the CDI2 Camera System or CDI2 Detectors, via dedicated hardware lines. Additionally, a ready signal (READY) from the CDI2 device to the BSM is provided. The BSM shall offer eight mechanical detector slots fully complying with the CDI2-TTS specification.

Signal Name	Direction (BSM-side)	Implemented as
Banknote Present (BP)	out	RS-422
Transport Clock (TC)	out	RS-422
RESET	out	Current loop
READY	in	Current loop
Power (+5V)	out	Supply Voltage

Figure 21: TTS signals, with direction on BSM-side and implementation

For the Transport Clock (TC) and Banknote Present (BP) signals, RS-422 is used as the transmission standard. The detector RESET and READY lines are implemented as current loops.

All digital lines have to be galvanically isolated (e.g. by opto-couplers) to prevent electrical damage to either the Detector or the BSM. For powering the Detector opto-couplers the +5V power line shall be supplied by the BSM. The BSM may use a common +5V supply for all TTS ports.

The TTS interfaces are offered by the BSM as mandatory interfaces for each detector slot, but a CDI2 device manufacturer may use it optionally. A respective parameter in the Device Description (see 6.7.3.2) indicates if the device requires a TTS signal connection.

See 5.4 for details on operating a CDI2 Device without TTS.

Note: The TTS slots provided by the BSM shall comply with CDI1 as well. Upon the machine configuration, a slot may be used either in CDI2 or in CDI1 mode. Please note that the supplied TTS cable shall be compatible to both CDI2 and CDI1.

5.2 Electronics

Signal Name	Banknote Present (BP)
Functionality	Dedicated interface line representing the banknote. It is used to align the inspection process of the Detector and to synchronise the Banknote ID with the banknote and detector result.
Electrical Standard	RS-422 galvanically separated **)
Logic level	Active-high signal
Timing	Resolution(rate): not relevant Length: min. 50 mm Jitter: +/- 2 mm In the nominal timing, the rising edge of BP occurs, when the Leading Banknote Edge passes the casing position. An offset may be requested in the CDI2 Device Info command. A valid Banknote Present signal has a leading edge distance to the previous Trailing Banknote Edge of at least 30 mm. Banknote Present signals are only valid in the sorting state of the BSM, thus BP shall be ignored throughout any state except sorting.
Remarks	BP is not used for an IEU without an optional sensor.

Guidance example BSM-side: see Figure 4 of CDI1.0B
Guidance example Detector-side: see Figure 9 of CDI1.0B

Signal Name	Transport Clock (TC)
Functionality	Dedicated interface line with a square wave clock from the BSM to the Detector. It synchronises the transport speed of the banknote with the inspection rate of the Detector.
Elec. Standard	RS-422 galvanically separated **)
Logic level	Active-high signal
Timing	Resolution (rate): 0.1 mm, 0.2 mm, 0.5 mm or 1 mm selectable at startup for each TTS slot. Length: min. 1 µs Duty-Cycle: 50% Jitter: < 10% of minimal spatial resolution Accuracy: < 0.6% deviation between clock speed and banknote movement
Remarks	The Transport Clock has to conform to these requirements only in BSM States BS_REQUEST_TO_SORT and BS_SORTING. Only in those states, a CDI2 Device shall check for the TTS error loss_of_TC and the TTS warning TC_out_of_range. In other BSM States, the BSM might send TC pulses with any frequency or no TC pulses at all. This must not have any negative impacts on a CDI2 Device. To achieve the required accuracy of the TC signal, a BSM may supply individual CDI2 devices with different clock pulses.

Guidance example BSM-side: see Figure 3 of CDI1.0B
Guidance example Detector-side: see Figure 8 of CDI1.0B

Signal Name	RESET
Functionality	Dedicated interface line from the BSM to a Detector to carry out hardware reset of the detector.
Elec. Standard	Current loop (20 mA max) *) galvanically separated **)
Timing	Resolution(rate): not relevant Length: >= 10 ms Jitter: not relevant On the receive side, a detector must not react on a RESET signal with a duration less than 100 µs.

Guidance example BSM-side: see Figure 5 of CDI1.0B
Guidance example Detector-side: see Figure 10 of CDI1.0B

Signal Name	READY
Functionality	Dedicated interface line from the Detector to the BSM to indicate that the Detector is fully operational for CDI2
Elec. Standard	Digital current loop (20 mA max) *) galvanically separated **)
Timing	Resolution(rate): not relevant Length: >= 10 ms Jitter: not relevant

Guidance example BSM-side: see Figure 6 of CDI1.0B
Guidance example Detector-side: see Figure 11 of CDI1.0B

Signal Name	POWER +5V / GND
Functionality	Powering of the Detector opto-couplers and RS-422 receivers
Elec. Standard	Power line 5 V +/- 5%, 200 mA The +5V power supply must withstand a short circuit between +5V and GND without any damage to components. Furthermore, such a short circuit on one TTS port may not disturb the function of another TTS port.

*) Digital current loop (20mA max)

Receiver specification

Input impedance: 100 to 130 ohm
OFF state current: < 1mA
ON state current: > 16 mA

Transmitter specification

The transmitter shall be implemented as either a (a) current source or as a (b) voltage source with fixed source resistor.

(a) Current source specification
OFF state current: 0 to 1mA
ON state current: 16 to 20mA with output voltage range from 0 to 4.0V

(b) Voltage source specification
Source resistance: 120 ohm
Open circuit voltage: 4.5 to 5.5V
An implementation example can be found in Figure 5 and Figure 11 of CDI1.0B.

**) Galvanically separated

The TTS interface circuits shall provide galvanic isolation to separate the TTS cable wires from the ground potential of the BSM and the device. The purpose of the functional isolation is common mode voltage immunity of the signal transmission. The interface shall be operable with a maximum ground voltage difference between BSM and device of +/-12V. Thus, clamping diodes from a signal to common ground (e.g. metal case or cable shield) can be used for ESD surge protection.

5.3 Connectors/Cables

The TTS connector shall be a 15-pin D-Sub HD, with socket contacts (female) at the device side and plug contacts (male) at the cable side. A dust proof version shall be used at the detector. At the BSM side no specific dust protection is required and the BSM manufacturer is free to use its own connector type.

Figure 22: TTS device connector example, Conec Part Number 15-002243

The DMB cables with the correct lengths for all available CDI slots (min. 8) and the CS (1) must be provided by the BSM manufacturer. The BSM manufacturer must make sure that cables are available to reach the Detector position in the BSM or the external evaluation unit in the storage rack. The cable length shall not exceed 20m.

In case the Detector consists of a measurement head and an external evaluation unit, the connection between these two parts of the detector is up to the Detector supplier.

TTS Pinout			
Pin	Signal	Remark	
1	BP+	Out	Twisted pair
6	BP-	Out	
3	TC+	Out	Twisted pair
8	TC-	Out	
5	Reserved TXD+	out *)	Twisted pair
10	Reserved TXD-	out *)	
7	Reserved RXD+	in *)	Twisted pair
12	Reserved RXD-	in *)	
9	RESET	Out	
14	READY	In	
11	+5V	power supply for from BSM for galvanic separation (200mA max)	
All other pins shall be connected to GND			

Table 18: TTS pinout

*) reserved for CDI1, the cable shall connect these pins to be compatible with CDI1 and CDI2.

5.4 Non-TTS Operation

Generally, any CDI2 device can be operated without a physical TTS connection. The actual startup, restart and reset scenarios for this case are addressed by chapter 6.7.7.

Furthermore, the signals indicating the presence of a banknote (BP) and indicating the actual transport speed (TC) are absent as well. In case a device requires this information, the DMB offers an alternative way to recover the proper timing.

To support Non-TTS operation, the BSM provides extra fields in the BSMINFO frame (see 6.7.4.2 BSMINFO 0x81) for each device, consisting of a transport clock counter value (TC_COUNTn) and a BN trigger information (TC_TRIGn).

The actual banknote present information for a specific banknote is transmitted in the TC_TRIGn value. The TC_TRIGn value represents the transport counter value at which the banknote will arrive at the device.

A device can recover a banknote present signal from the values provided in the BSMINFO command. As shown in Figure 23, the BSM broadcasts its device-specific transport counter as TC_COUNTn value at a constant time interval every 1 ms. The device can use the received TC_COUNTn value to update a local transport clock counter (tc_counter). Depending on the actual transport speed, the transport counter may have several increments between subsequent TC_COUNTn updates. As the update interval is well known, the device may use interpolation techniques to predict the time points for the tc_counter updates. It can be assumed that the errors induced by the interpolation can be neglected, as the banknote speed variations are small enough between TC_COUNTn updates. By this means the device will maintain a local tc_counter, which is running virtually synchronous to the BSM's transport counter (see Figure 24).

The device can derive a banknote present signal by continuously comparing the tc_counter value with the TC_TRIGn value received from the BSM. The banknote trigger occurs when the tc_counter is equal to or greater than TC_TRIGn. This point in time is equivalent to the rising edge of a BP signal as it would be received on a TTS port. The precision of this reconstructed BP pulse shall fulfil the same timing requirement as specified for the TTS BP signal (see 5.2 Electronics, BP).

Figure 25 shows an example of how a BP signal is generated in non-TTS mode.

For a CDI2 device in non-TTS mode, it is not mandatory to recover a Transport Clock (TC) signal as it would be received on the TTS port. If it recovers a TC signal from TC_COUNTn, the recovered signal shall fulfil the same timing requirements as specified in 5.2 Electronics, TC.

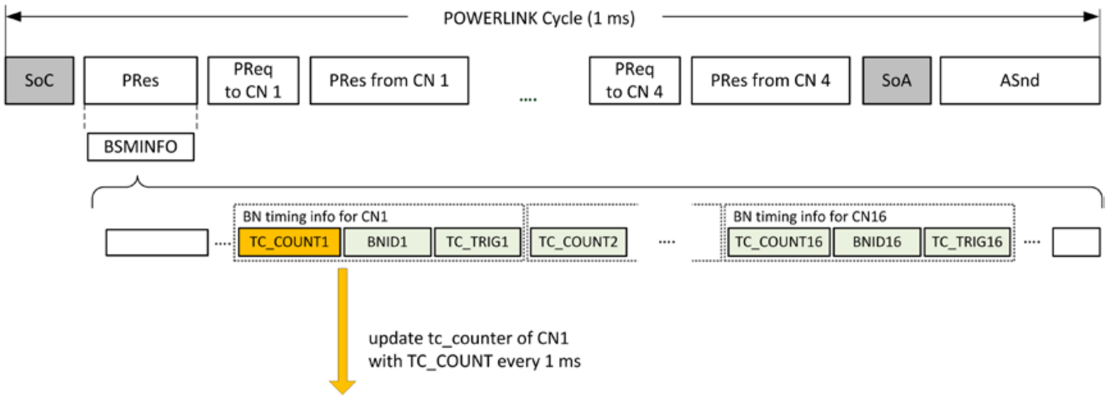


Figure 23: Readout of TC_COUNTn from BNINFO

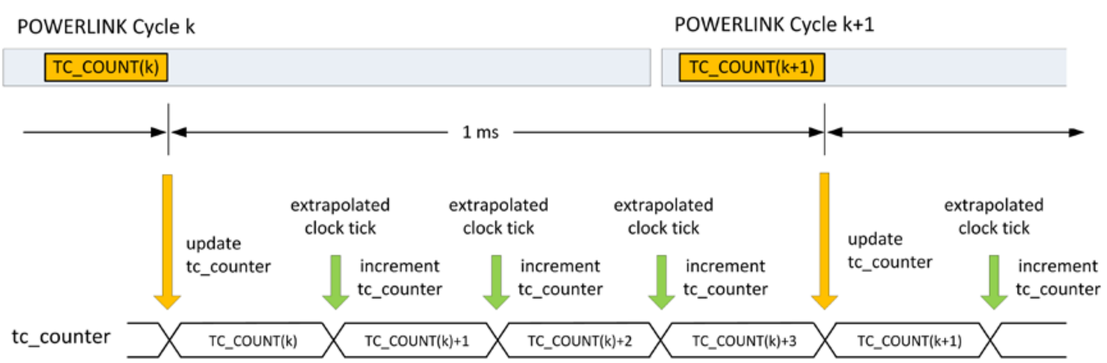


Figure 24: Recovery of tc_counter from TC_COUNTn

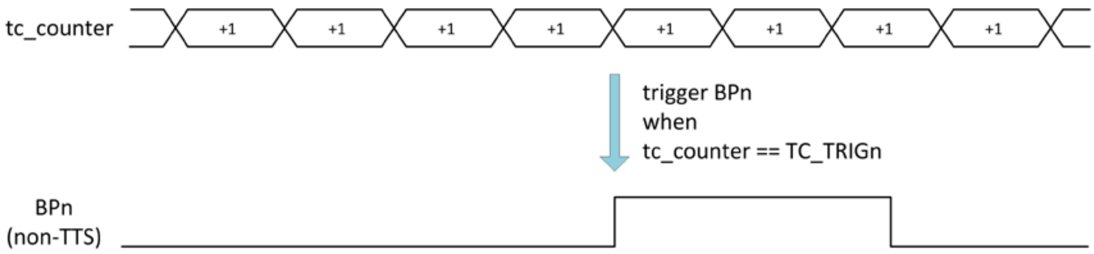


Figure 25: Generation of BP from tc_counter and TC_TRIGn

6 Detector Machine Bus (DMB)

The Detector Machine Bus connects the BSM with its CDI2 Devices (Camera System, Image Evaluation Units and Detectors). During all phases of machine operation, the DMB acts as the main communication path for exchanging control information between BSM and CDI2 devices. The DMB utilises POWERLINK, a real-time Ethernet field bus system, to ensure real-time response during the active sorting phase of the machine.

POWERLINK is a worldwide open technology, which gives customers the choice among various POWERLINK manufacturers and service providers and ensures an optimal price/performance ratio.

Features of the DMB:

- Is based on a 100Mbit Ethernet network implementing the industrial Ethernet POWERLINK protocol to avoid data collision
- Allows 1.4 kB (up to 5.6 kB in segmented mode) of data per note to be transmitted from each CDI2 device to the BSM
- Supports remote diagnosis and maintenance access of the CDI2 devices
- Is rugged and suitable for an industrial environment by using industrial connectors
- Supports the software update of CDI2 devices

6.1 Interface and Electrical Specification

The interface specification conforms to IEEE 802.3

Protocol	IEEE 802.3 MAC Layer
Physical Transmission	IEEE 802.3u Fast Ethernet 100 BASE-TX
Bitrate	100 Mbit/sec
Line Reach (max.)	100 m

6.2 POWERLINK Standard

A Managing Node (MN), acting as the master in the POWERLINK network, polls the Controlled Nodes (CN) cyclically. This process takes place in the isochronous phase of the POWERLINK cycle. Immediately after the isochronous phase an asynchronous phase for communication, which is not time-critical, follows, e.g. TCP/IP communication. The isochronous phase starts with the *Start of Cyclic* (SoC) frame on which all nodes are synchronised. This schedule design avoids collisions, which are usually present on standard Ethernet, and ensures the determinism of the hard-real-time communication. It is implemented in the POWERLINK data link layer. The POWERLINK network can be connected via gateways to non-real-time networks.

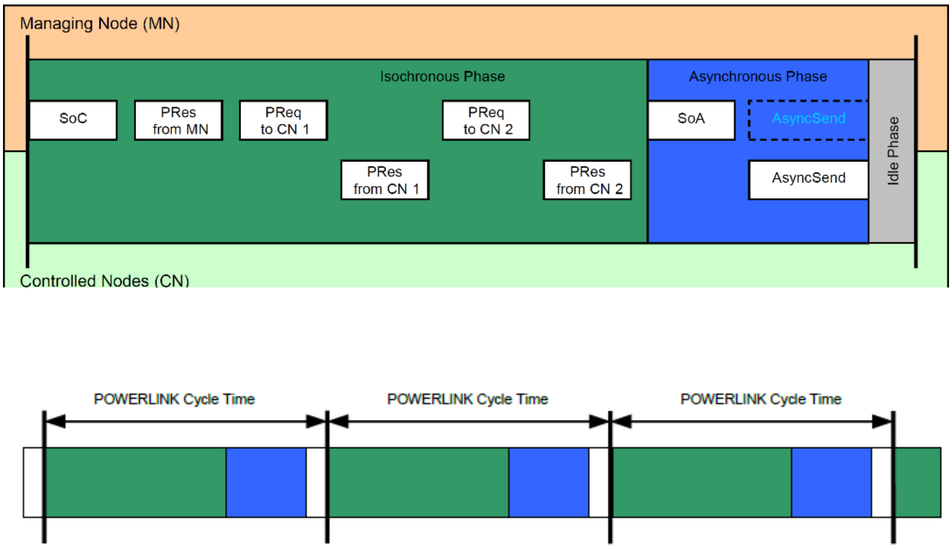


Figure 26: General POWERLINK frame structure

The communication profile of Ethernet POWERLINK is adapted from CANopen. Thus, design principles such as process data object (PDO) for the exchange of process variables and service data object (SDO) for the configuration of remote object dictionaries are reused. All PDOs are exchanged within the isochronous phase, similar to the synchronous PDOs of CANopen. This is because event-triggered PDOs would interfere with hard real-time requirements.

To be conforming to IEEE 802.3, each POWERLINK device has a unique MAC address. Additionally, each device is assigned a logical Node ID. If a particular POWERLINK device implements a TCP/IP stack, it gets a private IP address from class C within the network 192.168.100.0 where the host part equals the POWERLINK Node ID.

Please note that POWERLINK does not provide any means to repeat lost packets.

For POWERLINK references, see [Ref 2.] and [Ref 3.].

6.3 Managing Node (MN)

Only the POWERLINK Managing Node (MN) may send messages independently. POWERLINK Controlled Nodes (CN) may transmit only when requested by the MN. The MN establishes a cyclic time frame, with an isochronous phase and an asynchronous phase.

In CDI2, the BSM acts as a POWERLINK Managing Node with the permanently assigned Node ID Number 240.

6.4 Controlled Node (CN)

All DMB nodes, except the BSM, operate as POWERLINK Controlled Nodes. Each POWERLINK CN must have a unique Node ID in the range of 1 to 16.

6.5 CDI2 POWERLINK Frame

6.5.1 Frame Structure

The DMB takes advantage of the POWERLINK real-time capabilities in order to respect timing requirements of the machine during sorting.

A POWERLINK cycle consists of an Isochronous Phase and of an Asynchronous Phase. The isochronous part is a fixed communication scheme with predefined formats, whereas the asynchronous part can be used for additional, non-time-critical communication.

POWERLINK uses a set of predefined frames, SoC, PReq, PRes, SoA and ASnd. Please refer to chapter 4.6 of [Ref 3.] for a detailed description of the POWERLINK frame structure.

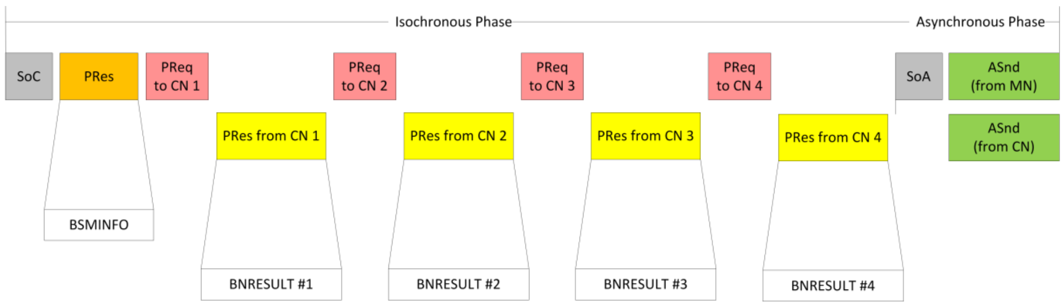


Figure 27: Basic CDI2 POWERLINK frame structure

As POWERLINK frames are repeated at strict regular intervals (POWERLINK cycle time), the interval time determines the maximum time lag of data packets transported in the POWERLINK isochronous phase. For CDI2, the POWERLINK frame structure is chosen in a way that a cycle time of 1 ms can be guaranteed.

Figure 27 shows the frame structure as used in CDI2. The MN indicates the start of the Isochronous Phase by sending a SoC packet. Then the MN sends a PRes packet with BSMINFO to all CNs listening. In the next step, the MN polls the CNs and requests a PRes response containing BNRESULT, if available. In CDI2 the MN uses a by 4 multiplexed scheme to poll the CNs, thus in each POWERLINK cycle four CNs can deliver a BNRESULT to the BSM. As CDI2 supports up to 16 CNs it needs four POWERLINK cycles to provide the BNRESULT of all CNs to the BSM.

In the Asynchronous Phase, indicated by SoA, POWERLINK transports data packets with lower priority. The data traffic in this phase is arbitrated by the MN. Thus, a CN having asynchronous data ready for transmission has to send an asynchronous request to the MN (using appropriate fields in the PRes packet). The MN manages the different priorities of asynchronous requests and grants the asynchronous phase accordingly. Asynchronous transport is used to transport Service Data Objects (SDOs) during startup and during operation (see 6.5.3, 6.6.2 and 6.6.3).

Additionally, POWERLINK can tunnel TCP/IP traffic in the Asynchronous Phase as well, which is used as CDI2 maintenance channel to CDI2 devices.

Note: The POWERLINK specification would not allow an MN to send a PRes packet (carrying BSMINFO) as the first packet after SoC. The POWERLINK specification [Ref 3.] states in Chapter 4.2.2.1 "Optionally, the last frame in the isochronous phase may be a multicast PRes frame of the MN (see Fig. 19)."

This statement is not valid because of technical reasons (see openPOWERLINK Discussion Forum https://sourceforge.net/p/openpowerlink/discussion/opendiscussion/thread/df1953e4/#61e2/af80

6.5.2 DMB command cycle

After the DMB initialisation has completed, the BSM operates in full POWERLINK mode (see Figure 30).

During sorting the BSM uses the DMB to send control commands (BSMINFO) to the CDI2 devices and obtain results (BNRESULT) from the CDI2 devices.

The DMB command cycle guarantees that data packets are delivered within a predefined maximum time, so that real-time requirements of the banknote sorting process are fulfilled.

The Managing Node is the bus master and all other nodes may only send in answer to a corresponding request of the Managing Node. Hence, a BNRESULT is only sent as answer to the corresponding PReq.

CDI2 uses the multiplexing mode of POWERLINK (see chapter 4.2.4.1.1.1 of [Ref 3.]) to accommodate larger BNRESULTS while keeping the cycle time low. Therefore, only 4 Controlled Nodes are polled in each cycle to deliver their result. The sequence of this multiplexed POWERLINK Cycle is shown in Figure 28.

Please note that the exact poll sequence does not need to be according to ascending node numbers.

Additional messages which are used for initialisation, error indication, and additional services are all tunnelled through the asynchronous part of the cycle and shown as ASnd block.

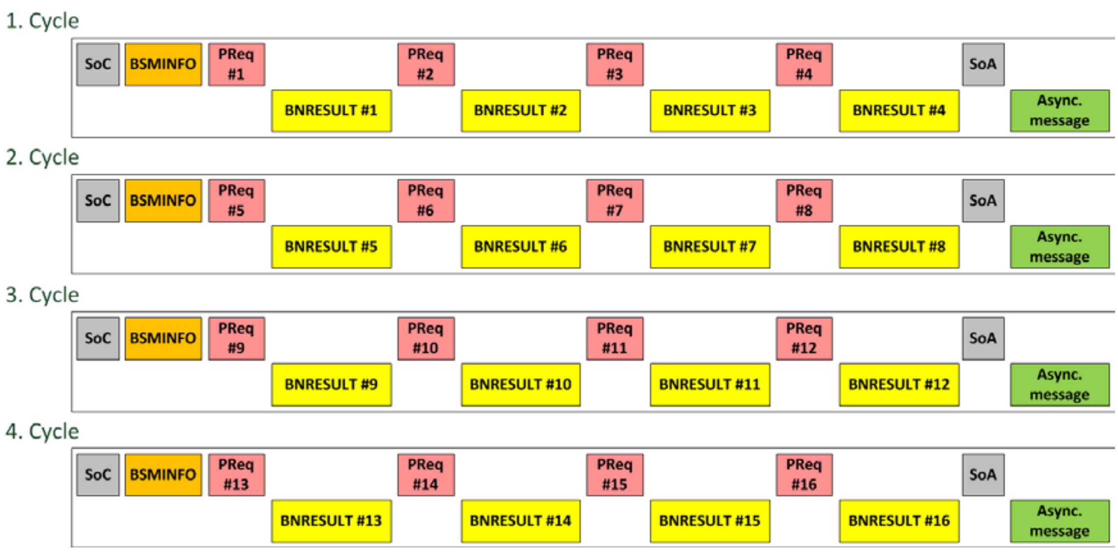


Figure 28: POWERLINK cycle as used in CDI2

POWERLINK Frame Cycle	PReq for CN #
1	1
	2
	3
	4
2	5
	6
	7
	8
3	9
	10
	11
	12
4	13
	14
	15
	16

Table 19: BNRESULT multiplexing scheme

The multiplexing scheme transports BNRESULT from a CN to the BSM with a rate of 4 ms, which results in a delay of 4 ms in the worst case. If segmentation is used for transferring larger BNRESULT blocks (see 6.7.4.4) the delay may add up to 16 ms in worst case.

With the above frame structure and an envisioned cycle time of 1 ms, the DMB can transport 4,000 BNRESULT messages/second. This gives sufficient margins, as the envisioned transport speed will require 800 BNRESULT messages/second.

16 Detectors @ 50 BN/s = 800 BNRESULT messages/second

A detailed description of DMB cyclic commands is given in chapter 6.7.1.

6.5.3 POWERLINK Asynchronous Communication

After the POWERLINK initialisation process has completed, the MN and the CNs are in their respective operational states (NMT_MS_OPERATIONAL and NMT_CS_OPERATIONAL). At this time, the POWERLINK communication between an MN and its CNs is up and data transfers can take place. POWERLINK operates in full mode, with frames being repeated regularly. POWERLINK Process Data Objects (PDO) are transported in the isochronous phase (using PReq and PRes frames) and various additional packets in the asynchronous phase. PDOs are used for the transmission of real-time data, like BSMINFO or BNRESULT, as described in 6.5.2. Asynchronous transport is used for the transmission of data without real-time requirements. Such data can be one of the following:

- Service Data Objects (SDO) which are used e.g. for a software update
- FTP packets to transfer files such as configuration files during the initialisation of the CDI2 system
- IP packets for HTTP communication

For SDO transport, CDI2 uses the transport mechanism via POWERLINK ASnd, as described in chapter 6.3.2.2 of [Ref 3.]. The asynchronous frames for FTP and IP packets use Legacy Ethernet messages according to the respective protocol (chapter 4.6.1.2 of [Ref 3.]).

In the asynchronous phase of the POWERLINK cycle, only a single asynchronous message (ASnd frame or Legacy Ethernet message) can be transmitted. The access is controlled by the MN and may be granted to one CN or to the MN itself.

If a CN wants to send an asynchronous frame, it informs the MN using the RequestToSend (RS) bit of the PRes frame (see chapter 4.6.1.1.4 of [Ref 3.]). The asynchronous scheduler of the MN determines in which cycle the right to send the asynchronous frame will be granted. Then the MN sends a SoA frame with a Requested Service Target (RequestedServiceTarget) identifying which node is allowed to send an asynchronous frame. The CN addressed by the Service Target will now respond with an asynchronous message. Please note that the RequestToSend bit is sent in a PRes frame, which is transferred in the Isochronous Phase upon a poll request (PReq) by the MN. For this kind of asynchronous communication it is therefore necessary that a CN has already been identified and put to the operational state (NMT_CS_OPERATIONAL) by the MN (see 6.6.2).

6.5.3.1 FTP Communication

Regarding FTP, the BSM and the CDI2 Devices must use only the required minimal implementation according to chapter 5.1 of [Ref 4.][Ref 3.], with the following restrictions and enhancements, respectively:

- All transfers must be possible with Anonymous FTP with a user ‘anonymous’ and an arbitrary (even empty or omitted) password. Therefore, the FTP server on a CDI2 Device must support the raw command PASS (send password), although it has no effect.
- All files are provided in the default directory of user ‘anonymous’. Thus, no commands are required (and supported) to navigate the file system hierarchy.
- The raw command PORT (open a data port) is not supported. Instead, the raw command PASV shall be used to open a passive data transfer.
- The only supported transfer type is I (Image). This is in contrast to the minimal implementation suggested in chapter 5.1 of [Ref 4.], where the default transfer type is A (ASCII). Consequently, the BSM as FTP client has to use the raw command TYPE (set transfer type) before each transfer to set the type to I (Image).
- As an additional command, the raw command LIST (list remote files) must be implemented.
- As another additional command, the raw command DELE (delete a remote file) must be implemented.

6.6 CDI2 Startup, Initialisation and Configuration Management

6.6.1 POWERLINK Node IDs

The BSM being the POWERLINK Managing Node (MN) uses the permanently assigned Node ID Number 240.

The Node IDs of Controlled Nodes (CNs) are in the range 1-16. They are assigned statically at installation time or at maintenance of the sorting machine. A CDI2 Device (Detector, Camera System or Image Evaluation Unit) shall provide means to set and store its specific POWERLINK Node ID permanently (e.g. by either using configuration switches or by saving the Node ID in EEPROM/FLASH memory using a configuration dialog).

6.6.2 POWERLINK Startup

The initiative for starting the POWERLINK network comes from the POWERLINK MN, which is located at the BSM. As a prerequisite, all POWERLINK nodes must have assigned a unique node ID to them (see chapter 6.6.1) and the network interfaces must be up.

The startup procedure shall comply with the "Ethernet POWERLINK Communication Profile Specification, EPSG DS 301 V1.3.0" ([Ref 3.]).

This chapter gives an introduction and an overview about the basic steps. Please refer to the appropriate POWERLINK chapters for further details (chapter 7.1 NMT State Machine in [Ref 3.]).

The POWERLINK Communication function provides the communication objects and the appropriate functionality to transport data items via the POWERLINK network structure. On top, the Network Management (NMT) state machine controls the behaviour of the POWERLINK Communication function. Regarding to CDI2, the NMT state machine must enter an operating state (NMT_MS_OPERATIONAL for an MN and NMT_CS_OPERATIONAL for a CN) before CDI2 application data can be transported by the POWERLINK network.

The NMT state machine consists of two super-states, a common initialisation state (NMT_GS_INITIALISATION) and a communication state which is specific to either MN or CN (MN NMT State Machine or CN NMT State Machine).

During the common initialisation state, which is entered at startup (or after restart), initialisation of POWERLINK data structures takes place (e.g. configuration can be read to initialise object descriptions and object dictionaries). At this state, no POWERLINK network communication takes place.

When the common initialisation is completed, the NMT communication states are entered. During these states, the MN establishes initial communication to the CNs. In the first stage, the MN requests identification from all CNs by issuing an SoA/IdentRequest. An addressed CN will respond with an ASnd/IdentResponse. If a CN is identified, the MN activates the appropriate PReq/PRes slot in the Isochronous Phase. Once this happened, the CN will be polled by the MN regularly. Still, the payload of the PRes is set invalid (Ready=0), but the PRes header provides valid information like NMT State and RequestToSend.

Typically, the MN will reach the operational phase (NMT_MS_OPERATIONAL) first. Then it will put each CN, after each became identified, into the operational state (NMT_CS_OPERATIONAL) using the NMTStartNode command. Please note that CDI2 specifies that all POWERLINK CNs are optional, which means that the MN will become/stay in operational state, even when no CNs have been identified. Thus, the DMB of the sorting machine is fully operational even if not all CDI2 devices are up. The MN will continue to issue IdentRequest frames to all configured but yet unidentified CNs in a regular manner. It is up to the BSM to check if the detected CNs match the actual machine configuration. In CDI2, POWERLINK just provides the connectivity, but it will not check specific CDI2 configurations.

More details about the machine configuration management are given in chapter 6.6.3.

During the startup phase, the communication mode on the Ethernet network changes from virtually no communication to reduced POWERLINK cycle mode and ends up with full POWERLINK mode (see Figure 30). Only full POWERLINK mode provides the functionality needed for the operation mode of a CDI2 BSM.

Please note that regarding CDI2, devices are defined as mandatory and it is not allowed for the BSM to put a device out of operation on-the-fly. This means that the actual CDI2 configuration with all (mandatory) devices is known to the BSM and that the BSM only should allow banknote processing if all (mandatory) devices are available. Therefore, it is not permitted for the BSM to deactivate a device.

NMT State Machine of Managing Node

Figure 29 depicts the full MN NMT State machine, as it is specified by the POWERLINK specification, with all possible transitions. The state colours correspond to the operational mode of the POWERLINK Ethernet, as shown in Figure 30. Please refer to the appropriate chapters for further details (chapter 7.1.3 MN NMT State Machine in [Ref 3.]).

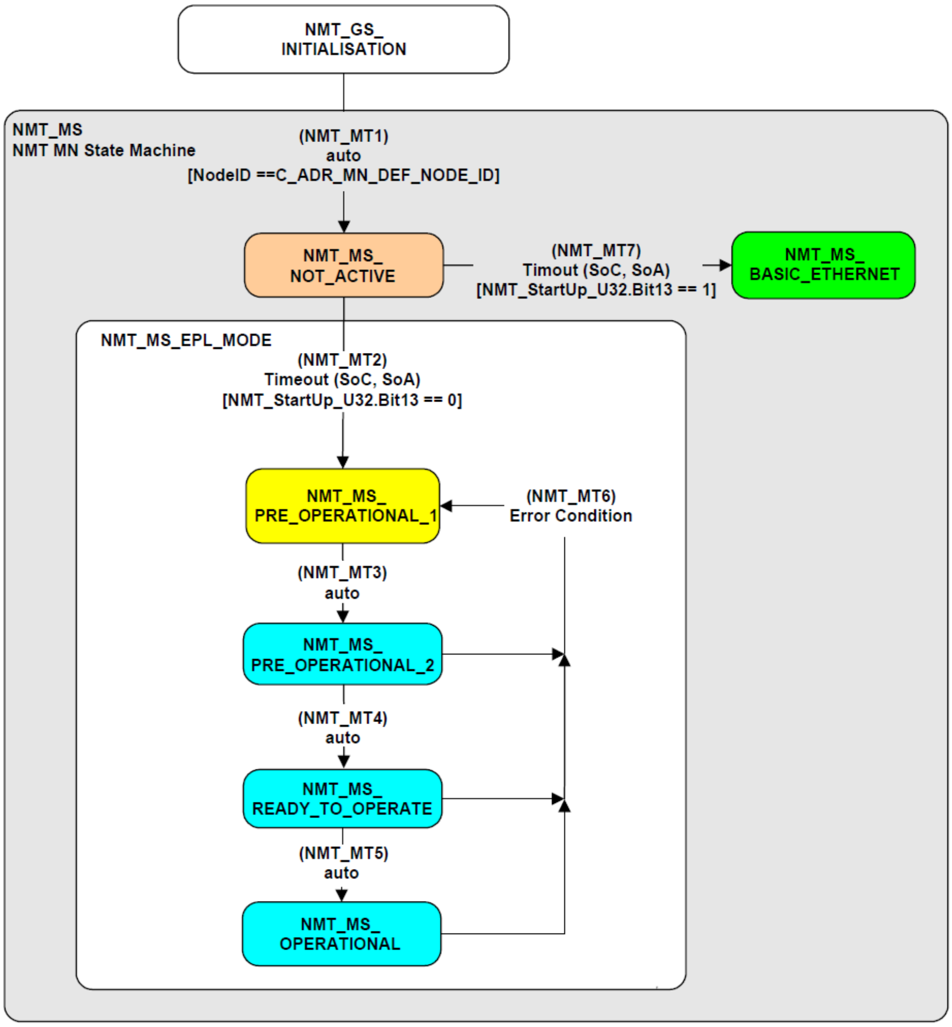


Figure 29: MN NMT state machine

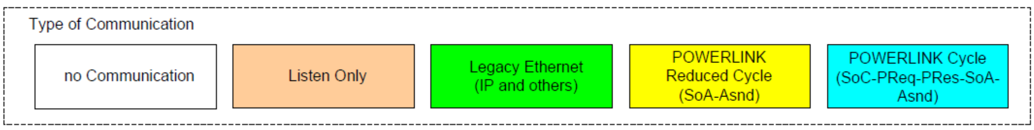


Figure 30: POWERLINK communication modes depend on MN NMT state (same colours)

NMT State Machine of Controlled Node

Figure 31 depicts the full CN NMT State machine, as it is specified by the POWERLINK specification, with all possible transitions. Please refer to the appropriate chapters for further details (chapter 7.1.4 CN NMT State Machine in [Ref 3.]).

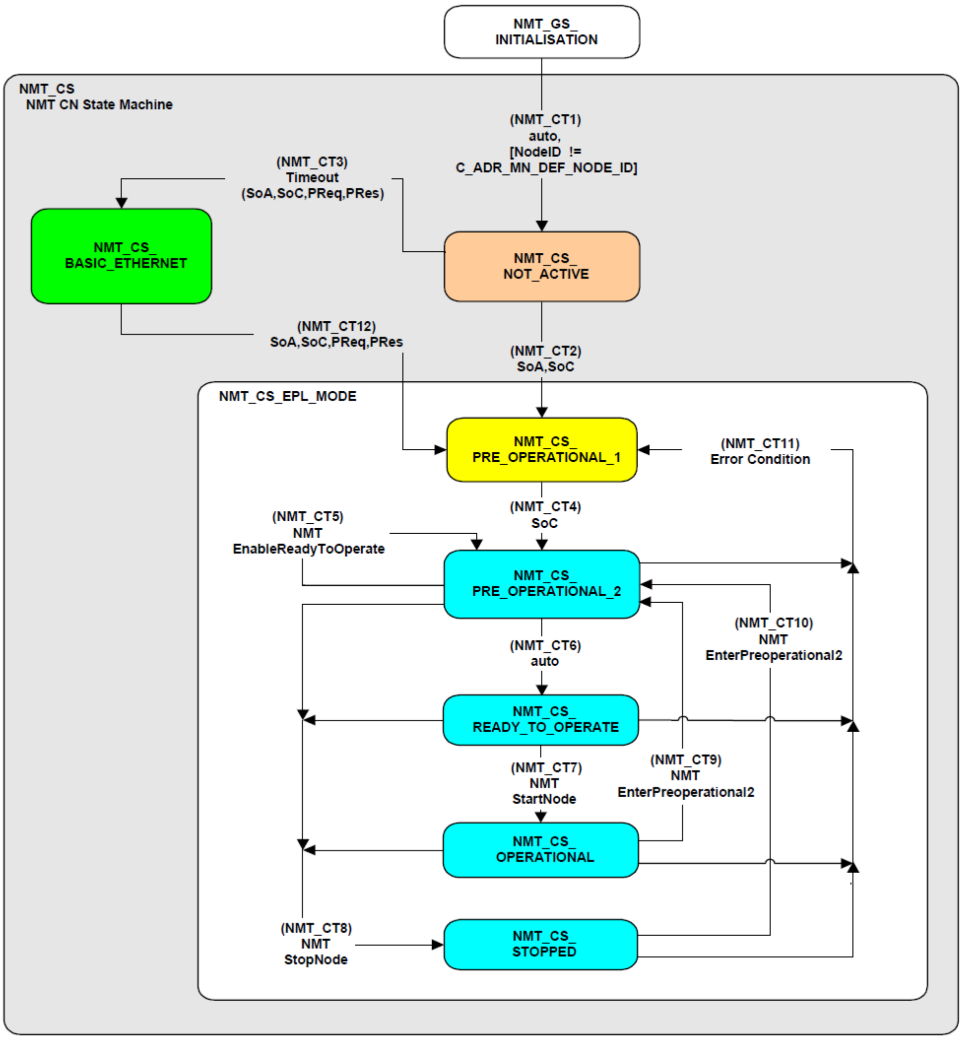


Figure 31: CN NMT state machine

6.6.3 CDI2 Configuration Management

The configuration of the BSM consists of a POWERLINK specific configuration and a CDI2 specific part. The POWERLINK configuration, which defines the detailed timing and structure of the POWERLINK frame, is virtually constant for CDI2, regardless of the actual CDI2 configuration of a particular sorting machine. An overview of the used POWERLINK standard/default entries is given in Appendix A.

Additionally, the BSM must maintain a CDI2 specific configuration. The BSM uses it on one hand to check if all expected CDI2 Devices are present and if their configuration is as expected (e.g. their software version) and on the other hand to provide additional configuration data to the CDI2 Devices with an updated Device Information (see below).

Figure 32 shows the configuration procedure as it happens at startup of the sorting machine. As a basis, the BSM initialises and configures the POWERLINK system (as described in 6.6.2). The POWERLINK configuration of a CDI2 device may be stored at the device locally as a file or it can be even hard-coded.

After POWERLINK startup has been completed, the BSM continues to setup and verify the configuration regarding CDI2. It requests the Device Info from each identified CDI2 device. The Device Information is an XML file which is transferred to the BSM (see 6.7.3.2 and 6.7.3.3). This file describes the properties and capabilities of the CDI2 device.

Once all Device Information files have been retrieved, the BSM provides specific Device Configurations back to the devices by sending the Machine Info (see 6.7.3.1) and the specific Device Configurations (see 6.7.3.4) back to the CDI2 devices, which shall update their own configuration thereafter.

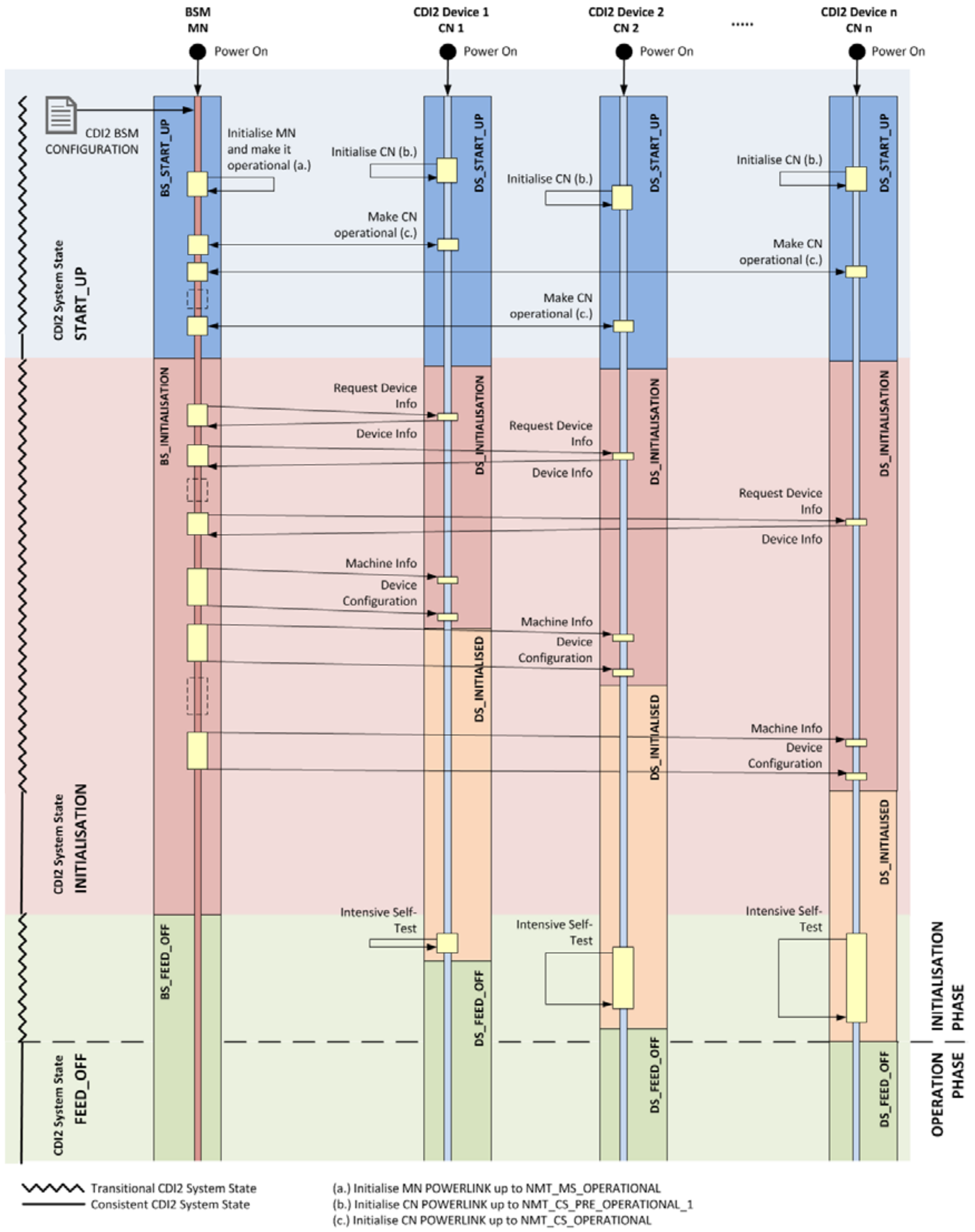


Figure 32: CDI2 configuration procedure

6.7 Message Protocol

In POWERLINK, the real-time data transfers are performed by means of Process Data Objects (PDOs), whereas non-real-time transfers use Service Data Objects (SDOs).

During the Sorting phase, CDI2 uses Process Data Objects (PDOs) to transfer data on the DMB. PDOs are transported in the isochronous part of the POWERLINK frame in a regular and deterministic fashion.

Note that the reception of PDO data is not acknowledged.

6.7.1 DMB command overview

During sorting the BSM uses the DMB to send control commands (BSMINFO) to the CDI2 devices and to obtain results (BNRESULT) from the CDI2 devices.

The DMB commands are transported in the isochronous phase of the POWERLINK cycle which guarantees that the command transport is fast enough for the real-time requirements of the sorting machine during operation. The fundamental command sequences during sorting are described in chapter 3.1.

A summary of the DMB commands is shown in Table 20. Note that the payload of the CDI2 data is encoded in little endian as defined in the POWERLINK specification (chapter 6.1 in [Ref 3.]).

Name	**POWER LINK message type**	**direction**	**Answer**	**contents**
BSMINFO 0x81 (see 6.7.4.2)	PRes	MN => CN cyclic, once per PL cycle	None	BSM state, Trigger information (TC_COUNTn, BNIDn, TC_TRIGn), BNINFO (BNID, Series, Denomination, Orientation)
PReq 0x82 (see 6.7.4.3)	PReq	MN => CN cyclic, to all CNs, multiplexed by 4	PRes	Request to send BNRESULT
BNRESULT 0x41 (see 6.7.4.4)	PRes	CN => MN cyclic, from all CNs, multiplexed by 4	none	CDI2 device state, BNRECOGNITION, BNRESULT, Request to send for ASnd message
Device Reset (see 6.7.7)	ASnd, NMTSwReset	MN => CN	none	BSM can cause a RESET of a CN with this command
Machine Info (see 6.7.3.1)	FTP, XML File Write	MN => CN	none	Machine Speed, Machine Name, …
Device Info (see 6.7.3.1, 6.7.3.2 and 6.7.3.3)	FTP, XML File Read	CN => MN	none	Detector Serial Nr, Detector Type, …
Device Configuration (see 6.7.3.4)	FTP, XML File Write	MN => CN	none	Configuration settings sent to the CN
Additional files (see 6.7.5)	FTP, XML File Read/Write	CN => MN MN => CN	none	e.g. error_log.xml
Software Update (see 6.7.6)	ASnd, SDO	CN => MN MN => CN	none	updateSwCommand, updateSwStatus

Table 20: DMB command overview

6.7.2 CDI2 State Machine

Figure 33 and Figure 34 show the CDI2 States of the BSM and the CDI2 Devices, respectively.

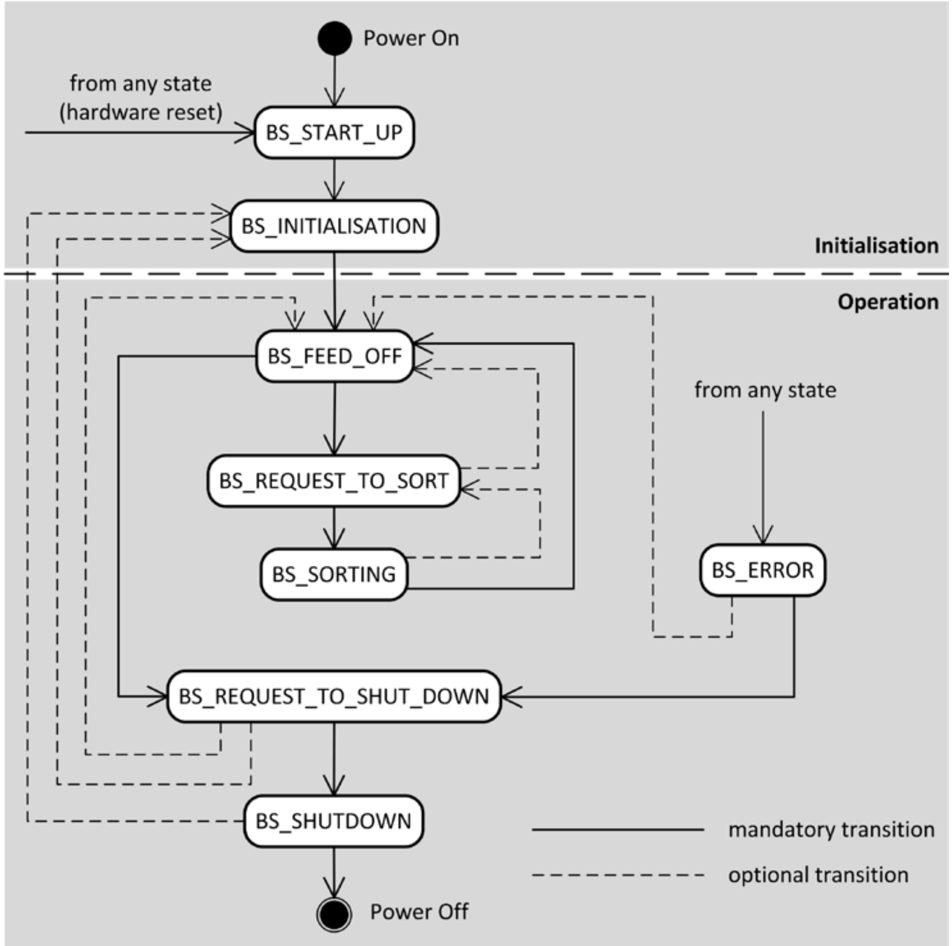


Figure 33: BSM States and transitions

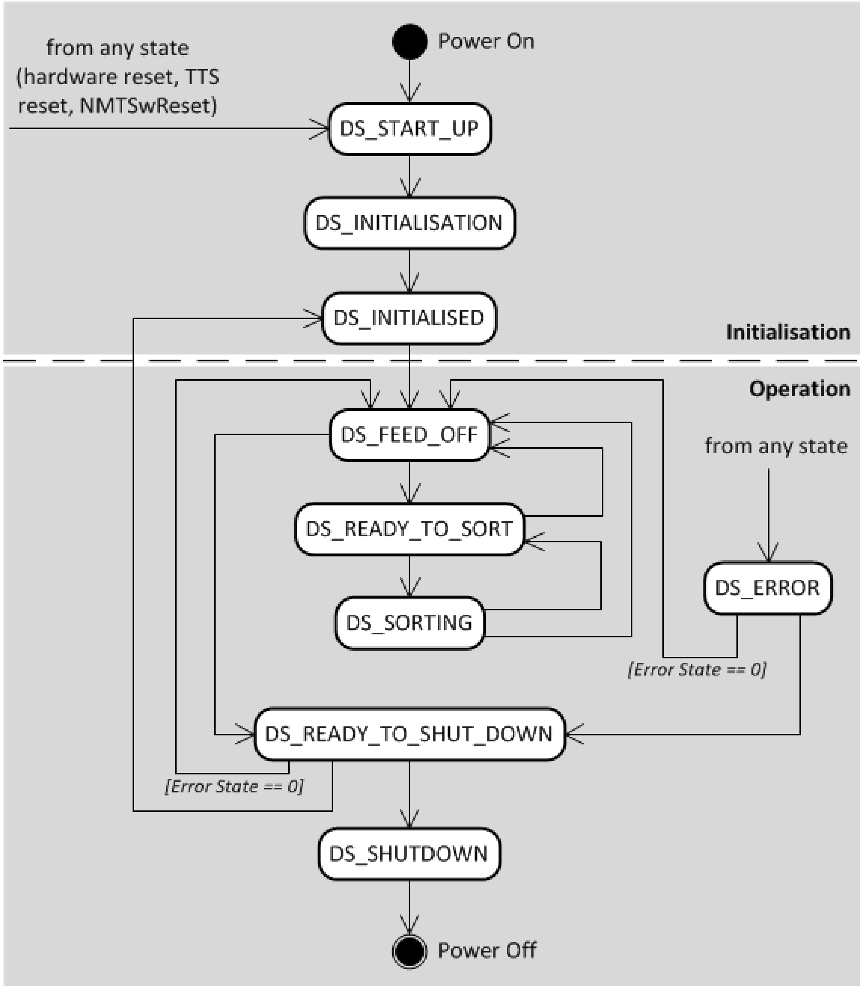


Figure 34: CDI2 Device States and transitions

The IDs of the BSM and CDI2 Device States are shown in the following table.

BSM State	ID
BS_START_UP	1
BS_INITIALISATION	2
BS_FEED_OFF	3
BS_REQUEST_TO_SORT	4
BS_SORTING	5
BS_REQUEST_TO_SHUT_DOWN	6
BS_SHUTDOWN	7
BS_ERROR	10

CDI2 Device State	ID
DS_START_UP	1
DS_INITIALISATION	2
DS_INITIALISED	3
DS_FEED_OFF	4
DS_READY_TO_SORT	5
DS_SORTING	6
DS_READY_TO_SHUT_DOWN	7
DS_SHUTDOWN	8
DS_ERROR	10

Table 21: IDs for BSM and CDI2 Device States

As you can see from Figure 33 and Figure 34, the state diagrams of the BSM and a CDI2 Device are quite similar. In fact, the states of the BSM and all CDI2 Devices are coupled to a high degree. Therefore, within normal operation the BSM and all CDI2 Devices will be in corresponding states. Consequently, it can be said that the CDI2 System is in a certain state.

The following table lists the states of the CDI2 System that result from the BSM and the CDI2 Devices being in corresponding states.

CDI2 System State	BSM State	CDI2 Device State
START_UP	BS_START_UP,	DS_START_UP
INITIALISATION	BS_INITIALISATION	DS_INITIALISATION, DS_INITIALISED
FEED_OFF	BS_FEED_OFF	DS_FEED_OFF
READY_TO_SORT	BS_REQUEST_TO_SORT	DS_READY_TO_SORT
SORTING	BS_SORTING	DS_SORTING
READY_TO_SHUT_DOWN	BS_REQUEST_TO_SHUT_DOWN	DS_READY_TO_SHUT_DOWN
SHUTDOWN	BS_SHUTDOWN	DS_SHUTDOWN
ERROR	BS_ERROR	DS_ERROR

Table 22: CDI2 System States

The transition from one state of the CDI2 System to another can only be initiated by the BSM. Exception: A CDI2 Device can trigger the transition to ERROR when it enters state DS_ERROR.

To initiate a state transition, the BSM first switches to some new BSM State. A CDI2 Device, which observes the BSM State transmitted in the BSMINFO message, will react by first carrying out any transition task that is assigned to this transition (see Table 27) and then by following to the corresponding CDI2 Device State. A special case is the switch to BSM State BS_INITIALISATION: An uninitialised CDI2 Device (i.e. one being in state DS_START_UP) will follow to DS_INITIALISATION, while an already initialised CDI2 Device (i.e. one being in state DS_READY_TO_SHUT_DOWN) follows to DS_INITIALISED.

For state transitions of a CDI2 Device to which a transition task is assigned, the maximum allowed transition time is defined in Table 27. For all other state transitions (e.g. from DS_START_UP to DS_INITIALISATION), these should be carried out within 10 ms.

Note that during normal operation situations can arise where the BSM and all CDI2 Devices are not necessarily in corresponding states (typically during the transition to some state or e.g. during a software update of a device). In those situations, it can be said that the CDI2 System is either in transition to some state or in an intermediate state, respectively.

The states of the BSM and a CDI2 Device can be separated into initialisation states and operation states and will be described in detail in the next chapters.

As a common principle during both initialisation and operation, the READY line shall indicate if a CDI2 Device is fully operational for CDI2. Thus, the READY line is logically low if the CDI2 Device is not yet fully initialised (i.e. it is in state DS_START_UP or DS_INITIALISATION), if it is shut down (i.e. it is in state DS_SHUTDOWN) or it has a non-zero Error State. In all other cases, the READY line is logically high.

If a change of CDI2 Device State shall also be indicated by a change of the logical level of the READY line, the READY line shall be set before the CDI2 Device State. This allows the BSM, after it has waited for a specific change of the CDI2 Device State (i.e. from DS_INITIALISING to DS_INITIALISED), to immediately verify that the READY line matches the state.

6.7.2.1 Initialisation Phase

In its initialisation phase, the BSM or the CDI2 Device, respectively, first initialise POWERLINK. Once the MN of the BSM is operational, it helps the CN of a CDI2 Devices to get operational also and, such, establish the isochronous communication between the MN and the CN. Afterwards, the CDI2 initialisation takes place and, when it is finished, the CDI2 System is ready to start the Operation Phase with a change to state FEED_OFF.

The initialisation steps of the BSM and the CDI2 Device, respectively, are described in more detail in the following tables.

BSM State	**Description**
BS_START_UP	The BSM enters this state after power on or any kind of reset. It uses its POWERLINK configuration and autonomously carries out its POWERLINK initialisation from MN state NMT_GS_INITIALISING until NMT_MS_OPERATIONAL. Subsequently, the MN of the BSM makes all CNs of the CDI2 Devices operational with respect to POWERLINK. The steps for this are listed in Table 25. When all CDI2 Devices are operational, as indicated by all devices signalling the CN state NMT_CS_OPERATIONAL and the CDI2 Device State DS_START_UP, the CDI2 System start is complete and the BSM may continue with BSM State BS_INITIALISATION.
BS_INITIALISATION	In this state, the BSM carries out the CDI2 initialisation of all CDI2 Devices. The steps for this are described in Table 26. When all CDI2 Devices are finally in CDI2 Device State DS_INITIALISED, the Initialisation Phase of the CDI2 System is finished. Subsequently, the BSM may enter BSM State BS_FEED_OFF to start the Operation Phase (see 6.7.2.2). Note that if the BSM does the last initialisation step “Update Configuration” one CDI2 Device after the other, it can check if the TTS cable is plugged correctly: First, the BSM checks that the READY line is logically low. When the BSM has sent both the Machine Info and the Device Configuration to the CDI2 Device, it waits until the CDI2 Device State changes to DS_INITIALISED. Now, the BSM checks that the READY line is logically high. If the checks for the READY line succeed, the TTS cable will be plugged correctly.

Table 23: BSM Initialisation

CDI2 Device State	Description
DS_START_UP	The CDI2 Device enters this state after power on or any kind of reset. It autonomously carries out its POWERLINK initialisation from CN state NMT_GS_INITIALISING until NMT_CS_PRE_OPERATIONAL_1. Subsequently, it will be made operational by the BSM's MN with the steps described in Table 25. After this, it can signal its CN state NMT_CS_OPERATIONAL and its CDI2 Device State DS_START_UP.
DS_INITIALISATION	An uninitialised CDI2 Device shall enter this state when it recognises that the BSM State is BS_INITIALISATION. The CDI2 Device gets initialised with respect to CDI2 according to the steps described in Table 26. Once the CDI2 Device is completely initialised, it will autonomously enter CDI2 Device State DS_INITIALISED.
DS_INITIALISED	This state indicates to the BSM that the CDI2 Device is fully operational for CDI2. When entering this state from DS_INITIALISATION, this shall additionally be signalled by setting the READY line to logical high immediately before the state change. In this state, the CDI2 Device shall observe the BSM State. As soon as this is BS_FEED_OFF, the CDI2 Device carries out its transition to state DS_FEED_OFF, i.e. it carries out an Intensive Self-Test before signalling the new state (see Table 26).

Table 24: CDI2 Device Initialisation

The following tables describe the initialisation steps in more detail. In the first table, the initialisation steps regarding POWERLINK are summarised (see Table 25, for more details refer to [Ref 3.]). Note that these steps will not only be carried out in the Initialisation Phase of the CDI2 System. Rather, these steps may also occur after any situation where the normal isochronous POWERLINK connection between the BSM and a CDI2 Device gets interrupted, e.g. after a POWERLINK error (see 6.8.2). Hence, these steps can be considered independent of the BSM State or CDI2 Device State, respectively.

Initialisation Step	Description for BSM	Description for CDI2 Device
Identification	The BSM requests identification from a CDI2 Device that shall be initialised by issuing IdentRequests, waiting for a corresponding IdentResponse and waiting until the CN state of the device is NMT_CS_READY_TO_OPERATE.	The CDI2 Device waits for an IdentRequest from the BSM and answers with an IdentResponse.
Start Operational	The BSM makes an identified CDI2 Device operational by sending it an NMTStartNode. It waits until the CDI2 Device enters CN state NMT_CS_OPERATIONAL and it transmits its CDI2 Device State.	When the CDI2 Device receives an NMTStartNode from the BSM, its CN enters state NMT_CS_OPERATIONAL. From now on, the CDI2 payload of the CDI2 Device's PRes is valid, thus the CDI2 Device can transmit its CDI2 Device State to the BSM.

Table 25: POWERLINK Initialisation Steps of BSM and CDI2 Device

The second table, Table 26, describes the steps that the BSM carries out to initialise a CDI2 Device regarding to CDI2. If several CDI2 Devices are initialised at once (this is typically the case when the BSM carries out the initial initialisation of the CDI2 System), it is recommended that the BSM passes the steps one after the other, proceeding to the next step only if the current step has been completed for all CDI2 Devices to be initialised.

The BSM may optionally carry out the initialisation steps of Table 26 for individual CDI2 Devices, if it supports such an approach (see optional transitions in Figure 33). This may be useful if a CDI2 Device shall be reinitialised after a software update or an individual reset. If the BSM supports such individual actions, it must assure that the configuration of the CDI2 System is still valid afterwards. If it does not support such individual actions, the BSM and all CDI2 Devices must be restarted in those situations.

Initialisation Step	**Description for BSM**	**Description for CDI2 Device**	**Timeout**
Request Configuration	The BSM starts the CDI2 initialisation of a CDI2 Device by requesting its Device Info. When receiving the Device Info, the BSM checks that the NodeID entry in the Device Info of the CDI2 Device matches its POWERLINK Node ID.	When the CDI2 Device receives a Device Info Request from the BSM, it sends its Device Info. The timeout specifies the time within which the CDI2 Device shall send its entire Device Info after the BSM`s corresponding request.	1 s
Update Configuration	The BSM sends the Machine Info and the Device Configuration (i.e. the updated Device Info) to the CDI2 Device. It waits until the CDI2 Device enters CDI2 Device State DS_INITIALISED.	The CDI2 Device waits for the Machine Info and the Device Configuration from the BSM. When both have been received and the CDI2 Device has processed them, it shall autonomously enter CDI2 Device State DS_INITIALISED. The timeout specifies the time within which the CDI2 Device shall enter CDI2 Device State DS_INITIALISED after it has received both the Machine Info and the Device Configuration from the BSM.	1 s

Table 26: CDI2 Initialisation Steps of BSM and CDI2 Device

Note that the BSM shall carry out any initialisation step listed in Table 26 only if the CDI2 Device is in the appropriate state. Therefore, a CDI2 Device e.g. needs to expect a Machine Info file only if it is in state DS_INITIALISATION.

6.7.2.2 Operation Phase

The Operation Phase of the BSM and a CDI2 Device comprises all states starting from and including BS_FEED_OFF and DS_FEED_OFF, respectively.

To carry out a state transition, the BSM signals the new state. As stated in 6.7.2, each CDI2 Device has to observe the BSM State. If it notices a transition, it carries out any tasks associated with this transition (see Table 27). When it is finished, it signals the new state. Exception: A CDI2 Device cannot signal DS_SHUTDOWN, see Table 28. The BSM shall proceed (e.g. with a transition to a next state) only if all CDI2 Devices have signalled the new state.

The following table lists the target states for state transitions of a CDI2 Device and the corresponding transition tasks (for the possible source states of each target state, please refer to Figure 34). For each state transition, a timeout is specified that the CDI2 Device has to meet. If the CDI2 Device has to carry out a task for this transition, this has to be finished within this timeout. If the BSM recognises that not all CDI2 Devices meet the timeout, it enters state BS_ERROR. Exception: The BSM may continue with a shutdown (conducted by states BS_REQUEST_TO_SHUT_DOWN and BS_SHUTDOWN, possibly preceded by state BS_ERROR) even if not all CDI2 Devices follow, see Table 28.

CDI2 Device State	Transition Task	Timeout
DS_FEED_OFF	Intensive Self-Test	7.5 s
DS_READY_TO_SORT	Short Self-Test	200 ms
DS_SORTING	-	10 ms
DS_READY_TO_SHUT_DOWN	Perform actions before shutdown	10 s
DS_SHUTDOWN	-	10 ms
DS_ERROR	-	10 s

Table 27: Transition Tasks and Timeouts for CDI2 Devices

When the CDI2 System changes from one state to another, the states of the BSM and the CDI2 Devices will not be consistent during the transition (e.g. during the transition to READY_TO_SORT, the BSM is in state BS_REQUEST_TO_SORT, some CDI2 Devices may already be in DS_READY_TO_SORT and others, which require a longer time to carry out their Short Self-Test, may still be in DS_FEED_OFF). If the states of the BSM and the CDI2 Devices are not yet consistent, the entire CDI2 System is said to be in transition to the new state.

If a CDI2 Device detects an error of its own, it shall set a non-zero Error State, set its READY line to logical low and then enter state DS_ERROR.

If the BSM observes that any CDI2 Device changes its state to DS_ERROR or if detects an error of its own, it shall enter BS_ERROR. Exception: If a CDI2 Device changes to DS_ERROR from either DS_READY_TO_SHUTDOWN or DS_SHUTDOWN, the BSM may ignore this transition. All CDI2 Devices shall mirror the state BS_ERROR, i.e. if a CDI2 Device observes that the BSM signals state BS_ERROR, it shall itself enter state DS_ERROR. Because of this behaviour, the whole CDI2 System is made consistent again.

The BSM may distinguish CDI2 Devices that generated DS_ERROR from CDI2 Devices that only entered DS_ERROR because of the BSM entering BS_ERROR by observing their Error State: CDI2 Devices that signal an Error State have generated DS_ERROR.

A CDI2 Device that has a non-zero Error State shall only carry out the state transitions from DS_ERROR to DS_READY_TO_SHUT_DOWN and from DS_READY_TO_SHUT_DOWN to DS_SHUTDOWN (see Figure 34). However, if the BSM state changes to BS_FEED_OFF, each CDI2 Device shall (independently of its Error State, if possible) perform an intensive self-test, update its Error State accordingly and change to DS_FEED_OFF (for a zero Error State) or to DS_ERROR (for a non-zero Error State). In this way, a device can recover from an error.

If the BSM observes an unexpected state of a CDI2 Device, i.e. the CDI2 Device shows some state that it is not expected to change to (see Figure 34), the BSM shall treat this as an error and, hence, change its BSM State to BS_ERROR. On the contrary, if a CDI2 Device observes an unexpected state of the BSM, i.e. if the BSM shows some state for which no transition from the current CDI2 Device State to the CDI2 Device State that would correspond to the BSM is specified (again see Figure 34), it shall ignore it. Note, however, that BS_ERROR is an expected state.

If the BSM carries out any individual actions for some device (e.g. a reset or a software update), it shall do this in state BS_REQUEST_TO_SHUT_DOWN. It is the responsibility of the BSM to check if, after such an individual action, the configuration of the CDI2 System stays consistent. If this is not the case, the BSM can always resolve this situation with a restart of all CDI2 Devices (see also chapter 6.7.7).

The following table summarises the CDI2 System States in the Operation Phase. For an overview on the Transition Tasks and their timeouts, please refer to Table 27.

CDI2 System State	Description
FEED_OFF	This is the normal state when no banknotes are sorted. The transition to this state is triggered by the BSM by entering BS_FEED_OFF. On the transition to state DS_FEED_OFF, the CDI2 Devices are requested to carry out an Intensive Self-Test. When the CDI2 System shall be switched from SORTING to FEED_OFF, the BSM shall signal BS_FEED_OFF only if the processing of the last sorted banknote has been finished by all CDI2 Devices.
READY_TO_SORT	Before switching to this state, the BSM has to start the transport belt and stabilise the transport speed. The belt speed shall not deviate from its nominal speed by more than +/-5%. The transition to this state is triggered by the BSM by entering BS_REQUEST_TO_SORT. On the transition to state DS_REQUEST_TO_SORT, the CDI2 Devices are requested to carry out a Short Self-Test.
SORTING	In this state, banknotes can be transported at any time. The transition to this state is triggered by the BSM by entering BS_SORTING.
READY_TO_SHUT_DOWN	The transition to this state is triggered by the BSM by entering BS_REQUEST_TO_SHUT_DOWN. On the transition to state DS_READY_TO_SHUT_DOWN, the CDI2 Devices are requested to carry out any necessary actions before a shutdown. An action could e.g. be the saving of data that has to be kept across a reset. Note, however, that a CDI2 Device must be able to change from DS_READY_TO_SHUT_DOWN back to normal operation including sorting. If not all CDI2 Devices enter state DS_READY_TO_SHUT_DOWN within the specified timeout, the BSM may proceed with the shutdown anyway.
SHUTDOWN	In this state, the CDI2 System has been shut down and may be powered off or reset. The transition to this state is started by the BSM by entering BS_SHUTDOWN. However, this transition is ignored by the CDI2 devices. The actual transition is triggered by the BSM by sending an NMTStopNode to every CDI2 Device. When a CDI2 Device accordingly enters CN state NMT_CS_STOPPED, this is equivalent to entering CDI2 Device State DS_SHUTDOWN. Additionally, it shall indicate this by setting the READY line to logical low immediately before the state change. Note that the CDI2 Device cannot transmit DS_SHUTDOWN to the BSM since it is not communicating isochronously anymore. However, the BSM can detect this state by observing if the CN state of the CDI2 Device is NMT_CS_STOPPED.
ERROR	This state indicates that some severe error has occurred. The BSM shall stop the feeding of banknotes and show an error message to the operator. The BSM enters state BS_ERROR either if it detects an error of its own or if it recognises that any CDI2 Device has entered state DS_ERROR. A CDI2 Device enters state DS_ERROR either if it detects an error of its own (additionally updating its Error State and setting the READY line to logical low, both immediately before the state change) or if it recognises that the BSM has entered state BS_ERROR. If not all CDI2 Devices enter state DS_ERROR within the specified timeout, the BSM may proceed with a shutdown anyway to shut down the CDI2 Devices that are still functional in an ordered way.

Table 28: CDI2 System States in Operation Phase

6.7.3 DMB Initialisation commands

During the process of the DMB initialisation, FTP is used to exchange configuration data (see 6.5.3 and 6.6.3 respectively). The files are formatted as XML.

Therefore, any CDI2 device needs to provide following standard files:

- machine_info.xml with write permission
- device_info.xml with read permission
- device_config.xml with write permission
- current_error.xml with read permission
- error_log.xml with read and write permission

Data types used as properties		
Code	**Data type**	**Size**
0x01	Signed char	1 Byte
0x02	Unsigned char	1 Byte
0x03	Signed Integer 16bit	2 Byte
0x04	Unsigned integer 16bit	2 Byte
0x05	Signed Long Integer 32bit	4 Byte
0x06	Unsigned Long Integer 32bit	4 Byte
0x07	Float single precision (IEEE-754)	4 Byte
0x0A	1 ASCII character	1 Byte
0x0B	4 ASCII characters	4 Byte
0x0C	8 ASCII characters	8 Byte
0x0D	16 ASCII characters	16 Byte
0x11	1 UTF16 character	2 Byte
0x12	4 UTF16 characters	8 Byte
0x13	8 UTF16 characters	16 Byte
0x14	16 UTF16 characters	32 Byte
0x21	1 UTF32 character	4 Byte
0x22	4 UTF32 characters	16 Byte
0x23	8 UTF32 characters	32 Byte
0x24	16 UTF32 characters	64 Byte
0x31	binary data	16 Byte
0x32	binary data	32 Byte
0x33	binary data	64 Byte
0x34	binary data	128 Byte
0x35	binary data	256 Byte
0x36	binary data	512 Byte

Table 29: Data types

For ASCII characters, only printable characters (0x20 – 0x7E) are allowed. Data types for multiple (i.e. 4, 8, 16) ASCII, UTF16 or UTF32 characters/units shall be used as a buffer, where unused characters/units are set to 0. For UTF16 and UTF32, note that, in principle, there are representable characters that require more than a single UTF16 or UTF32 unit, respectively. If such characters are possible as result for a property, a data type has to be chosen that can accommodate all encoding units even in the worst case.

6.7.3.1 Machine Info

The Machine Info file includes general information about the machine and the used CDI version. This XML structure is sent to the CDI2 device via an FTP file write to machine_info.xml.

The detailed description of the Machine Info snippet can be found in Appendix B.

Example:

```xml
<INFO>
    <CDIVersion major="2" minor="4">
    </CDIVersion>
    <Customer Name="OeBS" country="Austria" currency="Euro">
    </Customer>
    <Transport feedingDirection="right" minimumSpeed="9.5" maximumSpeed="10.5">
    </Transport>
</INFO>
```

6.7.3.2 Device Info – Camera System

The Device Info file includes all the necessary information about the Camera System (general information, image size, additional images, data structure of properties, image evaluation capabilities …)

This XML structure is retrieved from the CDI2 device via an FTP file read from *device_info.xml*.

Furthermore, this XML file carries the BSMInfo element, which will be filled out or modified by the BSM before it is sent back to the camera system via the Device Configuration file. The initial attributes of the BSMInfo element are meaningless when sent as Device Info.

Finally, yet importantly, there is the ConfigData element, which can be used to transfer proprietary data to the camera system. Such a regime has to be agreed bilaterally between the CS supplier and the BSM supplier.

The detailed description of the Device Info file can be found in Appendix B.

Note that the CS is required to read serial numbers ("numberreading" must be "true") and therefore must have a property named "serialnumber" (see also the XML description in Appendix B.9).

Example:

```xml
<CameraSystem NodeID="100" UseSecondBFA="true"/>
    <General manufacturer="CamTech" description="CS123" SWVersion="4.54aa" deviceclass="4"
serialnumber="123456" SWUpdateSupported="true"/>
    <Connections IDBsupport="true" TTSsupport="true" TTSTCresolution="0.1" BPresentOffset="20"/>
    <Images>
        <Image type="R_left " resolution="0.2" internalresolution="0.2" height="1016" width="508"
IDBstreamnr="0" GVSPPayloadType="1"/> <!--dimensions in pixels as put to the IDB (@127dpi)-->
        <Image type="G_left" resolution="0.2" internalresolution="0.2" height="1016" width="508"
IDBstreamnr="1" GVSPPayloadType="1"/>
        <Image type="B_left" resolution="0.2" internalresolution="0.2" height="1016" width="508"
IDBstreamnr="2" GVSPPayloadType="1"/>
        <Image type="IR_left" resolution="0.2" internalresolution="0.2" height="1016" width="508"
IDBstreamnr="3" GVSPPayloadType="1"/>
        <Image type="R_right" resolution="0.2" internalresolution="0.1" height="1016" width="508"
IDBstreamnr="4" GVSPPayloadType="1"/>
        <Image type="G_right" resolution="0.2" internalresolution="0.2" height="1016" width="508"
IDBstreamnr="5" GVSPPayloadType="1"/>
        <Image type="B_right" resolution="0.2" internalresolution="0.2" height="1016" width="508"
IDBstreamnr="6" GVSPPayloadType="1"/>
        <Image type="IR_right" resolution="0.2" internalresolution="0.1" height="1016" width="508"
IDBstreamnr="7" GVSPPayloadType="1"/>
        <Image type="transmission" resolution="0.2" height="1016" width="508" IDBstreamnr="8"
GVSPPayloadType="0x8000"/>
        <Image type="num" resolution ="0.1" height="800" width="250" IDBstreamnr="9"
GVSPPayloadType="0x8000"/>
        <Image type="UV" resolution ="0.5" height="360" width="180" IDBstreamnr="10"
GVSPPayloadType="1"/>
    </Images>
    <ImageEvaluation supported="true">
```

```
        <IECapabilities fitness="true" numberreading="true"/>
    </ImageEvaluation>
    <SupplementalData numBNRESULTSegments="1">
        <Property id="4" name="judgement" unit="" type="0x02" offset="0" />
        <Property id="5" name="result" unit="" type="0x02" offset="1" />
        <Property id="6" name="quality" unit="" type="0x02" offset="2" />
        <Property id="7" name="serialnumber" unit="" type="0x0D" offset="3" />
<!--id will be defined by BSM and sent back via the device configuration message-->
        <Property id="8" name="orientation" unit="" type="0x02" offset="19" />
        <Property id="9" name="denomination" unit="" type="0x02" offset="20" />
        <Property id="10" name="series" unit="" type="0x02" offset="21" />
        <Property id="11" name="bnlength" type="0x06" offset="22" />
        <Property id="12" name="bnwidth" type="0x06" offset="26" />
        <Property id="13" name="soil" type="0x06" offset="30" />
    </SupplementalData>
    <ServiceFiles>
    <!-- DeviceStatus, Statistics, Configuration and Diagnosis Data are mandatory  -->
        <ServiceFile description="DeviceStatus" filename="dev_stat.xml" filemode="r" type="text"/>
        <ServiceFile description="Statistics" filename="stat.txt" filemode="r" type="text"/>
        <ServiceFile description="Configuration" filename="myparam.cfg" filemode="rw" type="bin"/>
        <ServiceFile description="Diagnosis Data" filename="logfile.txt" filemode="rw" type="text"/>
        <ServiceFile description="LastMeasurement" filename="lastscan.bin" filemode="r" type="bin"/>
        <ServiceFile description="Last100" filename="allscans.bin" filemode="r" type="bin"/>
    </ServiceFiles>
    <BSMInfo mechanicalSlot="1" mountingPosition="left" timeBudgetForBNRESULT="120"/>
     <!--these attributes will be provided by BSM in the device configuration file
         these attributes do not have any meaning when sent as detector info
            - mechanicalSlot Number is just a reference to the detector casing position
            - mountingPosition is the mounting side with respect to the transport
            - timeBudgetForBNRESULT is the time between the trigger and the last time
               at which the BNRESULT must be delivered to the BSM in ms
        -->
    <ConfigData>
       <!--This section can be used to send additional configuration data to the
            detector (detector configuration message)
           Further structure and coding of this section is not specified
           Support of this configuration data transfer regime is optional and needs to
            be agreed bilaterally between detector and machine manufacturer
         -->
    </ConfigData>
</CameraSystem>
```

6.7.3.3 Device Info – Detector and Image Evaluation Units

The Device Info XML file for Detectors and Image Evaluation unit is identical and a reduced version of the Device Info of a Camera System.

This XML structure is retrieved from the CDI2 device via an FTP file read from *device_info.xml*.

The detailed description of the Device Info file can be found in Appendix B.

Example Detector:

```
<Detector NodeID="2">
    <General serialnumber="2013.1001.0097" description="UVP1" deviceclass="2" manufacturer="OeBS"
SWVersion="4.54aa" SWUpdateSupported="false"/>
    <Connections IDBsupport="false" TTSsupport="true" TTSTCresolution="0.5" BPresentOffset="50"/>
    <ImageEvaluation supported="false">
    </ImageEvaluation>
    <SupplementalData numBNRESULTSegments="1">
        <Property id="21" name="judgement" unit="" type="0x02 offset="0"" />
        <Property id="22" name="result" unit="" type="0x02" offset="1" />
        <Property id="23" name="quality" unit="" type="0x02" offset="2" />
        <Property id="24" name="intensity" unit="" type="0x06" offset="3" />
        <Property id="25" name="secret1" unit="" type="0x11" offset="7" />
    </SupplementalData>
    <ServiceFiles>
        <ServiceFile description="DeviceStatus" filename="dev_stat.xml" filemode="r" type="text"/>
        <ServiceFile description="Statistics" filename="statistics.txt" filemode="r" type="text"/>
        <ServiceFile description="Configuration" filename="config.cfg" filemode="rw" type="bin"/>
        <ServiceFile description="Diagnosis Data" filename="log.txt" filemode="rw" type="text"/>
        <ServiceFile description="LastMeasurement" filename="last.bin" filemode="r" type="bin"/>
        <ServiceFile description="Last100" filename="allscans.bin" filemode="r" type="bin"/>
    </ServiceFiles>
    <BSMInfo mechanicalSlot="1" mountingPosition="left" timeBudgetForBNRESULT="120"/>
    <ConfigData>
    </ConfigData>
</Detector>
```

Example Image Evaluation Unit:

```xml
<Detector NodeID="5">
   <General serialnumber="SMa_505" description="SoilMaster" deviceclass="4"
manufacturer="SoilTechnologies" SWVersion="4.54aa" SWUpdateSupported="true"/>
   <Connections IDBsupport="true" TTSsupport="false" TTSTCresolution="1" BPresentOffset="0"/>
   <ImageEvaluation supported="true">
      <IECapabilities fitness="true" numberreading="false"/>
   </ImageEvaluation>
   <SupplementalData numBNRESULTSegments="1">
      <Property id="14" name="judgement" unit="" type="0x02" offset="0" />
      <Property id="15" name="result" unit="" type="0x02" offset="1" />
      <Property id="16" name="quality" unit="" type="0x02" offset="2" />
      <Property id="17" name="denomination" unit="" type="0x02" offset="3" />
      <Property id="18" name="series" unit="" type="0x02" offset="4" />
      <Property id="19" name="orientation" unit="" type="0x02" offset="5" />
      <Property id="20" name="avg_soil" unit="" type="0x06" offset="6" />
      <Property id="21" name="max_soil" unit="" type="0x06" offset="10" />
   </SupplementalData>
   <ServiceFiles>
      <ServiceFile description="DeviceStatus" filename="dev_stat.xml" filemode="r" type="text"/>
      <ServiceFile description="Statistics" filename="stat.csv" filemode="r" type="text"/>
      <ServiceFile description="Configuration" filename="param.det" filemode="rw" type="bin"/>
      <ServiceFile description="Diagnosis Data" filename="diag.txt" filemode="rw" type="text"/>
      <ServiceFile description="LastResult" filename="last.scan" filemode="r" type="bin"/>
   </ServiceFiles>
   <BSMInfo mechanicalSlot="1" mountingPosition="none" timeBudgetForBNRESULT="120"/>
   <ConfigData>
   </ConfigData>
</Detector>
```

6.7.3.4 Device Configuration

The BSM uses the Device Configuration to configure a CDI2 Device. Initially the BSM reads the Device Info XML file, completes the information of the BSMInfo element, inserts the consecutive, unique property id and sends this information back to the CDI2 Device as Device Configuration.

Following elements shall be changed by the BSM:

- BSMInfo
  - mechanicalSlot
  - mountingPosition
  - timeBudgetForBNRESULT
- SupplementalData
  - propertyID(s)
- ConfigData

This Device Configuration is sent to the CDI2 device via an FTP file write to *device_config.xml*. For an IEU without an optional sensor, the BSM shall set mechanicalSlot="0" and the IEU shall ignore this value.

6.7.4 DMB cyclic commands

6.7.4.1 SoC (Start of Cycle)

	Offset	Length	Code / Data	Content
Ethernet Type II	0	6	0x 01-11-1E-00-00-01 (SoC multicast MAC)	Destination MAC Address
	6	6	MAC address of the BSM	Source MAC Address
	12	2	0x88AB (POWERLINK)	EtherType
POWERLINK	14	1	0x01 (SoC)	MessageType
	15	1	255 (broadcast)	Destination
	16	1	240 (MN)	Source
	17	1	0x00	reserved
	18	1	MC<<7 + 0	MC flag: multiplexed cycle has ended. PS flag: cycle prescaler
	19	1	0x00	reserved
	20	8	see 6.8.6	NetTime
	28	8	see 6.8.6	RelativeTime
	36	24	0x00	reserved
Ethernet Type II	60	4	…	CRC32
Total Size	64 Bytes			

Table 30: SoC frame

6.7.4.2 BSMINFO 0x81

The BSMINFO command is sent in each cycle from the BSM to all CDI2 devices. This message is used to transfer common information to all devices, like the actual BSM state and transport speed of the sorting machine. Furthermore, dedicated information is sent to each device having a physical casing position on the transport path.

Additionally, BSMINFO is used to broadcast the Series/Denomination/Orientation information as a separate block, designated as BNINFO. BNINFO consists of the BNID of the banknote to which the information belongs and the fields for the series, denomination and orientation.

Only Banknote IDs with values in the range from 0 to 0xFFFFFFFE are valid. For every banknote, the BNINFO shall only be sent once. As the BSMINFO message is sent periodically, a Banknote ID of 0xFFFFFFFF is used to signal that there is no new banknote approaching.

The same mechanism is used to indicate the validity of the BNINFO. BN series, BN denomination and BN orientation are only valid if its associated BNID is valid.

The Banknote ID number shall be increasing for each banknote, but does not need to be sequential.

The Banknote ID is a 32-bit number consisting of 4 bytes. Its numbering scheme is up to the BSM manufacturer e.g.:

- Session number + 3 Byte sequential number => 0x05123456 (Session 5 with banknote sequential number 123456)
- Timestamp + sequential number => 0x13375503 (13:37:55 Banknote 3 in this second)
- 4 Byte sequential number => 12345678 (sequential number 12345678)

The banknote ID may be reset after a power-off of the BSM.

Furthermore, the BSMINFO provides information fields, which allow a CDI2 device to determine the point in time when a banknote will pass the Nominal Casing Position. By this means a CDI2 device does not need to rely on the trigger signals provided by a TTS port; instead it can recover the proper timing information out of the BSMINFO command.

The trigger concept is based on the assumption that the BSM maintains a transport clock counter for each detector position. The transport clock counter is incremented with each TC tick, thus it increments by 1 for each 0.1 mm banknote travel. Any point of time at which a BN arrives at a detector's nominal position (the trigger time) can be represented by a certain TC counter value. The trigger time values for each BN and each detector position are known to the BSM. The BSM may use either a common transport clock counter for all detector positions, or it may maintain separate counters for specific detector positions.

For each BSMINFO frame the BSM captures the transport counters and broadcasts their values as TC_COUNTn fields. As a time reference the capture shall happen at the start of the current POWERLINK SoC frame.

The BSM uses the TC_TRIGn fields to provide the information about the BN trigger time to each CDI2 device. A CDI2 device operated in Non-TTS mode can use TC_COUNTn and TC_TRIGn to determine the arrival time for each banknote passing the detectors Nominal Position. The trigger time is defined as the point of time at which the TC_COUNTn value becomes equal to TC_TRIGn. In Non-TTS mode, a device may recover TTS equivalent BP and TC signals from the TC_COUNTn and TC_TRIGn fields, as described in chapter 5.4 Non-TTS Operation.

The timing requirements for TC_COUNTn are equivalent to the TTS TC signal timing requirements with 0.1 mm resolution (see 5.1 General). Specifically, the TC_COUNTn must be valid at BSM States BS_REQUEST_TO_SORT and BS_SORTING. TC_COUNTn may start with an arbitrary value when the BSM enters BS_REQUEST_TO_SORT.

TC_TRIGn values are valid only when BNIDn is valid, thus invalid BNIDn/TC_TRIGn pairs must use BNIDn=0xFFFFFFFF. The BSM must send exactly one valid BNIDn/TC_TRIGn pair for each banknote passing sensor position n. BNIDn/TC_TRIGn has to be provided by the BSM for each position, regardless of whether a device is using TTS or non-TTS mode. The BSM must send the BNIDn/TC_TRIGn pair early enough so that it is available at the CDI2 device when the leading edge of the banknote is 50 mm in front of the scheduled trigger point. But it must not send it before TC_COUNTn exceeds TC_TRIGn+200 of the previous banknote.

The notation BNIDn and TC_TRIGn applies to the CN with Node ID n. A special case are BNIDn and TC_TRIGn with index 16. A Camera System may use the second BFA, thus occupying both BFA#1 and BFA#2. In this case, the CS will provide a Device Information File with UseSecondBFA="true" (see chapter B.9 XML element description). To provide a second trigger at BFA#2 to the CS, the BSM by convention has to use BNID16 and TC_TRIG16 for this. Note that this BFA#2 trigger for a CS is available in non-TTS mode, only, i.e. no TTS connection is available for the CS at BFA#2. Furthermore, no other CDI2 device may use Node ID 16 in this case. If, however, BFA#2 is used for a standalone CDI2 detector, these restrictions do not apply: The detector will get its trigger according to its Node ID, and both TTS and non-TTS operation are available.

For an IEU without an optional sensor, BNIDn and TC_TRIGn are not used (i.e. its BNIDn is always 0xFFFFFFFF).

The order of BNIDn and TC_TRIGn info versus BNINFO is not guaranteed. BNIDn and TC_TRIGn information is sent as soon as the banknote is approaching the casing position, whereas the BNINFO for a particular BN is sent earlier, as soon as it is available.

Additionally, the BSMINFO frame contains an individual 32-bit sequence number field, SEQUENCE_NR. The purpose of this field is debug support. Note that the BNRESULT frame (see 6.7.4.4 BNRESULT 0x41) has a SEQUENCE_NR field, too, and that the following requirements apply to the SEQUENCE_NR in both the BSMINFO as well as the BNRESULT frame.

For the sender, it is mandatory to provide the SEQUENCE_NR and to increment it by 1 for each new frame. This shall be done independent of the actual CDI2 payload. The SEQUENCE_NR counter shall be implemented as modulo-n-counter, so that the counter starts at 0x00 when it overflows at 0xFFFFFFFF.

For a receiver, on the other hand, it is not required to evaluate the SEQUENCE_NR. An implementer is free to check the sequence number and use it during the development and debugging phase. CDI2 does not require any error handling depending on the SEQUENCE_NR field.

	Offset	Length	Code / Data	Content
Ethernet Type II	0	6	0x 01 11 1E 00 00 02 (PRes multicast MAC)	Destination MAC Address
	6	6	MAC address of BSM	Source MAC Address
	12	2	0x88AB (POWERLINK)	EtherType
POWERLINK	14	1	0x04 (PRes)	MessageType
	15	1	255 (broadcast)	Destination
	16	1	240 (MN)	Source
	17	1	…	NMTStatus of MN
	18	1	0x01 (RD=1, MS=0)	RD Ready flag MS Multiplexed Slot flag
	19	1	0x00 (PR=0, RS=0)	PR Priority flags RS RequestToSend flags
	20	1	0x00	PDOVersion
	21	1	0x00	reserved
	22	2	0x53 (83)	Size
CDI2	24	1	0x81 (BSMINFO)	Command ID
	25	4	0x00 - 0xFFFFFFFF	SEQUENCE_NR
	29	1	See Table 21	BSM State
	30	2	0x00	reserved
	32	4	0x00 - 0xFFFFFFFF	TC_COUNT1
	36	4	0x00 - 0xFFFFFFFF	BNID1 *)
	40	4	0x00 - 0xFFFFFFFF	TC_TRIG1
	44	4	0x00 - 0xFFFFFFFF	TC_COUNT2
	48	4	0x00 - 0xFFFFFFFF	BNID2 *)
	52	4	0x00 - 0xFFFFFFFF	TC_TRIG2
	56	4	0x00 - 0xFFFFFFFF	TC_COUNT3
	60	4	0x00 - 0xFFFFFFFF	BNID3 *)
	64	4	0x00 - 0xFFFFFFFF	TC_TRIG3
	68	4	0x00 - 0xFFFFFFFF	TC_COUNT4
	72	4	0x00 - 0xFFFFFFFF	BNID4 *)
	76	4	0x00 - 0xFFFFFFFF	TC_TRIG4
	80	4	0x00 - 0xFFFFFFFF	TC_COUNT5
	84	4	0x00 - 0xFFFFFFFF	BNID5 *)
	88	4	0x00 - 0xFFFFFFFF	TC_TRIG5
	92	4	0x00 - 0xFFFFFFFF	TC_COUNT6
	96	4	0x00 - 0xFFFFFFFF	BNID6 *)
	100	4	0x00 - 0xFFFFFFFF	TC_TRIG6
	104	4	0x00 - 0xFFFFFFFF	TC_COUNT7
	108	4	0x00 - 0xFFFFFFFF	BNID7 *)
	112	4	0x00 - 0xFFFFFFFF	TC_TRIG7
	116	4	0x00 - 0xFFFFFFFF	TC_COUNT8
	120	4	0x00 - 0xFFFFFFFF	BNID8 *)
	124	4	0x00 - 0xFFFFFFFF	TC_TRIG8
	128	4	0x00 - 0xFFFFFFFF	TC_COUNT9

	Offset	Length	Code / Data	Content
	132	4	0x00 - 0xFFFFFFFF	BNID9 *)
	136	4	0x00 - 0xFFFFFFFF	TC_TRIG9
	140	4	0x00 - 0xFFFFFFFF	TC_COUNT10
	144	4	0x00 - 0xFFFFFFFF	BNID10 *)
	148	4	0x00 - 0xFFFFFFFF	TC_TRIG10
	152	4	0x00 - 0xFFFFFFFF	TC_COUNT11
	156	4	0x00 - 0xFFFFFFFF	BNID11 *)
	160	4	0x00 - 0xFFFFFFFF	TC_TRIG11
	164	4	0x00 - 0xFFFFFFFF	TC_COUNT12
	168	4	0x00 - 0xFFFFFFFF	BNID12 *)
	172	4	0x00 - 0xFFFFFFFF	TC_TRIG12
	176	4	0x00 - 0xFFFFFFFF	TC_COUNT13
	180	4	0x00 - 0xFFFFFFFF	BNID13 *)
	184	4	0x00 - 0xFFFFFFFF	TC_TRIG13
	188	4	0x00 - 0xFFFFFFFF	TC_COUNT14
	192	4	0x00 - 0xFFFFFFFF	BNID14 *)
	196	4	0x00 - 0xFFFFFFFF	TC_TRIG14
	200	4	0x00 - 0xFFFFFFFF	TC_COUNT15
	204	4	0x00 - 0xFFFFFFFF	BNID15*)
	208	4	0x00 - 0xFFFFFFFF	TC_TRIG15
	212	4	0x00 - 0xFFFFFFFF	TC_COUNT16
	216	4	0x00 - 0xFFFFFFFF	BNID16 *)
	220	4	0x00 - 0xFFFFFFFF	TC_TRIG16
	224	4	0x00 - 0xFFFFFFFF	BNINFO: BNID *)
	228	1	see Table 32	BNINFO: BN Series
	229	1	see Table 32	BNINFO: BN Denomination
	230	1	see Table 33	BNINFO: BN Orientation
	231	1	0x00	BNINFO: reserved
Ethernet Type II	232	4	…	CRC32
Total Size:	236 bytes			

*) 0x00 - 0xFFFFFFFE: BNIDn and TC_TRIGn valid;
0xFFFFFFFF: BNIDn and TC_TRIGn not valid

Table 31: BSMINFO

Banknote Series			Denomination		
Code	**Name**	**Short Name**	**Code**	**Name**	**Short Name**
0	Test / Calibration	Test	1	Blank Sheet	Blank
			2	Calibration	Calib
			…		
1	Euro Series 1	ES1	1	Euro 5	E5
			2	Euro 10	E10
			3	Euro 20	E20
			4	Euro 50	E50
			5	Euro 100	E100
			6	Euro 200	E200
			7	Euro 500	E500
2	Euro Series 2	ES2	1	Euro 5	E5
			2	Euro 10	E10
			3	Euro 20	E20
			4	Euro 50	E50
			5	Euro 100	E100
			6	Euro 200	E200
			7	Euro 500	E500
3-10	Reserved for future Euro Series				
11	US Dollar Series 1	US1	1	US Dollar 1	US1
			2	US Dollar 2	US2
			3	US Dollar 5	US5
			4	US Dollar 10	US10
			5	US Dollar 20	US20
			6	US Dollar 50	US50
			7	US Dollar 100	US100
12	US Dollar Series 2	US2	3	US Dollar 5	US5
			4	US Dollar 10	US10
			5	US Dollar 20	US20
			6	US Dollar 50	US50
			7	US Dollar 100	US100
13	US Dollar Series 3	US3	3	US Dollar 5	US5
			4	US Dollar 10	US10
			5	US Dollar 20	US20
			6	US Dollar 50	US50
			7	US Dollar 100	US100
14-20	Reserved for future US Dollar Series				
21-254	Free to be used by other countries				
255	Undefined / error				

Table 32: Definition of banknote series / denomination codes

During normal operation, the BSM receives the Banknote Series and Denomination codes from the CS via BNRECOGNITION and copies these values into its BSMINFO message. However, a CS is not expected to recognise specimens used for testing and calibration. Therefore, in a test or calibration mode, the BSM must override the Banknote Series and Denomination codes received from the CS and set the appropriate values in its BSMINFO message itself.

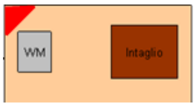
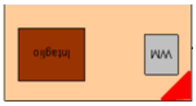
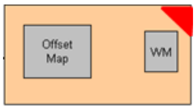
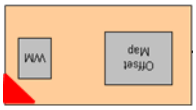
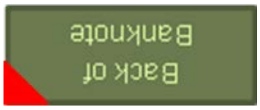
Orientation	Euro system name	Euro orientation	General name	General orientation
1	FF – front side face forward		Front	
2	FR – front side reverse		Front Reverse	
3	BF – back side face forward		Back	
4	BR – back side reverse		Back Reverse	

Table 33: Definition of orientation codes (as seen by the BSM operator when notes are on the feeder)

The above table describes the orientation based on the banknotes.

6.7.4.3 PReq (PollRequest) 0x82

The PReq command is sent in the isochronous cycle and is used to request a BNRESULT from the CN.

A PReq is sent to 4 controlled nodes per cycle. Therefore, this message is sent to a specific CN only every fourth cycle.

	Offset	Length	Code / Data	Content
Ethernet Type II	0	6	MAC address of respective CN	Destination MAC Address
	6	6	MAC address of the BSM	Source MAC Address
	12	2	0x88AB (POWERLINK)	EtherType
POWERLINK	14	1	0x03 (PReq)	MessageType
	15	1	respective Node ID	Destination
	16	1	240 (MN)	Source
	17	1	0x00	reserved
	18	1	0x21 (MS=1, EA=0, RD=1)	MS Multiplexed Slot flag EA Execption Acknowledge flag RD Ready flag
	19	1	0x00	reserved
	20	1	0x00	PDOVersion
	21	1	0x00	reserved
	22	2	0x24 (36)	size
CDI2	24	1	0x82 (PReq)	Command ID
	25	35	0x00	reserved
Ethernet Type II	60	4	…	CRC32
Total Size	64 Bytes			

Table 34: PReq frame

6.7.4.4 BNRESULT 0x41

The BNRESULT command is sent as answer to a PReq command and is used to retrieve the state of the controlled node, the Note Recognition and the Banknote Result data.

Note that the BNRESULT includes the 32-bit sequence number field SEQUENCE_NR just like the BSMINFO frame. For detailed information, please refer to chapter 6.7.4.2.

This command, as shown in Table 35, is sent cyclically.

	Offset	Length	Code / Data	Content
Ethernet Type II	0	6	0x 01 11 1E 00 00 02 (PRes multicast MAC)	Destination MAC Address
	6	6	MAC address of the CN	Source MAC Address
	12	2	0x88AB (POWERLINK)	EtherType
POWERLINK	14	1	0x04 (PRes)	MessageType
	15	1	255 (broadcast)	Destination
	16	1	respective Node ID	Source
	17	1	…	NMTStatus of CN
	18	1	0x01	RD Ready flag MS Multiplexed Slot flag
	19	1	PR<<3 + RS = Nr. of pending frames (0-7) +highest priority (0-7)<<3	PR Priority flags RS RequestToSend flags
	20	1	0x00	PDO Version
	21	1	0x00	reserved
	22	2	0x584 (1412)	size
CDI2	24	1	0x41 (BNRESULT)	Command ID
	25	4	0x00 - 0xFFFFFFFF	SEQUENCE_NR
	29	1	See Table 21	CDI2 device state
	30	1	...	Error state
	31	1	…	Maintenance state
	32	4	0x00 - 0xFFFFFFFF	BNRECOGNITION: BNID 0x00 - 0xFFFFFFFE ... valid Note Recognition, BNID 0xFFFFFFFF ... invalid Note Recognition
	36	1	see Table 32	BNRECOGNITION: BN Series
	37	1	see Table 32	BNRECOGNITION: BN Denomination
	38	1	see Table 33	BNRECOGNITION: BN Orientation
	39	1	0x00	BNRECOGNITION: reserved
	40	4	0x00 - 0xFFFFFFFF	BNRESULT: BNID 0x00 - 0xFFFFFFFE ... valid BN Result, BNID 0xFFFFFFFF ... invalid BN Result
	44	1	see Table 32	BNRESULT: BN Series
	45	1	see Table 32	BNRESULT: BN Denomination

	46	1	see Table 33	BNRESULT: BN Orientation
	47	1	0x00	BNRESULT: reserved
	48	1	0 - 3	BNRESULT: segment number
	49	3	0x00	BNRESULT: reserved
	52	1400	…	BNRESULT: Supplemental Data
Ethernet Type II	1452	4	…	CRC32
Total Size	1456 Bytes			

Table 35: BNRESULT frame

CDI2 device state

The CDI2 device state shall be valid any time and is used to indicate the current status of the CDI2 component according to Table 21.

Error state

The error state shall be valid at any time and is used to indicate CN error conditions to the BSM. Errors shall be indicated only when the CN is in state ERROR.

Error State Encoding:

Bit [0] POWERLINK error
0 ... no error
1 ... error(s) occurred

Bit [1] TTS error
0 ... no error
1 ... error(s) occurred

Bit [2] IDB error
0 ... no error
1 ... error(s) occurred

Bit [3] Application error
0 ... no error
1 ... error(s) occurred

Bit [7:4] reserved

Maintenance state

The maintenance state shall be valid at any time and is used to indicate required maintenance actions to be considered by the BSM. Such demand shall allow the BSM to initiate required actions like air pulse or give the CDI2 device time for a more detailed self-test before the CDI2 device enters Error State.

The detailed reaction to different maintenance requirements shall be customer configurable to e.g. only inform the operator but not stop the sorting, or initiate an air pulse in the next packet gap…

Maintenance State Encoding:

Bit [0] air pulse required

Bit [1] manual cleaning required

Bit [2] self-test required

Bit [3] calibration required

Bit [4:7] reserved

For maintenance actions that a device can detect (e.g. a calibration), it shall reset the corresponding maintenance status bit after performing this action. For other maintenance actions (e.g. air pulse), the device shall assume that this has been carried out until the next feed stop (i.e. in FEED_OFF state) and reset the maintenance state bit during the next self-test. The device should make this assumption even if the Maintenance State Bit has been raised in the FEED_OFF state.

BNRECOGNITION (Note Recognition)

The Note Recognition is used by the Camera System to send series, denomination and orientation information to the BSM. The Note Recognition information consists of the fields BNID, BN Series, BN Denomination and BN Orientation.

BNRECOGNITION: BNID

The Note Recognition information is only valid when its BNID is set to a value not equal to 0xFFFFFFFF, otherwise BN Series, BN Denomination and BN Orientation can be ignored.

BNRECOGNITION: BN Series, BN Denomination, BN Orientation

This is the result of the banknote recognition. Series, denomination and orientation are as specified in Table 32 and Table 33.

BNRESULT (Banknote Result)

A CDI2 Device sends its results of fitness or authentication processing in the Banknote Result message. The fields of this message are described in the following.

BNRESULT: BNID

The Banknote Result information is only valid when its BNID is set to a value not equal to 0xFFFFFFFF, otherwise all fields of this message can be ignored.

BNRESULT: segment number

To accommodate more than 1,400 Bytes of supplemental data it is possible to split up the data into up to 4 segments and send them as 4 consecutive BNRESULT telegrams (as answer to 4 consecutive PReq). The individual segments are indicated by the BNRESULT segment number, starting with 0 being the first segment. It is mandatory that BNID, BN Series, BN Denomination and BN Orientation are identical in all associated BNRESULT segments.

Segmented transmission of BNRESULT has to be indicated by a Detector during startup in the Device Info message, using the numBNRESULTSegments property (see 6.7.3.2 and 6.7.3.3).

BNRESULT: BN Series, BN Denomination and BN Orientation

This is the information about series, denomination and orientation of the banknote as specified in Table 32 and Table 33

Actually, this information is a copy of the BNINFO, as it has been received from the BSM in the BSMINFO message. If the information would not be available, for whatever reason, the fields shall be set to invalid. A device with its own Series/Denomination/Orientation detector will include the detected information as part of the Supplemental Data, independent of what has been sent as BN Series, BN Denomination and BN Orientation.

The BN Series, BN Denomination and BN Orientation information is marked as invalid when all three fields are set to 0xff. Namely BN Series (offset 33) = 0xff, BN Denomination (offset 34) = 0xff and BN Orientation (offset 35) = 0xff.

BNRESULT: Supplemental Data

This block contains Supplemental Data, as additional result properties of the Detector being sent to the BSM. The individual items and their offsets and formats within the Supplemental Data are provided by the Device in its Device Info file (see 6.7.3.2 and 6.7.3.3) during startup. The size of each data type shall follow Table 29 and shall use little endian byte order.

BNRESULT: Judgement and Result code

The BNRESULT message does not have explicit fields for Judgement and Result code. Instead the Supplemental Data carries two mandatory properties for this purpose. Thus, the first two properties of each CDI2 device are fixed to be Judgement and Result code (see 6.7.3.2 and 6.7.3.3).

The code values listed in Table 36 and Table 37 shall be used for Result and Judgement.

Result Code	Meaning
1	No BN Info received
2	Calculation not finished
3	Hardware error
4	Close feed
5	Denomination / Orientation error
6	Feature intensity
7	Feature shape
8	Feature presence
9-15	Reserved
16	Incomplete image data (packet loss on IDB)
17-31	Reserved
32-255	Detector specific result code (Must be described in the Detector manual if used)

Table 36: Banknote result codes

Judgement Code	Meaning
0	FIT
1	UNFIT
2	REJECT
3	SPECIAL
4-255	Not used

Table 37: Banknote judgement codes

BNRESULT: Measurement Quality

To indicate the reliability of each measurement to the BSM each CDI2 Device has to indicate the overall measurement quality via the mandatory property “quality”. The quality property is fixed to be the third property of each CDI2 Device.

This property can then be used via the Aggregation Unit to further refine the measurement results or to initiate maintenance actions as e.g. ask the operator for a cleaning cycle.

If useful a CDI2 device can have additional properties to indicate the measurement quality of detailed results. For example, the reliability of the serial number reading might be indicated via a property “SNR_certainty”.

6.7.4.5 SoA (Start of Asynchronous)

	Offset	Length	Code / Data	Content
Ethernet Type II	0	6	0x 01 11 1E 00 00 03 (SoA multicast MAC)	Destination MAC Address
	6	6	MAC address of the BSM	Source MAC Address
	12	2	0x88AB	EtherType
POWERLINK	14	1	0x05 (SoA)	MessageType
	15	1	255 (broadcast)	Destination
	16	1	240 (MN)	Source
	17	1	NMTState	NMTStatus of MN
	18	1	0x00	reserved
	19	1	0x00	reserved
	20	1	…	RequestedServiceID
	21	1	…	RequestedServiceTarget
	22	1	0x11	EPLVersion
	23	37	0x00	reserved
Ethernet Type II	60	4	…	CRC32
Total Size	64 Bytes			

Table 38: SOA frame

6.7.5 HTTP Port and Additional Services

The manufacturer of a CDI2 device must provide a HTTP port to implement device specific user dialogs for service and maintenance purposes. Each Detector shall implement a HTTP web server to provide these services in a user-friendly fashion:

- Display of device status
- Display of statistics
- Display of diagnosis information
- Specific dialogs for e.g. calibration

More information about HTTP access over POWERLINK is described in chapter 3.3.

Additional Services shall be provided in a standardised manner for the following purposes:

- Remote configuration with e.g. download/upload of model information, upload of parameters
- Provide raw measuring data and raw results
- Provide device status
- Provide statistics
- Provide diagnosis information, e.g. error reports and log files

Additional Services are implemented as FTP file transfers (see 6.5.3).

The Device Information of the CDI2 device shall provide a description of the available services, with filenames and the kind of information (see chapters 6.7.3.2 and 6.7.3.3).

The Additional Service for device status shall be an XML file containing the node DeviceStatus. A detailed description of this node can be found in Appendix B.

Example:

```xml
<DeviceStatus>
   <Device designation="Camera System" manufacturer="CamTech" deviceclass="4" />
   <SubDevice name="RGB123" serialnumber="12345" numberOfNotesMeasured="1111111" upTimeHours="111"
dateOfLastCalibration="[Date-Time-Format]" >
      <DeviceSpecificEntries>
         <Entry name="someRgbDeviceSpecificName1" value="123" />
         <Entry name="someRgbDeviceSpecificName2" value="234" />
         <Entry name="someRgbDeviceSpecificName3" value="345" />
         <Entry name="someRgbDeviceSpecificName4" value="456" />
         <Entry name="someRgbDeviceSpecificName5" value="567" />
         <Entry name="someRgbDeviceSpecificName6" value="678" />
         <Entry name="someRgbDeviceSpecificName7" value="789" />
         <Entry name="someRgbDeviceSpecificName8" value="890" />
      </DeviceSpecificEntries>
   </SubDevice>
   <SubDevice
      name="RGB456" serialnumber="23456" numberOfNotesMeasured="2222222" upTimeHours="222"
dateOfLastCalibration="[Date-Time-Format]" >
      <DeviceSpecificEntries>
         <Entry name="someRgbDeviceSpecificName1" value="123" />
         <Entry name="someRgbDeviceSpecificName2" value="234" />
         <Entry name="someRgbDeviceSpecificName3" value="345" />
         <Entry name="someRgbDeviceSpecificName4" value="456" />
         <Entry name="someRgbDeviceSpecificName5" value="567" />
         <Entry name="someRgbDeviceSpecificName6" value="678" />
         <Entry name="someRgbDeviceSpecificName7" value="789" />
         <Entry name="someRgbDeviceSpecificName8" value="890" />
      </DeviceSpecificEntries>
   </SubDevice>
   <SubDevice
      name="Electronics" serialnumber="12345" numberOfNotesMeasured="3333333" upTimeHours="333"
dateOfLastCalibration="[Date-Time-Format]" >
      <DeviceSpecificEntries>
         <Entry name="someElectronicsDeviceSpecificName1" value="123" />
         <Entry name="someElectronicsDeviceSpecificName2" value="234" />
         <Entry name="someElectronicsDeviceSpecificName3" value="345" />
         <Entry name="someElectronicsDeviceSpecificName4" value="456" />
         <Entry name="someElectronicsDeviceSpecificName5" value="567" />
         <Entry name="someElectronicsDeviceSpecificName6" value="678" />
         <Entry name="someElectronicsDeviceSpecificName7" value="789" />
         <Entry name="someElectronicsDeviceSpecificName8" value="890" />
      </DeviceSpecificEntries>
   </SubDevice>
</DeviceStatus>
```

HTTP and Additional Services shall be available whenever feasible. In real-time critical situations, however, a CDI2 device does not need to respond to HTTP and Additional Services. This is the case during DS_SORTING, but also during DS_READY_TO_SORT where the CDI2 device has to be able to switch to DS_SORTING within a very short time. Additionally, HTTP and Additional Services will not be feasible during states DS_STARTUP, DS_INITIALISATION and DS_SHUTDOWN.

6.7.6 Software Update

A software update procedure is initiated by a privileged user at the BSM. The BSM downloads the Software Update File by means of an FTP File Transfer (see 6.5.3) to the CDI2 device first. Then it initiates the actual firmware update by use of a dedicated update command. During the update, the CDI2 device may restart. Upon completion of the update sequence, the Device Information of the updated device will reflect the new version. It is in the responsibility of the BSM to check that the configuration of the CDI2 System is still consistent.

The BSM may initiate a Software Update only when the CDI2 System is in state READY_TO_SHUTDOWN. In the first step, the BSM shall ensure that the device is in updateSwStatus=IDLE by reading SDO updateSwStatus. Then it sends the Software Update File "firmware.bin" to the CDI2 Device using FTP file write and instructs the CDI2 device to prepare the software update by setting SDO updateSwCommand=PREPARE_UPDATE. At this point the device shall check if a software update is possible, e.g. it may check that "firmware.bin" is valid and contains a suitable software version. If the check succeeds, the device shall set updateSwStatus=UPDATE_REQUEST_ACCEPTED, otherwise it shall set updateSwStatus=UPDATE_REQUEST_REJECTED and log a warning.

The BSM shall wait until updateSwStatus=UPDATE_REQUEST_ACCEPTED or updateSwStatus=UPDATE_REQUEST_REJECTED, with a timeout of 30s. If the update has been rejected or the timeout has been exceeded, the BSM shall cancel the update by setting updateSWCommand=IDLE. This instructs the device to set updateSwStatus=IDLE as well.

Once the update request has been accepted by the device (updateSwStatus=UPDATE_REQUEST_ACCEPTED), the BSM initiates the actual software update by issuing updateSwCommand=PERFORM_UPDATE followed by a Device Reset (6.7.7). The device shall then perform the software update throughout the Device Reset, when it enters the NMT state NMT_GS_INITIALISATION. During the software update the device may become offline until the update process has been completed. It will then continue in state NMT_GS_INITIALISATION, proceeding the Device Reset as specified.

The device shall reset updateSwCommand and updateSwStatus to IDLE upon restart.

Once the BSM receives an IdentResponse from the updated device, it shall issue a message to the operator about the successful completion of the software update. In case that no IdentResponse has been received within 180 s, it shall issue an error message to the operator.

SDO updateSwCommand
Data Type: UNSIGNED8
Access: rw

0 ... IDLE (default)
1 ... PREPARE_UPDATE
2 … PERFORM_UPDATE

SDO updateSwStatus
Data Type: UNSIGNED8
Access: r

0 ... IDLE (default)
1 ... UPDATE_REQUEST_ACCEPTED
2 ... UPDATE_REQUEST_REJECTED

6.7.7 Startup, Restart and Reset scenarios

A CDI2 Device can be restarted by a power cycle or a reset. Sources of a reset can be a reset button on the device, the TTS RESET line or a POWERLINK plain NMT state command (of which, for CDI2, only NMTSwReset is used). If the BSM initiates a reset, it shall use the RESET line for CDI2 Devices with a TTS connection and the NMTSwReset command for CDI2 Devices without a TTS connection. A power cycle or any of the resets described above puts the CN into NMT state NMT_GS_INITIALISATION, sub-state NMT_GS_INITIALISING (chapter 7.1.2.1.1.1 of [Ref 3.]) and the CDI2 Device into CDI2 State DS_START_UP, respectively.

Note that a power cycle or a reset puts a CDI2 Device into CDI2 State DS_START_UP irrespective of its previous state. However, in case of an unexpected power off or reset (i.e. if its previous state was different to DS_READY_TO_SHUTDOWN or DS_SHUTDOWN), it is acceptable that a CDI2 Device has not stored the latest data.

There may be situations where the BSM needs to restart all CDI2 Devices. Some of those situations are mentioned below, but the BSM (possibly guided by an operator) may also apply the procedure when some unexpected error situation occurs. In such a situation, the BSM shall first carry out a shutdown of the CDI2 System by leading the CDI2 Devices via READY_TO_SHUT_DOWN – optionally preceded by ERROR – to CDI2 State SHUTDOWN (see also chapter 6.7.2). Note that a CDI2 Device that does not follow is either not fully initialised or not functional. When the CDI2 System is shut down, it can be restarted and reinitialised. For a BSM that does not support the optional transition from BS_SHUTDOWN to BS_INITIALISATION (see Figure 33), both the BSM as well as all CDI2 Devices have subsequently to be restarted and reinitialised. If the BSM supports the transition from BS_SHUTDOWN to BS_INITIALISATION, it can discard its old configuration of the CDI2 System, reset all CDI2 Devices (with the TTS RESET line or the NMT state command NMTSwReset, respectively), and initialise the CDI2 System anew.

The BSM may carry out individual actions for a device, e.g. a Software Update (mandatory) or an individual reset (optional). For this, it shall first lead the CDI2 System into state READY_TO_SHUT_DOWN. In the case of a Software Update, the BSM will now conduct the procedure described in chapter 6.7.6. If a BSM that does not support the optional transition from BS_REQUEST_TO_SHUT_DOWN to BS_INITIALISATION (see Figure 33), it (or an operator) has then to follow with the restart of the entire CDI2 System as described above. A BSM with support for the optional transition from BS_REQUEST_TO_SHUT_DOWN to BS_INITIALISATION can choose a different procedure: In case of an individual reset, it can shut down the specific device by sending it an NMTStopNode, putting the CDI2 Device into state DS_SHUTDOWN, and then reset this device. In the case of a Software Update, the reset of the specific device happens as part of the update procedure. Afterwards, the BSM will enter state BS_INITIALISATION, to which all already initialised CDI2 Devices react by changing to DS_INITIALISED. The BSM then proceeds by individually initialising the respective device up to CDI2 State DS_INITIALISED. Now the BSM has to check if the configuration of the CDI2 System is still consistent. If this is not the case, the only solution is to restart all CDI2 Devices (see description above). However, if the configuration is still consistent, the BSM can bring the entire CDI2 System into state FEED_OFF as normal by switching from BS_INITIALISATION to BS_FEED_OFF.

Restarting a CDI2 Device (without software update) shall not change the contents of its file "device_info.xml". So, when the BSM - while initialising a CDI2 Device after restarting it - gets a "device_info.xml" with a changed content, it may treat this as severe inconsistency, that can only be resolved by restarting and reinitialising the whole CDI2 System (see above).

A further situation may arise where a restart of all CDI2 Devices is necessary. When the BSM initialises a CDI2 Device, it will find out its state after it has made it operational (see chapter 6.7.2.1). Normally, when the entire CDI2 System has been started, all CDI2 Devices will be in state DS_START_UP. However, if, possibly because of some error, only the BSM has started, it will find all CDI2 Devices in state DS_ERROR (because they will have detected POWERLINK errors due to the MN being temporarily unavailable, see chapter 6.8.2). In this situation, the BSM will have to restart all CDI2 Devices as described above.

6.7.8 File Commands

6.7.8.1 Error report

Meaningful error messages shall be displayed to the operator in case of error. When a CDI2 device enters the ERROR state, the BSM shall retrieve error information and display it properly.

Examples would be:

- calibration required
- more time needed before shutdown
- not ready to start sorting

Each error shall be identified by an error code and a message box text string. The error code can be used to get further error descriptions from the Device user manual.

When a CDI2 Device has a non-zero Error State, the BSM shall retrieve error information from the CDI2 device by reading the file current_error.xml (using FTP). This file has the same file format as specified for the Error Log File (see 6.8.7), but shall contain the most recent error as the only ErrorEvent entry. When the Error State of a CDI2 Device is zero, the content of current_error.xml is undefined.

6.7.8.2 Service Files for Additional Services

The BSM shall provide means to transfer Service Files from and to a CDI2 Device. The actual file transfer shall be carried out by use of FTP (see 6.5.3). A CDI2 device provides the list of available Services Files in its Device Info (see 6.7.3.2 and 6.7.3.3).

The transfer of Service Files shall be initiated on the BSM upon a user request. The BSM shall offer to load/save the files from/to a hard drive or from/to a USB memory stick. Furthermore, the BSM shall provide a means to display the file contents of text files (type="text").

6.8 CDI2 Error Handling

6.8.1 General

Any CDI2 device has to observe its state of operation. In case of a deviation, the event shall be logged into an error history and, if the severity level of the event is an error, the CDI2 device state machine shall enter the BS_ERROR state. As the CDI2 device state is reflected in the BNRESULT response (see 6.7.4.4) the BSM can detect the error condition of a CN within the next 4 DMB command cycles.

The BSM by itself shall monitor its own state and the state of the CNs as well. In case the BSM gets notified about a CDI2 device having entered the DS_ERROR state, or it detects an error condition by its own, the BSM must enter BS_ERROR state as well.

Sources of error events are:

- POWERLINK
- IDB
- TTS
- Application

To document certain events, the BSM shall maintain a log file. As a minimum requirement, the following events shall be logged:

- device changes to a non-zero error state
- device changes to a non-zero maintenance state
- BSM detects an error of its own for which a change to BS_ERROR is designated
- IDB link down
- IDB bad link quality

The log file shall be formatted as human readable text (e.g XML) and shall include at least

- date time of occurrence
- affected device (e.g. with Node ID and Device Class)
- event description

Example:

> 2018-05-18,16:40:23.3,240,8,"IDB packet loss, BNID=1234"
> 2018-05-18,16:50:23.0,1,4,"air pulse required"
> 2018-05-18,16:50:33.8,4,2,"calibration required"

For any banknote which is in the belt path when the BSM is in BS_ERROR, the BSM must ensure that the banknote is rejected.

As the BSM stops sorting due to any CDI2 device entering the DS_ERROR state, it is a general rule that a CDI2 device shall only treat a deviation as error, if the regular operation of the CDI2 device can't be continued. Otherwise the deviation has a lower severity level and it shall be treated as warning only. It shall be reported in the error log but shall not cause a state transition.

So, regarding CDI2 Devices, deviations are classified into

> "warning"
> The CDI2 Device logs the event, but no state change happens. The regular operation is continued, but the deviation might cause e.g. note rejects.
>
> "error"
> The CDI2 Device logs the event and changes to CDI2 Device State DS_ERROR. Entering DS_ERROR shall be indicated additionally by setting the READY line to logical low immediately before the state change. Due to this state change, the BSM will stop sorting and enter BSM State BS_ERROR.

In case of an error the BSM has to notify the operator by means of a proper error message. Each error shall be identified by an error code and a message box text string. The error code can be used to get further error descriptions from the Device user manual.

When the BSM exits BS_ERROR, a CDI2 Device shall exit DS_ERROR only if all error conditions have been resolved (i.e. its Error State is zero).

Useful commands and operations for error recovery are:

- POWERLINK StatusRequest/StatusResponse
  is used by the MN to query the current status of CNs that are not communicating isochronously (see chapter 7.3.3.3 of [Ref 3.])
- Request Error Report
  see 6.7.8.1
- Device Reset
  see 6.7.7
- Read Error Log file (error_log.xml)
  FTP file read, see 6.5.3
- Optional Detector manufacturer specific operations
  HTTP Port for Service and Maintenance, see 3.3

Generally, error logs must be stored persistently and shall not be cleared by a device reset. This ensures that diagnosis information is available after a restart or a power cycle of the device. In a typical scenario, before shutdown the BSM would gather the error logs from all

CDI2 devices and store those to the Central Bank (CB) provided sFTP server (see chapter 9 for more details). The error log file shall have read and write permission. Any write operation of the BSM shall clear all ErrorEvent entries. If a CDI2 Device cannot report an error or warning into the error log (e.g. because the memory is exhausted), it shall treat this as an application error (see chapter 6.8.5).

6.8.2 POWERLINK Errors

POWERLINK provides its own error handling mechanism, enabling the detection and diagnosis of error symptoms on the POWERLINK network. The standard specifies a set of error and threshold counters with adjustable threshold levels. When a threshold counter reaches its threshold level it triggers an error event. Such an error event is logged in an error history and the error event is signaled to the NMT state machine.

This chapter gives a short overview about the POWERLINK error handling and how it is applied to CDI2. For details refer to 4.7 Error Handling Data Link Layer (DLL) of [Ref 3.].

Controlled Node

The CDI2 device shall observe its POWERLINK NMT state. During normal operation, the NMT state machine will be in the NMT_CS_OPERATIONAL state. In case the NMT state machine leaves this state, usually caused by a POWERLINK error event, the CDI2 device shall enter CDI2 Device State DS_ERROR.

The NMT State machine will change state, depending on the kind of error, e.g. an internal communication error (NMT_GT6) would put the NMT CN state machine into the NMT_GS_RESET_COMMUNICATION state.

Table 39 gives an overview about the CN error counters with associated NMT error transitions and the NMT state, which will be entered after the error transition occurs.

E.g. DLL_CNLossSoC_REC would generate an error transition NMT_CT11, which triggers a state transition of the NMT state machine into NMT_CS_PRE_OPERATIONAL_1.

Error Counter	NMT Error Event	NMT State
DLL_CNCRCError_REC	NMT_CT11	NMT_CS_PRE_OPERATIONAL_1
DLL_CNCollision_REC	NMT_GT6	NMT_GS_RESET_COMMUNICATION
DLL_CNSoCJitter_REC	NMT_CT11	NMT_CS_PRE_OPERATIONAL_1
DLL_CNLossPReq_REC	NMT_CT11	NMT_CS_PRE_OPERATIONAL_1
DLL_CNLossSoA_REC	NMT_CT11	NMT_CS_PRE_OPERATIONAL_1
DLL_CNLossSoC_REC	NMT_CT11	NMT_CS_PRE_OPERATIONAL_1

Table 39: POWERLINK CN errors

As POWERLINK has provisions to detect error events by use of threshold counters, a state change out of NMT_CS_OPERATIONAL is treated as "error" event.

Managing Node

The Managing Node maintains a set of counters for MN specific errors and a dedicated set of counters for each of the CNs.

The MN specific errors lead to NMT state changes, similar how it happens on a CN. In this case the BSM shall enter the BSM State BS_ERROR.

For error conditions regarding a specific CN, the MN will exclude the CN from isochronous processing and send it an NMTResetNode command (as specified in [Ref 3.]). As the CN will leave NMT_CS_OPERATIONAL, the BSM shall consider this CDI2 Device as unavailable and thus enter the state BS_ERROR. For error recovery, the BSM shall proceed as described in chapter 6.7.7, i.e. by optionally carrying out an individual reset for the respective CDI2 Device or by restarting the entire CDI2 System.

Error Counter	NMT Error Event	NMT State
DLL_MNCRCError_REC	NMT_MT6	NMT_MS_PRE_OPERATIONAL_1
DLL_MNCollision_REC	NMT_GT6	NMT_GS_RESET_COMMUNICATION
DLL_MNCycTimeExceed_REC	NMT_MT6	NMT_MS_PRE_OPERATIONAL_1

Table 40: POWERLINK MN specific errors

Error Counter	Error Action (see [Ref 3.])
DLL_MNCNLatePResCumCnt_AU32[CN Node ID]	Remove CN from the isochronous processing. Send NMTResetNode to the respective CN.
DLL_MNCNLossPResCumCnt_AU32[CN Node ID]	Remove CN from the isochronous processing. Send NMTResetNode to the respective CN.

Table 41: POWERLINK MN errors dedicated to a specific CN

6.8.3 IDB Errors

A BSM and a CDI2 device with IDB receive capabilities have to observe the status and the quality of the GigE Vision Ethernet connection. If the IDB link status does not allow normal operation, an IDB error event shall be generated. As a result, a BSM will change to the BS_ERROR or a CDI2 device to the DS_ERROR state. Other deviations, such as e.g. packet loss, shall be treated as a warning. In this case, the BSM shall sort the respective banknote to REJECT.

Deviation	Severity
Link down	error
Bad IDB link quality e.g. missing GigE Vision sequence numbers are detected	warning

Table 42: IDB deviations

A bad or missing network cable connection must be detected and has to be reported as IDB error.

6.8.4 TTS Errors

A CDI2 device with TTS capabilities has to observe the status of the TTS signals. In case of a deviation which does not allow regular operation, the CDI2 device shall issue an error event and change into the DS_ERROR state. Otherwise the deviation shall be treated as warning.

Deviation	Description	Severity
loss_of_TC	TC input clock is lost. The event shall be triggered when no TC edges are detected within a 1 sec time window.	error
TC_out_of_range	TC input clock frequency is out of the specified range from the received machine info (see chapter 6.7.3.1)	warning
BP_without_BNID	This event is triggered when a BP input edge is detected without a proper BNID being received at the DMB.	warning
BNID_without_BP	This event is triggered if BNIDn+TC_TRIGn was received but no valid BP occurred at the expected time (when TC_COUNTn exceeds TC_TRIGn+50).	warning

Table 43: TTS deviations

Generally. a bad or missing TTS cable connection must be detected and has to be reported as TTS error.

6.8.5 Application Errors

A CDI2 device shall observe the state of its application software. In case of a deviation which does not allow regular operation, the CDI2 device shall issue an error event and change into the DS_ERROR state. Otherwise the deviation shall be treated as warning.

Application deviations could be

- Out of memory
- No illumination
- Transport jam
- Calibration required

Application deviations must be described in the respective manual. This description has to consist of error code, severity (warning/error), a descriptive text and, if applicable, an error recovery procedure.

6.8.6 Real-time Clock and Clock Synchronisation

The BSM shall maintain a real-time master clock. The time format of the master clock shall comply with POWERLINK NetTime format (see 6.1.6.7 Net Time of [Ref 3.]). Furthermore, the BSM shall support the POWERLINK RelativeTime, which is set to 0 at POWERLINK startup. The BSM broadcasts the time information as part of the SoC frame in a regular manner to the CNs, so that each CDI2 device can synchronise its local clock to the BSM's clock. See chapter 4.6.1.1.2 Start of Cycle (SoC) of [Ref 3.] for further information.

The POWERLINK NetTime comprises 64 bits and is composed as follows:

seconds	32-bit unsigned integer
nanoseconds	32-bit unsigned integer

The POWERLINK RelativeTime is represented as 64-bit unsigned integer, with a resolution of 1 µs.

The BSM shall provide 1 µs (1,000 ns) resolution for both NetTime and RelativeTime.

The time information shall be used for timestamps of warning and error messages. Specifically, it shall be used for log entries, as described in chapter 6.8.7.

6.8.7 Error Log File

A CDI2 error log file has to be formatted as an XML file. It shall contain this information:

ErrorLog
A list of logging entries in chronological order.

Each log entry shall contain these attributes:

- Timestamps
  POWERLINK NetTime distributed by SoC frame
  POWERLINK RelativeTime distributed by SoC frame
- Error code
- CDI2 device state
- Text string

Example XML of ErrorLog section:

```
<ErrorLog>
<ErrorEvent NetTime="1032859810.500000000" RelativeTime="26307000" Date="2002-09-24"
Time="09:30:10.5" CNState="DS_SORTING" ErrorState="0.0.0.0" ErrorCode="4521" Severity="warning"
message="IDB - bad IDB link quality"/>"/>
<ErrorEvent NetTime="1032859820.000000000" RelativeTime="46307000" Date="2002-09-24"
Time="09:30:30.0" CNState="DS_SORTING" ErrorState="0.0.1.0" ErrorCode="4523" Severity="error"
message="TTS - loss of transport clock (TC)"/> />
</ErrorLog>
```

6.9 Indicators

Each POWERLINK node shall provide indicator LEDs, as specified by the POWERLINK Specification (chapter 10 in [Ref 3.]).

Each POWERLINK node shall support two LEDs

- a red ERROR LED
- a green STATUS LED

6.10 Connectors/Cables

The DMB connector of each CDI2 device shall use an M12 type connector with 4 pins (D-coded). This is different to the M12 connectors for IDB with 8 pins (X-coded), so that unintentional mix-up of the cables is prevented.

The BSM shall provide a network hub with 16 free connectors of type RJ-45. The cabling and the network hub shall comply with the POWERLINK recommendations (see chapter 3.1 in [Ref 3.]).

The DMB hub shall be in a dust protected area. Therefore, standard RJ-45 connector can be used.

The DMB cables with the correct lengths for all available CDI slots (min. 8) must be provided by the BSM manufacturer. The cable length shall not exceed 20m.

For an IEU or a Detector with External Evaluation Unit, the DMB cable must be delivered by its supplier. Since the cable to the DMB hub is located in the Storage Rack and thus in a dust-protected area, no special dust protection is required on the side of the Evaluation Unit and the supplier can use its own connector type (e.g. RJ-45).

Example:

Metz Connect, Part Number: 142M4D15100
Connection line M12 plug straight - RJ45 plug straight, AWG 26 4-pole, D-coded
https://www.metz-connect.com/en/products/142m4d15100

Figure 35 Example of a DMB cable

6.11 POWERLINK Implementation Notes

Various suppliers offer different solutions to support a POWERLINK development. As an example, companies like B&R ("http://www.br-automation.com") provide development support and there are other companies offering both software and development support.

Specifically, requirements to the POWERLINK data link layer to fulfil the real-time responsiveness could be challenging for a pure software based solution. To reduce the cost and effort, the timing critical function blocks can be implemented in FPGA hardware. As an example, a dedicated IP core (openMac) to support POWERLINK FPGA implementation on Xilinx or Altera is available:

openPOWERLINK
http://sourceforge.net/projects/openpowerlink

openMac
http://sourceforge.net/p/openpowerlink/openPOWERLINK2/ci/master/tree/hardware/ipcore/doc/openmac/omethlib.pdf?format=raw

Network cards handling the POWERLINK protocol are available for a PC as well as semi- or fully-integrated modules.

General Information:

http://www.ethernet-powerlink.org/en/products/interface-cards

Example for a PCI network card handling the POWERLINK protocol:

http://www.ixxat.com/products/products-industrial/pc-interfaces/specific-solutions/pl-ib-300-pci

http://www.br-automation.com/de-at/produkte/netzwerke-und-feldbus-module/powerlink

POWERLINK module with SPI interface as it could be used in a small CDI2 detector:

http://www.anybus.com/products/abcc40.shtml

7 Mechanics

This section describes the mechanical requirements for integrating the Camera System, CDI2 Detectors and CDI1 Detectors into a BSM.

7.1 CDI1 mechanical specifications

The mechanical specification of CDI1 Casings and their mounting remains unchanged.
https://www.ecb.europa.eu/euro/pdf/Common_Detector_Interface_CDI_Spec_1_0_rev_B.pdf

7.2 CDI2 Belt Free Area (BFA)

A BSM must have an area for at least one BFA with the option of adding a 2nd BFA later. The BFA must provide a complete banknote view visible from both sides and in transmission without any obstructions such as e.g. belts or wires.

The BFA has to fulfil the following criteria:

- To present the banknote to the CS with the flutter of the banknote (the parallel displacement of the banknote to the inspection window of the detector) being within 2 mm when sorting superfit to superunfit banknotes of the customer specific denomination (very stiff folds and crumples inside the banknote which are thicker than 3 mm are outside the scope of this specification).

The banknote flutter during testing of the BFA can be measured in several ways: • Placing a ruler at the baseplate and taking images with a high-speed camera. • Install a LASER triangulation system, which measures note displacement.

- The banknote speed must be constant within the BFA area.
- Be jam robust.
- Be easily accessible when a jam has occurred in this area
  (The operator must be able to recover from the jam state without assistance)
- Be easily accessible to clean and inspect the CS inspection window(s).
- If the image acquiring part of the CS consists of only one mechanical unit (in case of 2 BFAs), the opposite side of the CS must have a uniform surface, which needs to be provided by the CS manufacturer.

Two BFA solutions have been developed to demonstrate the feasibility of the above criteria's and concept drawings are available to potential CDI2 users. These solutions are:

- Banknotes are supported over the detector surface by a vacuum block system (VAC)
- Banknotes are pushed against the detector surface by an air pressure system (TAP)

Both approaches use the surface of the CS as a guidance of the banknote while the CS will have a clear view of the banknote. The CS could consist of one or two camera units (e.g. upper and/or lower camera unit, left and/or right camera unit). Inside one BFA only one camera unit is supporting the banknote.

BSM suppliers are free to develop other BFA solutions as long as the requirements are met and the CS as defined in this specification can be integrated.

Detailed Information about the developed BFA solutions can be found in Appendix C.

7.3 Detector mounting positions

7.3.1 Double sided position

6 of the 8 detector positions must allow the mounting of detector casing on both sides of the banknote transport. In these positions, the detector casings have an adjustable distance of 0-5 mm and belts are allowed on both sides of the banknote.

7.3.2 Single sided position

2 of the 8 detector positions shall be belt-free contact positions.
This means that the distance of the banknote to the detector has to be <1 mm and no belts are allowed between detector and banknote.
It shall be possible for both contact positions to change the side of the detector with reasonable effort. Two upper, two lower and one upper plus one lower detector shall be possible.

7.4 CDI2 Casings

Next to CDI1 Detectors, the BSM shall support CDI2 Detector Casings. These are in principle identical to CDI1, but shall have the possibility to extend through the baseplate, as well as the casings for the Camera System, which is installed in the BFA only. The various casings and mountings are described in this chapter.

7.4.1 Camera System Casing

The casing shall provide space for the camera, illumination arrays, electronic circuitry and supporting hardware. When more space is needed for the electronic circuitry this has to be placed inside the additional hardware which has to fit into 3U of a 19-inch storage rack.
The surface of the detection unit, which is in contact with the banknote, must be very scratch resistant. As a dust-proof sealing is mandatory, it is not required to change the window on site.
The size of the CDI2 Camera System Casing shall be as follows:

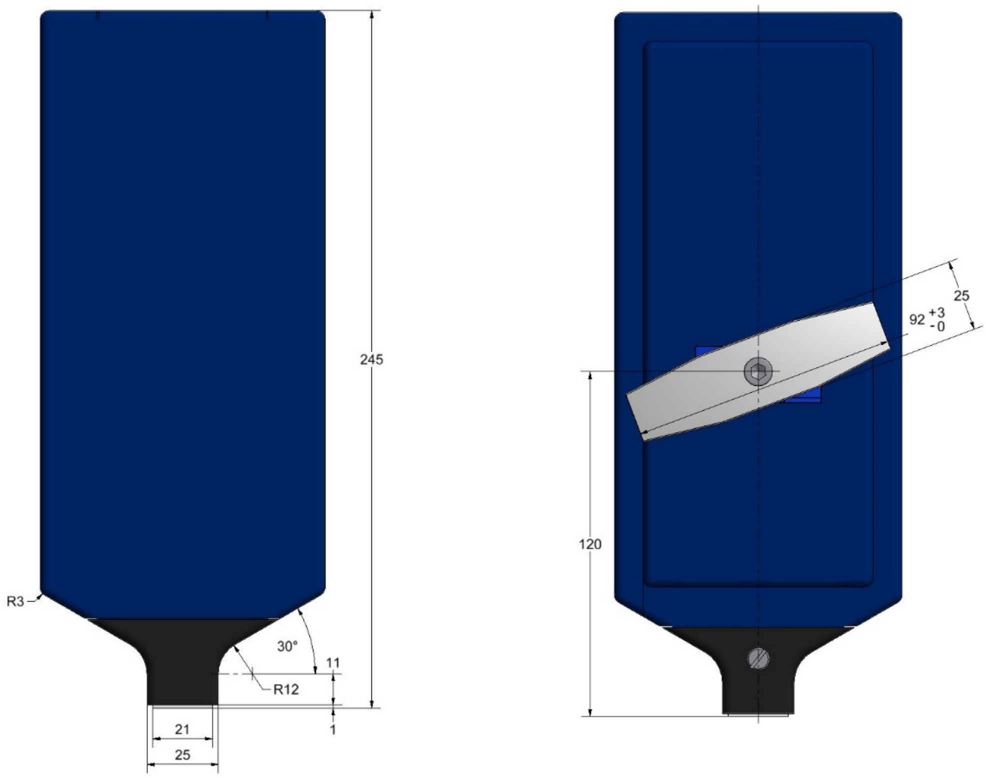


Figure 36: CDI2 Camera System dimensions (front/back view)

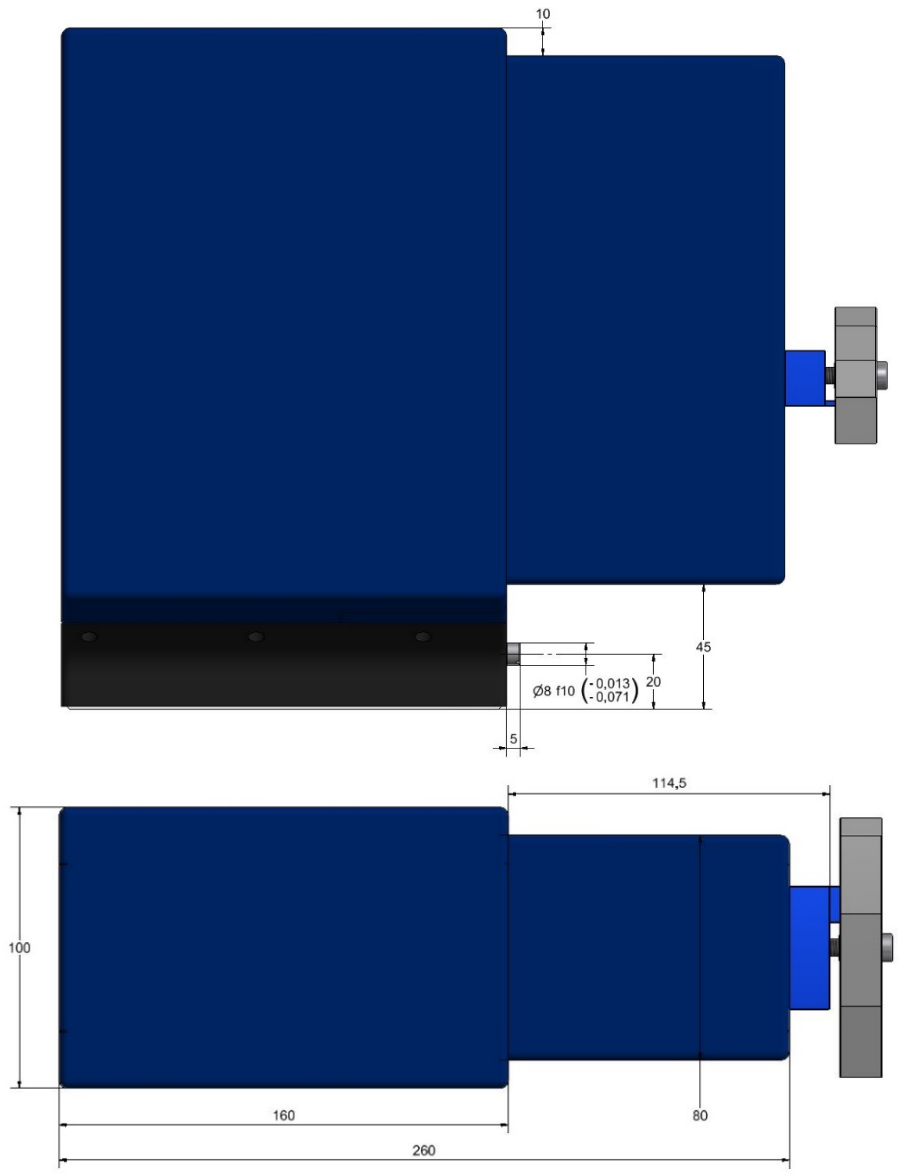


Figure 37: CDI2 Camera System dimensions (side/top view)

The casing must be IP5X and the optical end must be IP64 in order to avoid dust and moisture penetration. The sensor connectors must be IP65.

Each Camera System Casing may dissipate a maximum amount of heat of 150W. Therefore, the CS shall include cooling fins within the given casing outline. The banknote sorting machine supplier needs to ensure proper airflow to dissipate the heat.

7.4.2 Camera System mounting

The CDI2 Camera System consists of two opposite casings. The two casings are mounted asymmetrically to the banknote transport level: One casing is close to the banknote transport level, which will be called “Contact Casing” in the following and its mounting side as “Contact Side”. The opposite casing, the “Non-Contact Casing” on the “Non-Contact Side”, has a certain distance to the banknote transport level (see Figure 38 and Figure 39).

The location of the Contact Side and the Non-Contact Side are bound to the transport direction: If you stand (notionally) on the baseplate and look in transport direction, the Contact Side is on the left and the Non-Contact Side on the right (see the following figure). Note that this requirement applies to both BFA#1 and BFA#2.

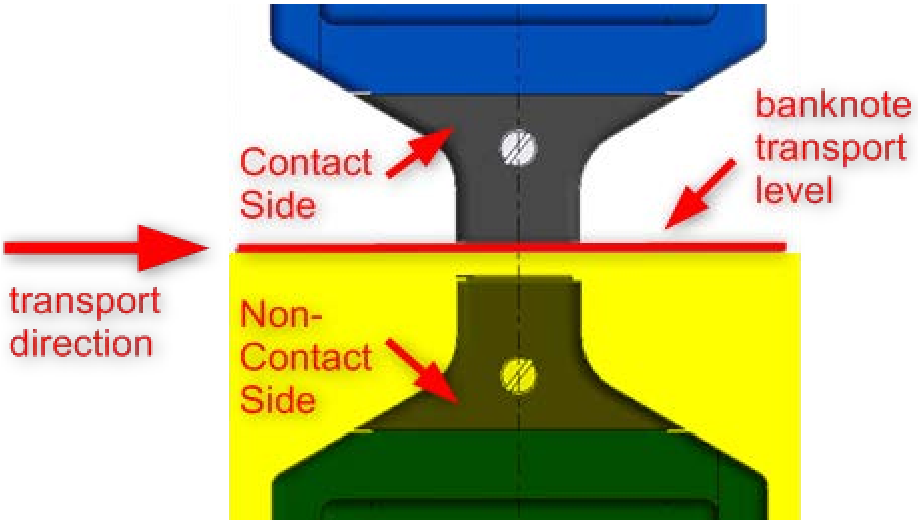


Figure 38: Location of Contact and Non-Contact Side relative to transport direction

CDI2 Camera Systems are mounted via the registration pin and the central locking bar. The distance between the registration pin and the banknote shall be adjustable to allow fine-tuning of the mechanical position.

The two co-located Camera System Casings need to be mounted with a 6 mm distance and exactly opposite each other.

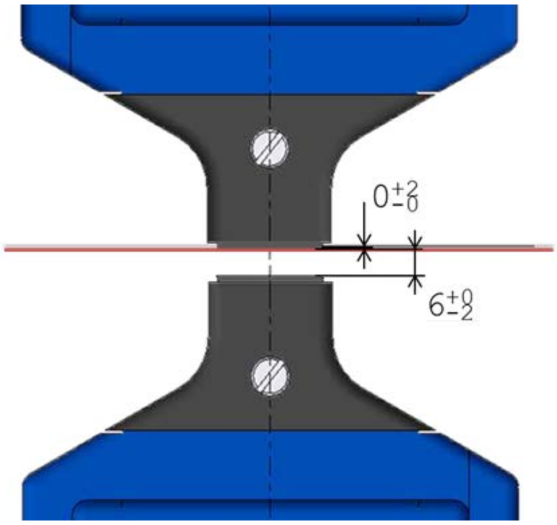


Figure 39: Camera System Casing - banknote position

The two casings shall be mounted with the following tolerances:

- Distance between the two CS Casings: 6 mm ±0.2 mm
- Alignment of the two CS Casings: ±0.062 mm

The mounting solution has to ensure that an operator without use of any tools can easily clean the sensor. The sorting machine supplier is free to choose any opening solution, which ensures an opening of at least 50 mm between co-located CS Casings in a BFA.
Such an opening must be possible without the use of any tools and without access to the rear side of the machine baseplate.
Furthermore, the solution needs to realign the two CS Casings within the defined tolerances.

7.4.3 CDI2 Detector Casing

The CDI2 Detector Casing has the same general outline as CDI1 detectors, but the total height is 200 mm and the casing may extend the upper 120 mm through the baseplate by 100 mm. When more space is needed for the electronic circuitry this has to be placed inside the additional hardware which has to fit into 1U of a 19-inch storage rack.

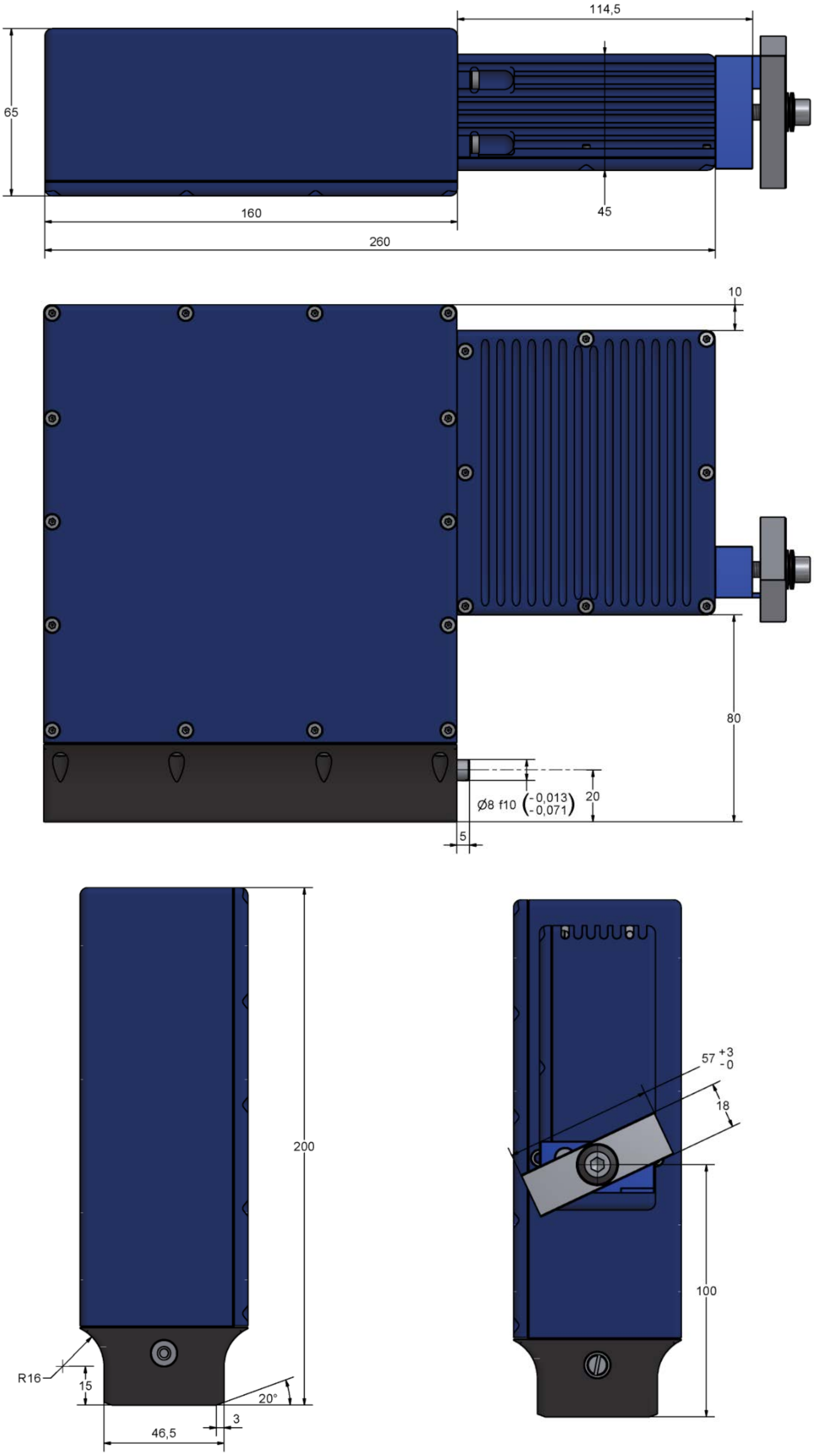


Figure 40: CDI2 Detector dimensions

7.4.4 CDI2 Detector Mounting

CDI2 Detectors are mounted via the registration pin and the central locking bar. The distance between the registration pin and the banknote shall be adjustable between 20 and 25 mm. As the resulting distance between the Detectors front surface and banknote is 0-5 mm the Detector profile needs to leave space for the belts. See more details about belt position in chapter 7.6.

The mounting solution has to ensure that an operator without use of any tools can easily clean the sensor. The sorting machine supplier is free to choose any opening solution, which ensures an opening of at least 50 mm between co-located DET Casings.
Such an opening must be possible without the use of any tools and without access to the rear side of the machine baseplate.
Furthermore, the solution needs to realign the DET Casings within 0.2 mm distance to banknote and alignment in case of a double-sided casing.

7.4.5 Connector position

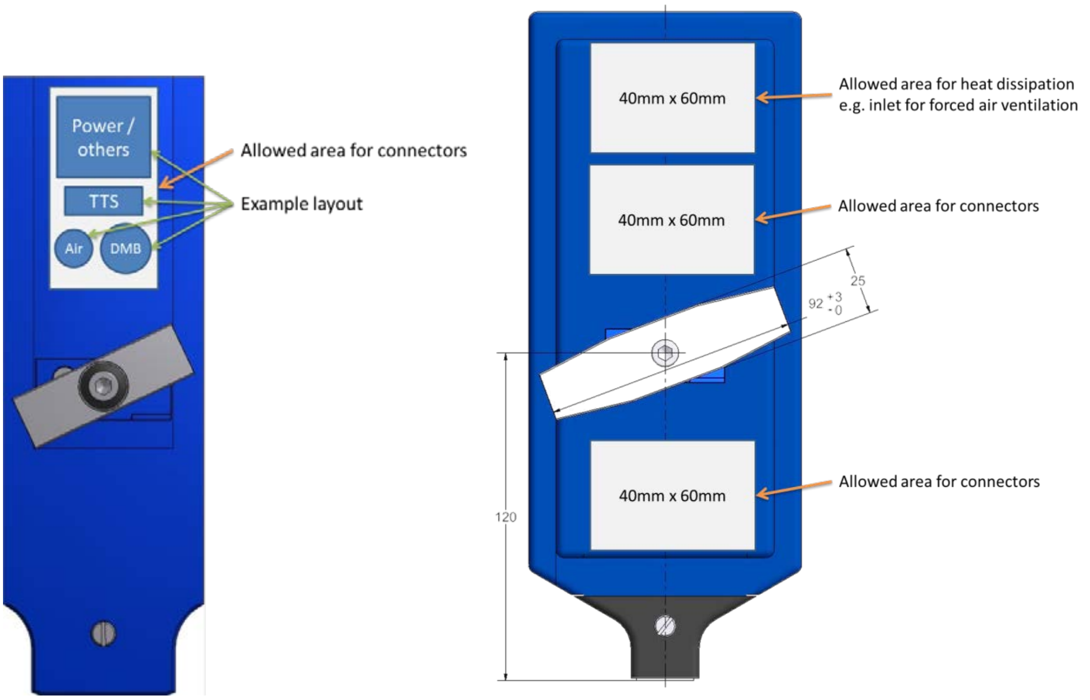


Figure 41: Allowed area for connectors (Detector left, Camera System right)

The BSM manufacturer has to ensure that the above-mentioned areas are kept free and allow cables or heat dissipation measures to extend up to 80 mm behind the CDI2 Casing.

7.4.6 Compressed Air supply

To remove dust the BSM supplies compressed air to the CDI2 Devices. This compressed air is supplied by a 6 mm hose connecting to a “Festo Quick Star”-connector in the casing.

The compressed air is supplied in 1-3 second long pulse in packet gaps at least once every 10,000 banknotes.

The supplied air has to be delivered with 600-800kPa and has to be class 2:4:1 according to ISO 8573-1:2010.

The CDI2 Device shall make sure that not more than 3 l/s of compressed air are consumed per unit. This is independent of whether the CDI2 device occupies one or both opposite mounting positions.

The timing of such an air pulse will be defined by the BSM but any CDI2 Device can request an air pulse via the Maintenance State of the BNRESULT message. See 6.7.4.4 for more details.

7.5 Note representation

The banknote position in respect to the Detectors and Camera Systems shall be as follows:

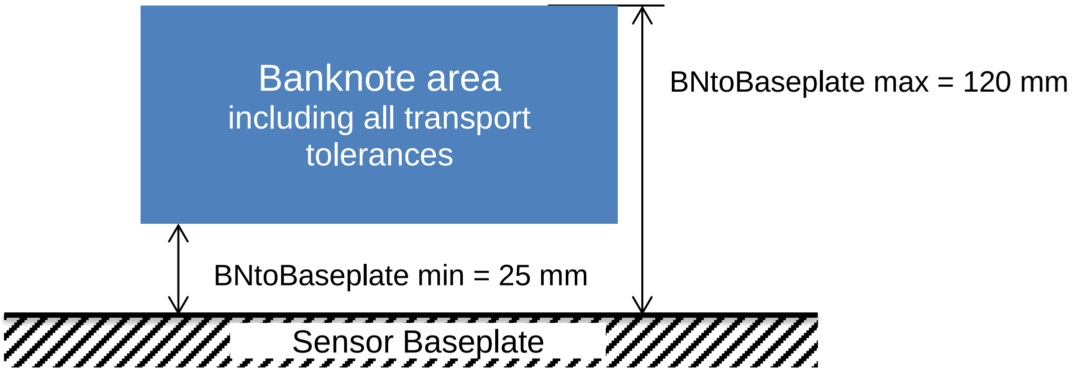


Figure 42: Note presentation

The banknote has to stay within the marked area including all allowed transport tolerances.

As far as the measurement technical design permits, the BSM should be designed for the following BN run tolerances at the banknote level:

- permissible high/low run ± 6 mm
- permissible skew run 12 mm height difference between leading and trailing edges of the banknote, but not more than ± 5°

7.6 Belt specification and Belt positions

Within the double-sided detector positions belts with following specification are allowed to be used on both sides of the banknote:

Width: max. 20 mm (including all tolerances, e.g. belt movement)
Thickness: max 2 mm (including all tolerances e.g. belt vibration)

The belts in the belt-free, one-sided detector position are not restricted.

For each Detector position the central bank can select a belt layout. Up to three different belt layouts can be incorporated in one BSM. Exchange of belt layouts must be possible during the lifetime of the sorting machine with limited effort.

For example, a central bank can select to have Layout A for the first three, Layout B for the 4th and Layout C for the last two double-sided Detector positions.

Belt layouts A, B, C and the detector positions can be selected by each customer individually.

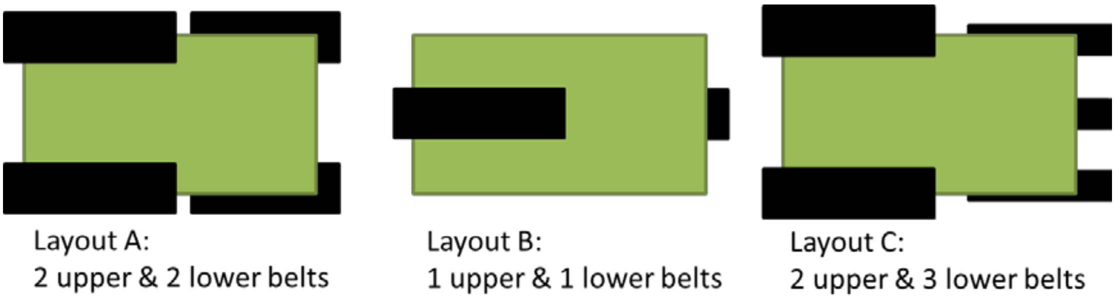


Figure 43: Exemplary belt layouts

7.7 Storage Rack for External Evaluation Units

Each BSM shall provide standard storage racks for integrating PC hardware.
The storage racks regarding the computer hardware for the sensors will be a standard 19-inch computer rack, minimum size 13 U. Preferably this storage rack is located inside the BSM. The BSM has to have precautions to remove the heat dissipated from the computers. The maximum power consumed by each single computer may not exceed 150 Watt per height unit and has to be provided or regulated by the BSM power supply.
If the storage rack cannot be put inside the BSM, the storage rack shall be attached to the BSM without any hindrance to the user of the BSM.
The 19-inch storage rack shall have a minimum depth of 800 mm (31.5 inch). Interface cables shall connect at the front panels and power cables are connected at the rear sides of the modules. All cables shall run through the floor exit of the storage rack.
The 19-inch casing for a CS, for an IEU and for an External Evaluation Unit of a Detector may have a maximum depth of 520 mm.
The casing for the CS may occupy up to 3U in height, whereas an IEU and an External Evaluation Unit of a Detector may only use 1U.
Furthermore, the switch for the IDB and the hub for the DMB shall be included in this storage rack.

7.8 General Operational Specifications

7.8.1 Safety

The Detectors and Camera Systems must comply with all applicable national regulations, including for instance:

- European CE conformity
- US Conformity

7.8.2 EMC

The Detectors and Camera Systems must comply with all applicable national EMC regulations.

7.8.3 ESD

The BFA as proposed in this specification result in banknotes sliding over the camera window at high speed. Depending on the used material this situation might lead to significant electro static charges in the front part of a Camera System.
Therefore, ESD immunity is particularly important and as far as possible materials which are less prone of generating electro static charges shall be used.

7.8.4 Other Compliances to be tested

Immunity against and prevention of unwanted emission of:

- External light influences

- Magnetic fields (and other kind of physical properties)
- High voltage fields (from neighbor detectors)

7.8.5 Physical and Chemical Environment Requirements

Detectors and Camera Systems must be tested under the following conditions, and retain full functionality: The supplier is required to certify that the equipment will operate in the below specified environments.
Operational:

- Operation between 10°C to 45°C
- Moisture between 30 to 80%
- Altitude: from sea level to 3000m
- Vibrations: +/- 5 g (Random until 500Hz)

Non-operational:

- The supplier shall ensure that the transport casing is appropriate to protect the equipment in shipping. Central banks may require specific packaging tests.

7.8.6 Water and Dust Proof requirements

The whole casing of a detector, consisting of all parts on the front and rear side of the baseplate, must comply with IP5X. The part on the front side (i.e. the banknote processing side) has to comply with IP64. To check the IP64 compliance, it is allowed to cover parts on the rear side of the baseplate.

7.9 Power Supply – Device side

Each Detector:

- Is expected to be powered with DC voltage <42V
- Has to be delivered with a power supply equipped with an IEC-60320 C14 coupler supporting 100-230V @50-60Hz
- May not consume more than 150W from the BSM power supply at any time

7.10 Power Supply – Banknote Sorting Machine side

The BSM has to provide:

- A power supply of 100-230V @50-60Hz with at least 150W for each CDI Device with a cable with an IEC-60320 C13 connector
- Alternatively, and upon bilateral agreement between the BSM supplier and Detector manufacturer, the detector can use the DC Power supply (<42V) of the BSM directly.

7.11 Connectors

All connectors must be foolproof and prevent any possible erroneous connections.

7.12 Device Cooling

All Devices must have the capacity to sink the self-heating at an ambient temperature of 10° to 45°C

7.13 Machine Cooling

The BSM must be able to extract the following maximum heat generated by all CDI Devices in addition to the standard non-CDI2 equipment. The ambient temperature within the BSM shall always be kept between 15° and 40°C.

A BSM manufacturer is free to have the storage rack outside of the BSM if necessary (see chapter 7.7).

max heat dissipation [W]	@ BFA areas (min 1, max 2)	@ CDI slots (min 8)	@ Storage Rack (min 13U)
Camera System			
casings	2*2*150 W		
additional hardware			3*150 W
optional CS IEU	already included in CS Casings and/or storage Rack		
CDI2 Detectors			
casings		2*1*30 W single detectors 6*2*30 W dual detectors	
additional hardware			8*150 W
CDI2 IEUs			
IDB switch			200 W
DMB hub			50 W
Overall	600 W	420 W	1,900 W

Table 44: Maximum heat dissipation at each CDI position

The maximum heat dissipation as shown in the table above shall be achievable for each CDI2 compliant machine but configurations with smaller cooling capacity are allowed as long as future upgrades are possible with reasonable costs and effort.

8 Aggregation Unit

A banknote sorting machine will have several Detectors installed, each providing its specific results. The various decisions and properties delivered by the detectors are aggregated in the Aggregation Unit of the BSM. As a result of the aggregation processes, the final fit/unfit/reject decision is made and supplemental data is collected.

Furthermore, the outcome of computational detectors shall allow to trigger following actions:

- Initiate an air pulse
- Stop feeding immediately
- Stop the machine at the next packet gap
- Initiate a self-test
- Inform the operator that a cleaning cycle is required
- Inform the operator that a calibration is needed
- Show user definable message to operator

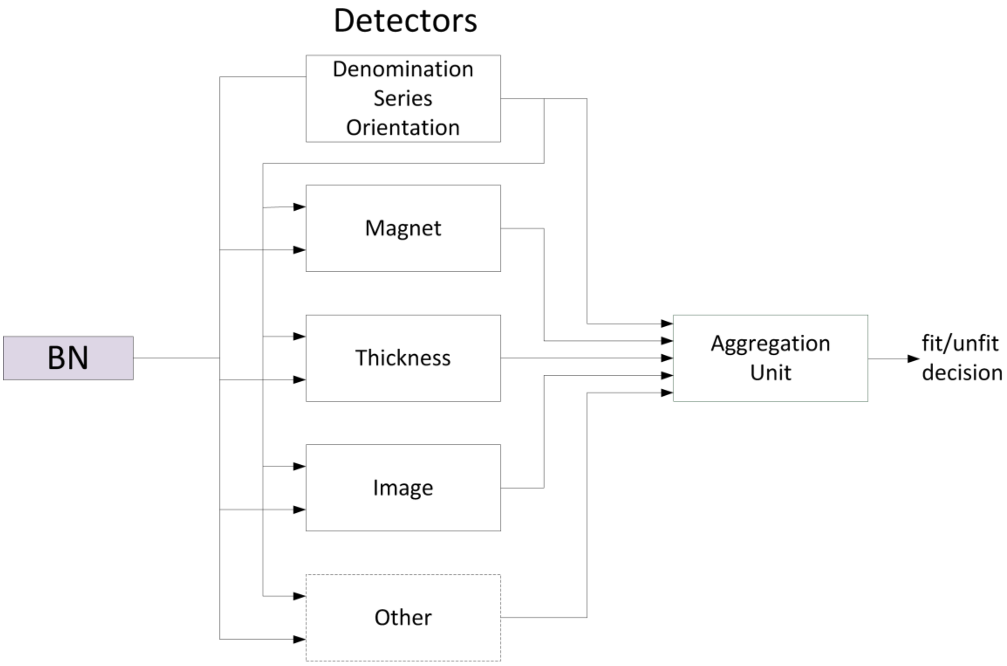


Figure 44: Example for aggregation of Detector data

8.1 Computational Detector

The process of aggregation is handled by so-called Computational Detectors, which combine properties measured or detected by the CS, or physical Detectors.

The BSM shall allow 500 of these Computational Detectors for each denomination used.

The configuration of these Computational Detectors shall be possible for central bank personal with sufficient user rights without the assistance of the BSM manufacturer.

As input for the Computational Detector, the BSM shall supply:

- ⇨ CDI2 properties
- ⇨ CDI1 judgements and supplemental data
- ⇨ At least the judgement of non-CDI detectors

8.1.1 Calculation Model

Each Computational Detector allows the combination of up to 5 decisions or properties with the following operations:

- Mathematical functions (+,-,/,*)
- Usage of constants instead of a Detector decision or property
- String functions (LEFT, RIGHT, MID, LEN)
- Boolean algebra (AND, OR, XOR, NOT)
- IF...THEN…ELSE conditions
- Reference to predefined serial number ranges specified in an XML file.
  - Serial numbers can be defined in ranges or non-sequential numbers.
  - The serial number look-up XML files can contain ranges and/or non-sequential serial numbers. The Aggregation Unit must support a look-up list with at least 20 entries. Entries can be single serial numbers, serial number ranges or look-up tables that do not exceed 10,000 banknotes per table.

The result of each Computational Detector shall always be a signed 32-bit integer, which will subsequently be compared against thresholds to come to a decision.

8.1.2 Thresholds

Each Computational Detector has 7 thresholds in increasing order forming 8 value ranges. Each of the 8 value ranges can have an individual Judgement. Furthermore, each value range can trigger data storage.

e.g.: Thresholds 0, 100, 200, 300, 400, 500, 800

Value Ranges	<0	1-100	101-200	201-300	301-400	401-500	501-800	>800
Judgement	FIT	REJECT	FIT	FIT	UNFIT	SPECIAL	SPECIAL	REJECT
Storage	1	130	0	0	2	132	196	130

Code	Storage Location
0	Don't store
1	Store aggregated data to file1
2	Store aggregated data to file2
4	Store aggregated data to file3
8	Store aggregated data to file4
16	Store aggregated data to file5
32	Store aggregated data to file6
64	Store aggregated data to file7
128	Store Images

Table 45: Storage Trigger flags

Storage Triggers can be or'd:

- 0 => no data is stored
- 1 => store aggregated data to file 1
- 196 => store image + store aggregated data to file 3 + store aggregated data to file 7

Each threshold shall have an upper and a lower limit, which is defined by the higher-level user. The lower level user may then change the threshold within these limits.

8.2 Final Decision

The final judgement shall be based on the results of the Computational Detectors as follows:

- ⇨ All judgements FIT => FIT
- ⇨ At least one UNFIT and no REJECT or SPECIAL => UNFIT
- ⇨ At least one REJECT and no SPECIAL => REJECT
- ⇨ At least five SPECIAL => SPECIAL1, SPECIAL2, SPECIAL3, SPECIAL4, SPECIAL5 (if there is no specific stacker for SPECIAL, these notes shall be sorted to REJECT)

Furthermore, Storage Trigger flags of all the Computational Detectors shall be or'd. If e.g. the outcome of the Computational Detectors is 1, 129 and 3, the final storage decision is 131.

Assignment of final decisions to physical stackers shall be made available for the central bank.

8.3 Graphical User Interface

The Graphical User Interface (GUI) for the Aggregation Unit shall enable central bank personnel with sufficient user rights to execute the following steps:

- ⇨ Add a new Computational Detector
- ⇨ View all defined Computational Detectors
- ⇨ Change the settings of a Computational Detector
- ⇨ Delete a Computational Detector
- ⇨ Import Computational Detector settings from a storage XML file
- ⇨ Export Computational Detector settings from a storage XML file

The import and export function needs to be available and support import and export at least within all the machines of one BSM supplier supporting CDI2. The BSM needs to check imported settings against the current machine configuration.

8.3.1 Access Rights

The user access shall be split into at least two levels where the highest user level can add/delete/change Computational Detectors, whereas the lower user level can only adjust the thresholds of Computational Detectors within a given range.

9 Data handling

For further analysis, the Aggregated Data of the last 2 million banknotes and Image Data of the last 1,000 banknotes shall always be stored on the BSM.

Additionally, the BSM shall provide a filter (e.g. rejected notes or notes with specific defects) to store the image data of the last 1000 filtered banknotes. This filter shall be applied by the Aggregation Unit and configured in its GUI.

Seven different XML files can be used to store the data of specific banknotes in separated files. The decision in which file the data shall be stored is defined by the threshold settings of the Computational Detectors (See 8.1.2).

Additionally, the BSM must provide a basic visualisation of this data and provide the possibility to export the data via a user command. Furthermore, the complete data shall be transferred to a central bank provided infrastructure via secure File Transfer Protocol (sFTP) at the end of a shift automatically.

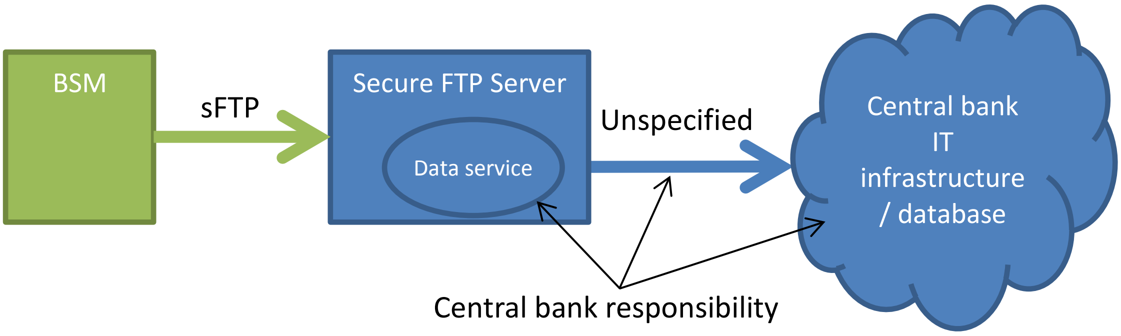


Figure 45: Data transfer schema

Such a sFTP server could be physically integrated into the BSM.

The BSM does not need to keep Aggregated Data or Image Data in case of a power-off.

9.1 Data Format

9.1.1 Aggregated Data

The aggregated data shall be available in an XML file containing the data as well as all the necessary information to read this data (machine description, sensor type description, sensor data description …).

The exported file has to be named:

DATE_TIME_SHIFT_MACHINENO_FILENO.xml
(e.g. “2011-05-21_14-02-56_5_AT-VIE#3_5.xml”).

The time stated in the filename shall be the current time of the BSM when the file is created.

Such an XML consists of three blocks of information:

1. INFO
   General Information like CDI Version, Machine type, customer…

2. CONFIG
   Details about the machine setup, the used detectors and the structure of the Supplemental Data

3. DATA
   Judgement and Supplemental Data of the banknotes

The detailed definition of the XML storage file can be found in Appendix B.

9.1.2 Image data

For each single banknote, a zip archive containing all the images shall be stored. The BSM is free to select an appropriate compression level setting for such a zip archive.

Furthermore, the BSM is free to select an appropriate lossless image format for the individual banknote images as long as the file format is widely used and documented (e.g. BMP, TIF, PNG).

10 CDI2 Tools

CDI2 Tool development is part of a separate project. Such tools are owned by the ECB/FRB and are made available for interested and qualified parties involved in CDI2 developments.

The following tools are developed in this project and form a reference system for all CDI2 components:

10.1 CDI2 Transport Simulator (TS)

For real banknote testing, a reduced banknote transport setup is developed and built. This banknote transport allows to move single banknotes in a circular way and has one CDI2 BFA and two CDI2 detector slots. For synchronising the banknote movement with the Banknote Sorting Machine Simulator, a transport clock and a banknote trigger for each casing position is provided.

The speed of the transport is adjustable remotely by the Banknote Sorting Machine Simulator between 1 m/s and 12.5 m/s.

10.2 CDI2 Banknote Sorting Machine Simulator (BSMS)

The CDI2 Banknote Sorting Machine Simulator acts like a real CDI2 BSM and may be connected with the CDI2 Transport Simulator. All commands and triggers to be sent to the CS, DET or IEU under testing are synchronised to the signals derived from the CDI2 Transport Simulator. Images provided by a Camera System will not be evaluated but stored.

The Banknote Sorting Machine Simulator provides all necessary debug, analysis and logging functions to conduct the acceptance test of a device under test (DUT), which can be a CS, DET or IEU. The tests to be conducted have an automatic evaluation as far as that could be implemented with a feasible effort (e.g. the BSMS simulates a banknote without sending BNINFO in time and automatically checks if the DUT is reacting with the right error code).

10.3 CDI2 Device Simulator (DS)

The CDI2 Device Simulator implements the functionality of a CDI2 Camera System, 8 Detectors and 6 Image Evaluation Units. All these devices act like a real CDI2 Device with the restriction of not having a real measurement unit and not being mechanically integrated into the sorting machine. The simulator provides a Banknote Displacement Detector, which is an external device based on laser triangulation, to support the qualification of the BSM's transport characteristics.

The Device Simulator provides all necessary debug, analysis and logging functions to conduct the acceptance test of a BSM. The tests to be conducted have an automatic evaluation as far as that could be implemented with a feasible effort (e.g. DS enters the error state and automatically checks if the BSM enters state BS_FEED OFF).

11 References

[Ref 1.] GigE Vision
Video Streaming and Device Control over Ethernet Standard, version 2.0
The document is supplied as an attachment to this specification or it can be obtained from AIA - Automated Imaging Association
http://www.visiononline.org/vision-standards-details.cfm?type=5

[Ref 2.] Ethernet POWERLINK Standardization Group
http://www.ethernet-powerlink.org

[Ref 3.] Ethernet POWERLINK Communication Profile Specification, EPSG DS 301 V1.3.0
https://www.ethernet-powerlink.org/fileadmin/user_upload/Dokumente/Downloads/TECHNICAL_DOCUMENTS/EPSG_DS_301_V-1-3-0__4_.pdf

[Ref 4.] File Transfer Protocol (FTP)
Postel, J. and J. Reynolds, "File Transfer Protocol", STD 9, RFC 959, DOI 10.17487/RFC0959, October 1985
https://www.rfc-editor.org/info/rfc959

[Ref 5.] Comma-Separated Values (CSV)
Shafranovich, Y., "Common Format and MIME Type for Comma-Separated Values (CSV) Files", RFC 4180, IETF, October 2005
https://www.rfc-editor.org/rfc/rfc4180.txt

Appendix A POWERLINK Details

A.1 POWERLINK Data Sheet

This is the POWERLINK configuration as used in CDI2.

For details see App. 4 Data Sheet Requirements (normative) in [Ref 3.].

Item	Value	Unit	Note
POWERLINK cycle time	1000	us	D_NMT_CycleTimeMax_U32 D_NMT_CycleTimeMin_U32
size of isochronous transmit buffer (CN)	1428	octets	maximal size of isochronous frames
size of isochronous receive buffer (CN)	208	octets	maximal size of isochronous frames
size of isochronous transmit buffer (MN)	208	octets	maximal size of isochronous frames
size of isochronous receive buffer (MN)	1428	octets	maximal size of isochronous frames
overall buffer size available for isochronous data	1490	octets	
PReq to PRes latency (CN)	10	us	CN isochronous reaction time
SoA to ASnd latency (CN)	25	us	CN asynchronous reaction time
minimum transmit-to-transmit gap (MN)	5	us	controls sequence of MN frame transmission
minimum receive-to-transmit gap (MN)	5	us	controls sequence of MN frame transmission
maximum asynchronous MTU	1500	octets	AsyncMTU_U16
ability to support multiplexed isochronous access	yes		NMT_CycleTiming_REC.MultiplCycleCnt_U8=4
asynchronous SDO transfer method	ASnd		UDP/IP and/or POWERLINK ASnd

Table 46: POWERLINK device data sheet, displaying critical device properties

A.2 POWERLINK Device Description

For details see chapter App. 2 Device Description Entries (normative) in [Ref 3.].

Bold means: setting differs from default.

Name	Description	MN	CN
D_CFM_ConfigManager_BOOL	Ability of a node to perform Configuration Manager functions	false	false
D_DLL_CNFeatureMultiplex_BOOL	node's ability to perform control of multiplexed isochronous communication	-	**true**
D_DLL_ErrBadPhysMode_BOOL	Support of Data Link Layer Error recognition: Incorrect physical operation mode	false	false
D_DLL_ErrMacBuffer_BOOL	Support of Data Link Layer Error recognition: TX / RX buffer underrun / overrun	false	false
D_DLL_ErrMNMultipleMN_BOOL	Support of MN Data Link Layer Error recognition: Multiple MNs	false	-
D_DLL_FeatureCN_BOOL	node's ability to perform CN functions	**false**	true

Name	Description	MN	CN
D_DLL_FeatureMN_BOOL	node's ability to perform MN functions	true	false
D_DLL_MNFeatureMultiplex_BOOL	MN's ability to perform control of multiplexed isochronous communication	true	-
D_DLL_MNFeaturePResTx_BOOL	MN's ability to transmit PRes	true	-
D_NMT_BootTimeNotActive_U32	Maximum boot time from cold start to NMT_MS_NOT_ACTIVEresp. NMT_CS_NOT_ACTIVE [µs]	**120000000**	**120000000**
D_NMT_CNPreOp2ToReady2Op_U32	maximum transition time of a CN from reception of NMTEnableReadyToOperate until the CN is in state NMT_CS_READY_TO_OPERATE [µs]	-	-
D_NMT_CNSoC2PReq_U32	CN SoC handling maximum time [ns], a subsequent PReq won't be handled before SoC handling was finished	-	0
D_NMT_CycleTimeGranularity_U32	POWERLINK cycle time granularity [µs] Value shall be 1 µs if POWERLINK cycle time settings may be taken from a continuum. Otherwise granularity should be a multiple of the base granularity values 100 µs or 125 µs.	1	1
D_NMT_CycleTimeMax_U32	maximum POWERLINK cycle time [µs]	1000	1000
D_NMT_CycleTimeMin_U32	minimum POWERLINK cycle time [µs]	1000	1000
D_NMT_EmergencyQueueSize_U32	maximum number of history entries in the Error Signaling emergency queue (see 6.5)	0	0
D_NMT_ErrorEntries_U32	Maximum number of error entries (Status and History Entries) in the StatusResponse frame (see 7.3.3.3.1) value range: 2 .. 14	**14**	**14**
D_NMT_ExtNmtCmds_BOOL	Support of Extended NMT State Command	false	false
D_NMT_FlushArpEntry_BOOL	Support of NMT Managing Command Service NMTFlushArpEntry	false	false
D_NMT_Isochronous_BOOL	Device may be accessed isochronously	true	true
D_NMT_MaxCNNodeID_U8	maximum Node ID available for regular CNs the entry provides an upper limit to the Node ID available for cross traffic PDO reception from a regular CN	16	16
D_NMT_MaxCNNumber_U8	Maximum number of supported regular CNs in the Node ID range 1 .. 239	**16**	**16**
D_NMT_MaxHeartbeats_U8	number of guard channels	254	254
D_NMT_MinRedCycleTime_U32	Minimum reduced cycle time [µs], i.e. minimum time between SoA frames	-	1000
D_NMT_MNASnd2SoC_U32	minimum delay between end of reception of ASnd and start of transmission of SoC [ns]	**5000**	-
D_NMT_MNBasicEthernet_BOOL	support of NMT_MS_BASIC_ETHERNET	false	-
D_NMT_MNMultiplCycMax_U8	maximum number of POWERLINK cycles per multiplexed cycle	**4**	-

Name	Description	MN	CN
D_NMT_MNPRes2PReq_U32	delay between end of PRes reception and start of PReq transmission [ns]	**5000**	-
D_NMT_MNPRes2PRes_U32	delay between end of reception of PRes from CNn and start of transmission of PRes by MN [ns]	**5000**	-
D_NMT_MNPResRx2SoA_U32	delay between end of reception of PRes from CNn and start of transmission of SoA by MN [ns]	**5000**	-
D_NMT_MNPResTx2SoA_U32	delay between end of PRes transmission by MN and start of transmission of SoA by MN [ns]	**5000**	-
D_NMT_MNSoA2ASndTx_U32	delay between end of transmission of SoA and start of transmission of ASnd by MN [ns]	**5000**	-
D_NMT_MNSoC2PReq_U32	MN minimum delay between end of SoC transmission and start of PReq transmission [ns]	**5000**	-
D_NMT_NetHostNameSet_BOOL	Support of NMT Managing Command Service NMTNetHostNameSet	false	false
D_NMT_NetTime_BOOL	Support of NetTime transmission via SoC	**true**	-
D_NMT_NetTimeIsRealTime_BOOL	Support of real time via NetTime in SoC	**true**	-
D_NMT_NodeIDByHW_BOOL	Ability of a node to support Node ID setup by HW	true	true
D_NMT_NodeIDBySW_BOOL	Ability of a node to support Node ID setup by SW	false	false
D_NMT_ProductCode_U32	Identity Object Product Code	0	0
D_NMT_PublishActiveNodes_BOOL	Support of NMT Info service NMTPublishActiveNodes	false	-
D_NMT_PublishConfigNodes_BOOL	Support of NMT Info service NMTPublishConfiguredNodes	false	false
D_NMT_PublishEmergencyNew_BOO L	Support of NMT Info service NMTPublishEmergencyNew	false	-
D_NMT_PublishNodeState_BOOL	Support of NMT Info service NMTPublishNodeStates	false	-
D_NMT_PublishOperational_BOOL	Support of NMT Info service NMTPublishOperational	false	-
D_NMT_PublishPreOp1_BOOL	Support of NMT Info service NMTPublishPreOperational1	false	-
D_NMT_PublishPreOp2_BOOL	Support of NMT Info service NMTPublishPreOperational2	false	-
D_NMT_PublishReadyToOp_BOOL	Support of NMT Info service NMTPublishReadyToOperate	false	-
D_NMT_PublishStopped_BOOL	Support of NMT Info service NMTPublishStopped	false	-
D_NMT_PublishTime_BOOL	Support of NMT Info service NMTPublishTime	false	false
D_NMT_RelativeTime_BOOL	Support of RelativeTime transmission via SoC	**true**	-
D_NMT_RevisionNo_U32	Identity Object Revision Number	0	0
D_NMT_ServiceUdpIp_BOOL	Support of NMT services via UDP/IP	false	-
D_NMT_SimpleBoot_BOOL	Ability of an MN node to perform only Simple Boot Process, if not set Individual Boot Process shall be provided	false	-
D_NWL_Forward_BOOL	Ability of node to forward datagrams	false	false
D_NWL_ICMPSupport_BOOL	Support of ICMP	false	false
D_NWL_IPSupport_BOOL	Ability of the node communicate via IP	true	true

Name	Description	MN	CN
D_PDO_DynamicMapping_BOOL	Support of dynamic PDO mapping	**false**	**false**
D_PDO_Granularity_U8	minimum size of objects to be mapped [bit]	8	8
D_PDO_MaxDescrMem_U32	maximum cumulative memory consumption of TPDO and RPDO mapping describing objects [byte]	**170**	**20**
D_PDO_RPDOChannelObjects_U8	Number of supported mapped objects per RPDO channel	**32**	**32**
D_PDO_RPDOChannels_U16	number of supported RPDO channels	**32**	**32**
D_PDO_RPDOCycleDataLim_U32	maximum sum of data size of RPDO data to be received per cycle [Byte]	**8196**	**2048**
D_PDO_RPDOOverallObjects_U16	maximum number of mapped RPDO objects, sum of all channels	**32**	**32**
D_PDO_SelfReceipt_BOOL	node's ability to receive PDO data transmitted by itself	false	false
D_PDO_TPDOChannelObjects_U8	maximum Number of mapped objects per TPDO channel	**32**	**32**
D_PDO_TPDOChannels_U16	number of supported TPDO channels	**32**	-
D_PDO_TPDOCycleDataLim_U32	maximum sum of data size of TPDO data to be transmitted per cycle [Byte]	**8196**	**2048**
D_PDO_TPDOOverallObjects_U16	maximum number of mapped RPDO objects, sum of all channels	**32**	**32**
D_PHY_ExtEPLPorts_U8	number of externally accessible Ethernet POWERLINK ports	**1**	**1**
D_PHY_HubDelay_U32	network propagation delay of the hub integrated in the device in [ns]	1000	1000
D_PHY_HubIntegrated_BOOL	indicates a hub integrated by the device	**false**	**false**
D_PHY_HubJitter_U32	jitter of the propagation delay caused by the integrated hub in [ns]	50	50
D_RT1_RT1SecuritySupport_BOOL	Support of Routing Type 1 security functions	false	false
D_RT1_RT1Support_BOOL	Support of Routing Type 1 functions	false	false
D_RT2_RT2Support_BOOL	Support of Routing Type 2 functions	false	false
D_SDO_Client_BOOL	device implements a SDO client	true	true
D_SDO_CmdFileRead_BOOL	Support of SDO command FileRead	false	false
D_SDO_CmdFileWrite_BOOL	Support of SDO command FileWrite	false	false
D_SDO_CmdLinkName_BOOL	Support of SDO command LinkName	false	false
D_SDO_CmdReadAllByIndex_BOOL	Support of SDO command ReadAllByIndex	false	false
D_SDO_CmdReadByName_BOOL	Support of SDO command ReadByName	false	false
D_SDO_CmdReadMultParam_BOOL	Support of SDO command ReadMultipleParam	false	false
D_SDO_CmdWriteAllByIndex_BOOL	Support of SDO command WriteAllByIndex	false	false
D_SDO_CmdWriteByName_BOOL	Support of SDO command WriteByName	false	false
D_SDO_CmdWriteMultParam_BOOL	Support of SDO command WriteMultParam	false	false
D_SDO_MaxConnections_U32	max. number of SDO connections	1	1
D_SDO_MaxParallelConnections_U32	max. number of SDO connections	1	1

Name	Description	MN	CN
	between a SDO client/server pair		
D_SDO_SeqLayerTxHistorySize_U16	max. number of frames in SDO sequence layer sender history value <= 31	5	5
D_SDO_Server_BOOL	device implements a SDO server	true	true
D_SDO_SupportASnd_BOOL	Support of SDO via ASnd frames	true	**true**
D_SDO_SupportPDO_BOOL	Support of SDO via PDO frames	false	false
D_SDO_SupportUdpIp_BOOL	Support of SDO via UDP/IP frames	false	false

Table 47: POWERLINK device description entries

A.3 POWERLINK Error Threshold Levels

These are the proposed error threshold levels. The values are subject to change.

Note: A threshold value of 1 means that the threshold triggers whenever a single error event occurs. Thus, the error event will lead to an immediate error condition.

CN errors:

CN Error	Threshold_U32
DLL_CNCRCError_REC	1
DLL_CNCollision_REC	1
DLL_CNSoCJitter_REC	1
DLL_CNLossPReq_REC	1
DLL_CNLossSoA_REC	1
DLL_CNLossSoC_REC	1

MN errors:

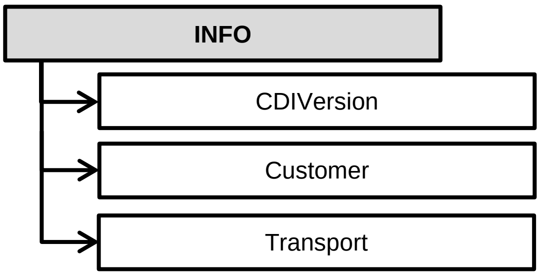
MN Error	Threshold_U32
DLL_MNCRCError_REC	1
DLL_MNCollision_REC	1
DLL_MNCycTimeExceed_REC	1

MN errors associated to a CN:

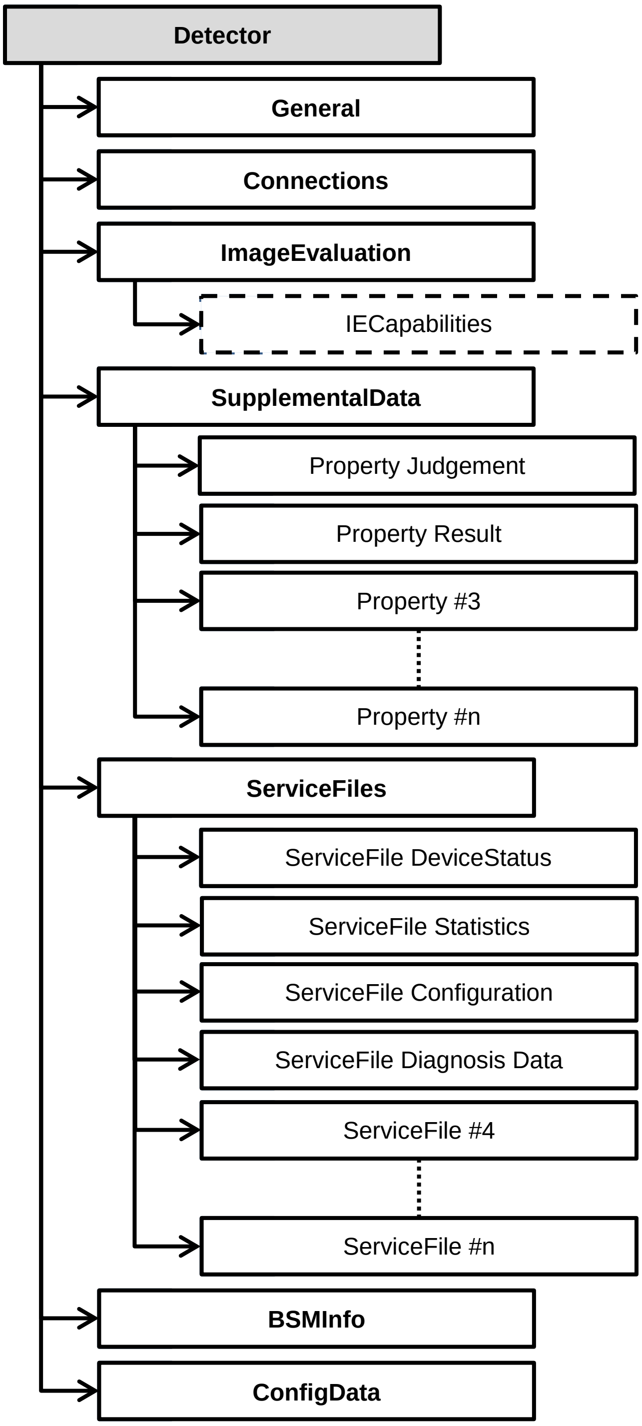
MN Error	Threshold_U32
DLL_MNCNLatePResCumCnt_AU32[CN Node ID]	1
DLL_MNCNLossPResCumCnt_AU32[CN Node ID]	1

Appendix B XML Definitions

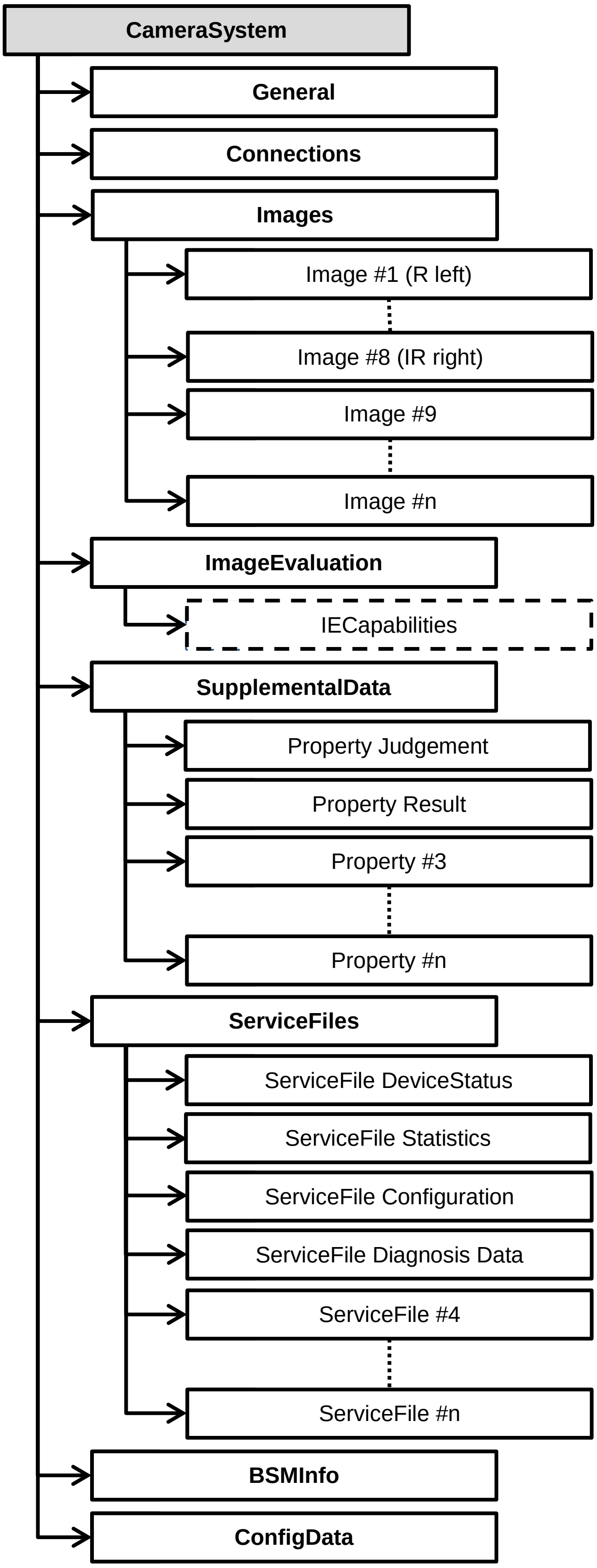
B.1 XML structure of MachineInfo



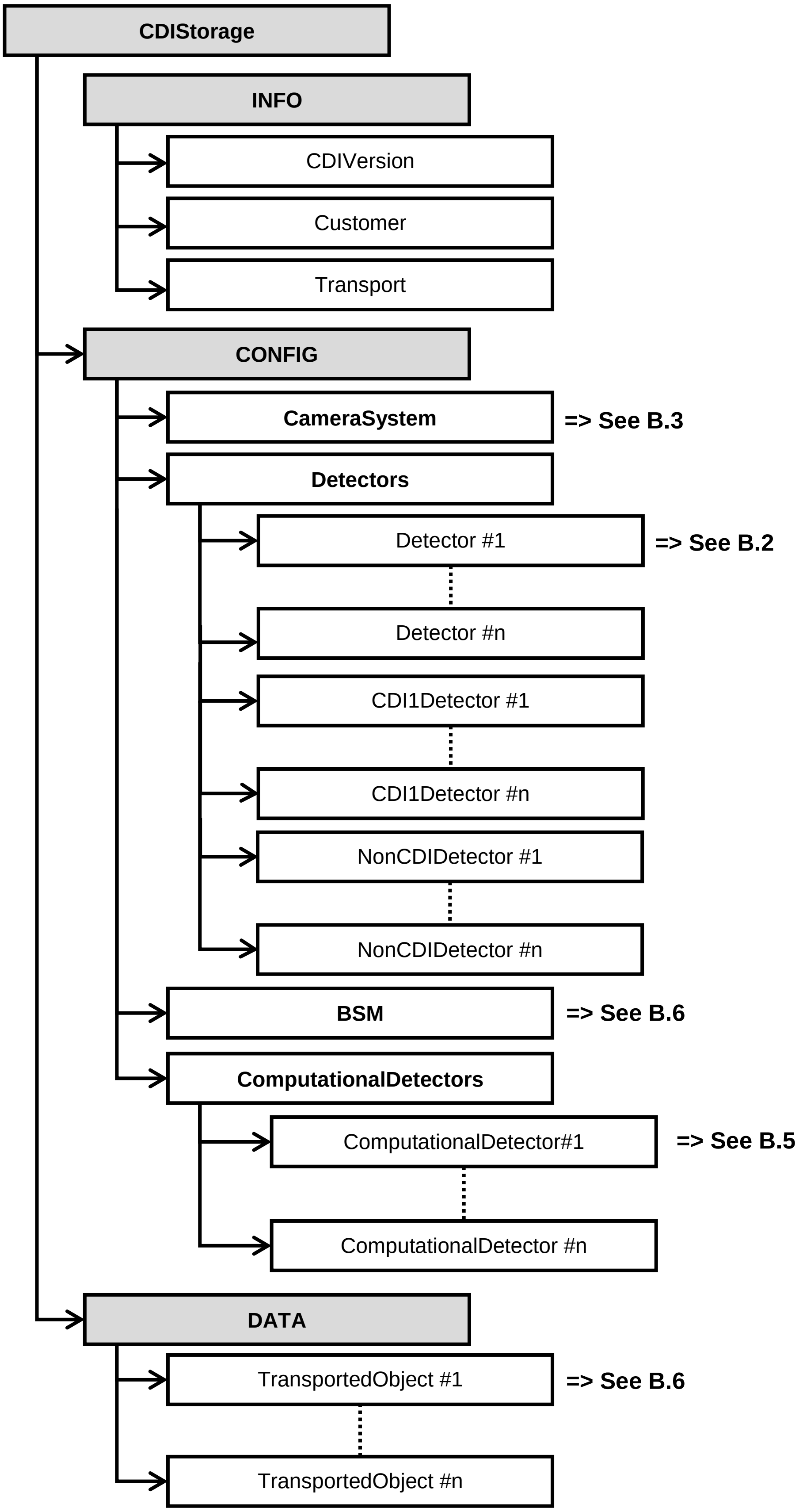
B.2 XML structure of DeviceInfo for a Detector or IEU



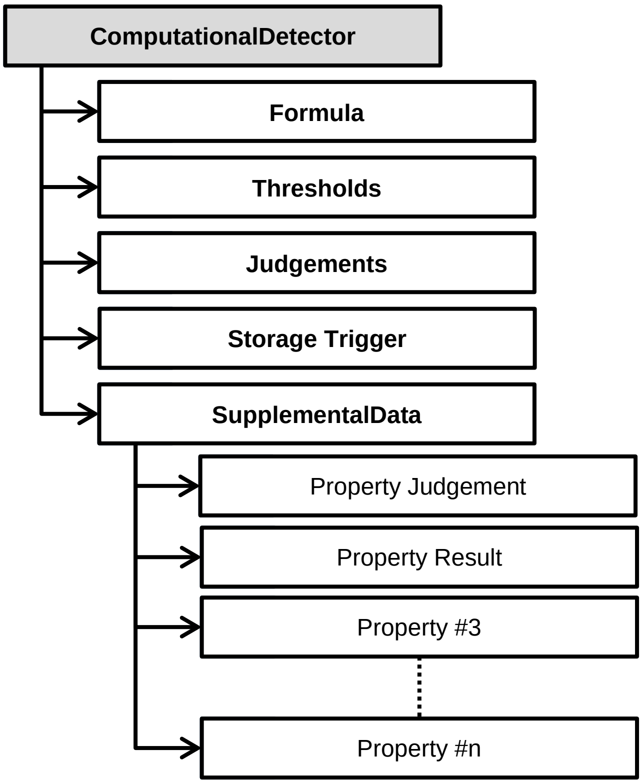
B.3 XML structure of DeviceInfo for a Camera System



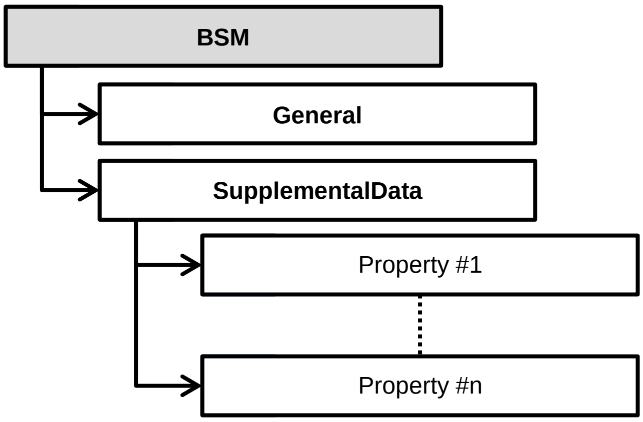
B.4 XML structure of a Data Storage File

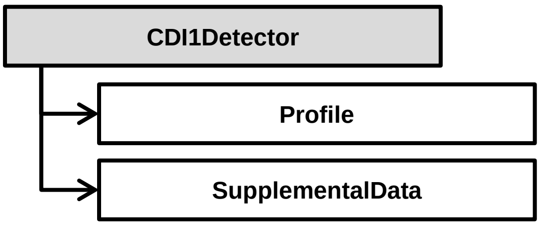


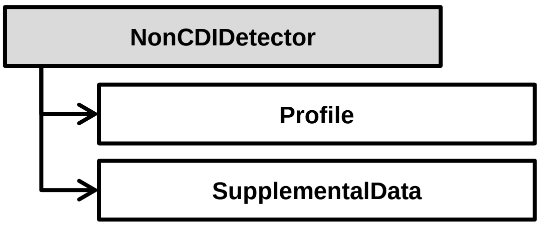
B.5 XML structure Computational Detector

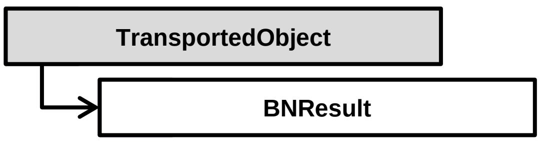


B.6 XML structure other

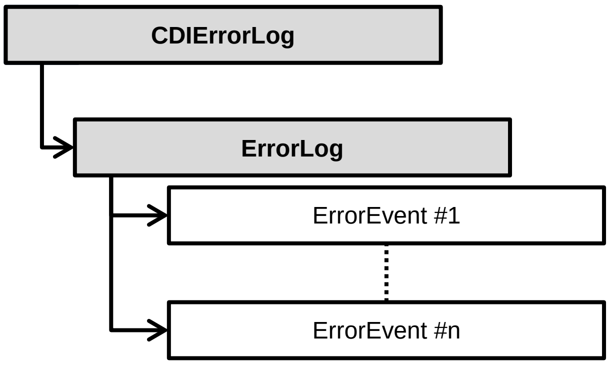




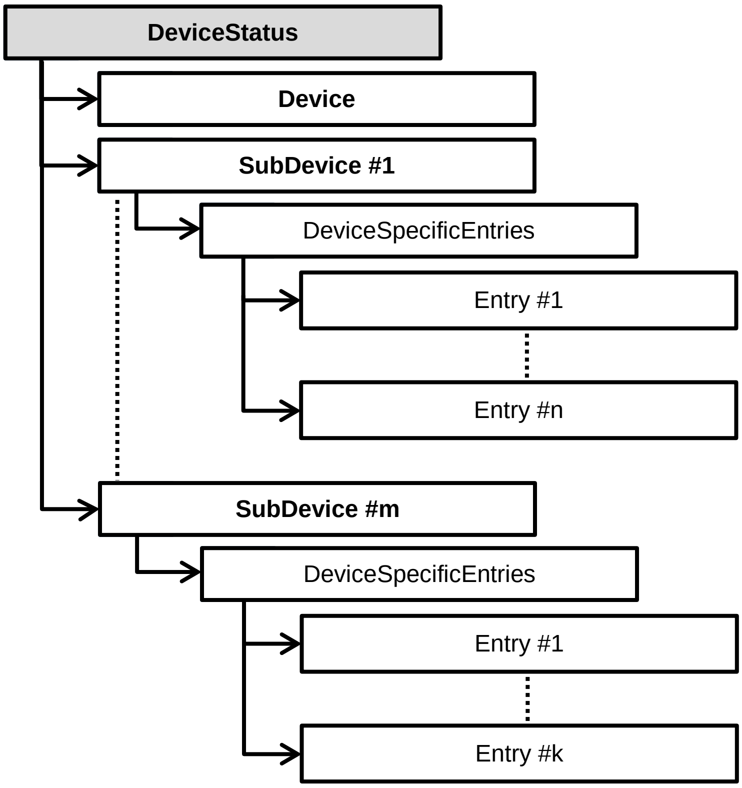




B.7 XML structure of the Error Log File



B.8 XML structure of DeviceStatus



B.9 XML element description

Node name	CDIStorage		
Parent node(s)	none		
Child node(s)	CONFIG, INFO, DATA		
The root node of a CDI2 storage file			
Attribute name	Data type	required	comment
Element Data	none		

Node name	INFO		
Parent node(s)	CDIStorage		
Child node(s)	CDIVersion, Customer, Transport		
This node holds general info about CDIVersion, Customer and BSM			
Attribute name	Data type	required	comment
Element Data	none		

Node name	CONFIG		
Parent node(s)	CDIStorage		
Child node(s)	BSM, CameraSystem, Detectors, ComputationalDetectors		
This node contains the complete configuration details of the used components			
Attribute name	Data type	required	comment
Element Data	none		

Node name	DATA		
Parent node(s)	CDIStorage		
Child node(s)	TransportedObject		
This is the collection of sorted banknotes including judgement and supplemental data			
Attribute name	Data type	required	comment
Element Data	none		

Node name	CDIVersion		
Parent node(s)	INFO		
Child node(s)	None		
This node holds details about the supported CDI version			
Attribute name	Data type	required	comment
major	xs:int	x	major version number
minor	xs:int	x	minor version number
Element Data	none		

Node name	Customer		
Parent node(s)	INFO		
Child node(s)	None		
This node holds details about the BSM customer			
Attribute name	Data type	required	comment
Name	xs:string	x	company name
country	xs:string	x	country name
currency	xs:string	x	currency of the inspected banknotes
Element Data	none		

Node name	Transport		
Parent node(s)	INFO		
Child node(s)	None		
This node holds details about the BSM transport			
Attribute name	Data type	required	comment
feedingDirection	xs:string	x	"left" or "right" (feeding direction of a banknote when seen by an operator in landscape orientation)
minimumSpeed	xs:string	x	minimum transport speed during Sorting in m/s
maximumSpeed	xs:string	x	maximum transport speed during Sorting in m/s
Element Data	none		

Node name	BSM		
Parent node(s)	CONFIG		
Child node(s)	General, SupplementalData		
Attribute name	Data type	required	comment
NodeID	xs:int	x	POWERLINK Node ID = 240 for MN
Element Data	none		

Node name	SupplementalData		
Parent node(s)	CameraSystem, BSM, Detector, ComputationalDetectors		
Child node(s)	Property		
The SupplementalData node holds the collection of Properties.			
Attribute name	Data type	required	comment
numBNRESULTSegments	xs:int		The number of used BNRESULT segments (1-4). If only 1 segment is used or if this attribute has no meaning in this context (i.e. if it is not used within a Device Info/Configuration) it can be omitted
Element Data	none		

Node name	Property		
Parent node(s)	SupplementalData		
Child node(s)	None		
Each Property Node holds the information about a measurement or calculation result. A CDI2 device can hold several properties within its data structure in addition to the required properties "judgement" and "result".			
Attribute name	Data type	required	comment
id	xs:int	x	consecutive number defined by BSM and sent to detector via Device Configuration message
name	xs:string	x	meaningful description of the property
unit	xs:string		unit of property if applicable
type	xs:int	x	data type, see Table 29: Data types
offset	xs:int		Byte offset of the property relative to the beginning of the Supplemental Data. Mandatory for properties within a Device Info/Configuration.
Element Data	none		

Node name	**Property – name=”Judgement”**		
Parent node(s)	SupplementalData		
Child node(s)	None		
Each CDI2 Device has to use the Judgement as first Property in its data structure.			
Attribute name	Data type	required	comment
id	xs:int	x	consecutive number defined by BSM and sent to detector via Device Configuration message
name	xs:string	x	“Judgement”
type	xs:int	x	0x01
offset	xs:int	x	0
Element Data	none		

Node name	**Property – name=”Result”**		
Parent node(s)	SupplementalData		
Child node(s)	None		
Each CDI2 Device has to use the Result as second Property in its data structure.			
Attribute name	Data type	required	Comment
id	xs:int	x	consecutive number defined by BSM and sent to detector via Device Configuration message
name	xs:string	x	“Result”
type	xs:int	x	0x01
offset	xs:int	x	1
Element Data	none		

Node name	**General**		
Parent node(s)	BSM, Detector, CameraSystem		
Child node(s)	None		
The General node holds general information about the BSM, Detector or CS function			
Attribute name	Data type	required	Comment
deviceclass	xs:int	x	see Table 1: CDI2 device classes
description	xs:string	x	
manufacturer	xs:string	x	
serialnumber	xs:string	x	serialnumber shall be unique for each device. If a device consists of two units, it shall encode the serial numbers of each unit into the serialnumber field.
SWVersion	xs:string	x	
SWUpdateSupported	xs:boolean		If omitted software update is not supported. For a device, this attribute expresses whether a software update is supported via DMB. For a BSM, this attribute has no meaning.
Element Data	none		

Node name	**Profile**		
Parent node(s)	CDI1Detector, NonCDIDetector		
Child node(s)	None		
The Profile node holds short information about a CDI1 or Non-CDI Detector			
Attribute name	Data type	required	Comment
manufacturer	xs:string		
description	xs:string	x	For CDI1 Devices, this attribute can be taken from the CDI1 Detector Info
serialnumber	xs:string		
deviceclass	xs:int		See Table 1 CDI2 device classes. For CDI1 Devices, this attribute can be taken from the CDI1 Detector Info
SWVersion	xs:string		For CDI1 Devices, this attribute can be taken from the CDI1 Detector Info
Element Data	none		

Node name	**Connections**		
Parent node(s)	Detector, CameraSystem		
Child node(s)	None		
Required connections / settings			
Attribute name	Data type	required	Comment
IDBsupport	xs:boolean	x	has IDB connection
TTSsupport	xs:boolean	x	has TTS connection
TTSTCresolution	xs:float	x	selected resolution of transport clock
BPresentOffset	xs:int	x	selected offset for BP signal in mm (leading edge of BP shall be BPresentOffset mm before leading edge of banknote arrives at the Nominal Casing Position. A maximum value of 50 mm is allowed for BPresentOffset.
Element Data	none		

Node name	**ImageEvaluation**		
Parent node(s)	Detector, CameraSystem		
Child node(s)	IECapabilities (optional)		
Indicates image evaluation capabilities of this CDI2 Device			
Attribute name	Data type	required	comment
supported	xs:boolean	x	IECapabilities child node required if supported=true
Element Data	none		

Node name	**IECapabilities**		
Parent node(s)	ImageEvaluation		
Child node(s)	None		
Attribute name	Data type	required	comment
fitness	xs:boolean	x	True if this device does fitness detection
numberreading	xs:boolean	x	True if this device can read the serial number If supported the device needs to implement a property “serialnumber”
Element Data	none		

Node name	BSMInfo		
Parent node(s)	Detector, CameraSystem		
Child node(s)	None		
These values will be supplied by the BSM via DeviceConfiguration, during DeviceInfo these values do not have any meaning			
Attribute name	Data type	required	comment
mechanicalSlot	xs:int	x	casing position of sensor
mountingPosition	xs:string	x	Allowed values: "left", "right", "none". For a Camera System, a CDI2 Detector or an IEU with optional sensor, the value shall either be "left" or "right". For an IEU without optional sensor, the BSM shall set this attribute to "none".
timeBudgetForBNRESULT	xs:int	x	Time between the trigger and the last time for BNRESULT in ms. For a CS or IEU without optional sensor, this time refers to the trigger time at BFA#1. For a Detector or IEU with optional sensor, it refers to the trigger time at the respective mounting position. This attribute is for information purposes only, and a Device does not have to process it. No information can be derived for BFA#2.
Element Data	none		

Node name	ServiceFiles		
Parent node(s)	Detector, CameraSystem		
Child node(s)	ServiceFile		
Attribute name	Data type	required	comment
Element Data	none		

Node name	ServiceFile		
Parent node(s)	ServiceFiles		
Child node(s)	none		
Attribute name	Data type	required	comment
description	xs:string	x	description
filename	xs:string	x	filename
filemode	xs:string	x	read/write permissions
type	xs:string	x	type of file - “text” for all files which can be read with a text editor (including e.g. CSV or XML) - “bin” for files which need special software
Element Data	none		

Node name	ConfigData		
Parent node(s)	Detector, CameraSystem		
Child node(s)	none		
Holds Device specific configuration data			
Attribute name	Data type	required	comment
Element Data	This section can be used to send additional configuration data to the detector (detector configuration message). Further structure and coding of this section is not specified. Support of this configuration data transfer regime is optional and needs to be agreed bilaterally between detector and machine manufacturer		

Node name	Detector		
Parent node(s)	Detectors		
Child node(s)	ImageEvaluation, ConfigData, ServiceFiles, BSMInfo, Connections, General, SupplementalData		
Attribute name	Data type	required	comment
NodeID	xs:int	x	POWERLINK Node ID of the CDI2 Device on the DMB. It must be unique inside the BSM (bilaterally agreed with customer).
Element Data	none		

Node name	Detectors		
Parent node(s)	CONFIG		
Child node(s)	Detector		
Attribute name	Data type	required	comment
Element Data	none		

Node name	ComputationalDetectors		
Parent node(s)	CONFIG		
Child node(s)	ComputationalDetector		
Collection of Computational Detectors			
Attribute name	Data type	required	comment
Element Data	None		

Node name	ComputationalDetector		
Parent node(s)	ComputationalDetectors		
Child node(s)	Formula, Thresholds, Judgements, StorageTrigger, SupplementalData		
Attribute name	Data type	required	comment
name	xs:string	x	meaningful description
lastChangeTime	xs:time	x	date time of last change
lastChangeUser	xs:string	x	username who did last change
Element Data	none		

Node name	Thresholds		
Parent node(s)	ComputationalDetector		
Child node(s)	None		
Threshold 1-7 (T1-T7)			
Attribute name	Data type	required	comment
Element Data	Threshold 1-7 (T1-T7) comma separated in increasing order		

Node name	Formula		
Parent node(s)	ComputationalDetector		
Child node(s)	None		
This section describes the Computational rules of the Aggregation Unit and shall integrate all information necessary to describe the rules. The description of the calculation is manufacturer specific but shall allow the transfer between all CDI2 compliant machines of one supplier			
Attribute name	Data type	required	comment
Element Data	Proprietary description of the formula		

Node name	Judgements		
Parent node(s)	ComputationalDetector		
Child node(s)	None		
Judgement codes as defined in Table 37 first entry = all notes below Threshold 1 (T1) second entry = all notes between T1 and T2			
Attribute name	Data type	required	comment
Element Data	Judgements comma separated		

Node name	StorageTrigger		
Parent node(s)	ComputationalDetector		
Child node(s)	None		
Storage Trigger definition see 8.1.2			
Attribute name	Data type	required	comment
Element Data	StorageTrigger comma separated		

Node name	CameraSystem		
Parent node(s)	CONFIG		
Child node(s)	ImageEvaluation, ConfigData, ServiceFiles, BSMInfo, Connections, General, SupplementalData, General		
Attribute name	Data type	required	comment
NodeID	xs:int	x	POWERLINK Node ID of the CDI2 Device on the DMB. It must be unique inside the BSM (bilaterally agreed with customer).
UseSecondBFA	xs:boolean	x	True if Camera System uses second BFA. In this case, BFA#2 is triggered in non-TTS mode with index 16 of the BSMINFO command (see 6.7.4.2 BSMINFO 0x81, TC_COUNT16, BNID16 and TC_TRIG16)
Element Data	none		

Node name	Images		
Parent node(s)	CameraSystem		
Child node(s)	Image		
Attribute name	Data type	required	comment
Element Data	none		

Node name	Image		
Parent node(s)	Images		
Child node(s)	none		
Attribute name	Data type	required	comment
type	xs:string	x	
resolution	xs:float	x	in mm/Pixel => 0.2 for standard images
internalresolution	xs: float	x	in mm/Pixel
height	xs:int	x	number of Pixels (transport direction)
width	xs:int	x	number of Pixels (scan direction)
IDBstreamnr	xs:int	x	
GVSPPayloadType	xs:int	x	GigE Vision payload type => 0x001 for standard images
Element Data	none		

Node name	TransportedObject		
Parent node(s)	DATA		
Child node(s)	BNResult		
The TransportedObject holds all information and results for a single Banknote.			
Attribute name	Data type	required	Comment
Date	xs:date	x	Date of transport
Time	xs:time	x	Time of transport
BNID	xs:int	x	Banknote ID
SerialNumber	xs:string	x	Banknote Number
FinalJudgement	xs:byte	x	Final Decision see Table 37: Banknote judgement codes
Series	xs:byte	x	Banknote INFO see Table 32 and Table 33
Denomination	xs:byte	x	
Orientation	xs:byte	x	
Element Data	None		

Node name	BNResult		
Parent node(s)	TransportedObject		
Child node(s)	None		
Lists the values of all properties ordered by ID. The values shall be formatted as follows: - All properties are printed in a single line organised as "text/csv" (Comma-Separated Values, for a detailed description see RFC4180 [Ref 5.]). - The data types of Table 27 shall be formatted as follows: • Signed/Unsigned char/16bit/32bit: Signed decimal value (where a minus symbol is possible only for signed types) • Float: Signed decimal string with at least 9 significant digits (to be able to restore the float without loss), dot as decimal separator, and without thousands separators • ASCII/UTF16/UTF32 1/4/8/16 Character: According to XML encoding, which is "UTF-8" as default • Binary data 16/32/64/128/256/512 Byte: Base64 encoded			
Attribute name	Data type	required	Comment
Element Data	List of entire Supplemental data		

Node name	**ErrorLog**		
Parent node(s)	CDIErrorLog		
Child node(s)	ErrorEvent		
Attribute name	Data type	required	comment
Element Data	none		

Node name	**ErrorEvent**		
Parent node(s)	ErrorLog		
Child node(s)	None		
This is an entry for a single error or warning event. Date and Time shall always refer to the date/time distributed by the MN.			
Attribute name	Data type	required	comment
NetTime	xs:long	x	POWERLINK NetTime
RelativeTime	xs:long	x	POWERLINK Relative Time
Date	xs:date	x	Readable Date
Time	xs:time	x	Readable Time
CNState	xs:byte	x	See Table 21
ErrorState	xs:byte	x	See Definition of Error States in 6.7.4.4
ErrorCode	xs:int	x	Error Code for machine operator
Severity	xs:string	x	“error” / “warning”
Message	xs:string	x	Error message for machine operator
Element Data	Additional debug information (max 1kByte)		

Node name	**DeviceStatus**		
Parent node(s)	none		
Child node(s)	Device, SubDevice		
This node contains data about a device's status and lifetime statistics			
Attribute name	Data type	required	comment
Element Data	none		

Node name	**Device**		
Parent node(s)	DeviceStatus		
Child node(s)	none		
This node contains general information about the device			
Attribute name	Data type	required	comment
designation	xs:string	x	the device’s purpose
manufacturer	xs:string	x	
deviceclass	xs:int	x	see Table 1 CDI2 device classes
Element Data	none		

Node name	**SubDevice**		
Parent node(s)	DeviceStatus		
Child node(s)	DeviceSpecificEntries		
This node contains general and lifetime information about the sub-device			
Attribute name	Data type	required	comment
name	xs:string	x	
serialnumber	xs:string	x	unique serial number of the sub-device
numberOfNotesMeasured	xs:int	x	number of notes measured during the entire lifetime
upTimeHours	xs:int	x	number of operating hours for the entire lifetime
dateOfLastCalibration	xs:dateTime	x	
Element Data	none		

Node name	**DeviceSpecificEntries**		
Parent node(s)	SubDevice		
Child node(s)	Entry		
This node is a container for Entry nodes			
Attribute name	Data type	required	comment
Element Data	none		

Node name	**Entry**		
Parent node(s)	DeviceSpecificEntries		
Child node(s)	none		
This node contains generic name value pairs			
Attribute name	Data type	required	comment
name	xs:string	x	
value	xs:string	x	
Element Data	none		

Appendix C BFA concepts

C.1 Overview

Two technologies to fulfil the requirements of a CDI2 BFA were developed and tested. The Vacuum Block (VAC) system and the Timed Air Pulses (TAP) were tested one by one and in a combined use.

Following concept drawings describe the concept, whereas the following chapters show the real implementation in a BSM.

Further details, statistics about fluttering, jam rates and technical drawings are available on request.

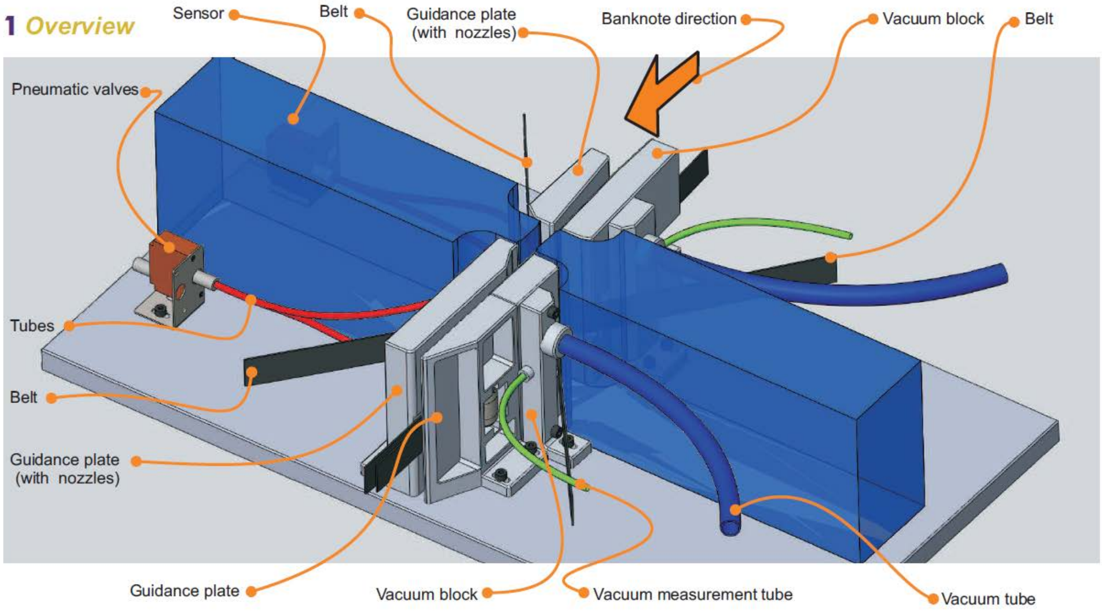


Figure 46: BFA concept overview

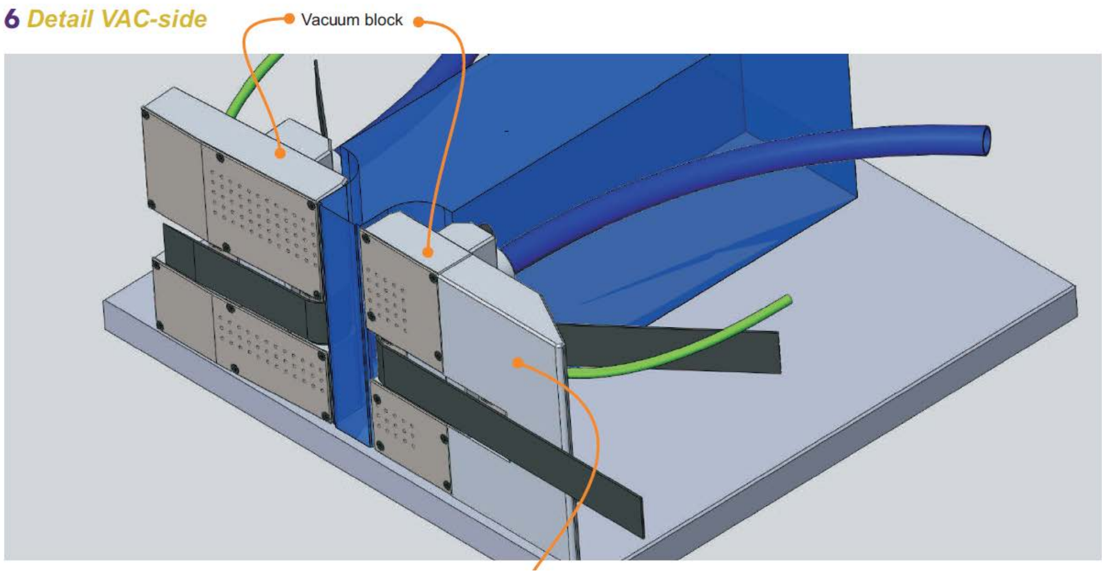


Figure 47: VAC concept

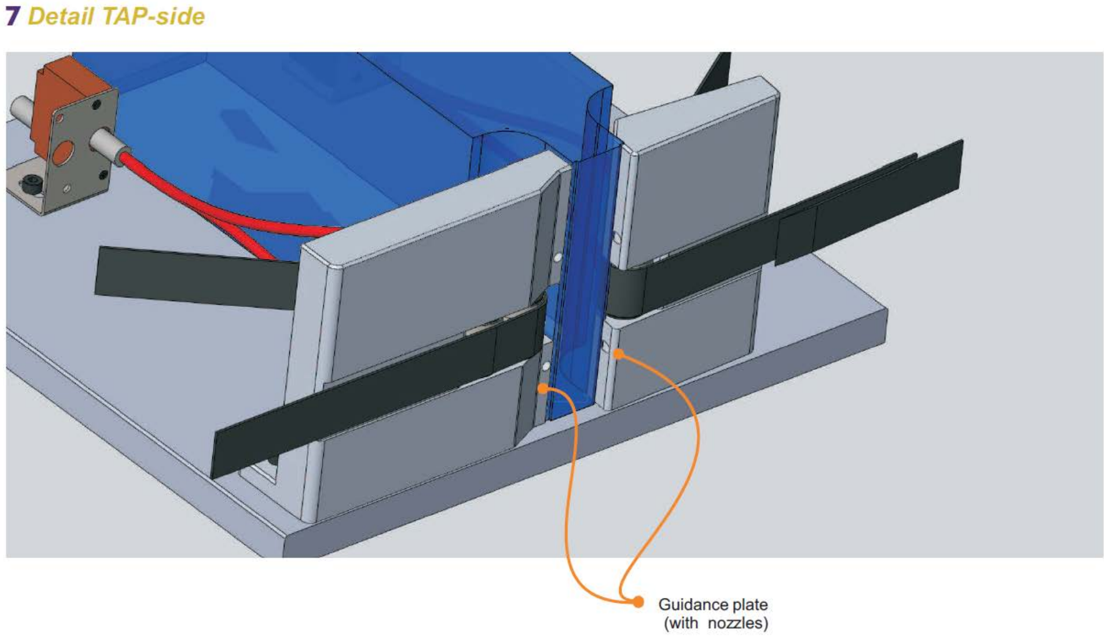


Figure 48: TAP concept

C.2 Vacuum block system

This system uses vacuum provided by a first vacuum block to suck the banknote to the surface of the detector. The first vacuum block is placed in front of one detection unit (seen in the direction of the transport of the banknote). The banknote is guided over the Detector via the detector surface (usually a scratch resistant glass window) and will be picked up on the other side of the detector unit by a second vacuum block.

When only one detection unit is used, the banknote can be supported over this detection unit or by a support bracket opposite the detection unit, depending of the depth of field of the detector. The responsibility of the BSM supplier is to supply a belt free transport area and brackets if no detector is mounted into the belt free area. The acceptance test will verify the belt free area using the brackets supplied by the vendor as well as a CS.

In the test system, the vacuum is activated when banknotes are processed. During the processing of the banknotes there is a constant flow of vacuum with pressure of -400 Pa (-5.8 Psi) to -600 Pa (-8.7 Psi) against the atmospheric environment. With a feeding rate of 40 BN/sec, the capacity of the vacuum pump is 10m^3/hour.

Below are some photos of the vacuum system mounted into a BSM. The red blocks are the dummy detectors (brackets). The blue/green blocks are the vacuum blocks. The inspection area is closed on all sides (glass window, banknote guide plates) to create a vacuum airflow.

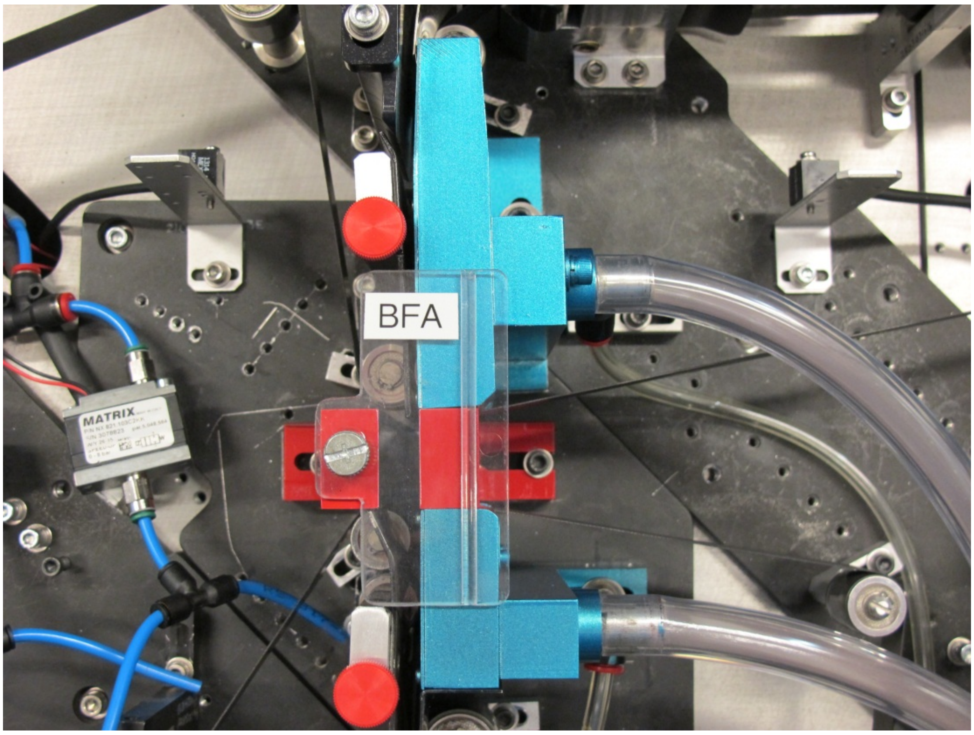


Figure 49: Vacuum system overview

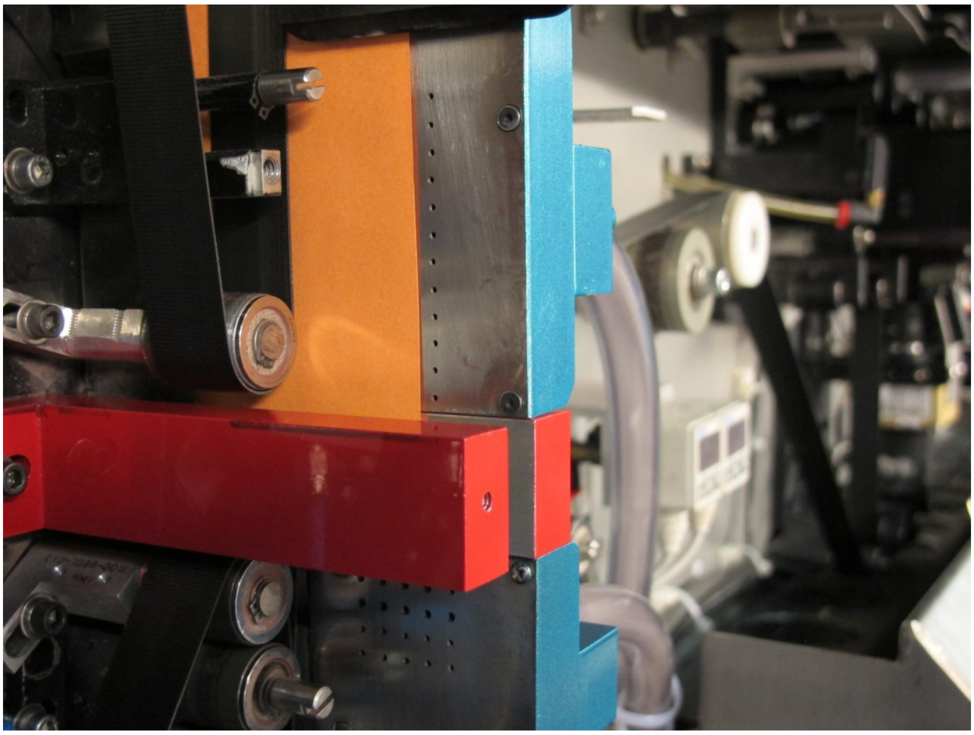


Figure 50: Vacuum system with banknote, size €50

The patent application of the vacuum concept is available at http://priorart.ip.com/IPCOM/000242046.

C.3 Air pressure system - Timed Air Pulses (TAP)

This system uses **Timed Air Pulses** (TAP) to push the banknote against the surface of one detector unit or a single background plate. This detector unit supports the banknote through the BFA. In the test system, the banknote will pass a photo barrier (alternatively, other signals from the BSM can be used) which triggers the timing of the TAP. The nozzles are placed in a mounting bracket opposite the detection unit against which the banknote is pushed. Between the mounting brackets of the first and second row of nozzles, the counterpart of the CS will be put in. If such counterpart is not necessary, a dummy detection unit or the bracket supplied by the BSM manufacturer will be used.

To determine the various timing moments of the different air nozzles the transport clock and information of the length of the banknote is used from the BSM.

The nozzles in the test setup are operating on an air pressure of up to 800 kPA (116 Psi). With a feeding rate of 40 BN/sec, the capacity of the pressure pump is about 18 m^3/hour. As this amount of air is blowing into the machine the BSM manufacturer needs to ensure that the amount is also removed.

Below are some photos of the TAP system in combination with the vacuum system mounted into a sorting machine. The red blocks are dummy detectors. The blue tubes are nozzles, blowing just after the last roller/belt/guide assembly and another set of nozzles blowing just before the next roller/belt/guide assembly.

The blue/green blocks are the vacuum blocks. The TAP system in the test setup has been successfully tested to work without the vacuum blocks and the vacuum blocks can then be replaced by banknote guide plates. The TAP system is in the test setup integrated in the red ‘detector casing’ as shown in the image below.

The TAP system shakes notes and blows off the remaining dust, while making noise (In the test setup an increase of 3dB in noise was measured with the BSM cover open. With the BSM cover closed no additional noise was measured) which can be reduced by designing a removable cover/shielding assembly surrounding the camera and belt free system connected to a suction vent.

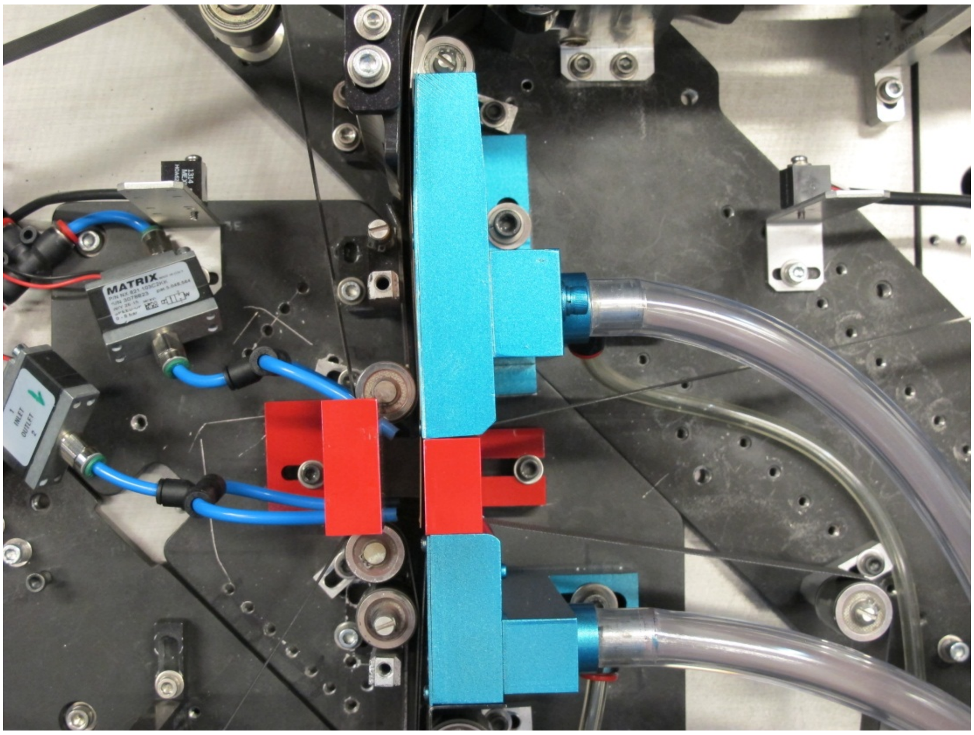


Figure 51: TAP system overview

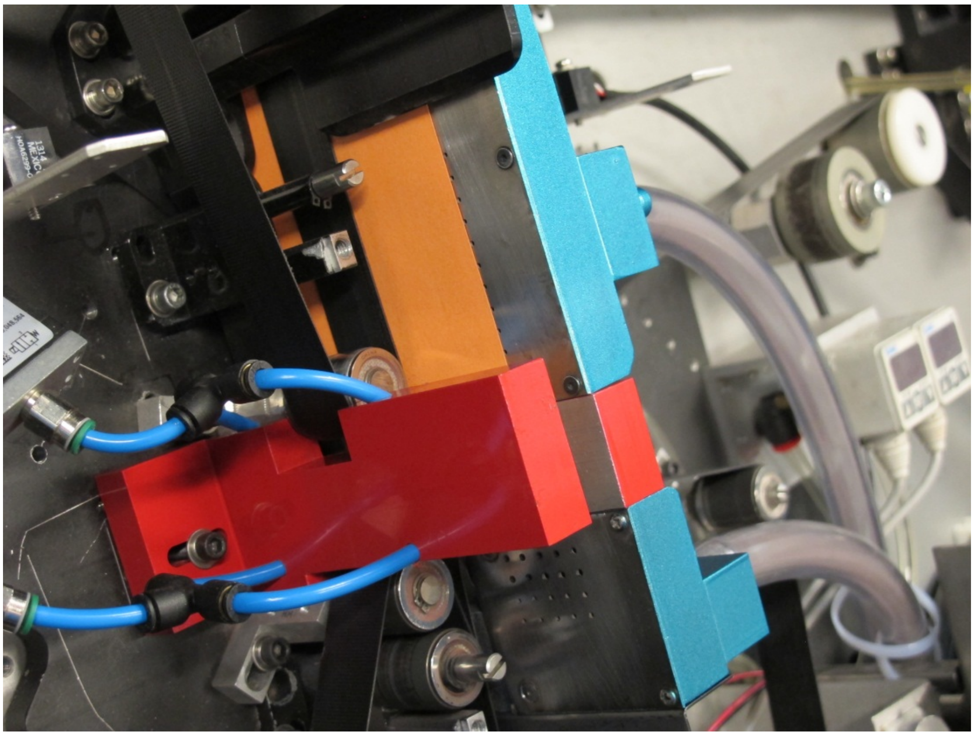


Figure 52: TAP system with banknote, size €50

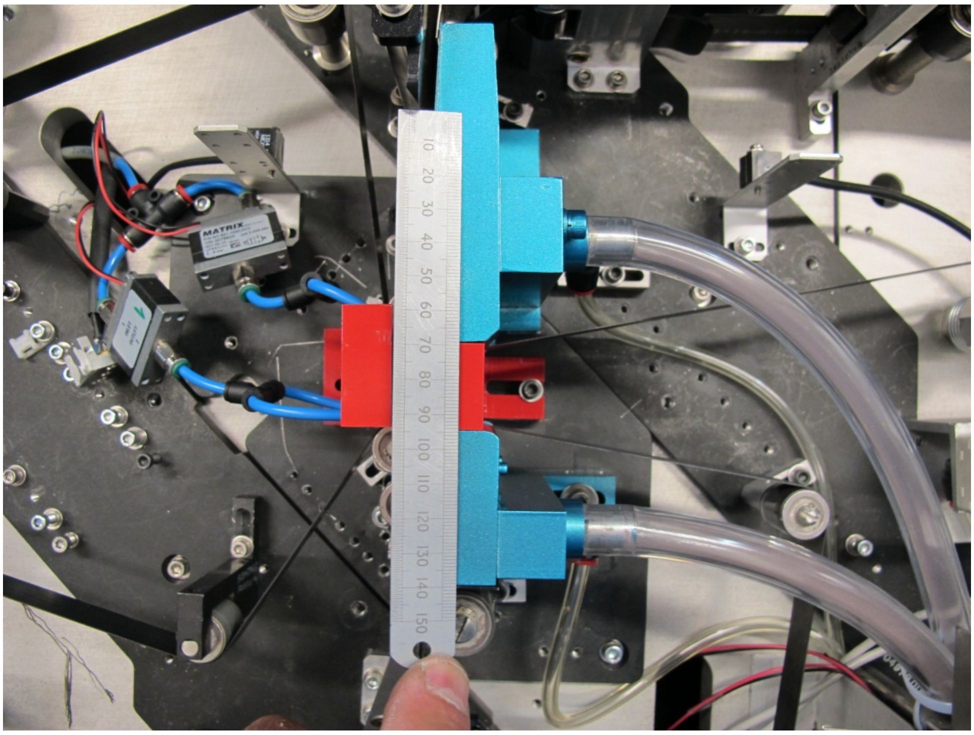


Figure 53: Length of BFA test setup

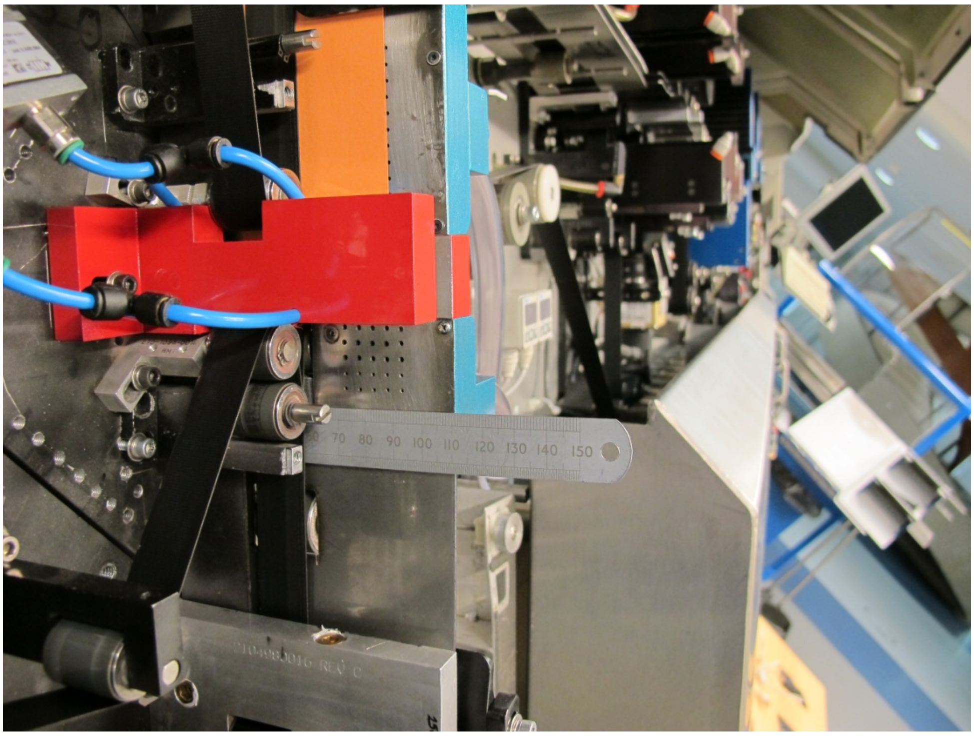


Figure 54: Width of BFA test setup

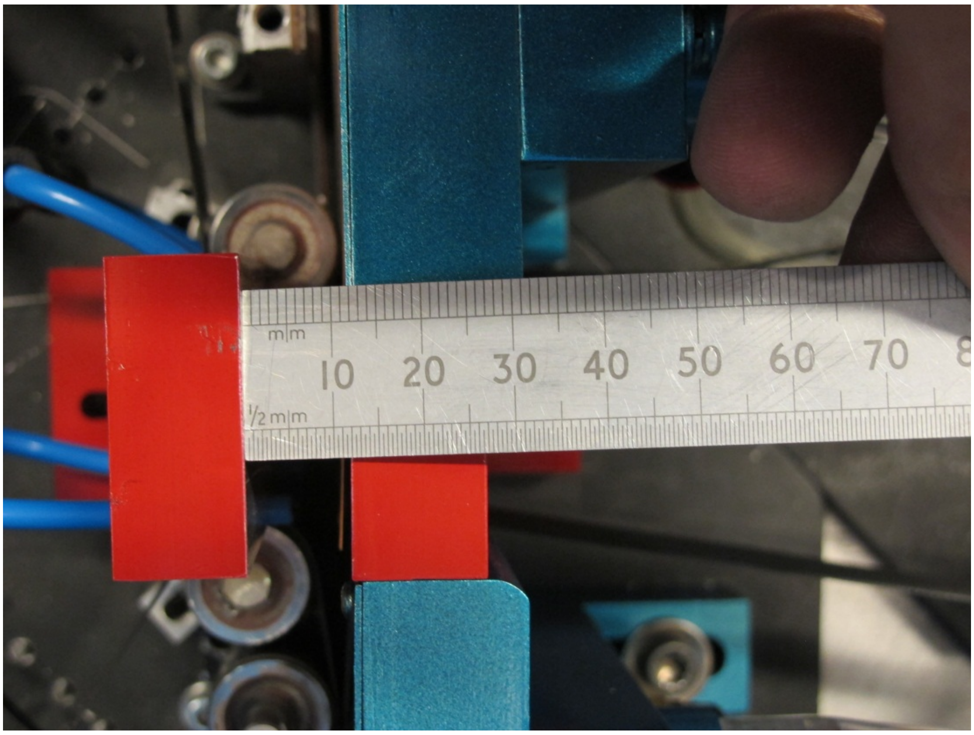


Figure 55: Distance between upper and lower detector in test setup

The patent application of the TAP system is available at
[http://priorart.ip.com/IPCOM/000243704.](http://priorart.ip.com/IPCOM/000243704)

Appendix D Example of a CDI2 Banknote Sorting Machine

This example CDI2 BSM shows the mounting locations of the CDI2 devices and how they are interconnected. In this example both BFA positions are occupied with cameras, whereas in many real CDI2 machine implementations BFA#2 will be unoccupied, as the use of BFA#2 is optional.

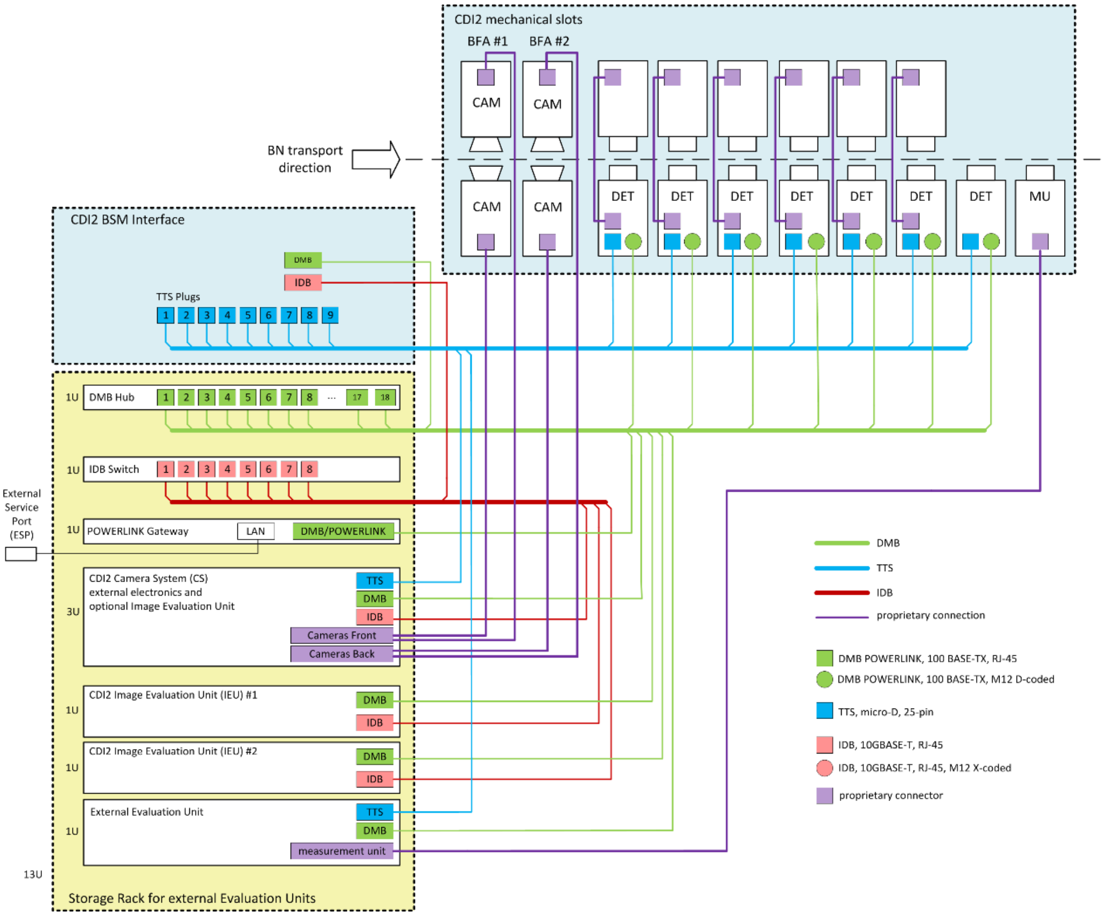


Figure 56: Example of a CDI2 Banknote Sorting Machine

Disclaimer

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