Common Detector Interface 2 (CDI2)

Specifications

Protocol Version 2.7
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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
2.2	A	Further revisions after Amsterdam conference	13 December 2016
2.3	A	Second release version	19 December 2016
2.4	A	Third release version	23 June 2017
2.5	A	Fourth release version. 91 issues addressed (see change list for details).	22 June 2018
2.6	A	26 issues addressed (see change list for details)	04 December 2018
2.7	A	Sixth release version (see change list for details)	14 October 2019

Main authors

Alois Hahn, Austrian Institute of Technology
Thomas Kern, Oesterreichische Banknoten- und Sicherheitsdruck GmbH

Main editors

Harald Deinhammer, European Central Bank
Charles A. Hodges, Federal Reserve System - Cash Product Office

Contributors

Jean-Claude Fremy, European Central Bank
Peter Markus, De Nederlandsche Bank
Lawrence Livermore National Laboratory
Giesecke+Devrient, Toshiba, Cash Processing Solutions

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1   Aim

The Common Detector Interface 2 (CDI2) aims to extend the existing CDI1 specifications [Ref 6.], creating the possibility to integrate a 3rd party camera system (with optional fitness *Detector*) into a central-bank used-*Banknote Sorting Machine* (*BSM*) as well as defining *Detector*-fusion capabilities for the *BSM* to merge the data and results from different *Detector*s of different manufacturers. This specification covers the definition of the electronic interface, the mechanical transport system and the *Detector*-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 they should comply with the CDI2 standard. This applies especially to the optional CDI2 functionality items listed in chapter 2.8.

2   Definitions

2.1   Definitions and abbreviations

2.1.1   Definitions

If a defined word is utilised in the specifications it will be in **Bold** and *Italic*.

Aggregated Data	Data-set for one banknote comprising *Judgement*s and *Supplemental Data* of all CDI1, CDI2 and *Non-CDI Detector*s.
Aggregation Process	A single process of combining the detector results using a set of *Computational Detector*s into a *Final Decision*.
Aggregation Unit	A dedicated unit in the *Banknote Sorting Machine* that collects all *Judgement*s and *Supplemental Data* from all *Detector*s (CDI1, CDI2 and non-CDI). The *Aggregation Unit* 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 *Banknote Sorting Machine* software. It identifies the banknote while present in the *Banknote Sorting Machine*, during the time it is processed and when check results are stored in a database.
Banknote Present	Dedicated *Transport Timing Signals* 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 Position*s within the banknote transport of a *BSM* providing two *Camera System Casing*s belt-free access to both sides of the banknote at the same time (see 7.2).
Camera System	An arrangement consisting of an imaging device occupying *Belt Free Area* #1(mandatory) and *Belt Free Area* #2 (optional), with CDI2 connections and an optional *Image Evaluation Unit*.
Casing	Physical housing of a *Detector* or *Camera System* (see section 7.3 for content).

Casing Position	Physical mounting position of a ***Detector, Camera System,*** or ***Measurement Unit***, defined by a reference pin.
CDI2 Device	A ***CDI2 Device*** has a ***DET Machine Bus*** connector. It can be a ***Detector***, an ***Image Evaluation Unit*** or a ***Camera System***. Each ***CDI2 Device*** is a ***Controlled Node*** on the ***POWERLINK*** network of the ***Detector Machine Bus*** (see a more detailed description in 2.1.3).
CDI2 Property	A measurement or calculation result provided by a ***Detector*** describing a measured banknote feature.
Computational Detector	A ***Computational Detector*** is part of the ***Aggregation Unit*** and can combine the measurement results (***Judgement***s and ***Supplemental Data***) of all physical ***Detector***s to build its own decision. Result outputs of ***Computational Detector***s are inputs for the ***Final Decision***.
Controlled Node	A ***Controlled Node*** in the ***POWERLINK*** network is polled cyclically by the ***Managing Node***.
Detector	A device for inspecting banknotes for authentication or fitness on a ***Banknote Sorting Machine***. 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 Device***s. It handles the control communication using ***POWERLINK*** as network protocol.
Evaluation Unit	The ***Evaluation Unit*** processes data captured by the ***Measurement Unit*** and applies specific algorithms to the data in order to make a **Judgement** decision on the properties of the banknote and/or in order to extract specific properties. The evaluated result is placed on the ***Detector Machine Bus.*** Each ***Evaluation Unit*** can only be connected to one ***Measurement Unit.***
External Evaluation Unit	Any kind of hardware conducting interim data processing tasks and providing a CDI2 compatible connection to the ***Banknote Sorting Machine***. 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	Used to connect an external device (e.g. PC) to a ***Detector*** using the HTTP port over the DMB.
Final Decision	The use of ***Computational Detector***s to provide a ***Judgement*** decision, e.g. a sort decision.
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 ***Banknote Sorting Machine*** and to ***Image Evaluation Units***.

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 receive images from the *Image Data Bus*. In the latter case, the *Image Evaluation Unit* is a separate *CDI2 Device* located in the storage rack (see 7.7). Each *Image Evaluation Unit* can only be connected to one *Measurement Unit.*
Judgement	A quality classification for a banknote, reference Table 38.
Managing Node	A *Managing Node* acts as the master in the *POWERLINK* network and polls the *Controlled Node*s cyclically. In CDI2, the *Banknote Sorting Machine* acts as the *Managing Node*.
Measurement Unit	The *Measurement Unit* performs the measurement of physical properties of a banknote that passes it. A Measurement Unit can occupy a single *Casing Position* or opposing *Casing Positions*.
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 *Detector Machine Bus*. 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 *Transport Timing Signals* interface line from the *Detector* to the *Banknote Sorting Machine* to indicate that the Detector is READY for receiving commands.
RESET	Dedicated *Transport Timing Signals* interface line from the *Banknote Sorting Machine* 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 *Detector)*.
Storage Trigger	The use of *Computational Detector*s to trigger the storage of *Aggregated Data* and banknote images.
Supplemental Data	A set of measurement data provided by a *Detector* and/or the result of a *Computational Detector* describing specific properties of a measured or calculated feature, e.g. the intensity.
Threshold	*Threshold*s are numerical constants which have an identifier associated with the value (e.g. a name like Thr_MinWidth with a value of 56). *Threshold*s have a minimum and maximum value that the actual current value can be set to. Users with appropriate permissions may adjust the current value of a *Threshold* within the minimum and maximum value range.
Timed Air Pulses	A method to stabilise banknotes in the *Belt Free Area* (see Appendix C).
Transport Clock	Dedicated *Transport Timing Signals* interface line. A square wave clock signal from the *Banknote Sorting Machine* 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 **Banknote Sorting Machine** to the **Detector** and a **READY** signal in the other direction. Signals are **Banknote Present**, **Transport Clock**, RESET and READY.

2.1.2 Abbreviations

If an abbreviation in the below table is utilised in the specifications, it will be in *Italic*.

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
EEU	External Evaluation Unit
ESP	External Service Port
EU	Evaluation Unit
FS	Full Scale
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** (*DET)* is a logical unit that may contain an **External Service Port** (*ESP*). It 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 or authentication parameters and/or **Supplemental Data**.

Thus, a *DET* 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 *DET* for magnetic features would capture magnetic properties, whereas a *DET* 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.
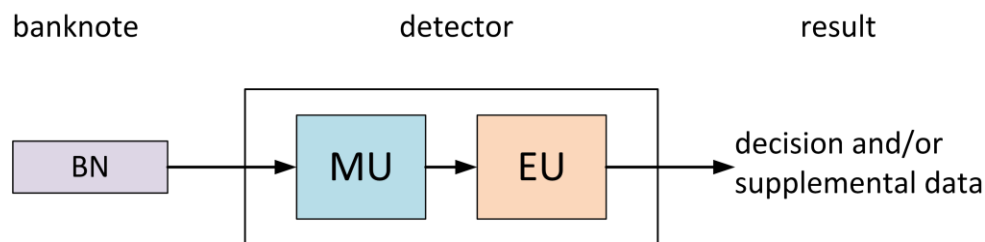
Figure 1: Detector definition

A *DET*, 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 *DET* 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 *EU*s, denoted as **Image Evaluation Unit** (*IEU*). In this case the *IDB* builds the interconnection between the *MU* and the *EU*s.

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.

Detector

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 *DET*. Therefore, a *DET* having *MU* and *EU* in a single **Casing** can be denoted as *DET* 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 *MU*s and in any case *EU*s. A **CDI2 Device** that consists of an *MU* and an *EU* will be a complete *DET* by itself, designated as a CDI2 *DET*. 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 *MU*s, 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** also includes an *IEU*.

A CDI2 *IEU* consists of an *EU* that can process images taken by the *CS*. Thereby a complete *DET* is setup by the combination of an *MU* in the *CS* and an *EU* located in the CDI2 *IEU*. Different *DET*s can be setup by the combination of *MU*s and *EU*s.
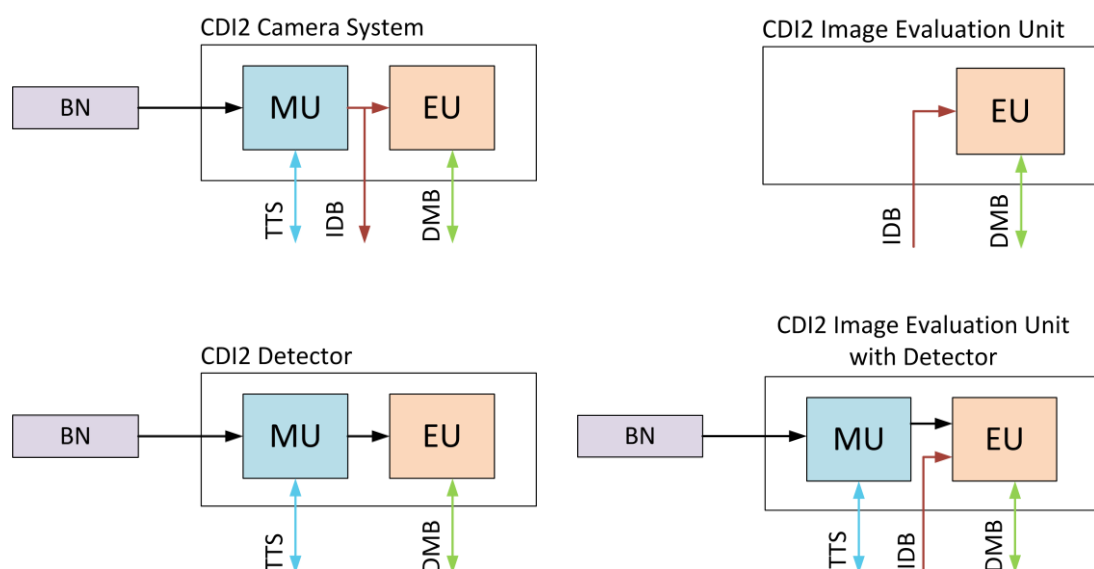
Figure 2: Four options for CDI2 Devices, other options are available

Device class	Description
0	Thickness **Detector**
1	Authenticity Level1 feature
2	Authenticity Level2 feature
3	Authenticity Level3 feature
4	Fitness **Detector**
5	Other
6	reserved
7	reserved
8	BSM

Table 1: CDI2 Device classes

2.2 CDI2 block diagram
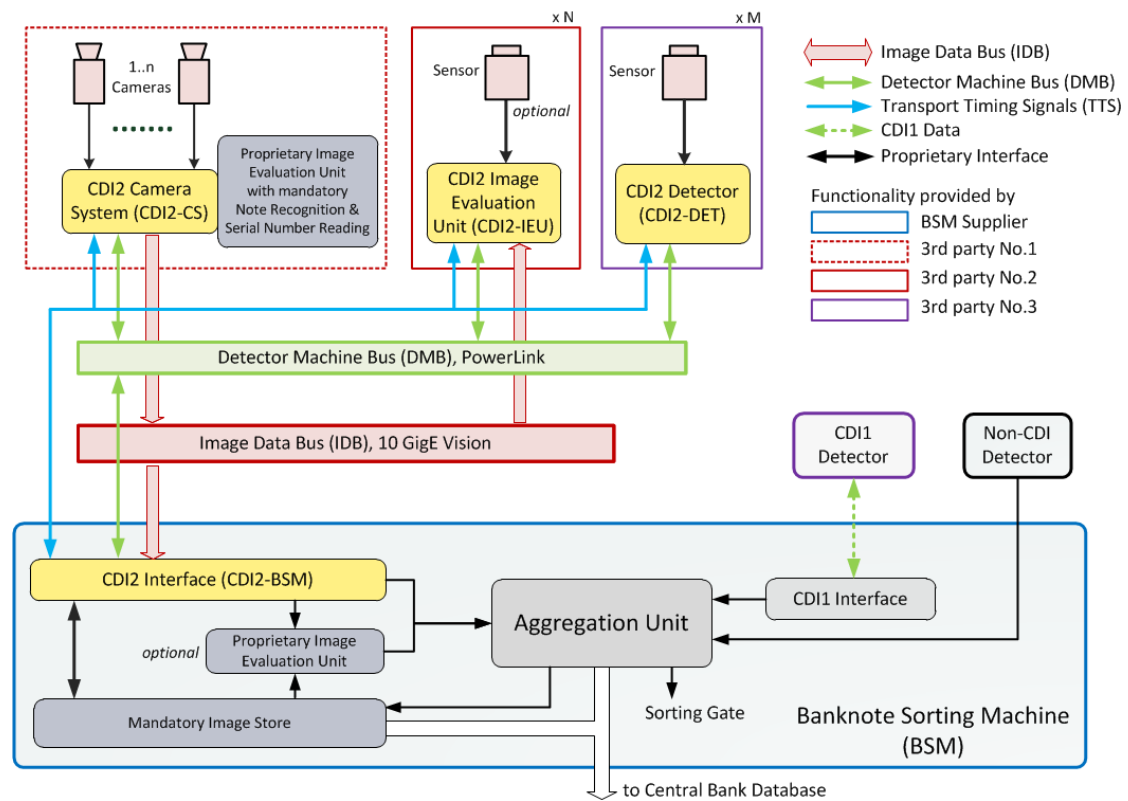
Figure 3: CDI2 block diagram

The colours in Figure 3 are used throughout the whole specification to 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

A schematic 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 defined in 7.5
- Shall be capable of transporting test charts with a size of 85 mm x 160 mm
- Conforms to dust, light and electric field specifications defined in 7.8
- Provides compressed air to **CDI2 Device**s (see 7.4.6 for details)
- Provides cooling airflow for *DET*s
- Supports the following number of CDI1/2 *DET*s:
  - o For **Aggregated Data** at the **Aggregation Unit** (*AU*): 16
  - o Mechanical, for CDI1/CDI2 *DET*s: minimum 8 in total
    - ▪ At least 6 of these **Casing Position**s must allow the mounting of *DET* **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 optional Image Evaluation Unit

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

2.3.4   CDI1 interface

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

2.3.5   Non-CDI Detector

- The *BSM* may implement *DET*s not conforming to CDI1 or CDI2 as **Non-CDI Detector**
- The *BSM* needs to make sure that the **Judgement** is available at the *AU* 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 Detector**s
- Provides tools for the combination of any of these parameters by mathematical operations and setting a result which will be used in 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 Detector**s) 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 utilising a minimum 1024-bit encryption key. In case the central bank wants to have a different transfer protocol it shall specify it in its requirements

2.4 CDI2 Camera System
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.

- Provides the note images via the *IDB* to image evaluation units (*IEU*s) 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 BNRECOGNITION
- Is connected to the *BSM* via the *DMB* and *IDB* and/or *TTS*
- Conforms to the specifications regarding depth of view and *BSM* tolerances specified in 7.5
- 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 *DET*
- Shall use only one *BFA* for front and reverse imaging (Use of the 2nd *BFA* requires prior authorisation of the buyer)
- 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") has to be provided as extra item

2.5 CDI2 Image Evaluation Unit
- Evaluates the note image delivered by the *CS*
- May either be integrated inside the *CS* **Casing** itself or be part of the storage rack receiving data from the *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 *DET*s (8 minimum in total CDI1 + CDI2) via adaptor plates, if necessary

- Can make use of a double-sided **Casing** but both co-located *DET* **Casing**s must act as a single logical *DET* (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 *IEU*s which then deliver results as **Supplemental 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 Device**s
- Is rugged and suitable for an industrial environment

2.7.3 Transport Timing Signals (TTS, blue line in Figure 3)
- Provides trigger, **Transport Clock** (*TC*), reset and **READY** line to the *DET*s 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 a (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	Optional tasks of note recognition (includes series, denomination and orientation) and handling	2.4	O
	CDI1 support	2.3.4	M
	Mounting positions and order of CDI2 *DET*s along the transport path	3.2	M
	Must guarantee that the BNINFO arrives early enough	3.2	M
	Must allow sorting of test charts	4.2	M
	Offer eight mechanical *DET* 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

Supplier of CDI2-	Functionality	Chapter reference	[M]andatory or [O]ptional
	Easily clean *DET* positions	7.4.2	M
	Cables for all available CDI components (length, specification, CDI1 compatible, …)	4.6 5.3 6.10	M
	AU requirements	8	M
	Store aggregated and image data	9	M
	IDB input	3	M
	DMB managing node	6.3	M
	9 *TTS* Plugs	5.3	M
	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 *DET*	2.3.3	O
	May send device specific parameters to CDI2 Devices	3.1.1	O
	The BSM shall meet the central bank requirements on how to handle Aggregated Data or image data in case of a power-failure.	9	M
	Select compression level and image format	9.1.2	O
	Timing Requirements	3.2	M
	Aggregation Unit	8	M
	Computational Detector	8.1	M
	Device and Property Naming	8.3	M
	Calculation Model	8.1.1	M
	Thresholds	8.1.2	M
	Final Decision	8.2	M
	Graphical User Interface	8.4	M
	Access Rights	8.4.1	M
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	6.4	M
	Camera unit fits mounting spec of *BFA* slot	7.4.1	M
	Casing must be dust-proof	7.4.1	M
	If at *BFA*#2 images are acquired only one-sided, the opposite side must have a uniform surface	7.2	M
	Max storage rack dimensions of 3U	7.4.1	M

Supplier of CDI2-	Functionality	Chapter reference	[M]andatory or [O]ptional
	Max power rating of 2*2*150 W	7.4.1	M
	Image of *BN* must be represented in proper orientation on *IDB*	4.1 Table 10	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	3.5	O
	Occupy 2nd *BFA* slot	7.2	O
	Electronics located in storage rack	7.4.1	O
	May incorporate a proprietary *IEU*	2.4	O
	Optional image data is allowed	4.1	O
	Image acquisition must also be possible with the lights turned off	4.2	M
	Timing Requirements	3.2	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	3 4	M
	DMB Controlled Node	6.4	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
	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	3.5	O
	Non *TTS* operation (optional for *IEU* with optional *DET*, mandatory for *IEU* without optional *DET*)	5.4	O/M
	Timing Requirements	3.2	M
Detector	Connection between two parts of a *DET*	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	6.4	M
	Unique MAC address on *DMB*	6.2	M
	Store **POWERLINK** Node ID permanently	6.6.1	M

Supplier of CDI2-	Functionality	Chapter reference	[M]andatory or [O]ptional
	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	O
	May provide means for remote software update	3.5	O
	Extra electronics in storage rack with proprietary interconnection	2.1 7.7	O
	Timing Requirements	3.2	M

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 **Detector Machine Bus** (*DMB*), the **Image Data Bus** (*IDB*) and the **Transport Timing Signals** (*TTS*).

The *DMB* (see chapter 6) connects the *BSM* with its **CDI2 Device**s, like **Camera System**, *IEU*s and *DET*s. During all phases of machine operation, the *DMB* acts as the main communication path for exchanging control information between the *BSM* and **CDI2 Device**s. 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 *IDB* (see chapter 4) carries banknote images captured by the **Camera System** to the *BSM* and to *IEU*s. The *IDB* uses a small subset of the **GigE Vision** interface standard, based on a 10Gbit/s network (10 GigE).

The *BSM* provides *TTS* (see chapter 5) to all physical **Casing Position**s. For each position, the *TTS* port provides three output signals consisting of a hardware **RESET**, a **Banknote Present** (*BP*) and *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 Device**s.

The major states of operation of the CDI2 System are:

1. INITIALISATION
2. FEED_OFF
3. SORTING
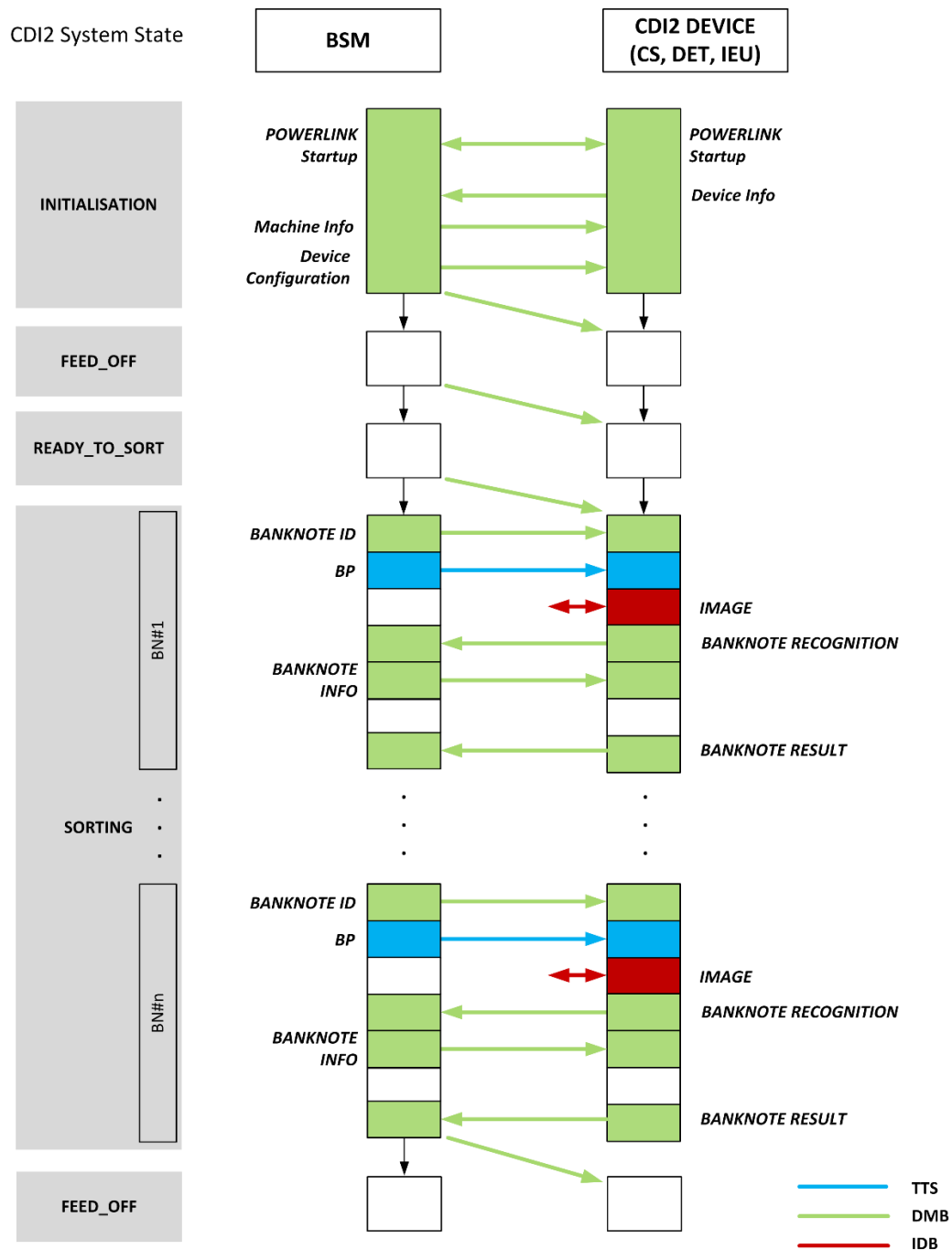
Figure 4: CDI2 start-up and operational sequence

Communication and synchronisation between *BSM* and the **CDI2 Device**s is accomplished via the *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 Device**s. 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 Device**s 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 **Banknote ID** in conjunction with a *BP* signal, so that a banknote passing a *DET* 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. 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 *TC* and *BP* signals from the *BSM* via the *TTS* interface.

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 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 BSMINFO and sends it via the *DMB* to all CDI2 nodes as part of a BSMINFO message (step 4).

The *IEU*s 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).
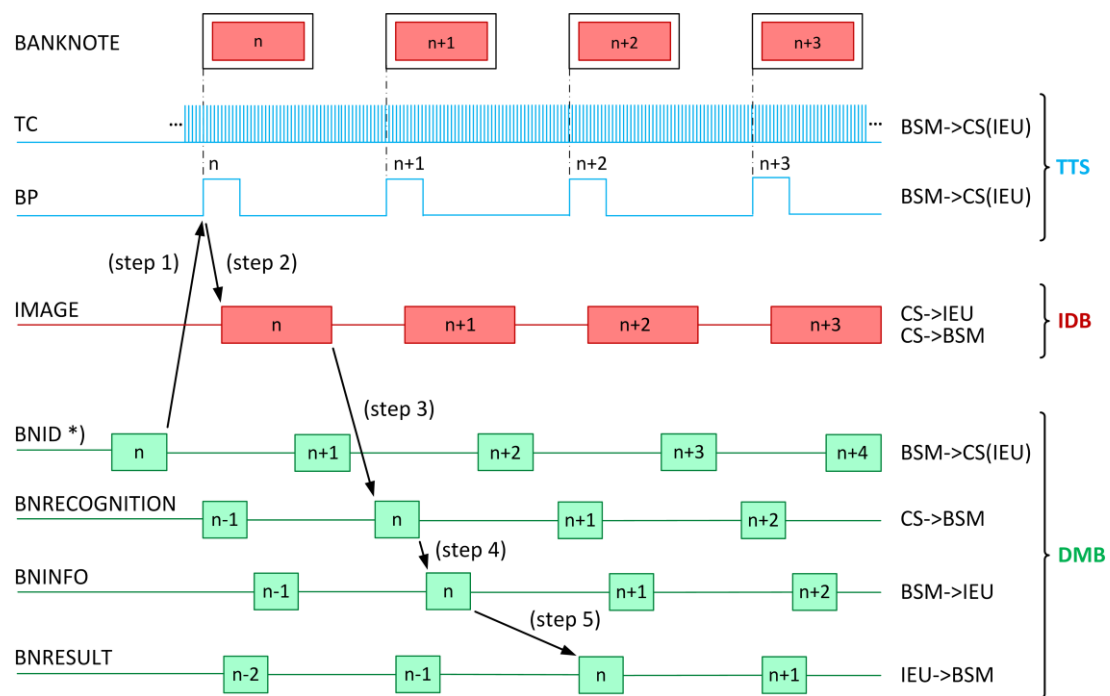
Figure 5: Communication sequence during banknote checking
(with camera image from CS)

*) BNID is sent in the BSMINFO packet (see 6.7.4.2) as part of the trigger information, as BNIDx along with TC_COUNTx and TC_TRIGx.

In case of a CDI2 *DET*, 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 *DET* before the corresponding banknote passes the **Casing Position** (step 1). Thus, the CDI2 *DET* has to respect this situation and store the BNINFO to have it available when the banknote is processed. A CDI2 *DET* 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.
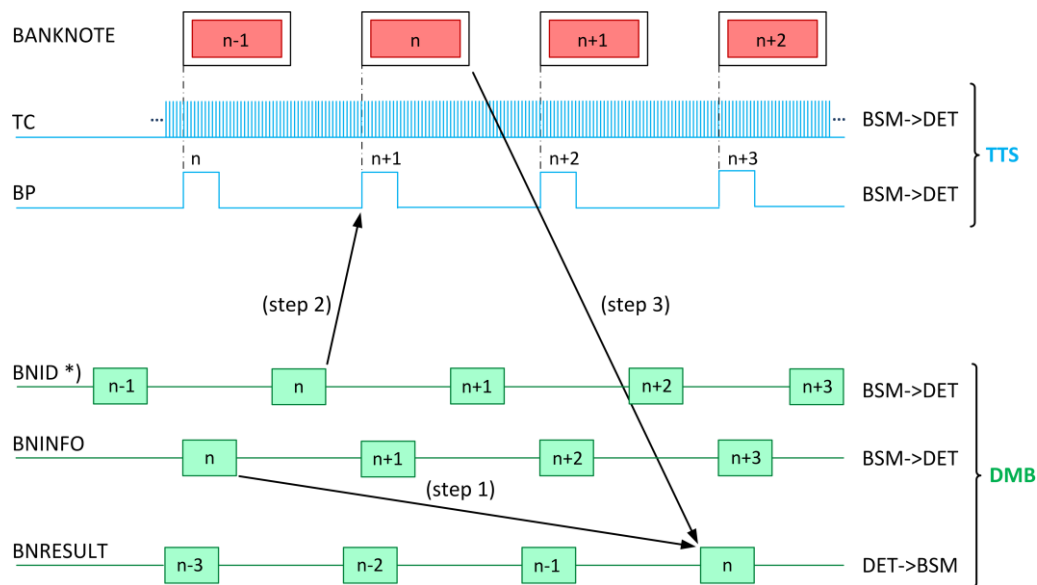
Figure 6: Communication sequence during banknote checking
(without using a camera Image from CS)

*) BNID is sent in the BSMINFO packet (see 6.7.4.2) as part of the trigger information, as BNIDx along with TC_COUNTx and TC_TRIGx.

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:

$\dot{t}$…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:

$\dot{t}$BP	Point in time when the capture of a *BN* is triggered (either with the *TTS BP* line or with *TC*_TRIGn on the *DMB*)
$\dot{t}$BNINFO	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.
$\dot{t}$IMAGE	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*, *DET*) 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 *DET* 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 *DET* 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 *DET* that is mounted in one of the *DET* 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 *DET* 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 *DET* must be READY to send its BNRESULT. For this, the *IEU* with optional *DET* is supposed to consist of two independent components: An *IEU* without optional *DET* and a *DET* in the position of the optional *DET*. 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 *DET* or an *IEU* with an optional *DET* for the capture of the *BN* (see Figure 8).

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

From the timing requirements for the **CDI2 Device**s, the distance requirements for the transport path of a *BSM* can be derived. An example of how the **Casing Position**s may be arranged on the transport path of a *BSM* is shown in Figure 7.
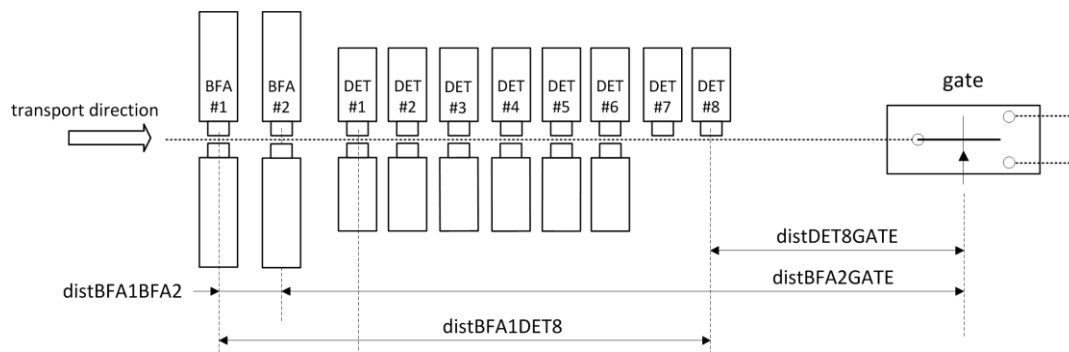
Figure 7: Exemplary Casing Positions on the transport path

Critical distances for the transport path of a *BSM* are the distance from *BFA*#1 to the first *DET* position *DET*#1 (distBFA1DET1) and either the distance from the last *DET* 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 *DET* 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 *DET* 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*s may be in the transport path between *BFA*#1 and the sorting gate. For example, if the *BN*s 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 *DET*, 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 *DET* may be 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 *DET* in *BFA*#2, the same timing requirements apply as for normal *DET*s mounted in *DET*#1 to *DET*#8. Note, however, a difference to normal *DET*s: Since the distance from *BFA*#1 to *BFA*#2 may be rather short (specifically shorter than distBFA1DET1), a *DET* 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 *DET* 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 BNINFO message (tA5). When a Device receives the BNINFO, it can now set up its capture unit (tA6) accounting for the received banknote orientation, series and orientation.
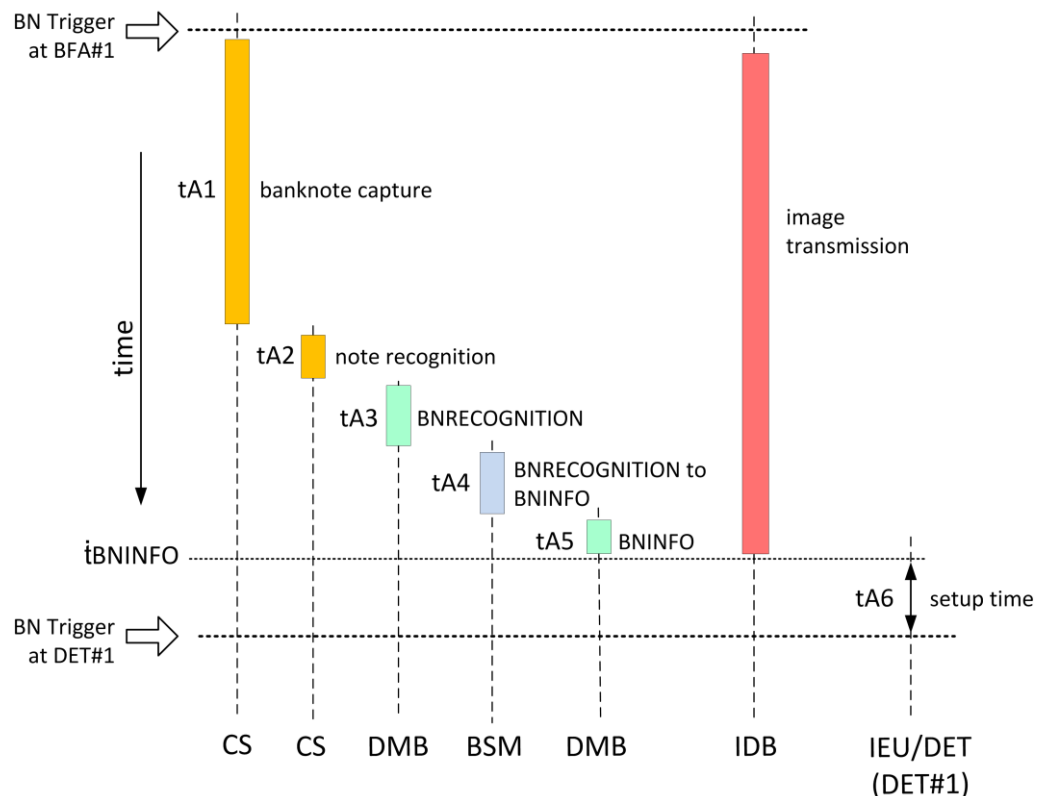
Figure 8: Timing sequence from trigger at BFA#1 to trigger at DET#1

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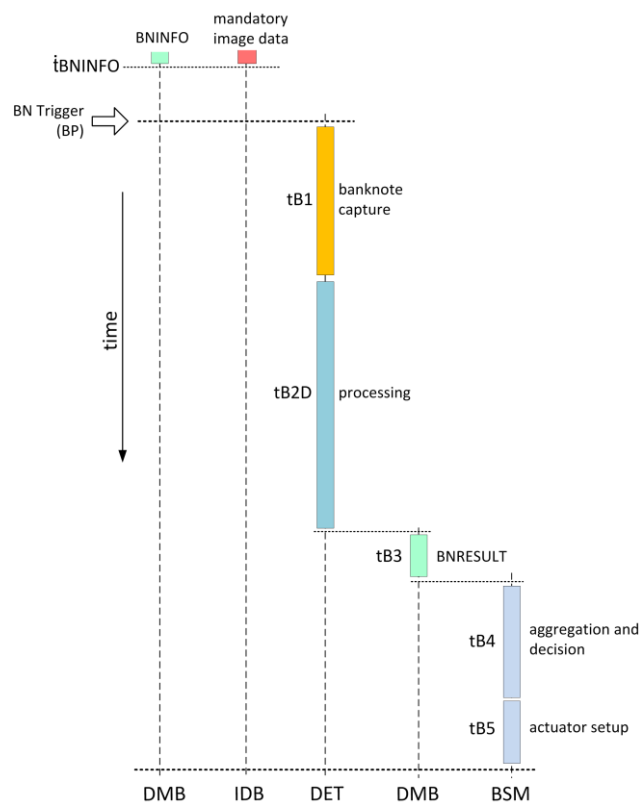
Figure 9: Timing sequence from trigger at the last detector position DET#8 to sorting gate

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 *DET* 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 *DET* 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 *DET* (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 *DET* 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.
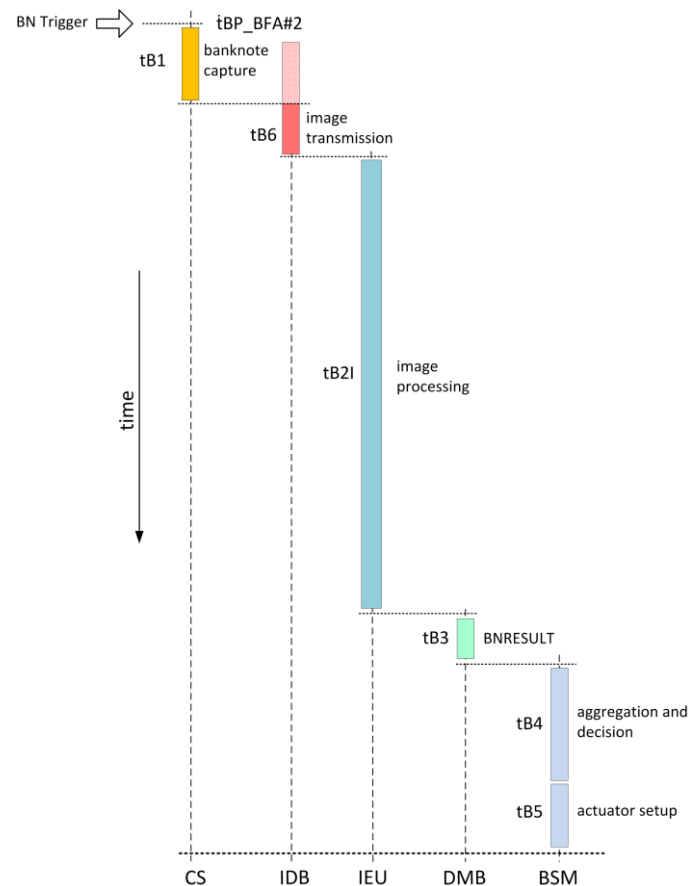
Figure 10: Timing sequence for an IEU from tBP_*BFA*#2 to sorting gate

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)	tB1 + tB6 = 220.0 mm / vBN + 5 ms
tB6	Image transmission time	
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 (tB2I) 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 *DET*: Regarding the timing considerations, an *IEU* with optional *DET* is treated as if it were an *IEU* without optional *DET* plus a *DET* in the position of the optional *DET*. 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 *DET* (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:

vBN (m/sec)	BFA1DET1		DET8GATE		BFA2GATE	
	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 an HTTP web server providing a user dialog.

The HTTP communication uses the Internet Protocol (IP) in the asynchronous phase of the **POWERLINK** cycle 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* shall have such a TCP/IP connection and shall 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 *DET*s 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 *ESP*. 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>.

192.168.100.POWERLINK Node ID

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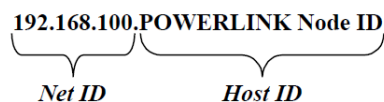
Self-Test, calibration and data up/download are examples for functions to be activated via the HTTP port.

Chapter 6.7.5 gives further information on service and maintenance operations.

3.4 Self-monitoring and Self-test

Each **CDI2 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 Device**s 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 via HTTP

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. As a minimum the possibility to update via USB 2.0 has to be provided. 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 *DET* Interface 2 (CDI2) Specifications contains two fields, the interface revision and the document revision.

<revision code> := <interface revision><document revision> (e.g. 2.6A)

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

<interface revision> := <major>.<minor> (e.g. 2.6)

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 shall 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 *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 **Supplemental Data** to the *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 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

In the initialisation phase, the *CS* sends information about its mandatory and optional images in its Device Info to the *BSM*. Of course, the *CS* is responsible to set up its images streams over the *IDB* accordingly.

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 *TC*_TRIGn 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 *DET*s.

One image data set consists of a group of up to 256 images for each banknote. Each image data set is sent together with the *BNID* previously received from the *BSM* 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). Optional 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 34).
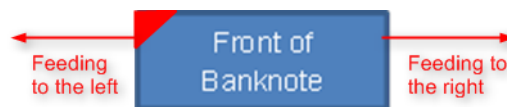
Figure 11: Feeding directions of banknotes

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 34) and the feeding direction. The terms "left" and "right" with respect to the **Casing**s refer to the transport direction: They are to be understood in the literal sense if you (notionally) stand on the baseplate and look in transport direction. Considering the mounting of the **Casing**s of the *CS* to the transport plane, the left side corresponds to the contact side and the right side to the non-contact side (see chapter 7.4.2).
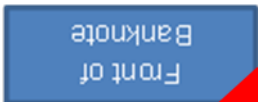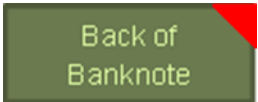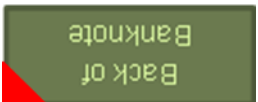
Orientation	Operator View	Image on IDB			
		Feeding to the right		Feeding to the left	
		left (contact) Casing	right (non-contact) Casing	left Casing	right Casing
1	Front of Banknote	Front of Banknote	Back of Banknote	Back of Banknote	Front of Banknote
2	Front of Banknote	Front of Banknote	Back of Banknote	Back of Banknote	Front of Banknote
3	Back of Banknote	Back of Banknote	Front of Banknote	Front of Banknote	Back of Banknote
4	Back of Banknote	Back of Banknote	Front of Banknote	Front of Banknote	Back of Banknote

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 **Casing**s 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 device 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 *DET* 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.

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 *DET* 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*.

The distortion test addresses the absolute distance measurement accuracy. Distortions in x-direction are caused exclusively by the *CS*. Note, however, that the distortions in y-direction can be attributed to influences from both the *BSM* and the *CS*. In fact, they may be caused by the inaccuracy of the *BSM* during mechanical transport, the inaccuracy of the *BSM* line trigger signal as well as the inaccuracy of the *CS* with respect to that trigger signal. Details of the test are given 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 a perfectly 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 the 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 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.
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 a 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).

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

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[1]	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 4.2.3
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	
y-Distortion (transport direction)	0	0.5 mm	A, moving	
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)

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[1] In the acceptance tests for a CS, Moiré is measured with the EvalChartA tool set. In this tool set, limits for Moiré are given.

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 the 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 *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*.
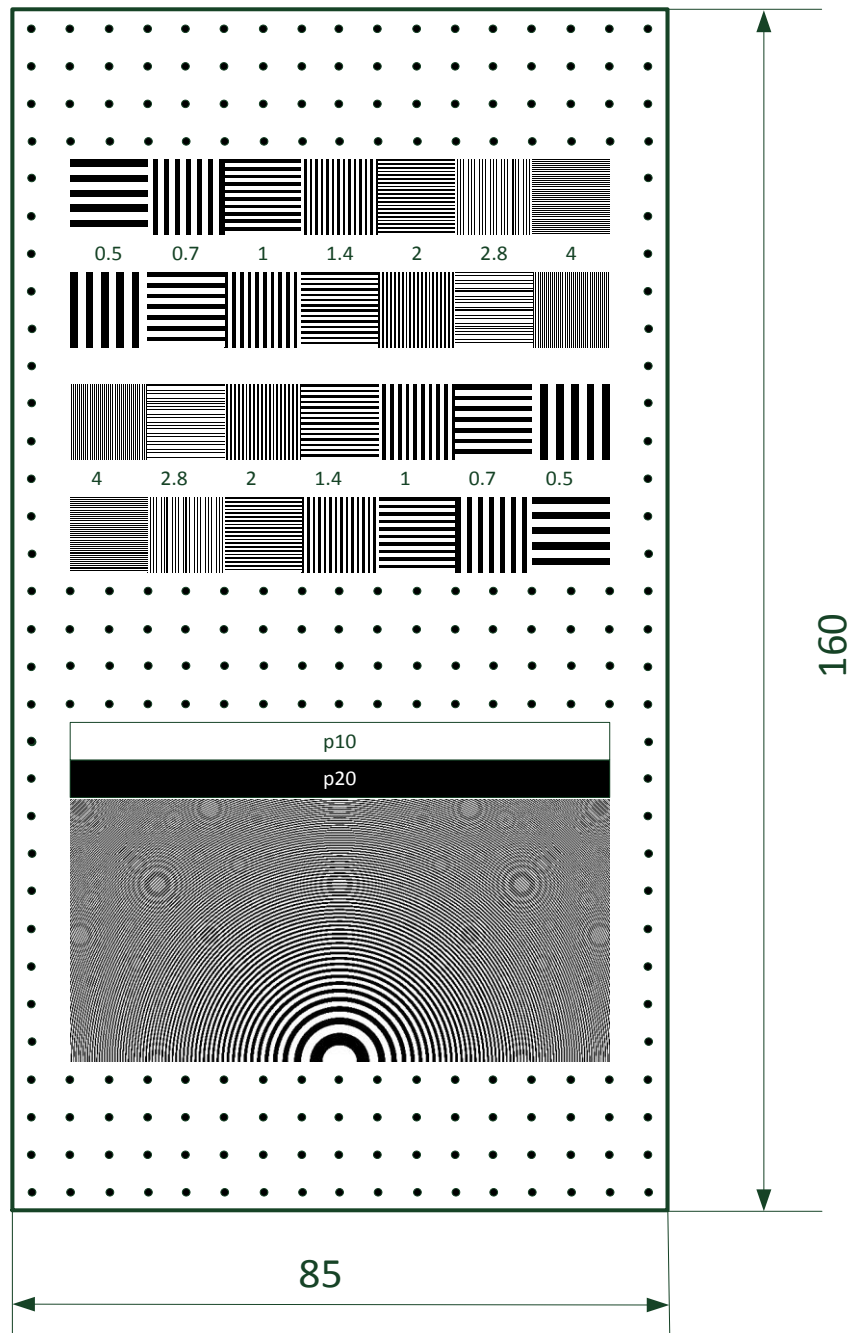
Figure 12: Test chart A to check *MTF*, Moiré, and Distortion. Not in scale. 70 mm x 35 mm Ring pattern (zone plate pattern) may not be correctly reproduced in this document due to artefacts of monitor or printing. Frequencies of ring pattern rising with 0.2 *LP*/mm per mm distance from centre (thus 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.
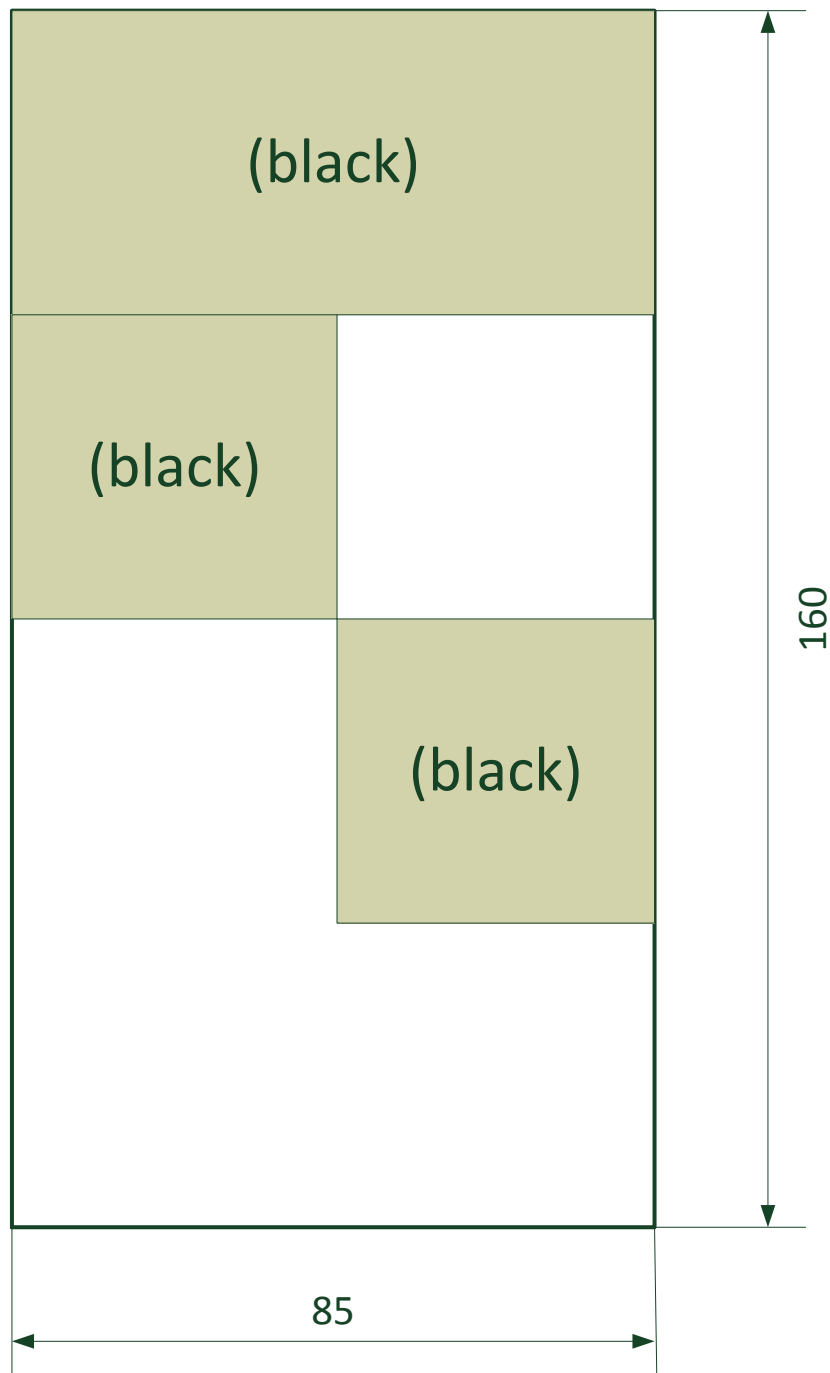
Figure 13: Test chart B - Black / White Reference Paper. Dimensions in mm.
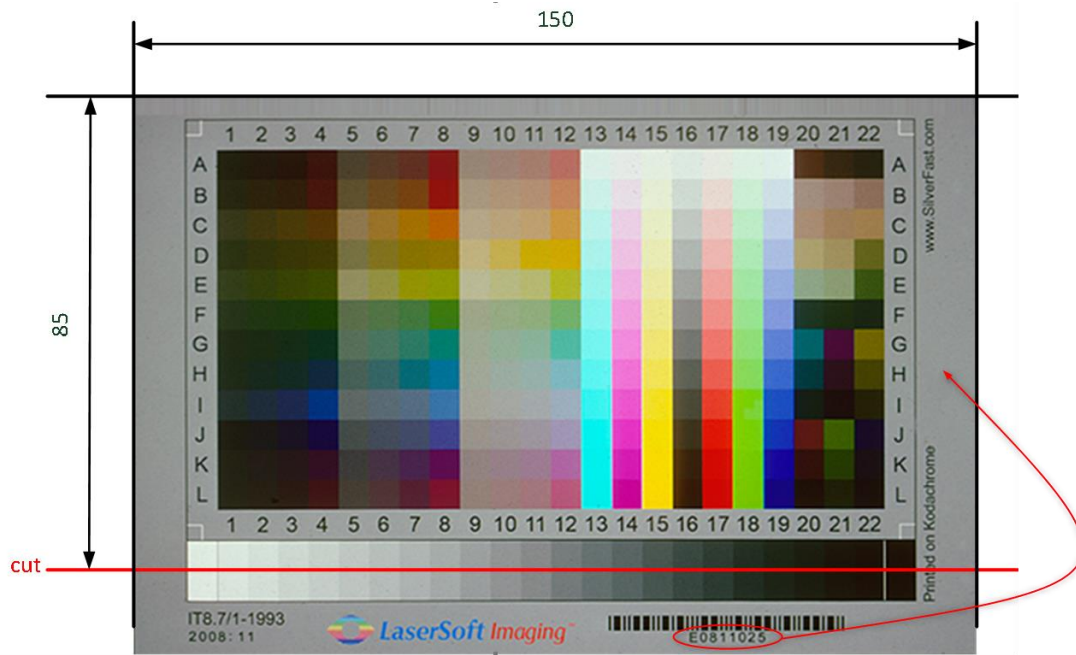
Figure 14: Test chart C: IT8.7/2 reflective test chart for colour calibration and test of colour linearity error, format 150 x 100 mm, cut to 150 x 85 mm.

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 (see Figure 14). 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 $(X_{i,\mathrm{meas}}, Y_{i,\mathrm{meas}}, Z_{i,\mathrm{meas}})$, with $i = 1 \dots n$ and S_{ref} denoting an $n \times 3$ matrix of the n reference colour values $(X_{i,\mathrm{ref}}, Y_{i,\mathrm{ref}}, Z_{i,\mathrm{ref}})$, a least square fit minimises the quadratic sum of the elements of the residual matrix

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

In other words, the expression

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

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 provides four protocols, the GigE Vision Stream Protocol (*GVSP*), the GigE Vision Control Protocol (GVCP), the GigE Device Discovery Mechanism and the Machine Vision Association's GenICam standard.

CDI2 utilises the *GVSP* for the transmission of image streams on the *IDB* as the only protocol. The real-time critical parts of CDI2 are being sent over *TTS* (triggers and *TC*) and *DMB* (*BNID*, BNINFO, BNRESULT). The *IDB* only needs to guarantee a maximum latency.

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 *IEU*s and the *BSM*. Figure 15 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.].
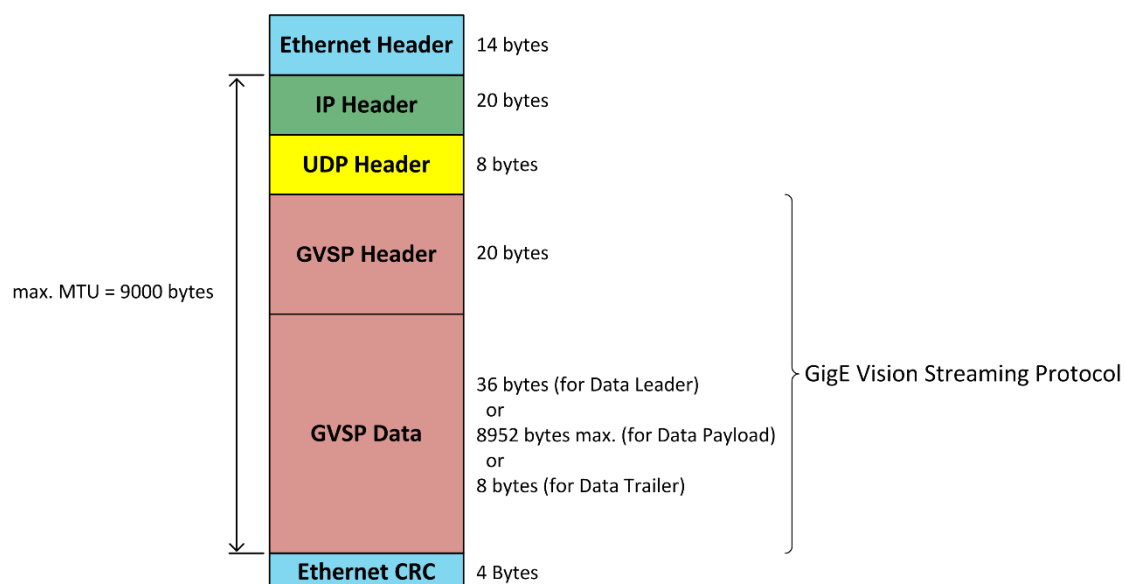
Figure 15: A GVSP UDP packet
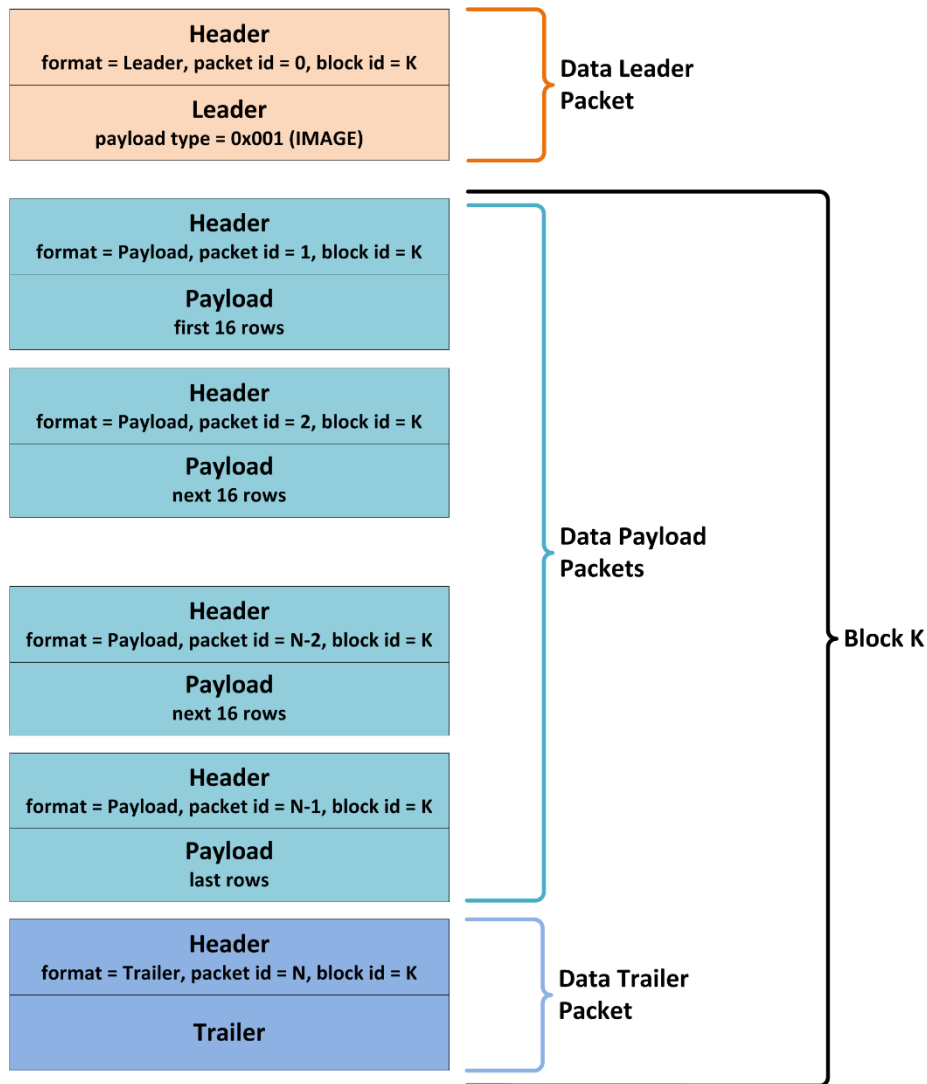
Figure 16: GVSP packetise and transmit data

Figure 16 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) for mandatory images 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* (see 6.7.4.4).

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 optional image data shall be sent to one or multiple *IEU*s using IP multicast addressing, with the multicast group set to 239.205.18.1.

All streams are unconditional to make sure that all simultaneous *IEU*s can continue receiving image data no matter what happens to other *DET*(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 *IEU*s act as *GVSP* receivers. Because the *IDB* does not use the control and message channel, the *CS* and *IEU*s must know all parameters for their image streams such as IP address, resolution, image size and *IDB* stream number in advance. The *CS* sends its configuration information to the *BSM* via the *DMB* in the CDI2 configuration phase (see 6.6.3). How an *IEU* is configured with the correct image parameters is up to the manufacturer (e.g. via its device configuration or some manual setup). Once configured, the *CS* initialises its *IDB* streaming channels and an *IEU* sets up 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 optional 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	optional 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	97
Length	mm	186
Resolution	mm	0.2
Width	# Pixel	485
Length	# Pixel	930
Pixels / Channel	# Pixel	451,050
Bits / Pixel	#	8
Data / BN	Kbyte	3,523.8
Data / s (at 50 BN/s)	Mbyte / s	172.06
Data / 1 Mio BN	Mbyte	3,441,238
Free for optional 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	97	97	97	97	97
Length	mm	60	186	186	186	186	186
Pixels	# Pixel	120,000	451,050	72,168	451,050	801,867	1,804,200
Bits/Pixel	#	8	16	16	8	8	8
Data/BN	Kbyte	117.2	881.0	141.0	440.5	783.1	1761.9
Data/s (at 50BN/s)	Mbyte/s	5.72	43.02	6.88	21.51	38.24	86.03
Data / 1Mio BN	Mbyte	114,441	860,310	137,650	430,155	764,720	1,720,619

Table 16: Example IDB data rates of different optional 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 images. 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 *IEU*s 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 17: 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 *DET* 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 EEUs" (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 18: 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

Figure 19: Example of an IDB cable

References:

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*), *TC* and **RESET** signals from *BSM* to **CDI2 Device**s, like the CDI2 **Camera System** or CDI2 *DET*s, via dedicated hardware lines. Additionally, a **READY** signal from the **CDI2 Device** to the *BSM* is provided. The *BSM* shall offer eight mechanical *DET* slots fully complying with the CDI2-*TTS* specification.

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

Table 18: TTS signals, with direction on BSM-side and implementation

For the *TC* and *BP* signals, RS-422 is used as the transmission standard. The *DET* **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 *DET* or the *BSM*. For powering the *DET* 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 *DET* 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* interface provided by the *BSM* shall comply with CDI1 as well. Upon the machine configuration, a *TTS* interface 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 *DET* and to synchronise the **Banknote ID** with the banknote and *DET* 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 **Banknote Edge (Leading)** passes the **Casing Position**. An offset may be requested in the **CDI2 Device** Info command. A valid *BP* signal has a leading edge distance to the previous **Banknote Edge (Trailing)** of at least 30 mm. *BP* 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 *DET*.

Guidance example *BSM*-side: see Figure 4 of CDI1.0B [Ref 6.]
Guidance example *DET*-side: see Figure 9 of CDI1.0B [Ref 6.]

Signal Name	Transport Clock (TC)
Functionality	Dedicated interface line with a square wave clock from the *BSM* to the *DET*. It synchronises the transport speed of the banknote with the inspection rate of the *DET*.
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* interface. Length: min. 1 µs Duty-Cycle: 50% Jitter: < 10% of minimal spatial resolution Accuracy: < 0.6% deviation between clock speed and banknote movement
Remarks	*TC* is not used for an *IEU* without an optional *DET*. The *TC* 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 Device**s with different clock pulses.

Guidance example *BSM*-side: see Figure 3 of CDI1.0B [Ref 6.]
Guidance example *DET*-side: see Figure 8 of CDI1.0B [Ref 6.]

Signal Name	RESET
Functionality	Dedicated interface line from the *BSM* to a *DET* to carry out hardware **RESET** of the *DET*.
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 *DET* must not react on a **RESET** signal with a duration less than 100 µs.

Guidance example *BSM*-side: see Figure 5 of CDI1.0B [Ref 6.]
Guidance example *DET*-side: see Figure 10 of CDI1.0B [Ref 6.]

Signal Name	READY
Functionality	Dedicated interface line from the *DET* to the *BSM* to indicate that the *DET* 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 [Ref 6.]
Guidance example *DET*-side: see Figure 11 of CDI1.0B [Ref 6.]

Signal Name	POWER +5V / GND
Functionality	Powering of the *DET* 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.

*) RS-422

Signal specification

      Voltage swing between signal pairs |U| >= 2.0 V
      Signal rise/fall time <= 1 µs (between 10% to 90% signal)

**) Digital current loop (20mA max)

Receiver specification

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

Transmitter specification

The transmitter shall be implemented as either an (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 4.0 V

(b) Voltage source specification
Source resistance: 120 ohm
Open circuit voltage: 4.5 to 5.5 V
An implementation example can be found in Figure 5 and Figure 11 of CDI1.0B [Ref 6.].

Signal specification

Voltage swing between signal and GND |U| >= 2.1 V
Signal rise/fall time <= 10 µs (between 10% to 90% signal)

***) Galvanically separated

The *TTS* interface 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 *DET*. At the *BSM* side no specific dust protection is required and the *BSM* manufacturer is free to use its own connector type.

Figure 20: TTS device connector example, Conec Part Number 15-002243

The *TTS* 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 *DET* position in the *BSM* or the EEU in the storage rack. The cable length shall not exceed 20m.

In case the *DET* consists of a measurement head and an EEU, the connection between these two parts of the *DET* is up to the *DET* 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 from *BSM* for galvanic separation (200 mA max)	
All other pins shall be connected to GND			

Table 19: 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) for each device, consisting of a *TC* counter value (TC_COUNTn) and a *BN* trigger information (TC_TRIGn).

The actual *BP* 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 *BP* signal from the values provided in the BSMINFO command. As shown in Figure 21, 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 *TC* 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 22).

The device can derive a *BP* 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 23 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 *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*.
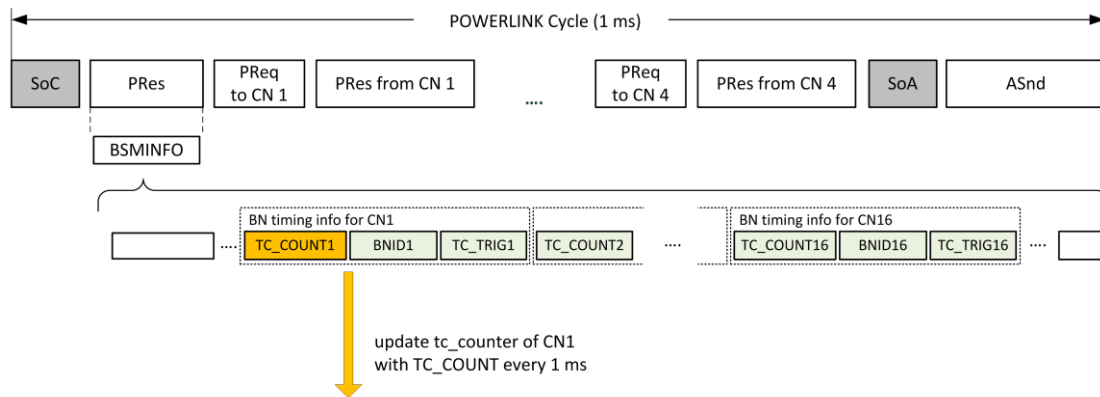
Figure 21: Readout of TC_COUNTn from BNINFO
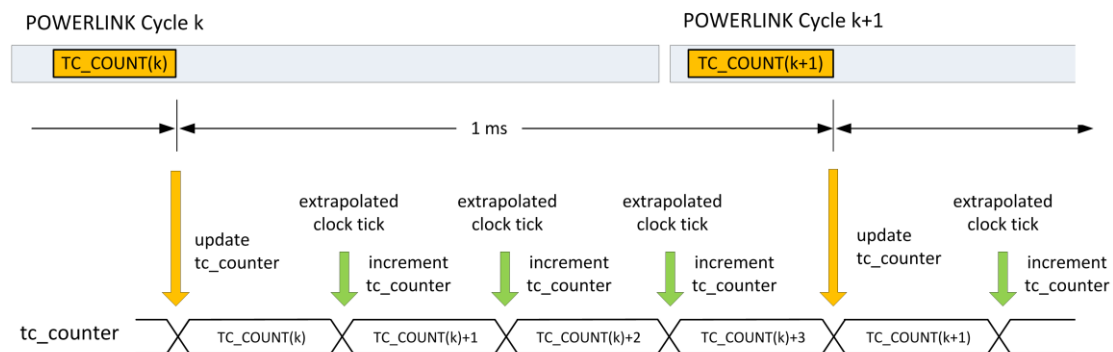
Figure 22: Recovery of tc_counter from TC_COUNTn
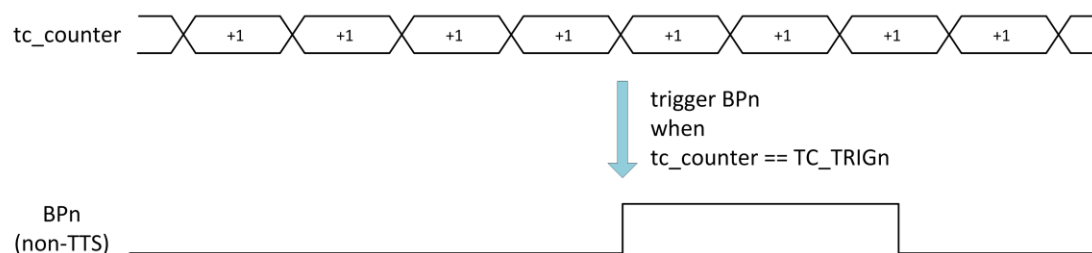
Figure 23: Generation of BP from tc_counter and TC_TRIGn

6   Detector Machine Bus (DMB)

The *Detector Machine Bus* DMB connects the BSM with its **CDI2 Device**s (**Camera System**, *IEU*s and *DET*s). During all phases of machine operation, the *DMB* acts as the main communication path for exchanging control information between *BSM* and **CDI2 Device**s. 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 Device**s
- Is rugged and suitable for an industrial environment by using industrial connectors
- Supports the software update of **CDI2 Device**s

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 *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.
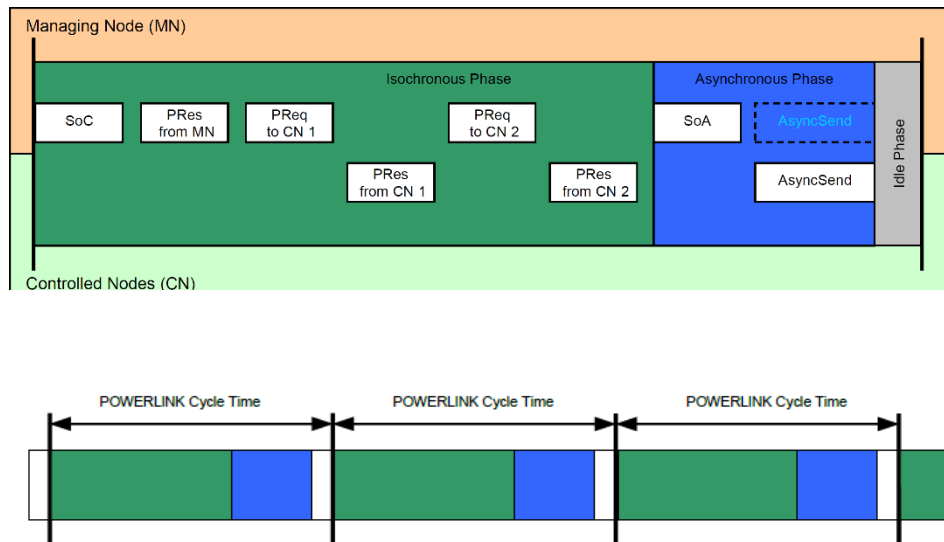
Figure 24: General POWERLINK frame structure

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** *MN* may send messages independently. **POWERLINK** *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** *MN* with the permanently assigned Node ID Number 240.

6.4   Controlled Node (CN)
All *DMB* nodes, except the *BSM*, operate as **POWERLINK** *CN*s. 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.
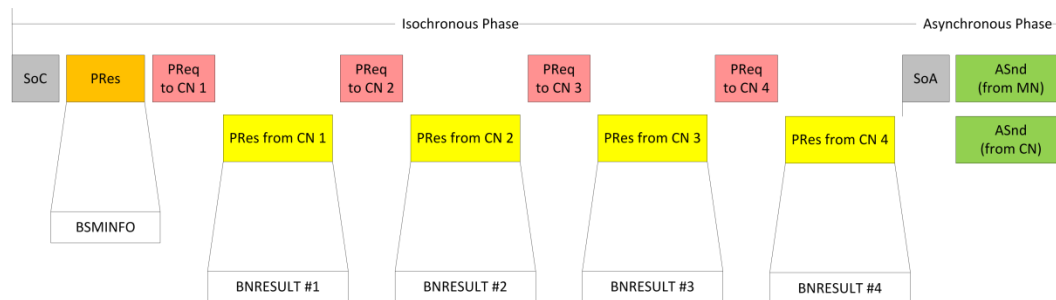
Figure 25: Basic CDI2 POWERLINK frame structure

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 25 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 *CN*s listening. In the next step, the *MN* polls the *CN*s and requests a PRes response containing BNRESULT, if available. In CDI2 the *MN* uses a by 4 multiplexed scheme to poll the *CN*s, thus in each **POWERLINK** cycle four *CN*s can deliver a BNRESULT to the *BSM*. As CDI2 supports up to 16 *CN*s, it needs four **POWERLINK** cycles to provide the BNRESULT of all *CN*s 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 Device**s.

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 open**POWERLINK** 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 28).

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

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 *MN* is the bus master and all other nodes may only send in answer to a corresponding request of the *MN*. 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 **CN**s are polled in each cycle to deliver their result. The sequence of this multiplexed **POWERLINK** Cycle is shown in Figure 26.

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.
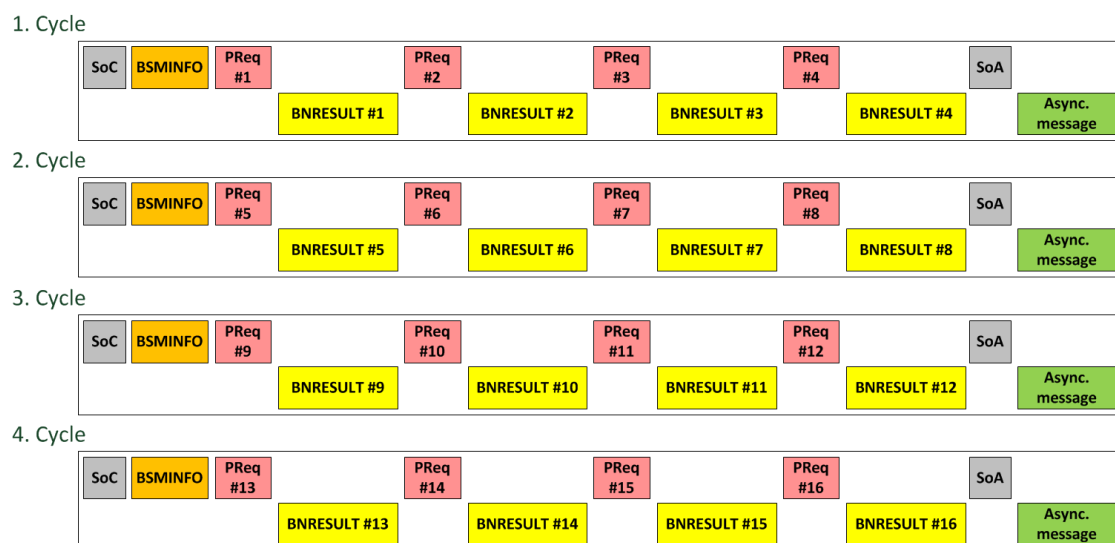
Figure 26: POWERLINK cycle as used in CDI2

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 20: 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 as worst case.

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

16 *DET*s @ 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 *CN*s are in their respective operational states (NMT_MS_OPERATIONAL and NMT_CS_OPERATIONAL). At this time, the **POWERLINK** communication between an *MN* and its *CN*s 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, e.g. 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 Device**s must use only the required minimal implementation according to chapter 5.1 of [Ref 4.], 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** *MN* uses the permanently assigned Node ID Number 240.

The Node IDs of *CN*s are in the range 1-16. They are assigned statically at installation time or at maintenance of the sorting machine.

A **CDI2 Device** (*DET*, **Camera System** or *IEU*) 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 a unique node ID assigned 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 *CN*s. In the first stage, the *MN* requests identification from all *CN*s 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** *CN*s are optional, which means that the *MN* will become/stay in operational state even when no *CN*s have been identified. Thus, the *DMB* of the sorting machine is fully operational even if not all **CDI2 Device**s are operational. The *MN* will continue to issue IdentRequest frames to all configured but yet unidentified *CN*s in a regular manner. It is up to the *BSM* to check if the detected *CN*s 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 28). 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 shall 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 27 depicts the full *MN* NMT State machine, as it is found in the **POWERLINK** specification, with all possible transitions. The state colours correspond to the operational mode of the **POWERLINK** Ethernet, as shown in Figure 28. Please refer to the appropriate chapters for further details (chapter 7.1.3 *MN* NMT State Machine in [Ref 3.]).
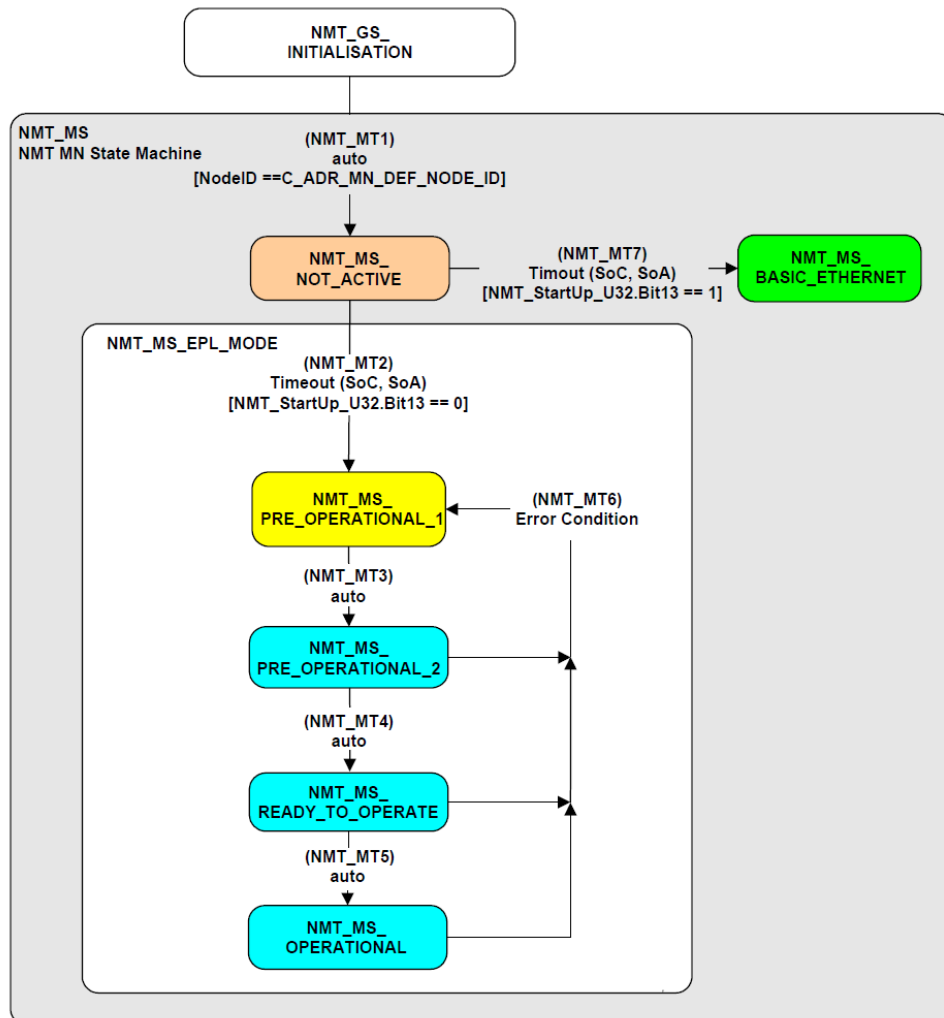
Figure 27: MN NMT state machine
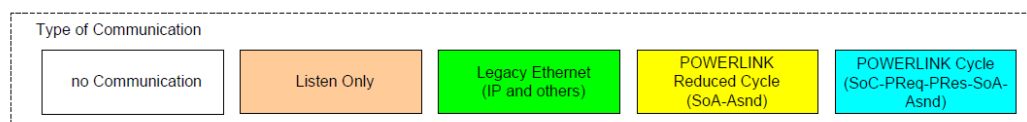
Figure 28: POWERLINK communication modes depend on MN NMT state (same colours)

NMT State Machine of Controlled Node

Figure 29 depicts the full *CN* NMT State machine, as it is found in 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.]).
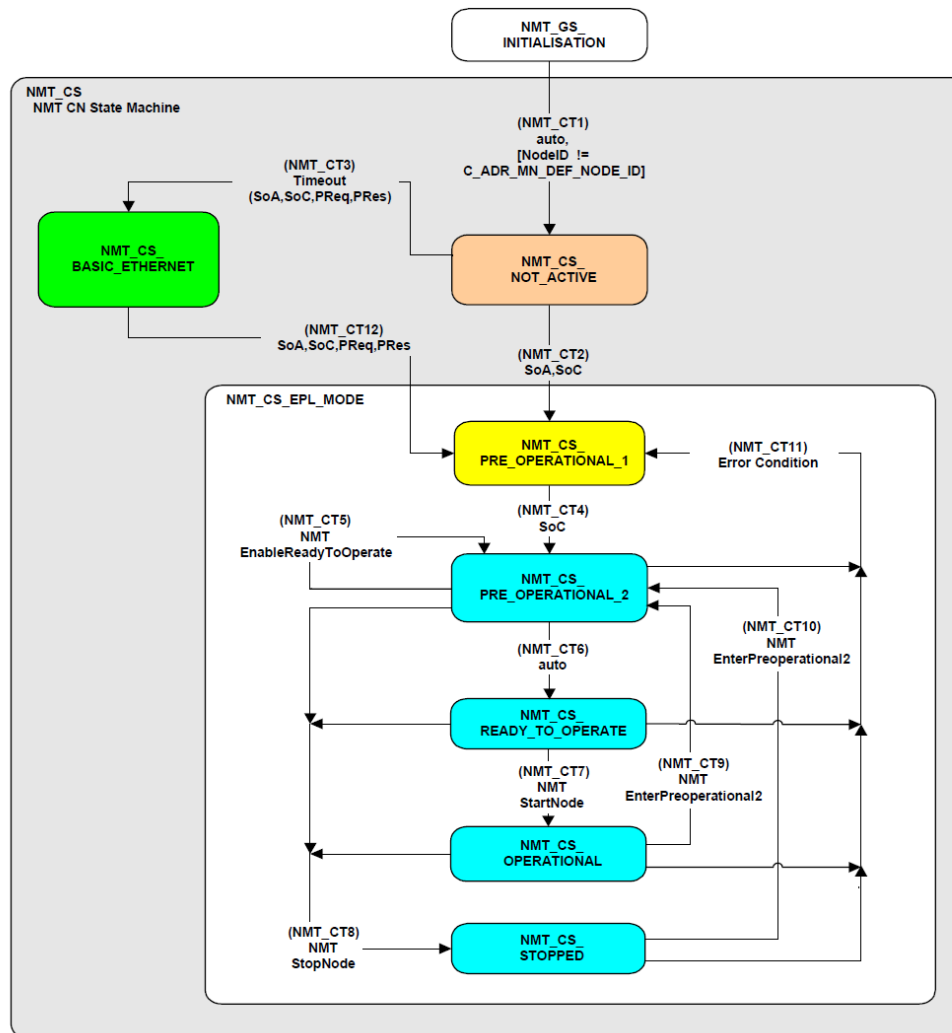
Figure 29: CN NMT state machine

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 Device***s 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 Device***s with an updated Device Info (see below).

Figure 30 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 Info 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 Info 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 Device**s, which shall update their own configuration thereafter.
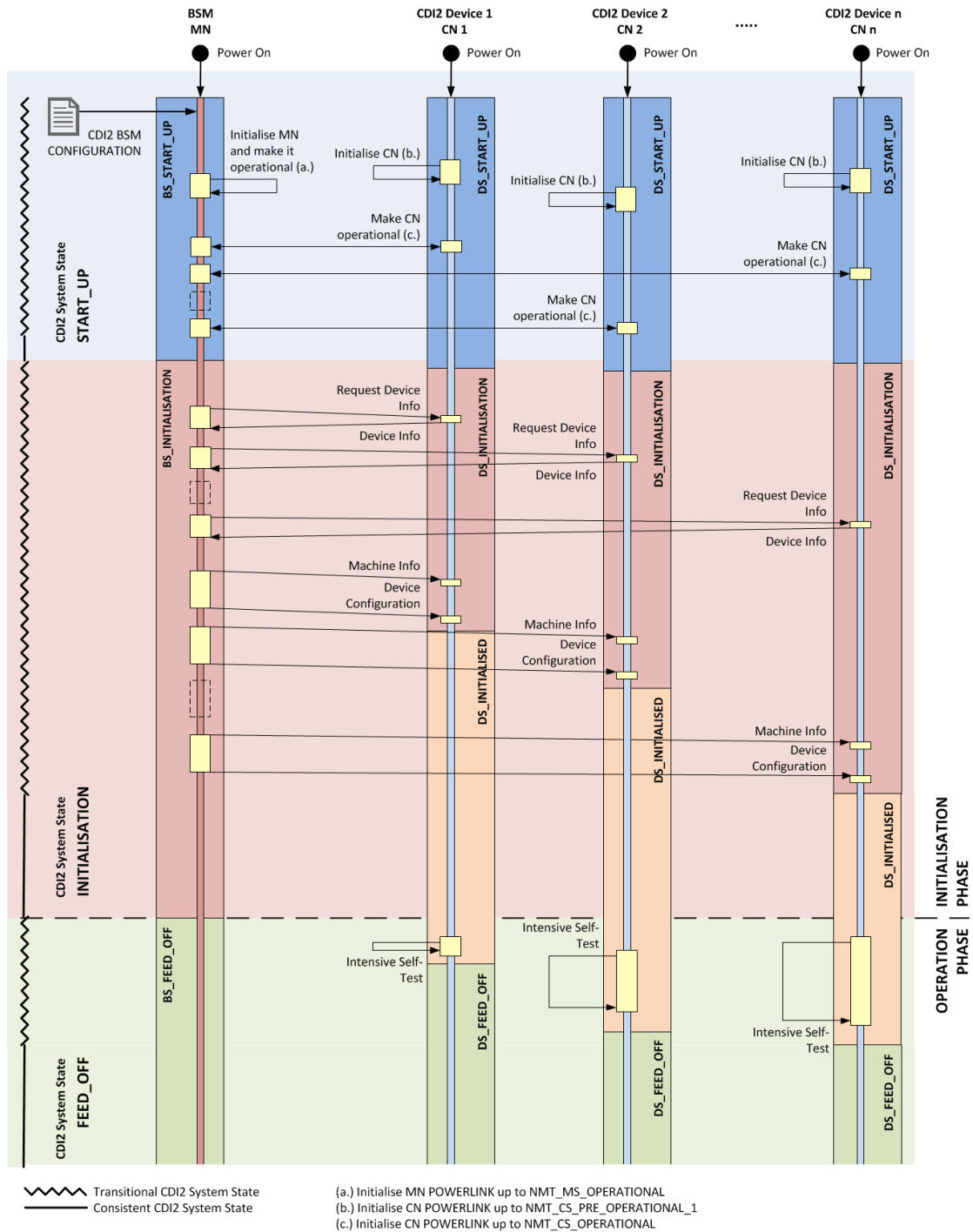
Figure 30: CDI2 configuration procedure

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 commands (BSMINFO) to the **CDI2 Device**s and to obtain results (BNRESULT) from the **CDI2 Device**s.

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 21. 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	*DET* Serial Nr, *DET* 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 21: DMB command overview

6.7.2 CDI2 State Machine

Figure 31 and Figure 32 show the CDI2 States and transitions of the *BSM* and the **CDI2 Device**s, respectively.
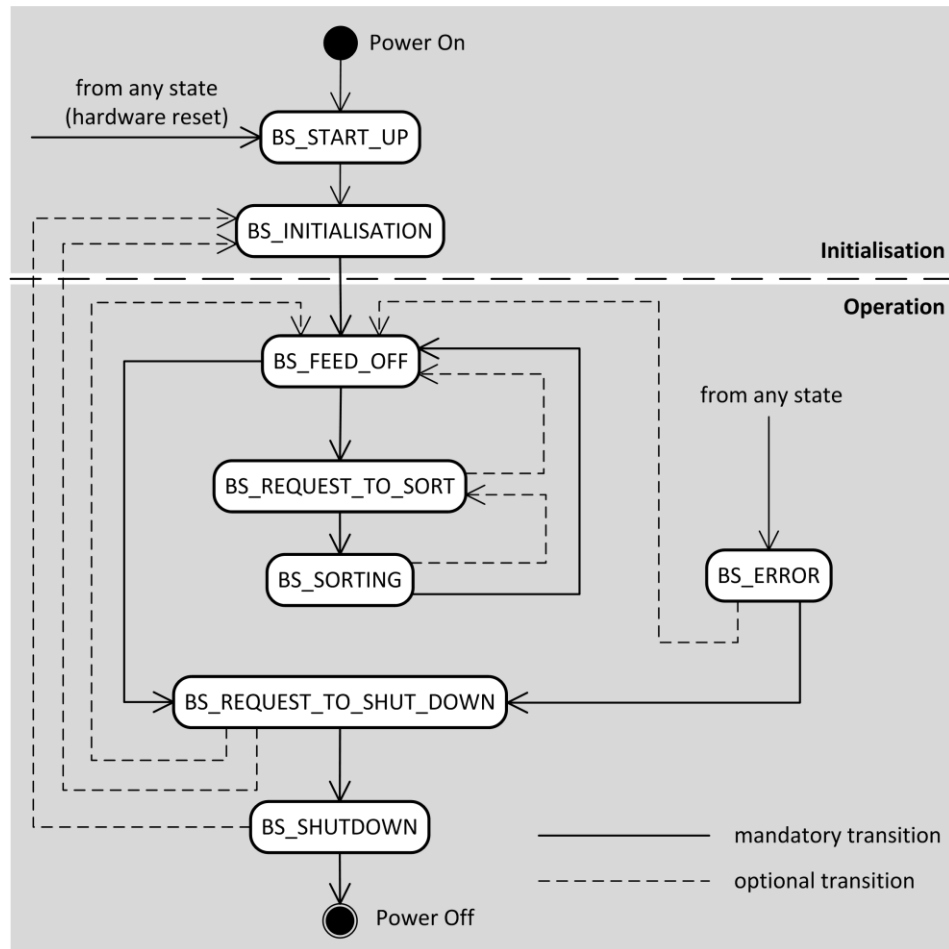
Figure 31: BSM states and transitions
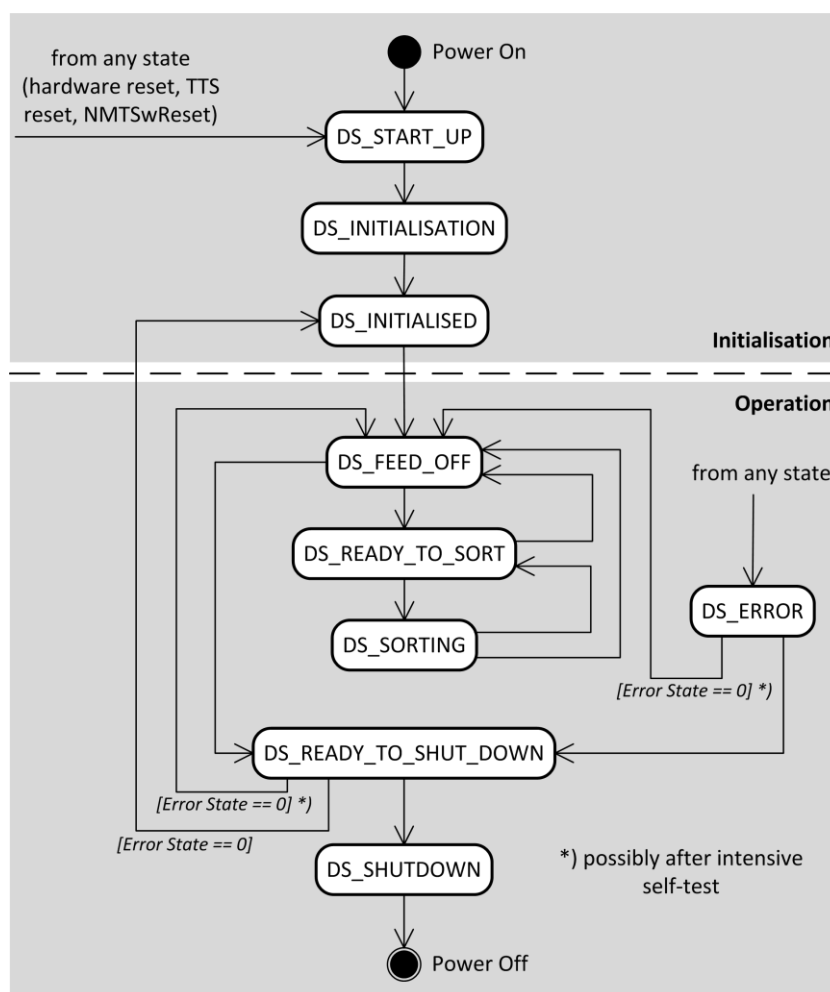
Figure 32: CDI2 Device states and transitions

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

BSM State	ID		CDI2 Device State	ID
BS_START_UP	1		DS_START_UP	1
BS_INITIALISATION	2		DS_INITIALISATION	2
			DS_INITIALISED	3
BS_FEED_OFF	3		DS_FEED_OFF	4
BS_REQUEST_TO_SORT	4		DS_READY_TO_SORT	5
BS_SORTING	5		DS_SORTING	6
BS_REQUEST_TO_SHUT_DOWN	6		DS_READY_TO_SHUT_DOWN	7
BS_SHUTDOWN	7		DS_SHUTDOWN	8
BS_ERROR	10		DS_ERROR	10

Table 22: IDs for BSM and CDI2 Device states

As you can see from Figure 31 and Figure 32, the state diagrams of the *BSM* and a **CDI2 Device** are quite similar. In fact, the states of the *BSM* and all **CDI2 Device**s are coupled to a high degree. Therefore, within normal operation the *BSM* and all **CDI2 Device**s 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 Device**s 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 23: 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 28) 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 28. For all other state transitions (e.g. from DS_START_UP to DS_INITIALISATION), these shall be carried out within 10 ms.

Note that during normal operation situations can arise where the *BSM* and all **CDI2 Device**s 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 Device**s 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 *CN*s of the **CDI2 Device**s operational with respect to **POWERLINK**. The steps for this are listed in Table 26. When all **CDI2 Device**s 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 27. 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 24: 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 26. 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 27. 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 27).

Table 25: 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 26, 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. After power on or reset, a **CDI2 Device** shall respond with an IdentResponse within 30 s.
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 26: POWERLINK Initialisation Steps of BSM and CDI2 Device

The second table, Table 27, describes the steps that the *BSM* carries out to initialise a **CDI2 Device** regarding to CDI2. If several **CDI2 Device**s 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 Device**s to be initialised.

The *BSM* may optionally carry out the initialisation steps of Table 27 for individual **CDI2 Device**s, if it supports such an approach (see optional transitions in Figure 31). 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 Device**s 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 27: CDI2 Initialisation Steps of BSM and CDI2 Device

Note that the *BSM* shall carry out any initialisation step listed in Table 27 only if the **CDI2 Device** is in the appropriate state. Therefore, a **CDI2 Device** 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 a **CDI2 Device** notices a transition, it carries out any tasks associated with this transition (see Table 28). When the **CDI2 Device** is finished, it signals the new state. Exception: A **CDI2 Device** cannot signal DS_SHUTDOWN, see Table 29. The *BSM* shall proceed (e.g. with a transition to a next state) only if all **CDI2 Device**s 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 32). 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 Device**s 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 Device**s follow, see Table 29.

CDI2 Device State	Transition Task	Timeout (not to exceed)
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 28: 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 Device**s 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 Device**s 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 Device**s 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_SHUT_DOWN or DS_SHUTDOWN, the *BSM* may ignore this transition. All **CDI2 Device**s 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. If a **CDI2 Device** changes its state to DS_ERROR, it must not leave DS_ERROR until it has observed the *BSM* being in state BSM_ERROR at least one time.

The *BSM* may distinguish **CDI2 Device**s that generated DS_ERROR from **CDI2 Device**s that only entered DS_ERROR because of the *BSM* entering BS_ERROR by observing their error state: **CDI2 Device**s 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 32). 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 32), 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 32), 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 Device**s (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 28.

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 Device**s 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 Device**s.
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 Device**s 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 Device**s 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 Device**s 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 Device**s enter state DS_ERROR within the specified timeout, the *BSM* may proceed with a shutdown anyway to shut down the **CDI2 Device**s that are still functional in an ordered way.

Table 29: 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 accept/provide the 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**
1	Signed char	1 Byte
2	Unsigned char	1 Byte
3	Signed Integer 16bit	2 Byte
4	Unsigned integer 16bit	2 Byte
5	Signed Long Integer 32bit	4 Byte
6	Unsigned Long Integer 32bit	4 Byte
7	Float single precision (IEEE-754)	4 Byte
10	1 ASCII character	1 Byte
11	4 ASCII characters	4 Byte
12	8 ASCII characters	8 Byte
13	16 ASCII characters	16 Byte
17	1 UTF16 character	2 Byte
18	4 UTF16 characters	8 Byte
19	8 UTF16 characters	16 Byte
20	16 UTF16 characters	32 Byte
33	1 UTF32 character	4 Byte
34	4 UTF32 characters	16 Byte
35	8 UTF32 characters	32 Byte
36	16 UTF32 characters	64 Byte
49	binary data	16 Byte
50	binary data	32 Byte
51	binary data	64 Byte
52	binary data	128 Byte
53	binary data	256 Byte
54	binary data	512 Byte

Table 30: 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="6"/>
    <Customer name="OeBS" country="Austria" currency="Euro"/>
    <Transport feedingDirection="right" minimumSpeed="9.5" maximumSpeed="10.5"/>
</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, 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
<?xml version="1.0" encoding="UTF-8"?>
<CameraSystem nodeId="1" useSecondBfa="true">
    <General manufacturer="CamTech" description="CS123" swVersion="4.54aa" deviceClass="4"
serialNumber="123456" swUpdateSupported="true"/>
    <Connections idbSupport="true" ttsSupport="true" ttsTcResolution="0.1" bpOffset="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" internalResolution="0.1" height="1016"
width="508" idbStreamNr="8" gvspPayloadType="32768"/>
        <Image type="num" resolution ="0.1" internalResolution="0.1" height="800" width="250"
idbStreamNr="9" gvspPayloadType="32768"/>
        <Image type="UV" resolution ="0.5" internalResolution="0.1" height="360" width="180"
idbStreamNr="10" gvspPayloadType="1"/>
    </Images>
    <ImageEvaluation supported="true">
        <IeCapabilities fitness="true" numberReading="true"/>
```

```xml
        </ImageEvaluation>
        <SupplementalData numBnResultSegments="1">
            <Property id="4" name="judgement" unit="" type="2" offset="0" />
            <Property id="5" name="result" unit="" type="2" offset="1" />
            <Property id="6" name="quality" unit="" type="2" offset="2" />
            <Property id="7" name="serialNumber" unit="" type="13" offset="3" />
<!--id will be defined by BSM and sent back via the device configuration message-->
            <Property id="8" name="orientation" unit="" type="2" offset="19" />
            <Property id="9" name="denomination" unit="" type="2" offset="20" />
            <Property id="10" name="series" unit="" type="2" offset="21" />
            <Property id="11" name="bnlength" type="6" offset="22" />
            <Property id="12" name="bnwidth" type="6" offset="26" />
            <Property id="13" name="soil" type="6" offset="30" />
        </SupplementalData>
        <ServiceFiles>
        <!-- DeviceStatus, Statistics, Configuration and DiagnosisData are mandatory  -->
            <ServiceFile description="Configuration" filename="myparam.cfg" filemode="rw" type="bin"/>
            <ServiceFile description="DeviceStatus" filename="dev_stat.xml" filemode="r" type="text"/>
            <ServiceFile description="DiagnosisData" filename="logfile.txt" filemode="rw" type="text"/>
            <ServiceFile description="Statistics" filename="stat.txt" filemode="r" 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 *DET*s 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 *DET*:

```xml
<?xml version="1.0" encoding="UTF-8"?>
<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" bpOffset="50"/>
    <ImageEvaluation supported="false"/>
    <SupplementalData numBnResultSegments="1">
        <Property id="21" name="judgement" unit="" type="2" offset="0" />
        <Property id="22" name="result" unit="" type="2" offset="1" />
        <Property id="23" name="quality" unit="" type="2" offset="2" />
        <Property id="24" name="intensity" unit="" type="6" offset="3" />
        <Property id="25" name="secret1" unit="" type="17" offset="7" />
    </SupplementalData>
    <ServiceFiles>
        <ServiceFile description="Configuration" filename="config.cfg" filemode="rw" type="bin"/>
        <ServiceFile description="DeviceStatus" filename="dev_stat.xml" filemode="r" type="text"/>
        <ServiceFile description="DiagnosisData" filename="log.txt" filemode="rw" type="text"/>
        <ServiceFile description="Statistics" filename="statistics.txt" filemode="r" 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 *IEU*:

```xml
<?xml version="1.0" encoding="UTF-8"?>
<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" bpOffset="0"/>
    <ImageEvaluation supported="true">
        <IeCapabilities fitness="true" numberReading="false"/>
    </ImageEvaluation>
    <SupplementalData numBnResultSegments="1">
        <Property id="14" name="judgement" unit="" type="2" offset="0" />
        <Property id="15" name="result" unit="" type="2" offset="1" />
        <Property id="16" name="quality" unit="" type="2" offset="2" />
        <Property id="17" name="denomination" unit="" type="2" offset="3" />
        <Property id="18" name="series" unit="" type="2" offset="4" />
        <Property id="19" name="orientation" unit="" type="2" offset="5" />
        <Property id="20" name="avg_soil" unit="" type="6" offset="6" />
        <Property id="21" name="max_soil" unit="" type="6" offset="10" />
    </SupplementalData>
    <ServiceFiles>
        <ServiceFile description="Configuration" filename="param.det" filemode="rw" type="bin"/>
        <ServiceFile description="DeviceStatus" filename="dev_stat.xml" filemode="r" type="text"/>
        <ServiceFile description="DiagnosisData" filename="diag.txt" filemode="rw" type="text"/>
        <ServiceFile description="Statistics" filename="stat.csv" filemode="r" type="text"/>
        <ServiceFile description="LastResult" filename="last.scan" filemode="r" type="bin"/>
    </ServiceFiles>
    <BsmInfo mechanicalSlot="0" 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
  - o mechanicalSlot
  - o mountingPosition
  - o timeBudgetForBnResult

- SupplementalData
  - o 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 *DET*, the *BSM* shall set mechanicalSlot="0", mountingPosition="none" and the *IEU* shall ignore these values.

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

<center>Table 31: SoC frame</center>

6.7.4.2 BSMINFO 0x81

The BSMINFO command is sent in each cycle from the *BSM* to all **CDI2 Device**s. This message is used to transfer common information to all devices, like the actual *BSM* state 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 ID**s 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 *TC* counter for each *DET* position. The *TC* 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 *DET*'s nominal position (the trigger time) can be represented by a certain *TC* counter value. The trigger time values for each *BN* and each *DET* position are known to the *BSM*. The *BSM* may use either a common *TC* counter for all *DET* positions, or it may maintain separate counters for specific *DET* 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 *DET*s 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 *DET* 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. However, it must not be sent until 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 Info 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 *BNID*16 and TC_TRIG16 for this. Further, the *BSM* shall use the bpOffset value of *BFA#1* to calculate the *BFA#2* trigger. Note that this *BFA*#2 trigger for a *CS* is provided in non-*TTS* mode, only, as 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 *DET*, these restrictions do not apply: The *DET* will get its trigger according to its Node ID, and both *TTS* and non-*TTS* operation are available.

The *BSM* shall also send triggers to an *IEU* without optional *DET*. It shall use exactly the same trigger time as for the *CS*, but with bpOffset=0. The *IEU* without optional *DET* shall only accept a banknote on the *IDB* if its *BNID* has previously been announced by a *BNID*/TC_TRIGn in the BSMINFO.

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 22	*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 33	BNINFO: BN Series
	229	1	see Table 33	BNINFO: *BN* Denomination
	230	1	see Table 34	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 32: 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 33: 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.
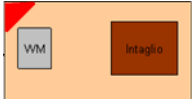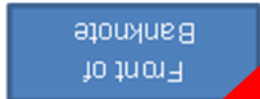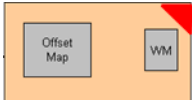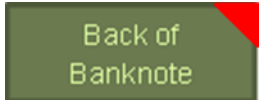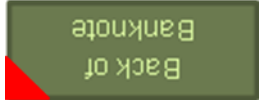
Orientation	Euro system name	Euro orientation	General name	General orientation
1	FF – front side face forward		Front	
2	FR – front side reverse		Front Reverse	
3	BF – back side face forward		Back	
4	BR – back side reverse		Back Reverse	

Table 34: 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 **CN**s 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 35: 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 *CN*, 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 36, 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 22	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 33	BNRECOGNITION: *BN* Series
	37	1	see Table 33	BNRECOGNITION: *BN* Denomination
	38	1	see Table 34	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 33	BNRESULT: *BN* Series
	45	1	see Table 33	BNRESULT: *BN* Denomination

	46	1	see Table 34	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 36: 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 22.

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 they have been carried out in the next feed stop (i.e. FEED_OFF state) and reset the maintenance state bit during the next self-test after this state. The device shall 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 33 and Table 34.

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 *DET* 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 33 and Table 34

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 (see below). A device with its own Series/Denomination/Orientation *DET* 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 *DET* 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 30 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 37 and Table 38 shall be used for Result and **Judgement**.

Result Code	Meaning
0	No error
1	No BNINFO 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	*DET* specific result code (Must be described in the *DET* manual if used)

Table 37: Banknote result codes

Judgement Code	Meaning	Priority
0	FIT	Lowest
1	UNFIT	
2	REJECT	
3	SPECIAL1	
4	SPECIAL2	
5	SPECIAL3	
6	SPECIAL4	
7	SPECIAL5	Highest
8-255	SPECIAL6 to SPECIAL253 (Utilised by *Computational Detectors* only. A *DET* shall not use these codes)	

Table 38: 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 be used via the *AU* 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 39: SOA frame

6.7.5 HTTP Port and Additional Services

The manufacturer of a **CDI2 Device** must provide an HTTP port to implement device specific user dialogs for service and maintenance purposes. Each **CDI2 Device** shall implement an 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 Info 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
<?xml version="1.0" encoding="UTF-8"?>
<DeviceStatus>
    <Device designation="Camera System" manufacturer="CamTech" deviceClass="4" />
    <SubDevice name="RGB123" serialNumber="12345" numberOfNotesMeasured="1111111" upTimeHours="111"
dateOfLastCalibration="2018-03-01T00:00:00" >
        <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="2018-03-01T00:00:00" >
        <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="2018-03-01T00:00:00" >
        <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_SHUT_DOWN. 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 Device*s with a *TTS* connection and the NMTSwReset command for *CDI2 Device*s 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 the DS_START_UP state 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_SHUT_DOWN 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 Device**s. 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 Device**s via READY_TO_SHUT_DOWN – optionally preceded by ERROR – to CDI2 System 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 31), both the *BSM* as well as all **CDI2 Device**s 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 Device**s (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 31), 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 Device**s react by changing to DS_INITIALISED. The *BSM* then proceeds by individually initialising the respective device up to **CDI2 Device** 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 Device**s (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 Device**s 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 Device**s will be in a DS_START_UP state. However, if, possibly because of some error, only the *BSM* has started, it will find all **CDI2 Device**s 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 Device**s 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 DS_ERROR state, the *BSM* shall retrieve error information and display it properly.

Examples would be:

- calibration required
- 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 *CN*s 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 Device**s, 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 *CN*s 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 *DET* 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 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 signalled 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 40 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 40: 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 *MN* maintains a set of counters for *MN* specific errors and a dedicated set of counters for each of the *CN*s.

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 41: 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 42: 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 43: 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	*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 44: 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
- Not initialised *)

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.

*) In general, an uninitialised **CDI2 Device** must never enter DS_FEED_OFF. An uninitialised **CDI2 Device** in DS_ERROR has to signal an Application Error after an intensive self test.

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 the **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 *CN*s, 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
- *CDI2 Device* state
- Error state
- Error code
- Severity
- Text string

Example XML of ErrorLog section:

```xml
<?xml version="1.0" encoding="UTF-8"?>
<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 connectors 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 *DET* with EEU, 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 *EU* 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 33 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:

open**POWERLINK**
http://sourceforge.net/projects/openpowerlink

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

Example for a PCI network card handling the *POWERLINK* protocol:

https://www.ixxat.com/products/products-industrial/pc-interfaces/inpact-mp-interfaces/inpact-powerlink

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 *DET*:

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

7   Mechanics

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

N.B.: Section 7 provides basic dimension information on the *Casings*, for detailed dimensions and CAD file please view the *Casing* file attached to the CDI2 website.

7.1   CDI1 mechanical specifications

The mechanical specification of CDI1 *Casing*s and their mounting remains unchanged (see [Ref 6.]).

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, with a minimum width of 21mm.

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 *CS*) 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 greater than 2 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. The specification of the accepted jam rate is upon the commissioning central bank.
- 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 at *BFA*#2 the image acquiring part of the *CS* consists of only one mechanical unit, the opposite side 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 and concept drawings are available to potential CDI2 users. These solutions are:

- Banknotes are supported over the *CS* surface by a vacuum block system (VAC)
- Banknotes are pushed against the *CS* 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 *DET* positions must allow the mounting of *DET Casing*s on both sides of the banknote transport. In these positions, the *DET Casing*s 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 *DET* positions shall be belt-less contact positions.
This means that the distance of the banknote to the *DET* has to be <1 mm and no belts are allowed between *DET* and banknote.
It shall be possible for the two contact positions to change the side of the *DET* with reasonable effort. Two upper, two lower and one upper plus one lower *DET* shall be possible.

7.4   CDI2 Casings
Next to CDI1 *DET*s, the *BSM* shall support CDI2 *DET Casing*s. These are in principle identical to CDI1, but shall have the possibility to extend through the baseplate, as well as the *Casing*s for the *Camera System*, which is installed in the *BFA* only. The various *Casing*s 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.
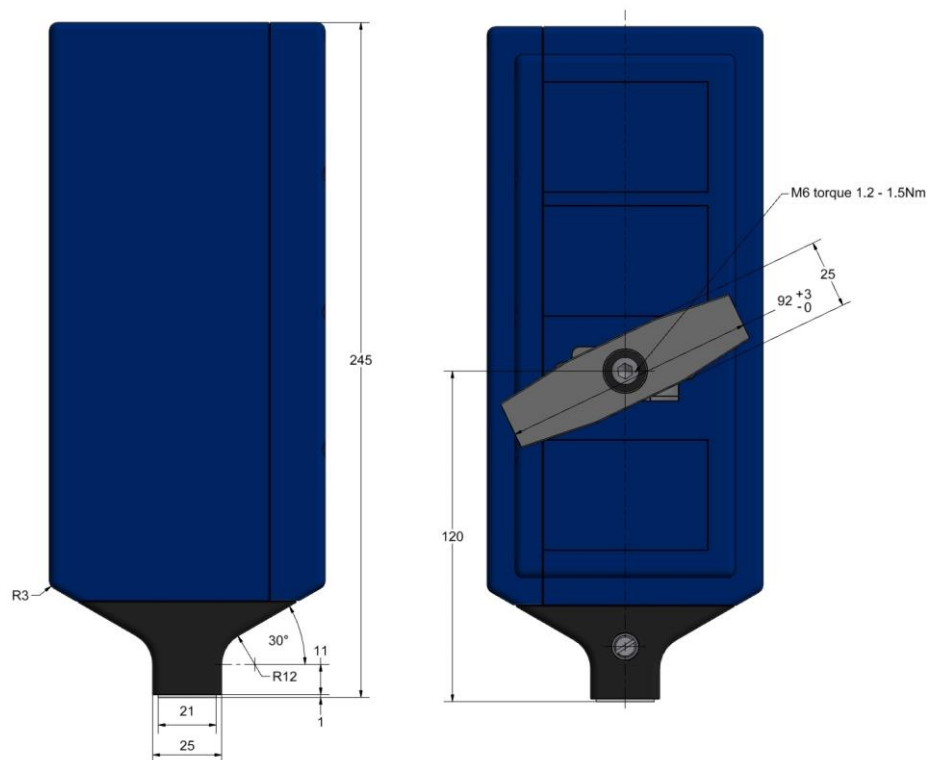The size of the CDI2 *Camera System Casing* shall be as follows:

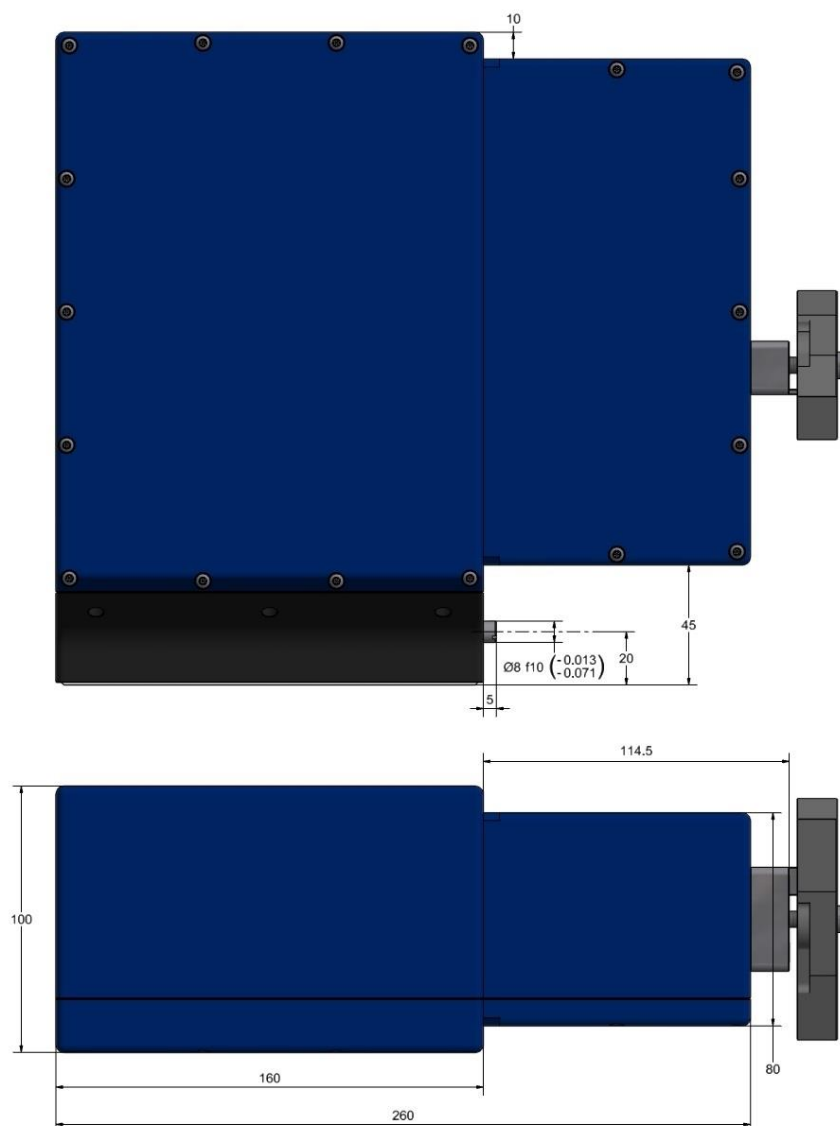Figure 34: CDI2 Camera System dimensions (front/back view)

Figure 35: CDI2 Camera System dimensions (side/top view)

The 92mm x 25mm central locking bar has to be connected to the **Camera System Casing** in a way that it can be tightened in horizontal position (parallel to the sensor window) with a distance of 14.5 to 16.5mm to the rear of the **Camera System Casing**.

In Figure 34 and Figure 35 a recommended proposal is shown. It uses a 14.5mm thick mounting block and a rotating locking bar which is tightened with the support of disc springs.

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 *BSM* supplier needs to ensure proper airflow to dissipate the heat.

7.4.2   Camera System mounting

The CDI2 **Camera System** consists of two opposite **Casing**s. The two **Casing**s 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 36 and Figure 37).

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.
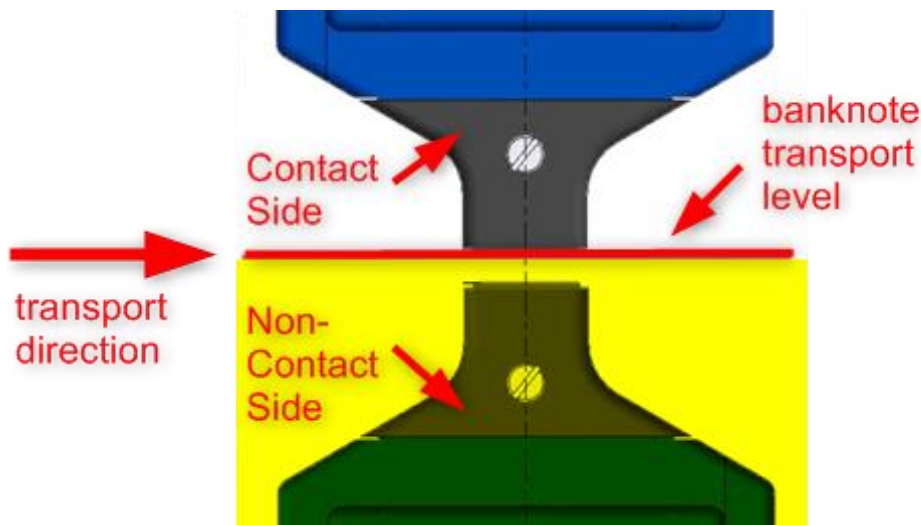

Figure 36: Location of Contact and Non-Contact Side relative to transport direction

CDI2 **Camera System**s 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 **Banknote Sorting Machine** shall provide a mechanical support for the central locking bar 115 to 116.5mm behind the front side of the base plate. Such mechanical support shall be placed left and right of the **Camera System Casing** but not behind the casing. This will allow for different central locking receivers to be developed by the machine manufacturers (see Figure 41 for an indication of the allowed area).

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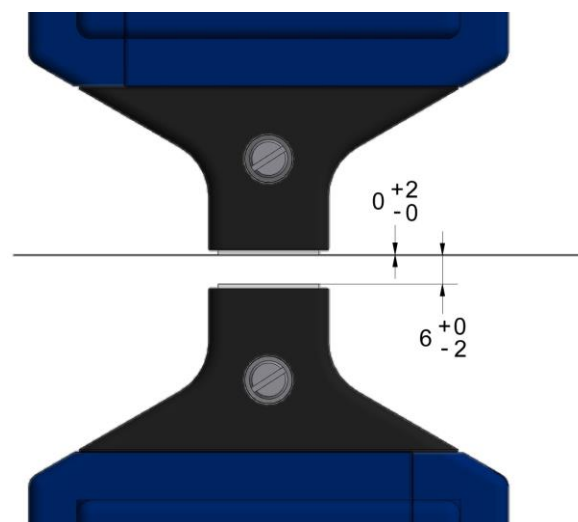

Figure 37: Camera System Casing - banknote position

The two **Casing**s shall be mounted with the following tolerances:

- Distance between the two *CS **Casing**s: 6 mm ±0.2 mm
- Alignment of the two *CS **Casing**s: ±0.062 mm

The mounting solution has to ensure that an operator without use of any tools can easily clean the *DET*. The sorting machine supplier is free to choose any opening solution, which ensures an opening of at least 50 mm between co-located *CS **Casing**s 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 **Casing**s within the defined tolerances.

7.4.3 CDI2 Detector Casing

The CDI2 *DET* **Casing** has the same general outline as CDI1 *DET*s, but the total height is 200 mm and the **Casing** may extend 100 mm through the baseplate in the upper 120 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.
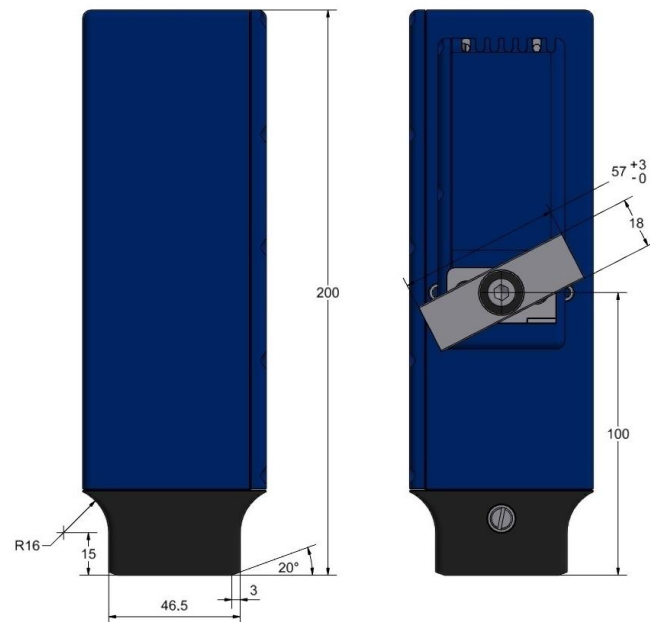

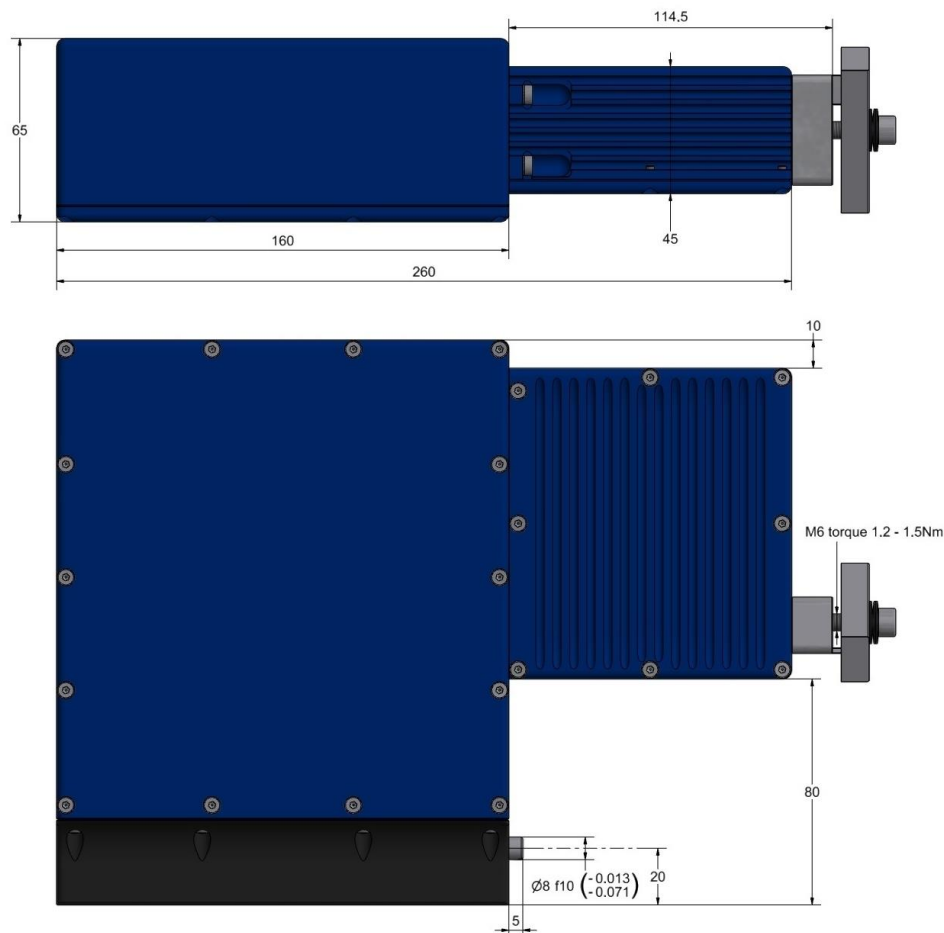Figure 38: CDI2 Detector dimensions (front/back view)

Figure 39: CDI2 Detector dimensions (top/side view)

The 57mm x 18mm central locking bar has to be connected to the **Detector Casing** in a way that it can be tightened in horizontal position (parallel to the sensor window) with a distance of 14.5 to 16.5mm to the rear of the **Detector Casing**.

In Figure 39 a recommended proposal is shown. It uses a 14.5mm thick mounting block and a rotating locking bar which is tightened with the support of disc springs.

7.4.4 CDI2 Detector Mounting

CDI2 *DET*s 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 *DET*s front surface and the banknote is 0-5 mm, the *DET* profile needs to leave space for the belts. See more details about the belt position in chapter 7.6.

The **Banknote Sorting Machine** shall provide a mechanical support for the central locking bar 115 to 116.5mm behind the front side of the base plate. Such mechanical support shall be placed left and right of the **Detector Casing** but not behind the casing. This will allow for different central locking receivers to be developed by the machine manufacturers (see Figure 41 for an indication of the allowed area).

The mounting solution has to ensure that an operator without use of any tools can easily clean the *DET*. The sorting machine supplier is free to choose any opening solution, which ensures an opening of at least 50 mm between co-located *DET* **Casing**s.
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* **Casing**s within 0.2 mm distance to banknote and alignment in case of a double-sided **Casing**.

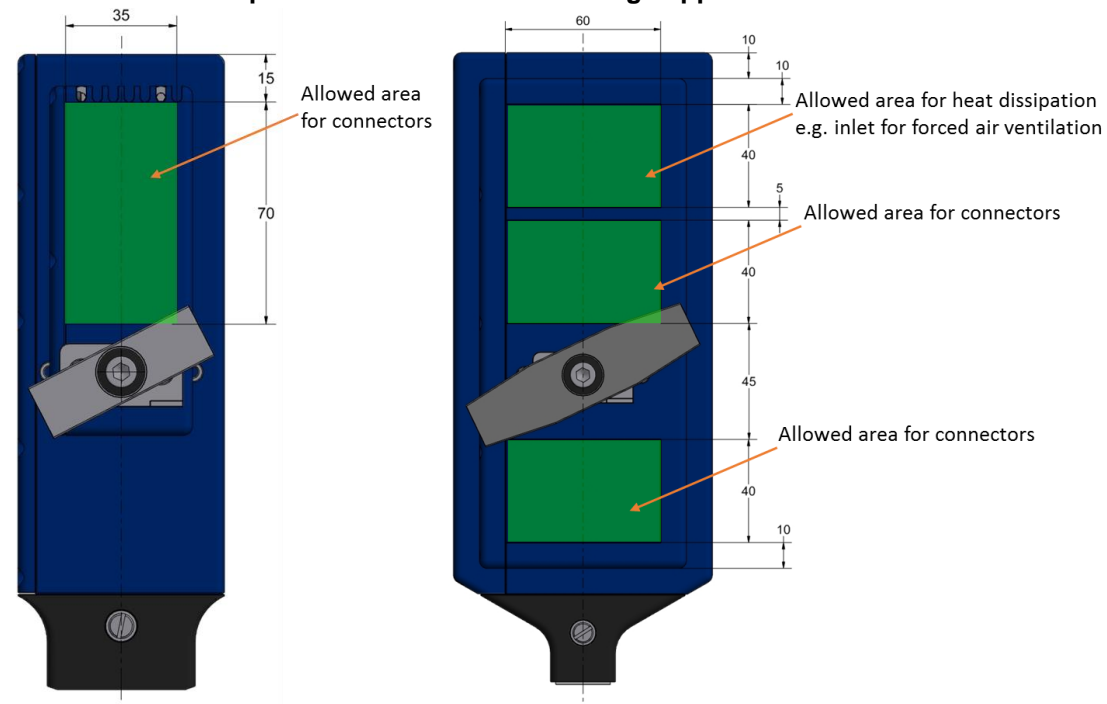### 7.4.5 Connector position and area for mounting supports

Figure 40: Allowed area for connectors (DET left, Camera System right)

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

The ***Banknote Sorting Machine*** shall provide supports for the locking bar which are 115 to 116.5mm behind the front of the base plate. Such supports shall be placed left and right of the *DET/CS* ***Casing*** and shall not interfere with the area behind the *DET/CS* ***Casing*** (see Figure 41). Furthermore, such supports shall be built in a way that airflow around the ***Casing*** is still possible to dissipate the generated heat.
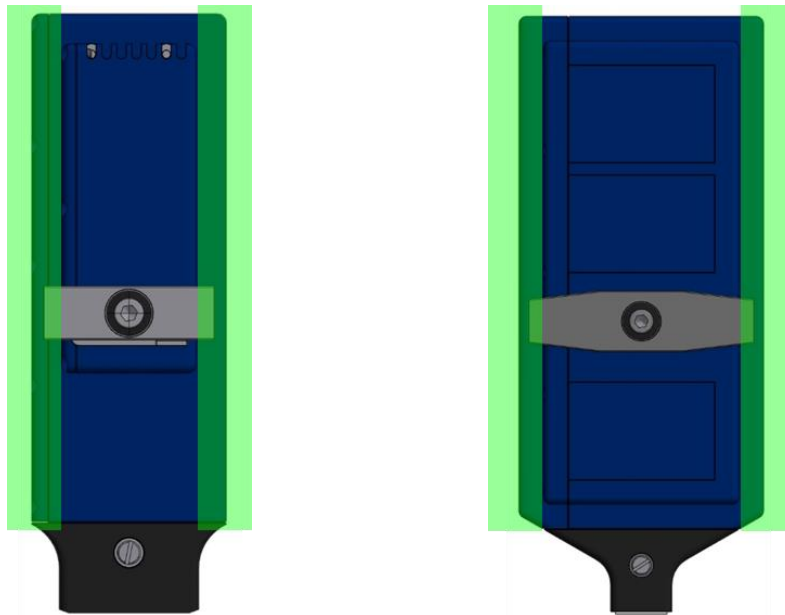
Figure 41: Allowed area for mounting support

7.4.6 Compressed Air supply

To remove dust, the *BSM* supplies compressed air to the ***CDI2 Device***s. 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 as a 1-3 second long pulse in packet gaps at least once every 10,000 banknotes.

The supplied air has to be delivered with 600-800 kPa 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 details.

7.5 Note representation

The banknote position in respect to the *DET*s and ***Camera System***s shall be as follows:

Figure 42: Note presentation

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

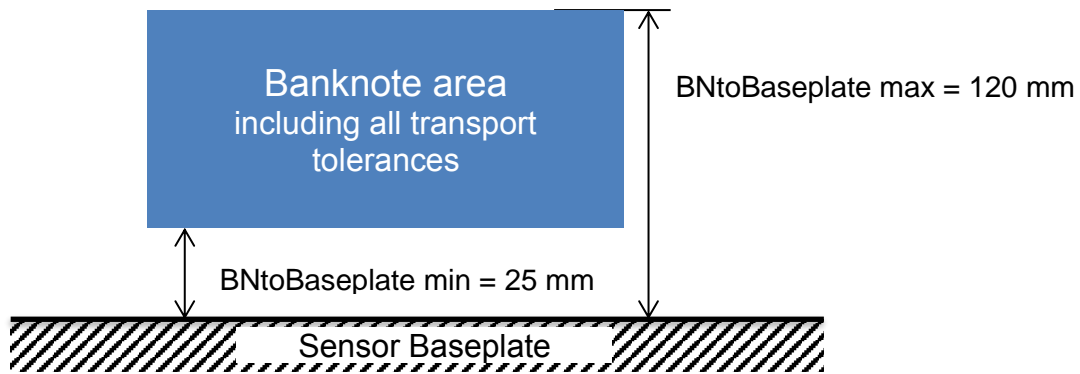As far as the measurement technical design permits, the **CDI2 Device** shall be designed for the following *BN* run tolerances at the banknote level:
- permissible high/low run $\pm$ 6 mm
- permissible skew run 12 mm height difference between leading and trailing edges of the banknote, but not more than $\pm$ 5°

7.6   Belt specification and Belt positions

Within the double-sided *DET* positions, belts with the 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 *DET* position are not restricted.

For each *DET* 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 *DET* positions.

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

Layout A:
2 upper & 2 lower belts

Layout B:
1 upper & 1 lower belts

Layout C:
2 upper & 3 lower belts

Figure 43: Exemplary belt layouts
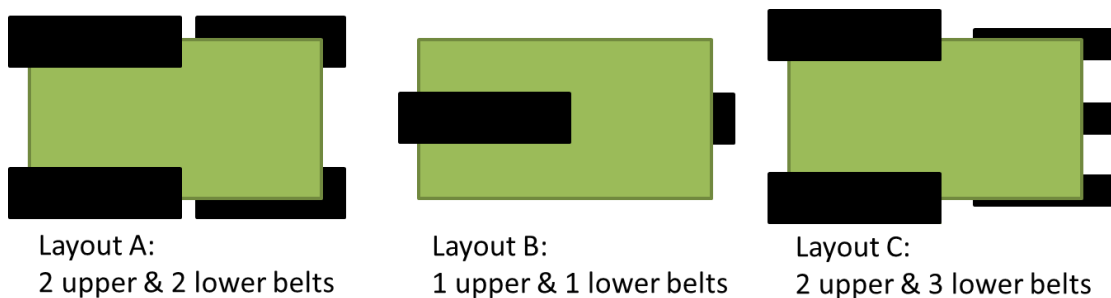
7.7   Storage Rack for External Evaluation Units

Each *BSM* shall provide standard storage racks for integrating PC hardware.
The storage racks for the computer hardware of the *DET*s will be a standard 19-inch computer rack, minimum size 13 U. Preferably, this storage rack is located inside the *BSM*. The *BSM* must 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 EEU of a *DET* 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 EEU of a *DET* 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 *BSM, DET*s and *Camera System*s must comply with all applicable national regulations, including for instance:
- European CE conformity
- US Conformity

7.8.2   EMC
The *BSM, DET*s and *Camera System*s must comply with all applicable national EMC regulations.

7.8.3   ESD
The *BFA* as proposed in this specification results 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 *DET*s)

7.8.5   Physical and Chemical Environment Requirements
*DET*s and *Camera System*s 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
- Humidity between 30 and 80%, non-condensing
- 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**, consisting of all parts on the front and rear side of the baseplate, must comply with IP5X or better. 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 *DET*, *EEU* and *IEU*, if utilised by a *DET*:
- Has to be delivered with a power supply equipped with an IEC-60320 C14 coupler supporting 100-230V @50-60Hz. The size of the power supply shall not exceed 100mm x 150mm x 50mm.
- *DET*s may not consume more than 30W single *DET* or 60W dual *DET* from the *BSM* power supply at any time.
- *EEU*'s and *IEU*'s may not consume more than 150W from the *BSM* power supply at any time.
- Alternatively, and upon bilateral agreement between the *BSM* supplier and *DET* manufacturer, the *DET* can use the DC Power supply (<42V) of the *BSM* directly.

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, this includes the **Camera System**, *DET*s, *EEU*'s, and *IEU*'s.
- Room for power supplies allowing 100mm x 150mm x 50mm per mechanical *DET* position and *EEU* and/or *IEU*, if utilised.
- Alternatively, and upon bilateral agreement between the *BSM* supplier and *DET* manufacturer, the *DET* 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 be able to absorb their own heat 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 *DET*s			
Casings		2*1*30 W single *DET*s 6*2*30 W dual *DET*s	
additional hardware			8*150 W
CDI2 *IEU*s			
IDB switch			200 W
DMB hub			50 W
Overall	600 W	420 W	1,900 W

Table 45: Maximum heat dissipation for various sections of the BSM

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 *BSM* will have several *DET*s installed, each providing its specific results. The various decisions and properties delivered by the *DET*s are aggregated in the *AU* of the *BSM*. As a result of the **Aggregation Process**es, the final fit/unfit/reject decision is made and **Supplemental Data** is collected. The *BSM* shall allow for different **Aggregation Process**es which can be applied in single- or multiple-denomination sorting mode (e.g. have a setup for normal sorting and one for sampling for quality checks).

Furthermore, the outcome of **Computational Detector**s shall allow to request a trigger[2] of the 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 a user definable message to operator
- Store aggregated data or images
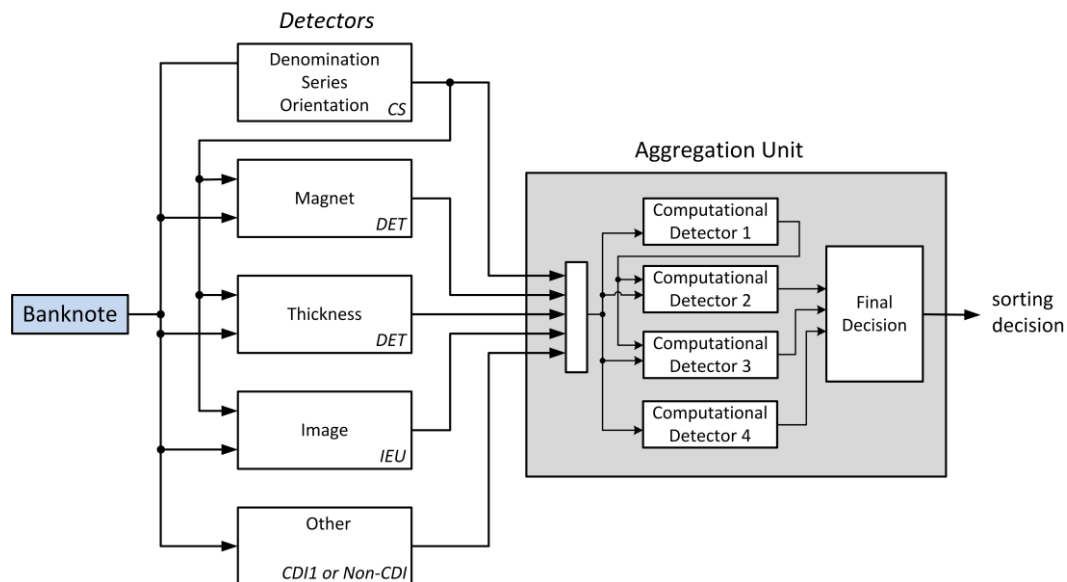
Figure 44: Example for aggregation of detector data

8.1   Computational Detector
The process of aggregation is handled by so-called **Computational Detector**s, which combine properties measured or detected by the *CS* or physical *DET*s.

The *BSM* shall allow **at least** 500 of these **Computational Detector**s for each **Aggregation Process**. It shall be possible to use the **Computational Detectors** across denominations.

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

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[2] The trigger action shall be carried out by the BSM after the request at the appropriate time.

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

⇨ **CDI2 Property**(s)
⇨ **CDI2 Device** state, maintenance state and error state (see 6.7.4.4)
⇨ **Computational Detector** results
⇨ CDI1 **Judgement**s and **Supplemental Data**
⇨ At least the **Judgement** of **Non-CDI Detector**s

Cascading of **Computational Detectors** shall be possible up to a depth of at least 500.

8.1.1   Calculation model

Each **Computational Detector** allows the combination of at least 20 decisions or properties with the following operations:

- Mathematical functions (+, -, /, *, <, >, =, <=, >=, (,))
- Usage of constants instead of a *DET* decision or property
- String functions (LEFT, RIGHT, MID, LEN, CONCAT)
- Boolean algebra (AND, OR, XOR, NOT, ==, !=)
- IF...THEN…ELSE conditions
- Bitwise functions (<<, >>, &, |)
- Serial number look-up lists shall support at least 10 million serial numbers, summed over the total amount of look-up lists utilised (example: 10 look-up lists are utilised. Each look-up list contains 1 million serial numbers. 10 times 1 = 10 million serial numbers).
    o Serial number look-up lists shall support at least 10 look-up lists.
    o Look-up lists should be reusable across computational detectors.
    o XML files shall be utilised for look-up lists[3].

Computational Detectors shall offer the calculation result as signed 32-bit integer. Boolean is required if thresholds are utilised.

8.1.2   Thresholds

BSM manufacturers are free to design thresholds to meet their needs, as long as the above criteria is met. A minimum implementation would be a single threshold converting the 32-bit integer into a true/false decision. Examples of threshold implementations can be found in Appendix E.

8.2   Final Decision

The **Final Decision** shall always be based on the results of the **Computational Detector**s, which can respect or ignore the **Judgement**s of individual **CDI2 Device**s, CDI1 **Detector**s or **Non-CDI Detector**s.

The assignment of this **Final Decision** to physical stackers in the *BSM* shall be configurable by the central bank.

BSM manufacturers are free to implement the calculations done by the **Aggregation Unit** as they see fit as long as the above criteria are met. Examples of final banknote sorting decisions can be found in Appendix F.

8.3   CDI2 Device and CDI2 Property Naming

CDI2 Device and **CDI2 Property** naming requirements prevent potential issues when processing in a real time environment or during banknote **Sort** development.

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[3] XML is used as import format only, the BSM is not restricted about its internal storage format.

- Required notation is Upper Camel Case (example: ThisIsUpperCamelCase). The notation cannot start with a number. A valid name is limited to A-Z, a-z, 0-9.
- *CDI2 Device* or *CDI2 Property* names shall not exceed 63 characters and be unique between devices
- Properties shall start with a source indication of the property provided by the central bank (e.g. a condensed sensor name)
- The *BSM* has to support up to 63 characters, source indication included. The full property name including source indication shall be provided by the *Detector* vendor in the corresponding configuration file.

8.4   Graphical User Interface

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

⇨ Add/create a new *Computational Detector*
⇨ View all defined *Computational Detector*s
⇨ Change the settings of a *Computational Detector*
⇨ View a diagram overview of the aggregation steps
⇨ Delete a *Computational Detector*
⇨ Import *Computational Detector* settings from a storage XML file
⇨ Export *Computational Detector* settings to 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.

8.4.1   Access Rights

The user access shall be split into at least two levels where the highest user level can add/create/delete/change *Computational Detector*s, whereas the lower user level can only adjust the thresholds of *Computational Detector*s within a pre-defined 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 for a trigger request based on **Computational Detector** results to store the image data of a banknote. Minimally, the last 1,000 requested images shall be stored. This trigger request shall be applied by the *AU* and configured in its GUI.

Seven different XML files[4] 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 Detector**s (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.
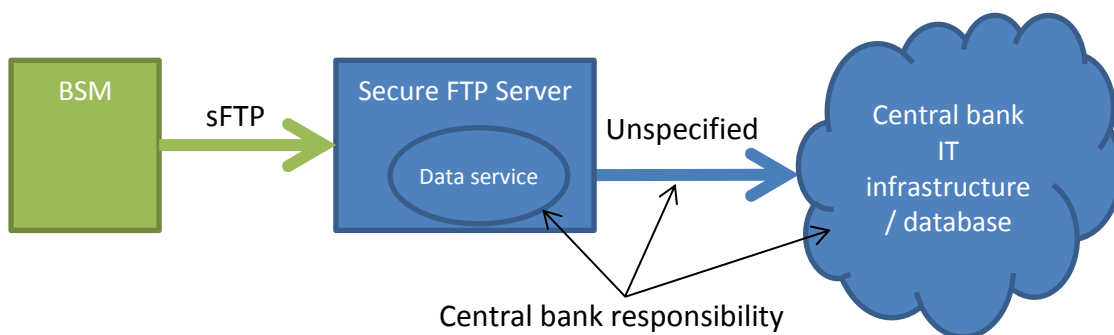
Figure 45: Data transfer schema

Such an sFTP server could be physically integrated into the *BSM*.

The *BSM* shall meet the central bank requirements on how to handle **Aggregated Data** or image data in case of a power-failure.

9.1 Data Format

9.1.1 Aggregated Data

The **Aggregated Data** shall be available in an XML file[5] containing the data as well as all the necessary information to read this data (machine description, *DET* type description, *DET* 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 field in the filename shall be the current time of the *BSM* when the file is created.

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[4] XML is used as export format only, the BSM is not restricted about its internal storage format.

[5] XML is used as export format only, the BSM is not restricted about its internal storage format.

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 *DET*s 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 *DET* slots. For synchronising the banknote movement with the *BSMS*, a *TC* and a banknote trigger for each **Casing Position** is provided.

The speed of the transport is adjustable remotely by the *BSMS* between 1 m/s and 12.5 m/s.

10.2   CDI2 Banknote Sorting Machine Simulator (BSMS)

The CDI2 *BSMS* 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 *BSMS* 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 *DET*s and 6 *IEU*s. 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 *DET*, 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

[Ref 6.]   Common Detector Interface (CDI)
European Central Bank, Protocol Version 1.0, Document Revision B,
https://www.ecb.europa.eu/euro/pdf/Common_Detector_Interface_CDI_Spec_1_0_rev_B.
pdf

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	µs	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	µs	*CN* isochronous reaction time
SoA to ASnd latency (*CN*)	25	µs	*CN* asynchronous reaction time
minimum transmit-to-transmit gap (*MN*)	5	µs	controls sequence of *MN* frame transmission
minimum receive-to-transmit gap (*MN*)	5	µs	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_BOOL	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

Name	Description	MN	CN
D_SDO_MaxParallelConnections_U32	max. number of SDO connections between a SDO client/server pair	1	1
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 proposed error threshold levels have to be in place during normal operation of the *BSM*. It is permissible to increase threshold levels during startup (System State START_UP) to avoid inadvertent POWERLINK error events.

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

The following naming conventions were utilised for the XML definition.

XML Elements

Utilise Upper Camel Case (Pascal Case), which is a casing convention where the first letter of each word is capitalised, and no separating character is included between words.
Example: "ThisIsUpperCamelCase"

XML Attributes

Utilise Camel Case, which is a casing convention where the first letter is lower case, words are not separated by any character but have their first letter capitalised.
Example: "thisIsCamelCase"

SupplementalData -> Property -> name

Utilise Camel Case, which is a casing convention where the first letter is lower case, words are not separated by any character but have their first letter capitalised.
Example: "thisIsCamelCase"

ServiceFiles -> ServiceFile -> description

ServiceFile descriptions are text strings and are allowed to be in any convention.
Examples are: "LastMeasurement", "Last Measurement", "Last measurement", "last Measurement", "last measurement", "lastmeasurement"

N.B.: XML schema files can be used for automatic verification of XML files. Such files are attached to the CDI2 website.
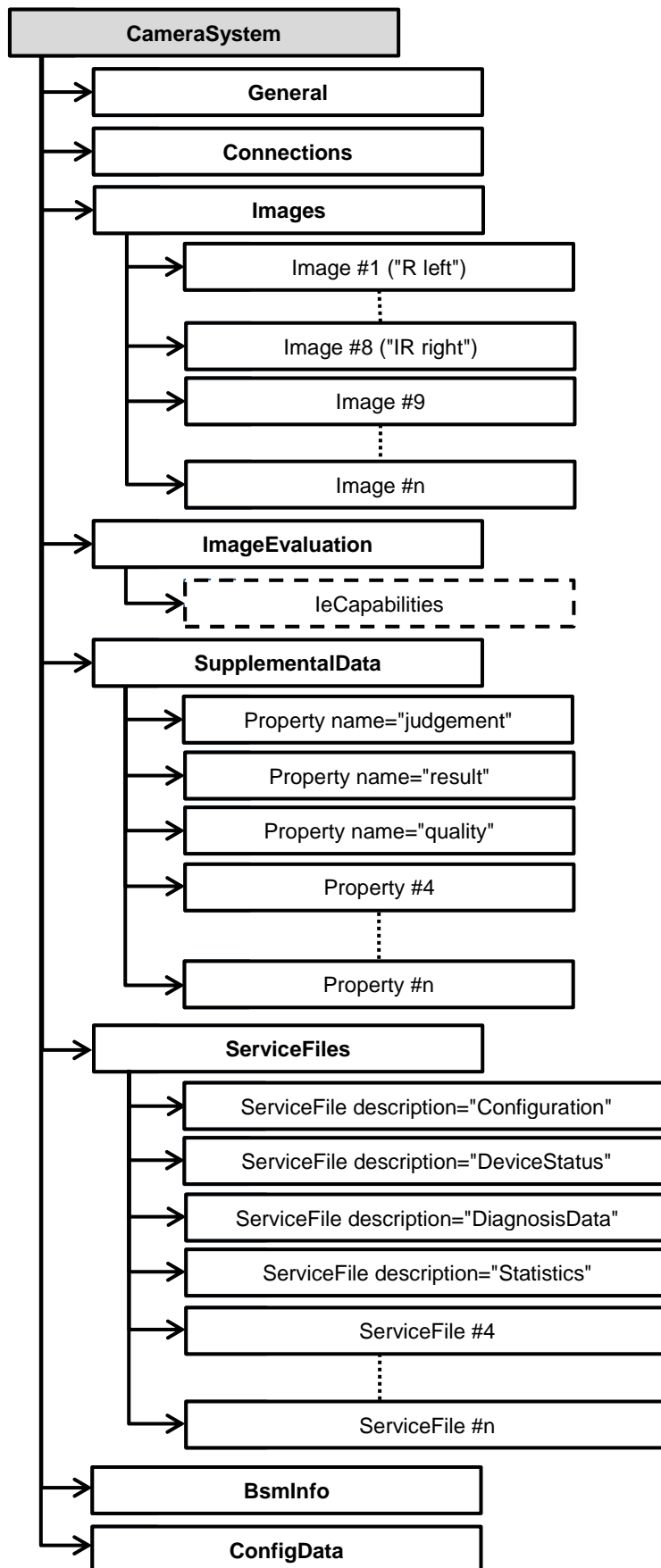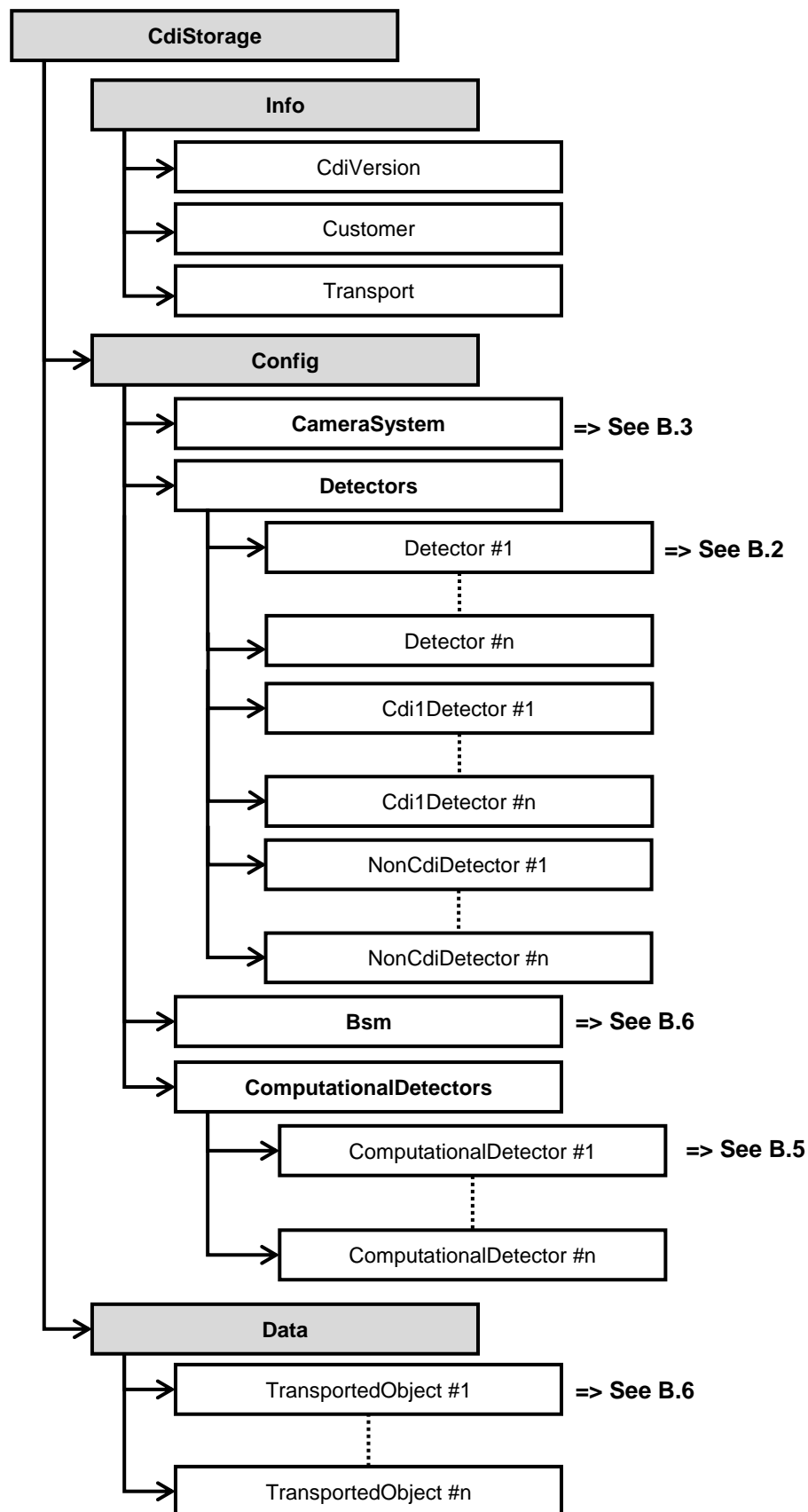
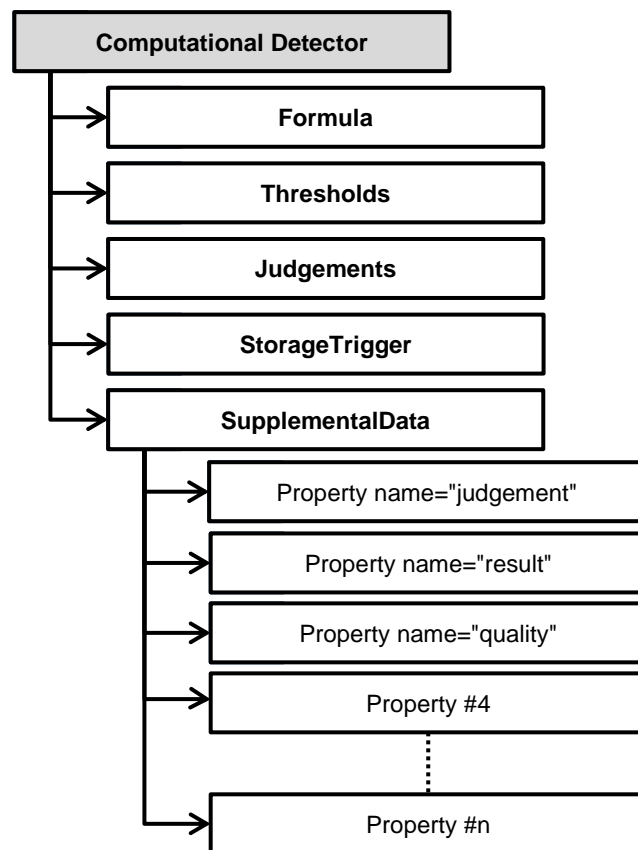## B.1   XML structure of MachineInfo
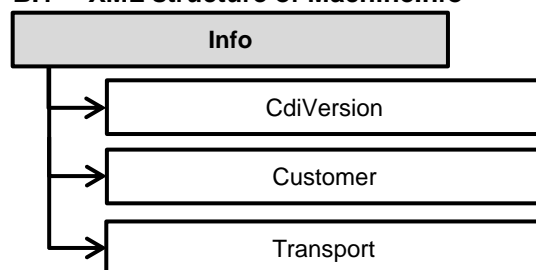
B.2 XML structure of DeviceInfo for a Detector or IEU
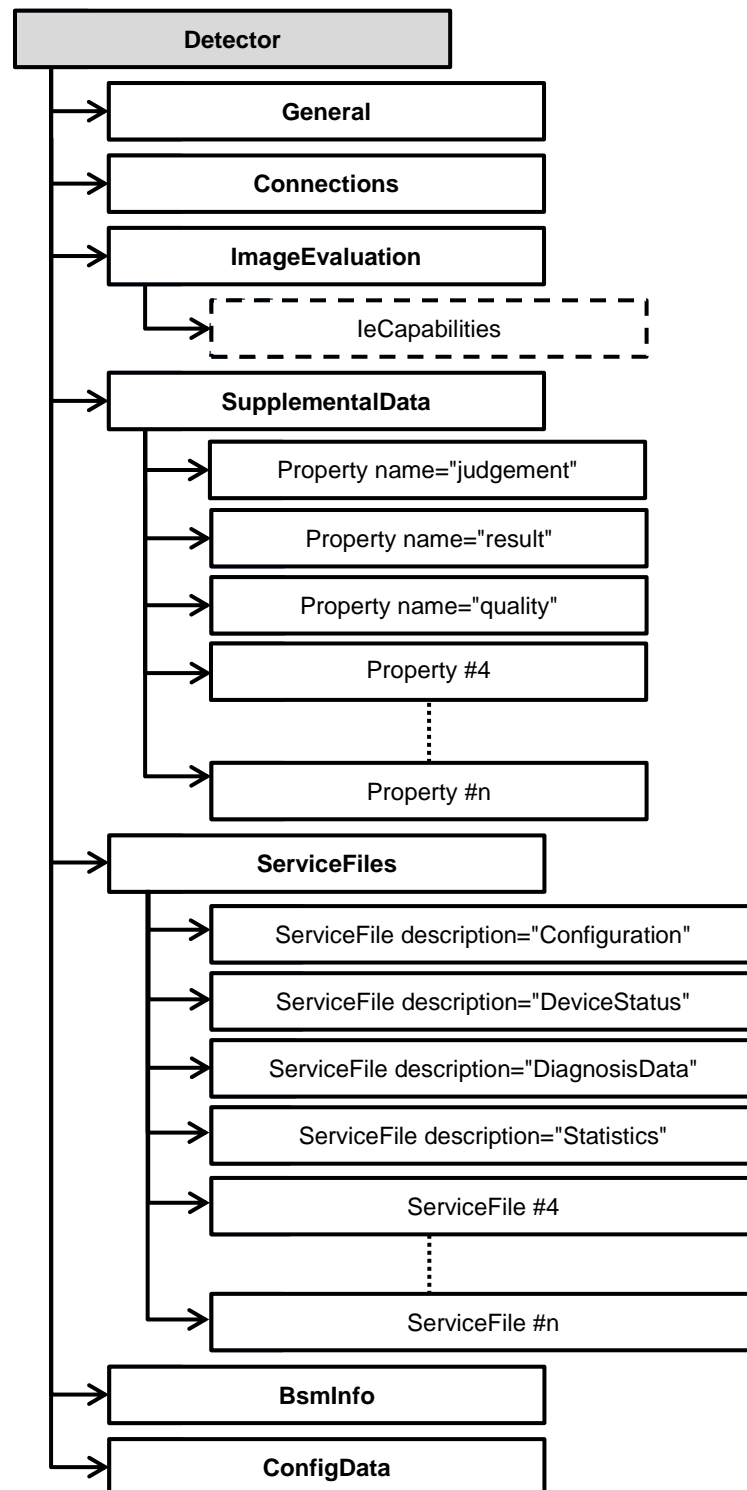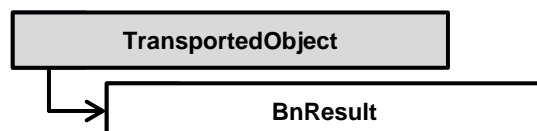
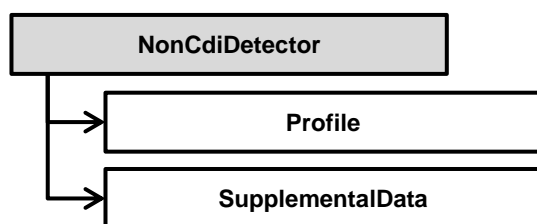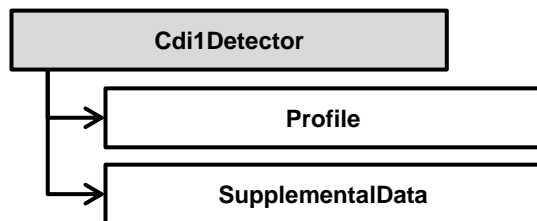## B.3   XML structure of DeviceInfo for a Camera System

B.4   XML structure of a Data Storage File

B.5 XML structure Computational Detector

```
┌─────────────────────────────────────┐
│       Computational Detector        │
└─┬───────────────────────────────────┘
  │  ┌──────────────────────────────┐
  ├─▶│           Formula            │
  │  └──────────────────────────────┘
  │  ┌──────────────────────────────┐
  ├─▶│          Thresholds          │
  │  └──────────────────────────────┘
  │  ┌──────────────────────────────┐
  ├─▶│          Judgements          │
  │  └──────────────────────────────┘
  │  ┌──────────────────────────────┐
  ├─▶│        StorageTrigger        │
  │  └──────────────────────────────┘
  │  ┌──────────────────────────────┐
  └─▶│       SupplementalData       │
     └─┬────────────────────────────┘
       │  ┌──────────────────────────────┐
       ├─▶│   Property name="judgement"  │
       │  └──────────────────────────────┘
       │  ┌──────────────────────────────┐
       ├─▶│    Property name="result"    │
       │  └──────────────────────────────┘
       │  ┌──────────────────────────────┐
       ├─▶│    Property name="quality"   │
       │  └──────────────────────────────┘
       │  ┌──────────────────────────────┐
       ├─▶│         Property #4          │
       │  └──────────────────────────────┘
       │                 ⋮
       │  ┌──────────────────────────────┐
       └─▶│         Property #n          │
          └──────────────────────────────┘
```
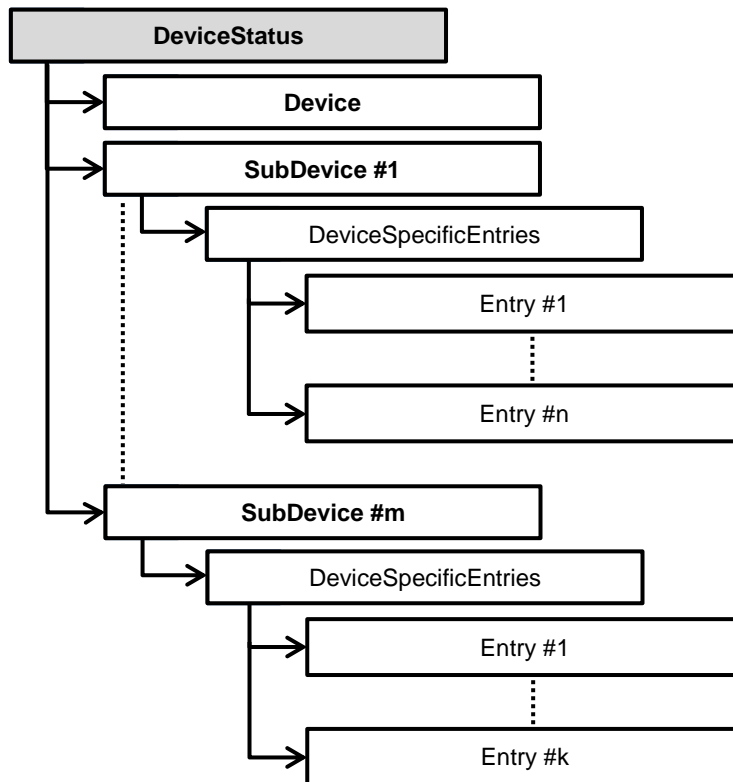
B.6 XML structure other
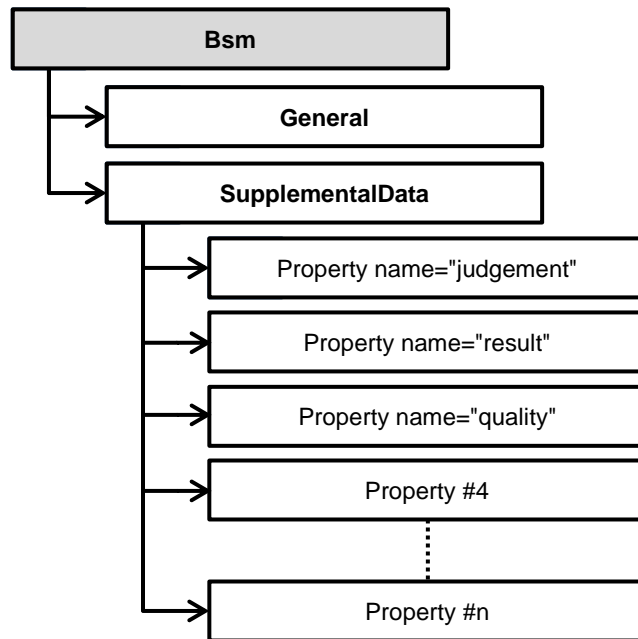
B.7 XML structure of the Error Log File
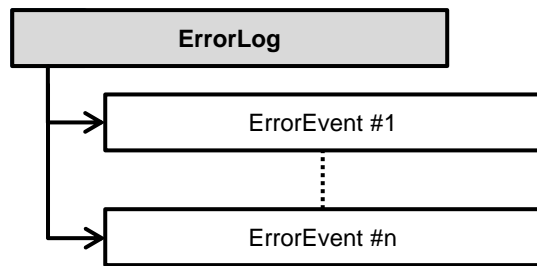
B.8 XML structure of DeviceStatus

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:unsignedInt	x	major version number allowed value for this version: 2
minor	xs:unsignedInt	x	minor version number allowed value for this version: 6
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:float	x	minimum transport speed during Sorting in m/s Allowed range: 0.5 <= minimumSpeed <= 13.0, includes 0.5 m/s speed margin
maximumSpeed	xs:float	x	maximum transport speed during Sorting in m/s Allowed range: 0.5 <= maximumSpeed <= 13.0, includes 0.5 m/s speed margin
Element Data	none		

Node name	Bsm		
Parent node(s)	Config		
Child node(s)	General, SupplementalData		
Attribute name	Data type	required	comment
nodeId	xs:unsignedByte	x	fixed value 240, as **POWERLINK** Node ID = 240 for *MN*
Element Data	none		

Node name	SupplementalData		
Parent node(s)	CameraSystem, Bsm, Detector, ComputationalDetectors, Cdi1Detector, NonCdiDetector		
Child node(s)	Property		
The SupplementalData node holds the collection of Properties.			
Attribute name	Data type	required	comment
numBnResultSegments	xs:unsignedByte		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", "result" and "quality". Property "serialNumber" must be present if numberReading is set true.			
Attribute name	Data type	required	comment
id	xs:unsignedInt	x	consecutive number defined by *BSM* and sent to *DET* via Device Configuration message, id value must be unique in the XML file
name	xs:string	x	meaningful description of the property. Camel Case naming convention shall be used.
unit	xs:string		unit of property if applicable
type	xs:unsignedInt	x	data type, see Table 30: Data types
offset	xs:unsignedInt		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:unsignedInt	x	consecutive number defined by *BSM* and sent to *DET* via Device Configuration message
name	xs:string	x	"judgement"
type	xs:unsignedInt	x	2
offset	xs:unsignedInt	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:unsignedInt	x	consecutive number defined by *BSM* and sent to *DET* via Device Configuration message
name	xs:string	x	"result"
type	xs:unsignedInt	x	2
offset	xs:unsignedInt	x	1
Element Data	none		

Node name	Property – name="quality"		
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:unsignedInt	x	consecutive number defined by *BSM* and sent to *DET* via Device Configuration message
name	xs:string	x	"quality"
type	xs:unsignedInt	x	2
offset	xs:unsignedInt	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*, *DET* or *CS* function			
Attribute name	Data type	required	Comment
deviceClass	xs:unsignedInt	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 *DET* Info
serialNumber	xs:string		
deviceClass	xs:unsignedInt		For CDI1 Devices, this attribute is taken from the CDI1 *DET* Info
swVersion	xs:string		For CDI1 Devices, this attribute is taken from the CDI1 *DET* 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 *TC*. Allowed values: "0.1", "0.2", "0.5" and "1.0".
bpOffset	xs:unsignedInt	x	selected offset for *BP* signal in mm (leading edge of *BP* shall be bpOffset mm before leading edge of banknote arrives at the **Nominal Casing Position**. A maximum value of 50 mm is allowed for bpOffset.
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 provide 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, within DeviceInfo they have no meaning			
Attribute name	Data type	required	comment
mechanicalSlot	xs:unsignedInt	x	**Casing Position** of *DET*. For an IEU without optional *DET*, the *BSM* shall set this attribute to 0.
mountingPosition	xs:string	x	Allowed values: "left", "right", "none". For a **Camera System**, a CDI2 *DET* or an IEU with optional *DET*, the value shall either be "left" or "right". This attribute shall be set to "none" if attribute mechanicalSlot equals 0.
timeBudgetForBnResult	xs:unsignedInt	x	Time between the trigger and the last time for BNRESULT in ms. For a *CS* or IEU without optional *DET*, this time refers to the trigger time at *BFA*#1. For a *DET* or IEU with optional *DET*, 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		
Mandatory ServiceFile elements are: description="Configuration", "DeviceStatus", "DiagnosisData" and "Statistics".			
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 Allowed values: "r", "w" and "rw".
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	Element type xs:anyType This section can be used to send additional configuration data to the *DET* (*DET* 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 *DET* 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:unsignedByte	x	**POWERLINK** Node ID of the **CDI2 Device** on the *DMB*. The nodeId value must be in the range 1 to 16 and must be unique in the XML file. 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, Cdi1Detector, NonCdiDetector		
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:dateTime	x	date time of last change
lastChangeUser	xs:string	x	username who did last change
Element Data	none		

Node name	Formula		
Parent node(s)	ComputationalDetector		
Child node(s)	None		
This section describes the Computational rules of the *AU* 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	Element type xs:anyType Proprietary description of the formula		

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

Node name	Judgements		
Parent node(s)	ComputationalDetector		
Child node(s)	None		

Judgement codes as defined in
 	
 <table><tr><th>Judgement Code</th><th>Meaning</th><th>Priority</th></tr><tr><td>0</td><td>FIT</td><td>Lowest</td></tr><tr><td>1</td><td>UNFIT</td><td></td></tr><tr><td>2</td><td>REJECT</td><td></td></tr><tr><td>3</td><td>SPECIAL1</td><td></td></tr><tr><td>4</td><td>SPECIAL2</td><td></td></tr><tr><td>5</td><td>SPECIAL3</td><td></td></tr><tr><td>6</td><td>SPECIAL4</td><td></td></tr><tr><td>7</td><td>SPECIAL5</td><td>Highest</td></tr><tr><td>8-255</td><td>SPECIAL6 to SPECIAL253 (Utilised by Computational Detectors only. A DET shall not use these codes)</td><td></td></tr></table>
 Table 38
   first entry = judgement for value range below Threshold 1 (T1)
   second entry = judgement for value range between T1 and T2
   etc.			

Attribute name	Data type	required	comment
Element Data	Element type xs:string Judgements comma separated		

Node name	StorageTrigger		
Parent node(s)	ComputationalDetector		
Child node(s)	None		
Storage Trigger definition see Appendix E			
Attribute name	Data type	required	comment
Element Data	Element type xs:string StorageTrigger comma separated		

Node name	CameraSystem		
Parent node(s)	Config		
Child node(s)	ImageEvaluation, Images, ConfigData, ServiceFiles, BsmInfo, Connections, General, SupplementalData		
Attribute name	Data type	required	comment
nodeId	xs:unsignedByte	x	**POWERLINK** Node ID of the **CDI2 Device** on the *DMB*. The nodeId value must be in the range 1 to 16 and must be unique in the XML file. 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, *BNID*16 and TC_TRIG16)
Element Data	none		

Node name	Images		
Parent node(s)	CameraSystem		
Child node(s)	Image		
Mandatory Image elements are: type="R_left", "G_left", "B_left", "IR_left", R_right", "G_right", " B_right" and "IR_right" (according Table 14)			
Attribute name	Data type	required	comment
Element Data	none		

Node name	Image		
Parent node(s)	Images		
Child node(s)	none		
Limits for mandatory images according chapter 4.1			
Attribute name	Data type	required	comment
type	xs:string	x	
resolution	xs:float	x	in mm/Pixel units, valid values greater 0.0, fixed 0.2 for mandatory images
internalResolution	xs: float	x	in mm/Pixel units, valid values greater 0.0
height	xs: unsignedInt	x	number of Pixels (transport direction), valid range is 870 <= height <= 1024
width	xs: unsignedInt	x	number of Pixels (scan direction), valid range is 485 <= width<= 512
idbStreamNr	xs: unsignedInt	x	
gvspPayloadType	xs: unsignedInt	x	GigE Vision payload type => 1 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:unsignedInt	x	**Banknote ID**
serialNumber	xs:string	x	Banknote Number
finalJudgement	xs:unsignedByte	x	Final Decision see

Inside finalJudgement comment cell:

Judgement Code	Meaning	Priority
0	FIT	Lowest
1	UNFIT	
2	REJECT	
3	SPECIAL1	
4	SPECIAL2	
5	SPECIAL3	
6	SPECIAL4	
7	SPECIAL5	Highest
8-255	SPECIAL6 to SPECIAL253 (Utilised by *Computational Detectors* only. A *DET* shall not use these codes)	

Table 38: Banknote judgement codes

series	xs:unsignedByte	x	Banknote Info see Table 33 and Table 34
denomination	xs:unsignedByte	x	
orientation	xs:unsignedByte	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 30 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	Element type xs:string List of entire **Supplemental Data**		

Node name	ErrorLog		
Parent node(s)	none		
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:float	x	*POWERLINK* NetTime
relativeTime	xs:unsignedLong	x	*POWERLINK* Relative Time
date	xs:date	x	Readable date
time	xs:time	x	Readable Time
cnState	xs:string	x	See Table 22
errorState	xs:string	x	See definition of error states in 6.7.4.4. errorState bits 0..3 are encoded as formatted string with pattern "[01].[01].[01].[01]", e.g. "1.0.0.0" means bit[0]=1, bit[1]=0, bit[2]=0 and bit[3]=0
errorCode	xs:unsignedInt	x	Error Code for machine operator
severity	xs:string	x	"error" / "warning"
message	xs:string	x	Error message for machine operator
Element Data	Element type xs:string 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:unsignedInt	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:unsignedInt	x	number of notes measured during the entire lifetime
upTimeHours	xs:unsignedInt	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	name value must be unique per SubDevice
value	xs:string	x	
Element Data	none		

Node name	Cdi1Detector		
Parent node(s)	Detectors		
Child node(s)	Profile, SupplementalData		
Attribute name	Data type	required	comment
Element Data	none		

Node name	NonCdiDetector		
Parent node(s)	Detectors		
Child node(s)	Profile, SupplementalData		
Attribute name	Data type	required	comment
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) and the **Timed Air Pulses** (*TAP*) system 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.
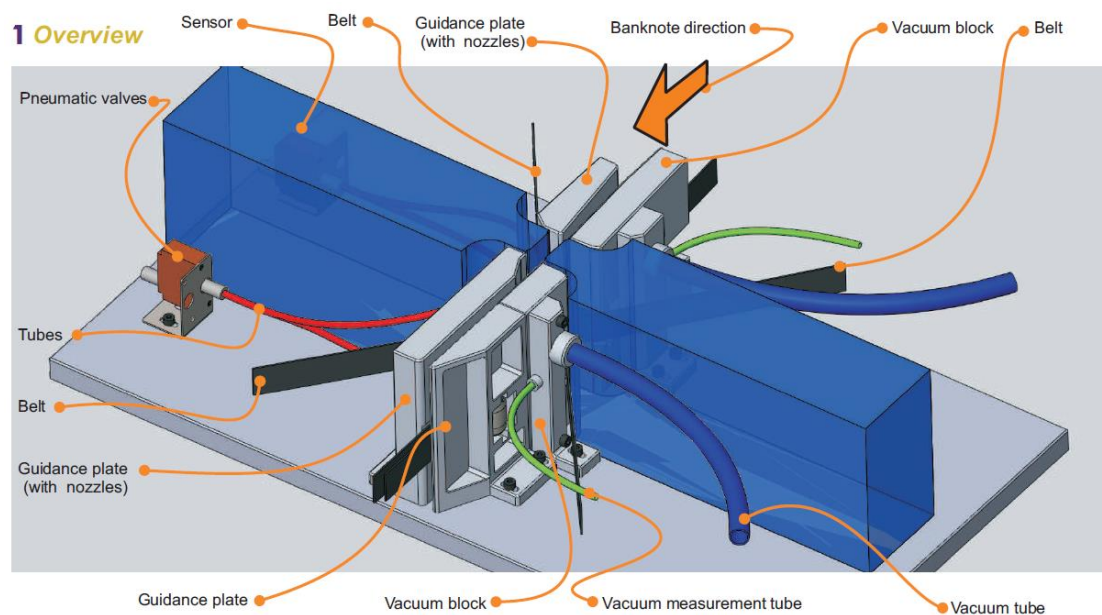
Figure 46: BFA concept overview
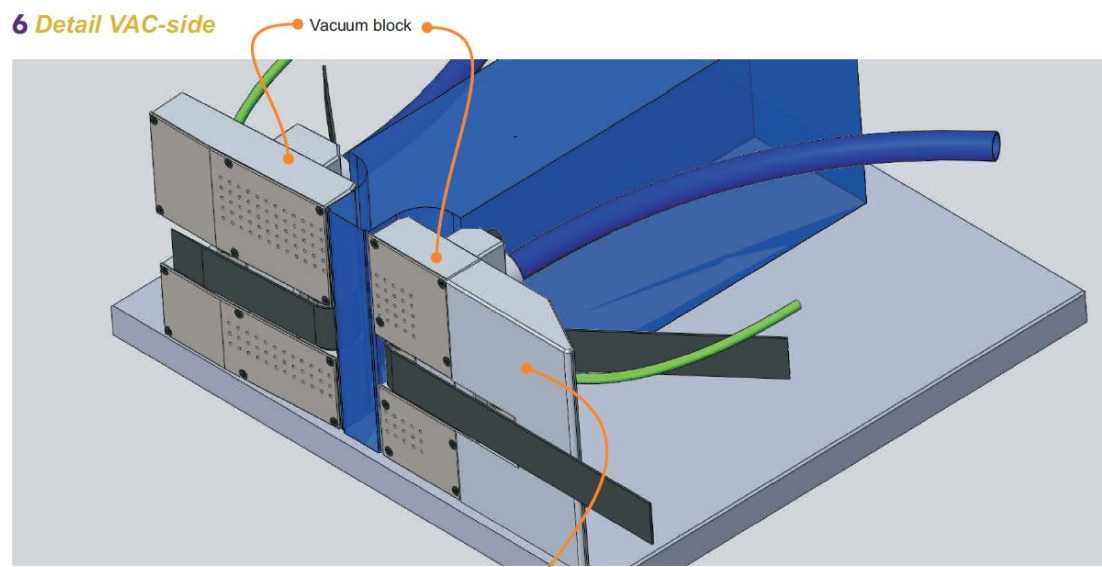
Figure 47: VAC concept

Guidance plate
(with nozzles)
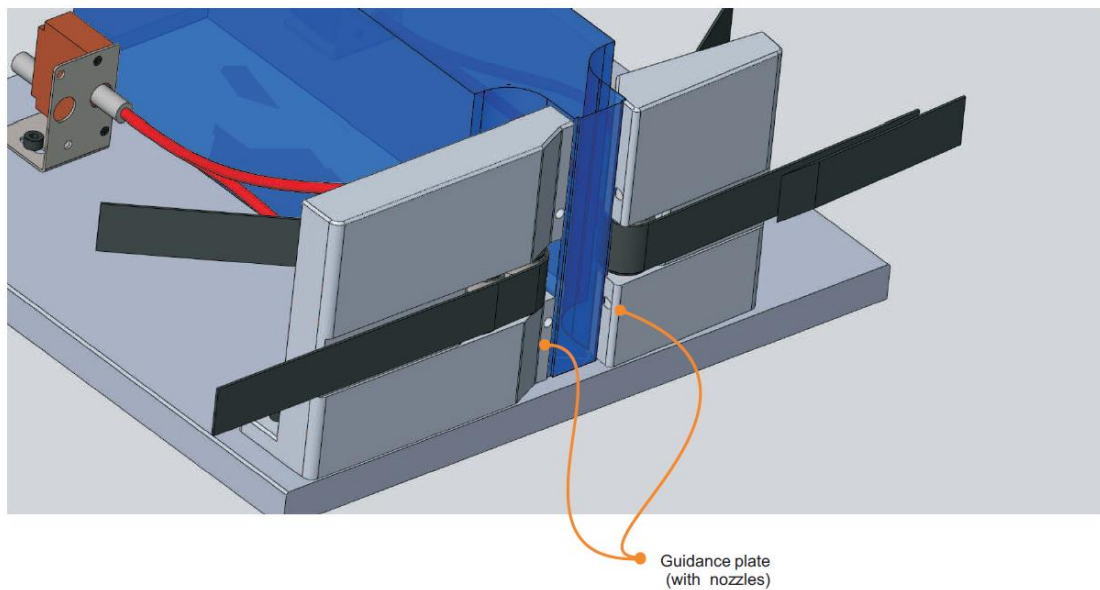
Figure 48: TAP concept

C.2 Vacuum block system

This system uses vacuum provided by a first vacuum block to suck the banknote to the surface of the *DET*. 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 *DET* via the *DET* surface (usually a scratch resistant glass window) and will be picked up on the other side of the *DET* 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 on the depth of field of the *DET*. The responsibility of the *BSM* supplier is to supply a belt free transport area and brackets if no *DET* is mounted into the *BFA*. The acceptance test will verify the *BFA* 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 *DET*s (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.
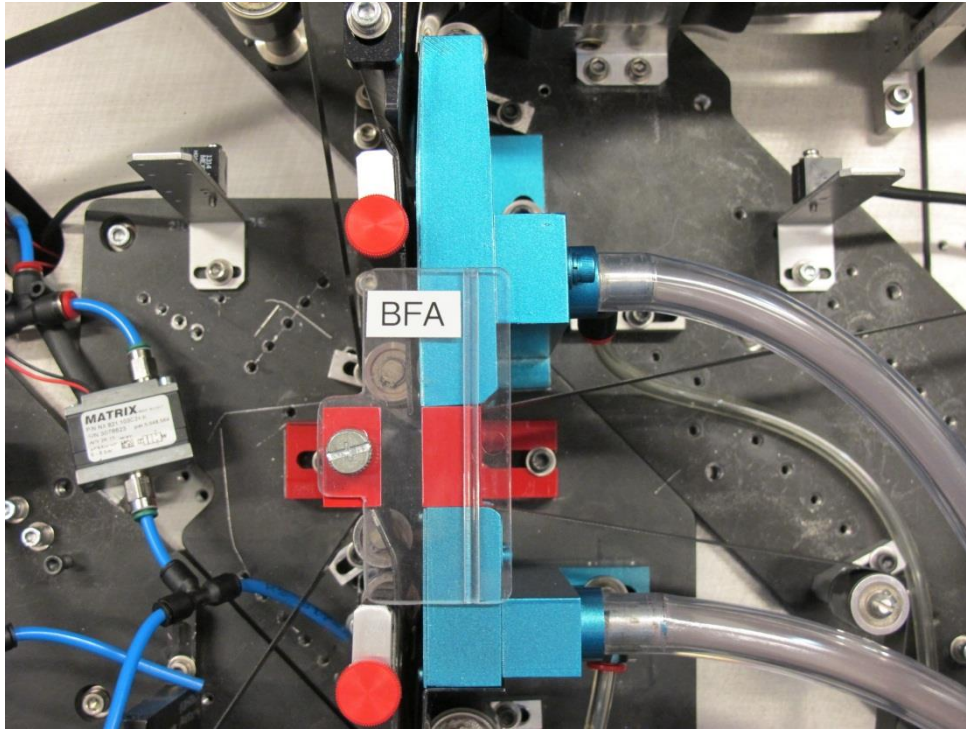
Figure 49: Vacuum system overview
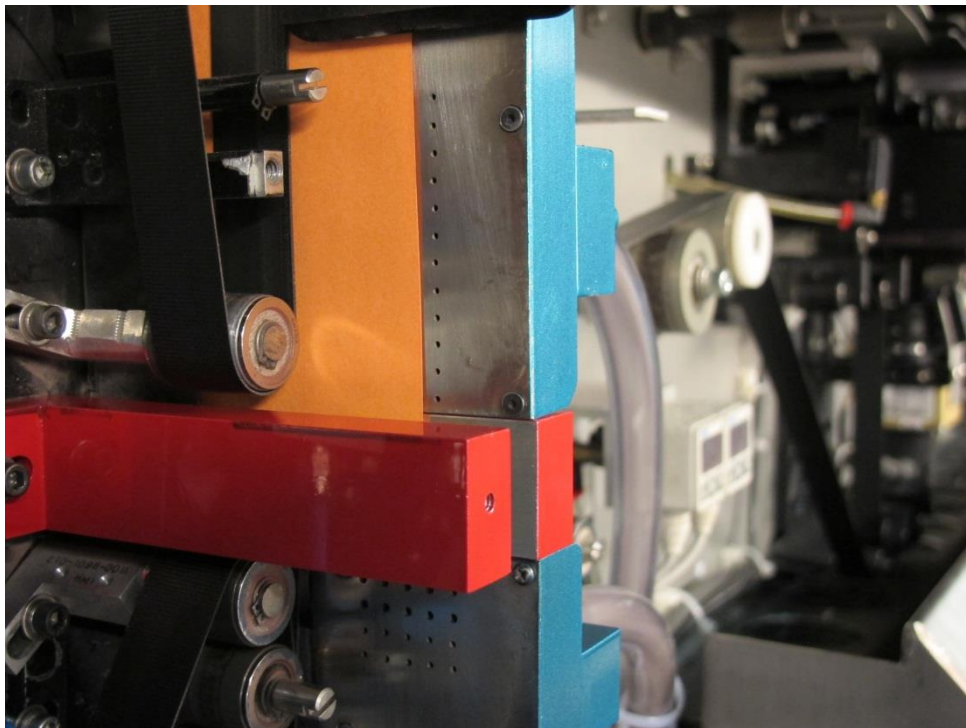
Figure 50: Vacuum system with banknote, size €50

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 *TAP* to push the banknote against the surface of one *DET* unit or a single background plate. This *DET* 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 *TC* 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 *DET*s. 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 integrated in the test setup in the red '*DET **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.
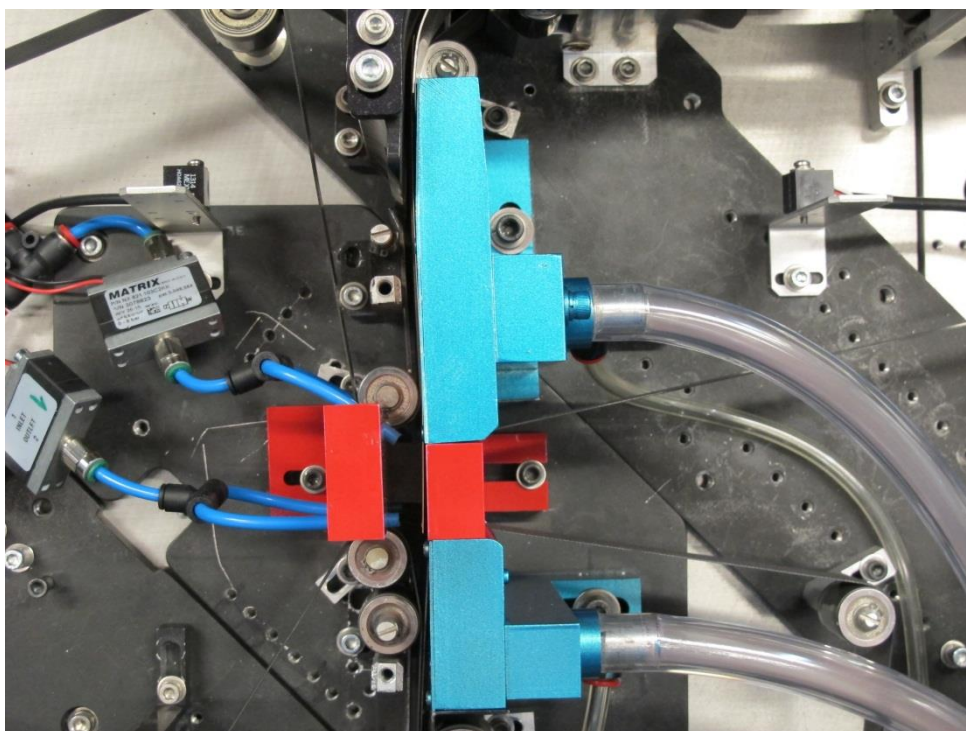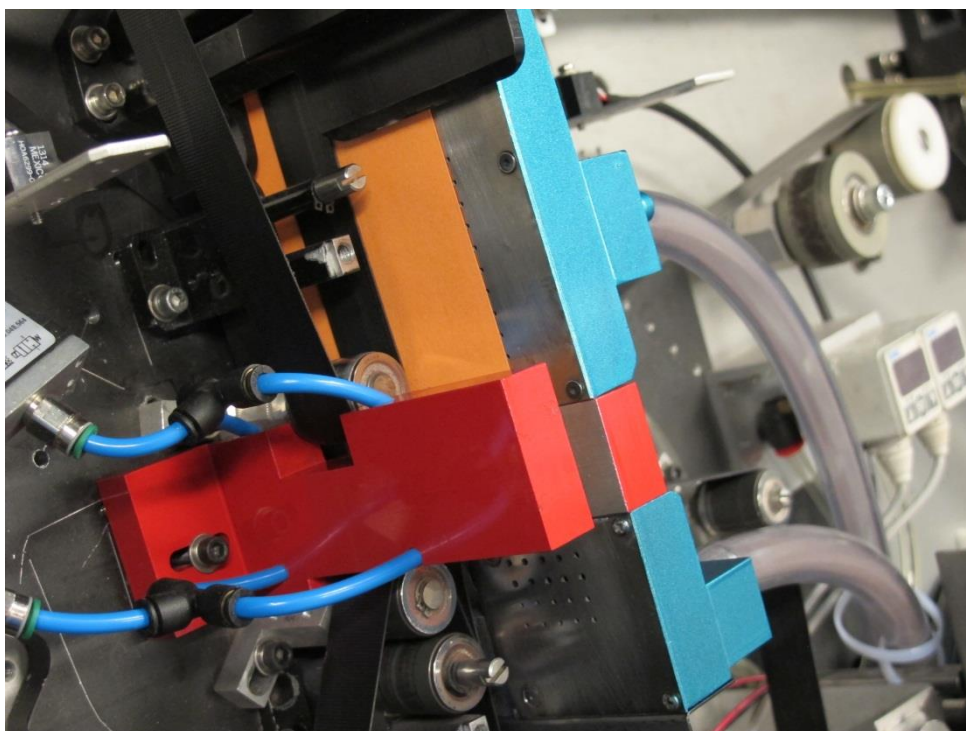
Figure 51: TAP system overview

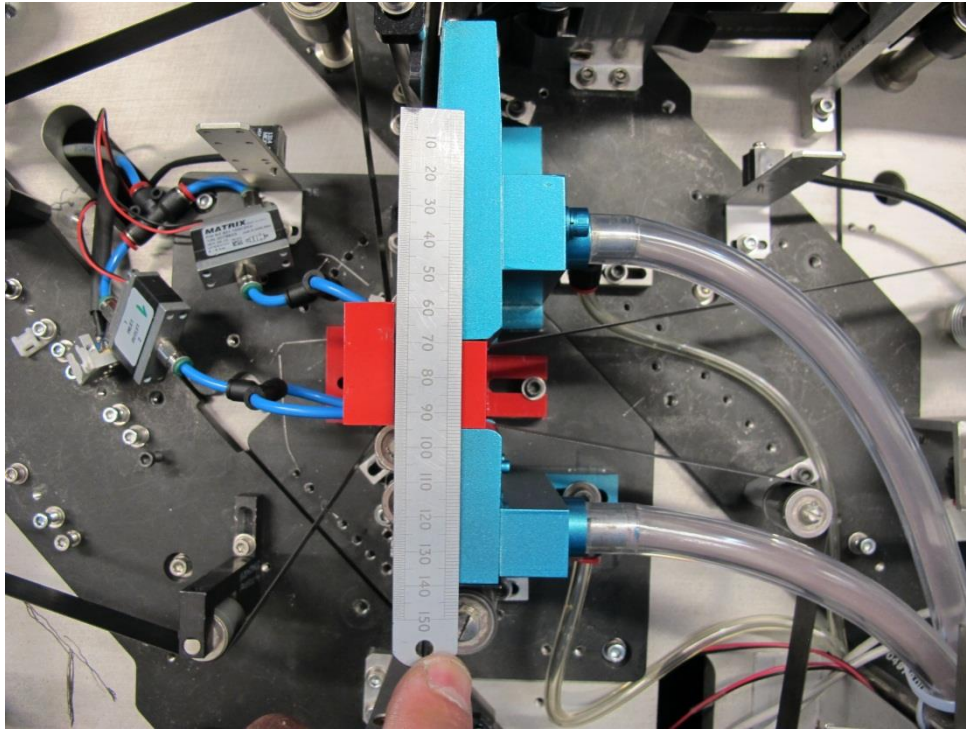Figure 52: TAP system with banknote, size €50
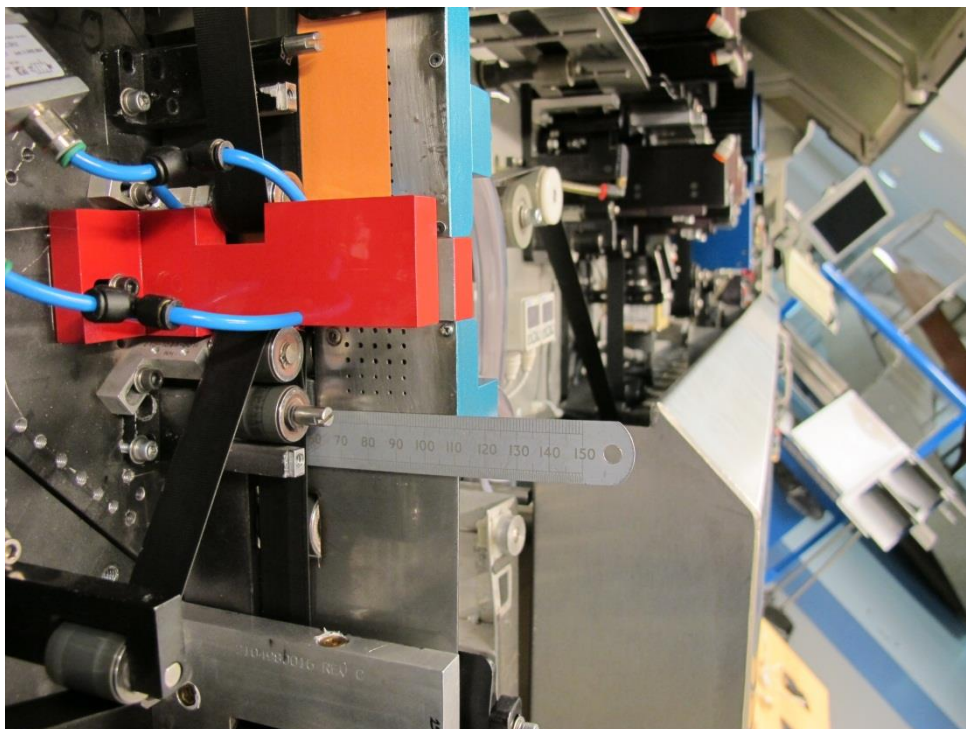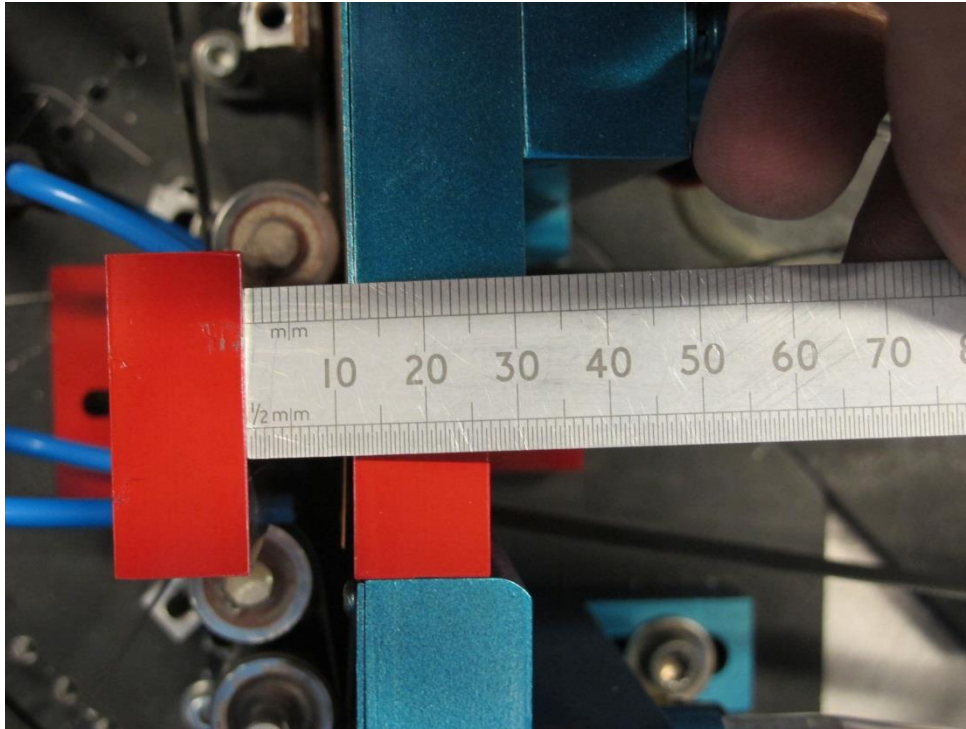
Figure 53: Length of BFA test setup

Figure 54: Width of BFA test setup

Figure 55: Distance between upper and lower *DET* in test setup

The patent application of the TAP system is available at
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 Device***s 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.
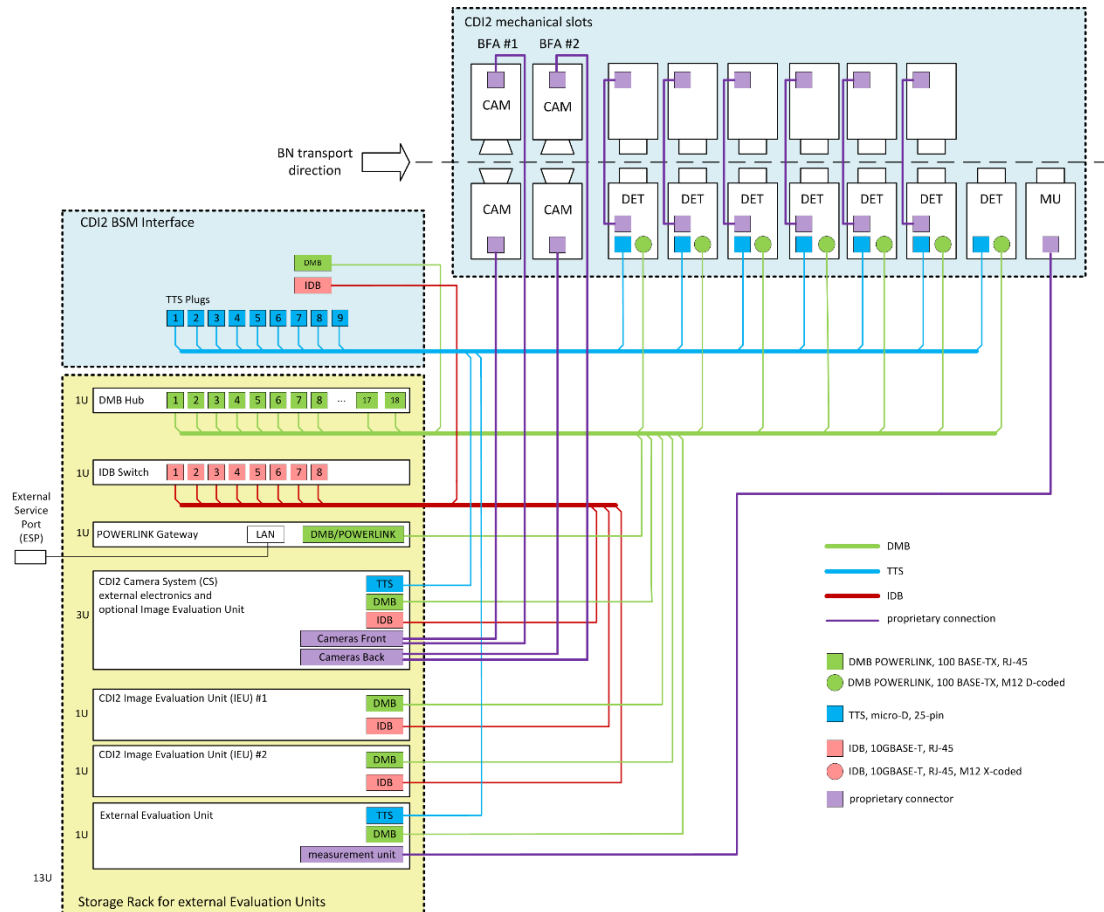
Figure 56: Example of a CDI2 Banknote Sorting Machine

Appendix E   Examples of Thresholds

Example 1: Minimal Thresholds Implementation

Each **Computational Detector** has a value range specified with an assigned boolean result. The boolean result assigned to values outside of the specified value range is the inverse.

e.g.: Value range 1-5 is True

Value Ranges	<1	1-5	>5
Result	False	True	False

Example 2: Multiple Thresholds with Judgement Code and Storage Trigger Implementation

Each **Computational Detector** has at least 7 thresholds in increasing order forming at least 8 value ranges. Each of the 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	SPECIAL1	SPECIAL3	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 48: 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 file3 + store **Aggregated Data** to file7

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.

Appendix F   Examples of Final Decision

Example 1: Minimal Final Decision Implementation

A banknote's **Final Decision** is derived from the results of **Computational Detector**s. The decision begins at a start node and progresses through **Computational Detector**s. The result of each **Computational Detector** determines which node the decision advances to next. When the decision reaches a **Judgement** code node, that node's **Judgement** is the **Final Decision**.
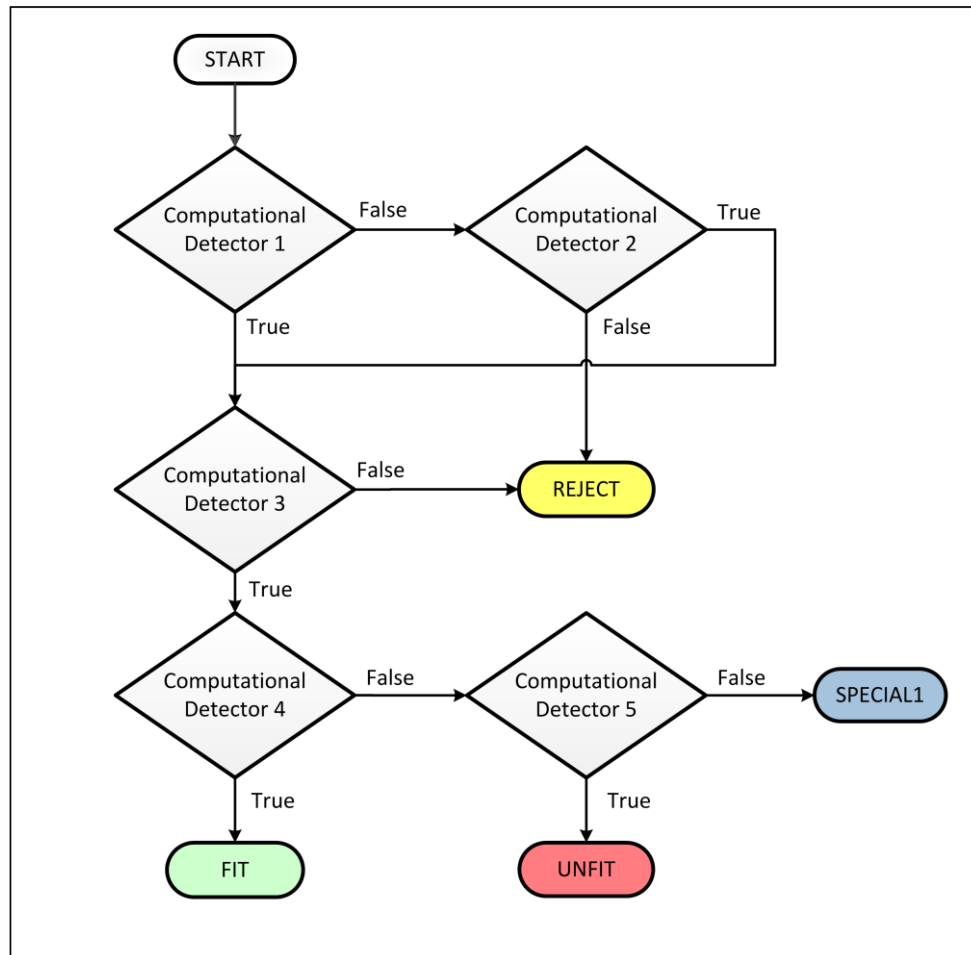

Figure 57: Minimal final decision example

Example 2: Final Decision on Judgement Codes

If **Computational Detector**s deliver a **Judgement** code, all **Judgement**s shall be combined by their priority.

The **Final Decision** for a banknote is derived from the **Judgement** with the highest priority[6] (see Table 38 "Banknote judgement codes"):

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

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

---

[6] An implementation could calculate the maximum value of all **Judgement** codes to get the **Final Decision**.