Current Standards Requirements for Using DC/DC Converter in Battery Powered Rail Applications

1- General

1-1 Introduction

This application note underlines the different requirements that are in used for battery powered railway applications and describes how to comply with GAIA Converter DC/DC modules in the design of complex boards.
When using DC/DC modules two options of requirements can be retained :
- The first is at «sub system level» considering the DC/DC module as a complex electronic system.
- The second is at component level considering the DC/DC module as a component.

1-2 DC/DC Modules as Sub-system

If considered as electronic sub-systems, DC/DC modules have to comply with stringent requirements and have to come with documented files on :
- development methodology,
- recommended component derating factor,
- circuit diagrams, layout,
- track layout requirements,
- bill of materials,
- maintenance files, ...

Those requirements are governed by different standards among which the most popular are the French NF-F 67001 and application file MTCE, the Italian «Specifica 306158» or the English BRB/RIA 13.
But more and more designers are considering DC/DC module as components, relying on the manufacturer quality and qualification approvals.

1-3 DC/DC Modules as Components

If considered as components, DC/DC modules have to comply with external environmental requirements that apply to electronic boards.
In this context, DC/DC converters used in battery powered railway electronic applications are relevent of two major categories :
- for electronics on mobile equipment,
- for electronics on fixed equipments.

For these two major categories, requirements and standards are different.

1-4 Standards

Until recent years, railway systems have been subjected to various standardization bodies. As a consequence a tremendeous quantities of standards both for mobile and fixed equipment are existing among which the most popular being :

- The French NF F standards : NF-F 48 series, NF-F-01-510, NF-F67000, ...
- The UK BRB/RIA standards : RIA12, RIA13, RIA18, RIA20, BR1900, ..
- The German standards : VDE 0435, IEC571, 19 Pfl, ...
- The Italian FS standards : ST306158, ST304142, ...
- The American standards published by the Association of American Railroads : «Signal Manual», Specification 110, ...
- The Chinese standard TB/T3021

Major works have been achieved to harmonize railway standards in Europe and the following EN's standards have been fully adopted :
- The EN 50155 standard : "Railways Applications Electronic Equipment Used on Rolling Stock",
- The EN50125 standard :"Railway applications; Environmental Conditions for rolling stock"
- The EN50163 standard :"Supply voltages of Traction Systems"

This application note does not intend to describe individual standards but to resume the five most important requirements that apply for DC/DC converters when considered as component :
- Input requirements,
- Electromagnetic compatibilty requirements,
- Mechanical requirements,
- Thermal (temperature, humidity),
- Isolation and safety requirement.

For each points GAIA Converter will compare the different requirements with actual module performances to fulfill the specifications.

2- Compliance with Input Requirements

Railway electronic systems powered directly from batteries with no voltage stabilization shall sustain wide input voltage excursions both for permanent operations, brown-out operations, transient and spikes operations.
Those input range requirements are described in different standards both for fixed equipments and mobile equipments. In general, constraints are lower for fixed equipments (defined for example in the French standard NF-F 48-220, NF-F 48-515 or NF-F 48-230) than for mobile equipments. The following section is only focused on mobile equipments.

The input variations for mobile equipments are described in different standards, among which the most frequently used are :

- The European EN50155(:2017) standard : "Rail Applications Electronic Equipment Used on Rolling Stock",
- The International CEI 77 standard :"Règles applicables à l'appareillage de traction".
- The International IEC-571 standard :"Rules for Electronic Equipment used on Rail Vehicle".
- The International CEI-850 standard : "Tensions d'alimentation des réseaux de traction".
- The French NF F 01-510 standard : "Railway Rolling Stock Environment Conditions Sustaines or Produced by Devices or Organs in Vehicles",
- The UK BRB/RIA12 standard : "General Specifications for Protection of Traction and Rolling Stock Equipment from Transients and Surges in DC Control Systems".

These different standards are defining 5 major input voltage requirements :

- The permanent input voltage range,
- The brown-out and transient voltage range,
- The surges voltage excursion,
- The input voltage drop-out,
- The input voltage change-over,

Each single permanent input range requirement can be commonly achieved by the majority of standard DC/DC converters on the marketplace.

The brown-out and transient voltages are more aggressiv and achieved by dedicated wide input range DC/DC converters. The RIA12 rapid transient (20ms) is very aggressiv and necessitates external active limitor.

The surges require in general external filtering in front to protect DC/DC modules.

A major goal for equipment designers is to standardize their product whatever the input voltage is.
This can be achieved by using GAIA Converter DC/DC module with ultra-wide input range to cover the permanent input voltage range ranging from 24V to 110V batteries nominal voltage.

2-1 Permanent, Transients and Brown-out Input Voltage Requirements

Table hereafter specifies (according to 3 different standards) for each nominal input voltage (Vin) provided directly from batteries with no voltage stabilization, the permanent input voltage excursion, the brown-out voltage during 100ms and the transient voltage for 100ms or 1 sec.

	EN50155 standard			NF F 01-510 standard			RIA12 standard			
Nominal input	Permanent input range (0,7-1,25 Vin)	Brownout 100ms (0,6xVin)	Transient 1s (1,4xVin)	Permanent input range	Brownout 100ms (0,5xVin)	Transient 100ms	Permanent input range (0,7-1,25 Vin)	Brownout 100ms (0,6xVin)	Transient 1s (1,5xVin)	Transient 20ms (3,5xVin)
24 V	16,8 - 30 V	14,4 V	33,6 V	18 - 34 V	12 V	40 V	16,6 - 30 V	14,4 V	36 V	84 V
28 V	19,6 - 35 V	16,8 V	39,2 V	/	/		/	/	/	/
36 V	25,2 - 45 V	21,6 V	50,4 V	/	/	/	/	/	/	/
37,5 V	/	/	/	/	/	/	26 - 47 V	22,5 V	56,25 V	131,25 V
48 V	33,6 - 60 V	28,8 V	67,2 V	/	/	/	33,6 - 60 V	28,8 V	72 V	168 V
72 V	50,4 - 90 V	43,2 V	100,8 V	50 - 90 V	36 V	115 V	50,4 - 90 V	43,2 V	112,5 V	252 V
96 V	67,2 - 120 V	57,6 V	134,4 V	/	/	/	67,2 - 120 V	57,6 V	144 V	336 V
110 V	77 - 137,5 V	66 V	154 V	77 - 137	55 V	176 V	77 - 137,5 V	66 V	165 V	385 V

2-2 Surge Requirements on Input Voltage

Railway electronic equipments shall be protected from surges either directly induced or indirectly coupled such that no damage or failure occurs during operations. The magnitude, duration and source impedance of these surges for design purposes are defined in particular in EN 50155, RIA 12 standards and compared with the general purpose EN61000-4-5 industrial spike requirement standard as follow :

	EN50155 standard			BRB/RIA 12 standard			EN61000-4-5 standard		
	Level	Waveform	Source impedance	Level	Waveform	Source impedance	Level	Waveform	Source impedance
Direct spikes Line to line coupling	1.800 V	5/50 µs	100 Ω	800 V	10/100µs	5 Ω	1 : 500 V	1,2/50 µs	2 Ω
	1.800 V	5/50 µs	5 Ω	1.500 V	5/50µs	5 Ω	2 : 1.000 V	1,2/50 µs	2 Ω
				3.000 V	0,5/5µs	100 Ω	3 : 2.000 V	1,2/50 µs	2 Ω
				4.000 V	0,1/1µs	100 Ω	4 : 4.000 V	1,2/50 µs	2 Ω
	8.400 V	0,05/0,1 µs	100 Ω	7.000 V	0,05/0.1µs	100 Ω			
Direct spikes Line to earth coupling	1.800 V	5/50 µs	100 Ω	800 V	10/100µs	5 Ω	1 : 500 V	1,2/50 µs	12 Ω
	1.800 V	5/50 µs	5 Ω	1.500 V	5/50µs	5 Ω	2 : 1.000 V	1,2/50 µs	12 Ω
				3.000 V	0,5/5µs	100 Ω	3 : 2.000 V	1,2/50 µs	12 Ω
				4.000 V	0,1/1µs	100 Ω	4 : 4.000 V	1,2/50 µs	12 Ω
	8.400 V	0,05/0,1 µs	100 Ω	7.000 V	0,05/0.1µs	100 Ω			

2-3 Input Voltage Drop-Out Requirements

The widespread EN50155 (:2017) standard specifies interruption that may occur on the input voltage bus.

- Class S1 : in case of voltage interruption, no performance criterion is requested but the equipment shall continue to operate as specified after the voltage interruption.
- Class S2 : in case of voltage interruption up to 10 ms, the equipment shall behave according to performance criterion A*
- Class S3 : in case of voltage interruption up to 20 ms, the equipment shall behave according to performance criterion A*

criterion A : The apparatus shall continue to operate as intended during and after the drop-out with no degradation of performance. If agreed the normal performance can be replaced by a minimum performance level

2-4 Input Voltage Supply Change Over Requirements

The EN50155 (:2017) standard specifies input change over according to 2 classes :

- Class C1 : voltage dip at 0,6 x Vin during 100ms with performance according to criterion A
- Class C2 : supply break during from Vin with possible apparatus degraded performance

2-4 GAIA Converter DC/DC Converters Compliance

GAIA Converter is proposing various standardized solutions to cope with these input voltage requirements :

- permanent, transient, brown-out and voltage change over requirements are achieved with standard DC/DC converters either wide input voltage range DC/DC per input voltage batteries or ultra-wide input voltage range DC/DC to cover multi-batteries applications.
- surge requirements are achieved with additionnal off-the-shelf qualified front-end components such as limitors (LGDSI series), or discrete components schematics proposed in our applications notes.
- voltage drop-out are achieved using hold-up off-the shelf front-end components or discrete components schematics proposed in our application notes.

Please consult LGDSI series datasheet or EN50155 application notes for further details.

3- Compliance with Electromagnetic Interference Requirements

Railway electronic systems are subjected to different level of electromagnetic interference requirements.
Those requirements are defined in different standards both for fixed equipments and/or mobile equipments. The following section is only focused on mobile equipment for which the most commonly standards are :

• The European EN50121-1 standard : "EMC standard for the Railway Environment",

• The European EN50121-3-2 standard : "Railways Applications Electromagnetic Compatibility Part 3-2 Rolling Stock Apparatus",

• The European EN50121-4 standard : "Railways Applications Electromagnetic Compatibility Part 4 : Standard for Emission and Immunity of the Signalling and Telecommunication Apparatus",

• The French NF F 01-510 standard : "Railway Rolling Stock Environment Conditions Sustaines or Produced by Devices or Organs in Vehicles",

• The UK BRB/RIA18 standard : "General Specifications for Interference Testing for Electronic Equipment Used on Traction of Rolling Stock".

The applicability and the different requirements are depending on equipment location and are resumed :

In the EN50121-3-2 standard for rolling stock equipment : locomotive, driver's cab, passenger components, interior of power equipment, ...

and in the EN50121-4 standard for signalling equipments.

It is important to note that DC/DC converters are considered as components and the requirements are applicable to the total electronic equipment apparatus defined as "a finished product with an intrinsec function intended for implementation into a rolling stock installation, but not at a component level".

Nevertheless, GAIA Converter provides hereafter a comparison of the various requirements and the module compliance. The module compliance has to be considered module stand-alone with no additionnal external components unless otherwise specified.

Description of the different requirements according to 2 standards including the EN50155 are resumed in the table hereafter.

Requirements	Generic Standards	EN 50155 (apply only for EN50121-3-2)	NF F 05-510	GAIA Converter module compliance
Electromagnetic conducted emission <30MHz 0,09 - 0,15 MHz (quasi peak) 0,15 - 0,5 MHz (quasi peak) 0,5 - 30 MHz (quasi peak)	EN50121-3-2	EN55011 level + 20 dB : No limit 79 dBµV + 20dB (quasi peak) 73 dBµV + 20dB (quasi peak)	Level : < 46 dB/µA 26 dB/µA	Compliance with companion filter (LGDSI series)
Radio magnetic emission 30 MHz - 230 MHz 230 MHz - 1 GHz	EN50121-3-2	Measurement at 10m 40 dBµV/m 47 dBµV/m		Module stand alone
Electromagnetic conducted emission <30MHz 0,15 - 0,5 MHz (quasi peak) 0,5 - 5 MHz (quasi peak) 5 - 30 MHz (quasi peak)	EN50121-4	EN55011 level +20 dB : 79 dBµV (quasi peak) 73 dBµV (quasi peak) 73 dBµV (quasi peak)	Level : < 46 dB/µA 26 dB/µA	Compliance with companion filter (LGDSI series)
Radio magnetic emission 30 MHz - 230 MHz 230 MHz - 1 GHz	EN50121-4	Measurement at 10m 40 dBµV/m 47 dBµV/m		Module stand alone
Electrostatic discharge immunity	EN61000-4-2 or IEC-801-2	Level : 6KV contact criteria B Level : 8KV air criteria B	/ /	6KV contact criteria B module stand alone 8KV air criteria B module stand alone
Fast transient burst immunity (DC power port and I/O ports)	EN50121-3-2 EN50121-4	Level : 2KV criteria A	Level : 2KV	Level : 0.5KV criteria A module stand alone Level : 2KV criteria B with LGDS-50 filter
Surges immunity (see section 2)	EN 61000-4-5	Level : 2KV criteria B Impedance 42 Ohm	/	Level : 4KV with companion filter (LGDSI series)
Conducted disturbances induced by radio frequency fields (150KHz-80MHz) (DC power port and I/O port)	EN50121-3-2 EN50121-4	Level : 10Veff criteria A Modulation 1 KHz 80% AM Impedance 150 Ohm	/	Level 10V criteria A module stand alone

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4- Compliance with Mechanical Requirements

Railway electronic systems are subjected to high level of mechanical environmental constraints depending on their implementation

- Ground equipment,
- Wayside equipment,
- Mobile equipment.

These constraintss are defined in different standards among which the most commonly used are :

• The European EN 50155 standard : "Railway Application Electronic Equipments Used on Rolling Stock",

• The International IEC-9-335-CD standard : "Vibration and Shok Testing of Equipment for Use on Rail Vehicles".

• The International IEC68 or EN60068 standard : "Basic Environmental Testing Procedures".

• The French NF F 05-510 standard : "Railway Fixed Equipment Environmental Conditions Generated by or to which Signalling or Driver aid Devices or Equipment are Subjected",

• The UK BS2011 standard : "Basic Environmental Testing Procedures".

• The UK BRB/RIA 13 standard : "General specification for Electronic Equipment used on Traction and Rolling Stock".

• The UK BRB/RIA 20 standard : "Requirements for Vibration and Shock Testing of Equipment for Railway Vehicles".

Description of the different requirements are resumed in the table hereafter.

GAIA Converter modules have been qualified according to the levels defined in the table hereafter. The qualification have been undertaken directly on a printed circuit board with the modules soldered on to it; representative of a real environment.

GAIA Converter modules due to their integral potting can sustain easily the mechanical constraints by themselves; nevertheless special attention is recommended on the soldering and wiring on the boards together with the boards mechanical of resonance.

Equipment location	Parameter	EN50155	NF F 01-510(Rolling stock NF F 05-510(Fixed equipment)	BRB/RIA20	GAIA Converter modules Qualification
Rolling equipment	Vibration Frequency range Acceleration	Category < 0,3 Kg 5 - 150 Hz 5g	Category «Bogies» 0 - 150 Hz ASD density : 0,1g²/Hz	Category 2 «Bogies» 20 - 600 Hz ASD density : 0,1g²/Hz	Compliant
	Shock (Half sinus) Peak acceleration Duration	Long. / Trans. / Vert. axis 5g / 2g / 1g 50 ms / 20ms / 20ms	Category «essieu» 50g 10 ms	Category 2 «Bogies» 50g 11 ms	Compliant
Ground equipment	Vibration Frequency range Acceleration	/	Category «traverses» 6-2.000 Hz 9 g	/	Compliant
	Shock (Half sinus) Peak acceleration Duration	/	Category «traverses» 80g 11 ms	/	Compliant

5- Compliance with Temperature/Humidity Requirements

5-1 Temperature Requirements of EN50155 Standard

The EN50155 (:2017) standard specifies 6 classes of operating temperature requirements from OT1 to OT6.
Classes OT1 and OT2 should be used for passenger compartments and the driver's cab, OT3 and OT4 can be used for equipment in technical cabinets. OT5 and OT6 for specific applications.
An additionnal +15°C extended temprature can be applied at swith-on operation.
Temperature classes have to be considered as ambient temperature aroud DC/DC converters. As ambient temperature is an ambiguous measurement and for DC/DC converter it has to be used in conjunction with the maximum case temperature of DC/DC converter specified by the manufacturer.

GAIA Converter proposes two grades of products :

- An industrial grade with an operating temperature range of -40°C/+71°C ambient with no derating and a maximum case temperature of 91°C,
- A Hi Rel grade with an operating temperature range of -40°C/+85°C ambient with no derating and a maxi mum case temperature of 105°C.

To ensurre correct design-in, the case temperature should be measured with the DC/DC converter fitted in the complete equipment and under worst conditions. If temperatures are too high, corrective measures should be taken that may include heatsink, relocation, ...

Category	Equipment Oporating Temperature Range	GAIA Converter modules temperature range
OT1	-25°C / +55°C	Industrial line : -40°C / +71°C ambient
OT2	-40°C / +55°C	Industrial line : -40°C / +71°C ambient
OT3	-25°C / +70°C	Industrial line : -40°C / +71°C ambient
OT4	-40°C / +70°C	Industrial line : -40°C / +71°C ambient
OT5	-25°C / -85°C	Hi-rel line : -40°C / +85°C ambient -40°C / +105°C case
OT6	-40°C / +85°C	Hi-rel line : -40°C / +85°C ambient -40°C / +105°C case

5-2 Humidity Requirements

Mobile or fixed railway equipments have also to comply with humidity requirements. GAIA Converter modules have been qualified with EN60068-2-3 standard and comply with the following requirement of EN50155, NF01-510 or BS2011 standards.

Standards	Requirements
EN50155	30 days 95% relative humidity
NF F 01-510	100% relative humidity
BS2011 / IEC-68-2-3	56 days 93% relative humidity

6- Compliance with Isolation and Safety Requirements

6-1 Isolation Requirements of EN50155 Standard

Railway electronic equipment shall be protected against dielectric strengh through different isolation barriers. The levels are defined in different standards such as EN50155, NF F 670001 or NF 05-510 and are resumed in the following table.

Input Nominal	Rolling stock EN50155 requirements	Rolling stock NF F 670001 requirements	Ground equipment NF F 05-510 requirements
24 VDC	500Veff/50Hz/1min. or 750Vdc/1min.*	group A : 1.500Veff/1min.	2.000Veff/50Hz/1min.
48 VDC	500Veff/50Hz/1min. or 750Vdc/1min.*	group A : 1.500Veff/1min.	2.000Veff/50Hz/1min.
72 - 125 VDC	1.000Veff/50Hz/1min. or 2.500Vdc/1min.*	group A : 1.500Veff/1min.	2.000Veff/50Hz/1min.
125 - 315 V	1.500Veff/50Hz/1 min. or 2.200Vdc/1min.*	group A : 1.500Veff/1min.	2.000Veff/50Hz/1min.

* EN50155 standard states that if an alternative voltage is not applicable an equivalent DC voltage shall be applied.

6-2 Safety Isolation Requirements

In many applications, DC-DC converter requires isolation to provide a 'safety barrier' between its input and output/case.
Safety barrier isolation is necessary to protect against fault conditions. If a single fault could put a dangerous voltage on the input to a DC-DC converter and an operator can touch the output/case, a minimum level of safety isolation is necessary in the converter. This can work in reverse as well, if a fault condition could put a dangerous voltage on the output of a converter and an operator could touch the input, again a level of safety isolation is necessary.

Isolation in DC-DC converters can have various levels/ strengths.
The minimum protection is called 'functionnal' isolation a higher class is called 'Basic' or 'one level of protection' the third class is called 'Reinforced', or 'two levels of protections'.

The various standards take into account the potential dangerous voltage level, (system voltage), the pollution degree of the environment, the possibility of transient voltages on the system voltage (over-voltage category), altitude and the general operating environment ....

The EN50155 does not specify functionnal safety or personal safety.

The main sources of requirements have to be found in the EN/UL/CSA 62368-1 safety standard.
This internationnal safety standard 62368-1 is a hazard-based standard : this hazard-based standard engineering (HBSE) is based on the principle that safety is not dependent on the product, but rather on the energy within the equipment.
The EN62368-1 applies not only at the product/system level but also – where relevant – to components such as DC/DC converter.

To be meaningful, a statement that a DC-DC converter meets a safety standard must include the level of protection; functionnal/basic/reinforced
and the system voltage that applies. If no level of safety isolation is stated, it must be assumed that the isolation of the DC-DC converter is only functional.

GAIA Converter is proposing various DC/DC converter choices with different levels or class of isolation :
- standard functionnal isolation : 1.500 Vdc, or higher isolation up to 3.000 Vdc (LLP family)
- re-inforced isolation : 3.000 Vdc (WLP family)

6- Compliance with Fire Protection Requirements

Requirements for fire protection for rail have been documented in various standards (among which the French NF F16-101/102, STM-S-001, the UK BSI - BS 6853 ..). Nowerdays the widespread EN50155 specifies that guidelines of EN45545 for applicability/protection against spread of fire shall be used.
The EN45545 applicability for DC/DC converters is first dependant of Section 4.3.2 Rule 1: non applicable if a maximum of 100g weight of flammable material is present; then if above are those define in R26 requirements for small electronic products and hazard level has to be defined among the 3 levels : HL1, HL2 and HL3.

For more detailed specifications and applications information, contact :

International Headquarters
GAÏA Converter - France
ZI de la Morandière
33185 LE HAILLAN - FRANCE
Tel. : + (33)-5-57-92-12-80
Fax : + (33)-5-57-92-12-89

North American Headquarters
GAÏA Converter Canada, Inc
4038 Le Corbusier Blvd
LAVAL, QUEBEC - CANADA H7L 5R2
Tel. : (514)-333-3169
Fax : (514)-333-4519

Represented by :

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