Using Modular DC/DC Converter for Battery Powered Railway Applications

1- General

1-1 Introduction

This application note underlines the different requirements that are in use 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 protected national activities with protective standardization bodies. As a consequence a tremendeous quantities of standards both for mobile and fixed equipment are existing among

which the most popular are :

- 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, ...

A major work has been done to harmonize railway standards in Europe. The introduction of European Norm EN's is being adopted slowly by railways electronics manufacturers among which :

- 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 do not intend to describe each standard but to resume 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 requirement.

For each of this five points GAIA Converter compares the different requirements with the actual performance of the modules and details the different solutions to fulfill the specifications.

2- Compliance with Input Requirements

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

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

- The European EN50155 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 define 3 main excursions to sustain :

- The permanent input voltage range,
- The brown-out and transient range,
- The spikes excursion.

The permanent input range requirements are commonly achieved by the majority of standard DC/DC converters on the marketplace.

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

The spikes necessitate an external filter in front of the 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. For example, the MGDS-R family allows to cover the permanent input voltage range from 24V to 110V batteries nominal voltage.

Description of the following levels are resumed in the table thereafter.

2-1 Permanent, Transients and Brown-out requirements

The 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 excursion, the brown-out voltage during 100ms and the transient 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
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

Railway electronic equipment 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 EN 50155, RIA 12 or the international standard IEC-801-5 renamed EN61000-4-5 as follow :

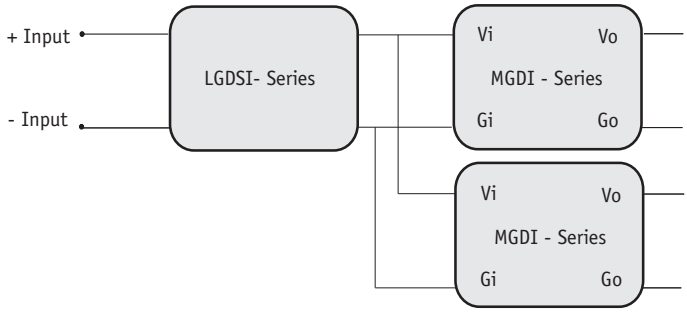
	EN50155 standard			BRB/RIA 12 standard			EN61000-4-5 standard		
	Level	Waveform	Source impedance	Level	Waveform	Source impedance	Level	Waveform	Source impedance
Direct spikes Line to line coupling	1.800 V	5/50 µs	100 Ω	800 V	10/100µs	5 Ω	1 : 500 V	1,2/50 µs	2 Ω
	1.800 V	5/50 µs	5 Ω	1.500 V	5/50µs	5 Ω	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 Schematics Proposed

Gaïa Converter stand-alone DC/DC module cannot sustain such levels ; additionnal off-the-shelf qualified front end components are necessary.
To sustain surge requirements of EN50155, RIA 12 and EN61000-4-5 standards, Gaïa Converter proposes the following two solutions :

2-3-1 Using a Limitor Module (LGDSI series)

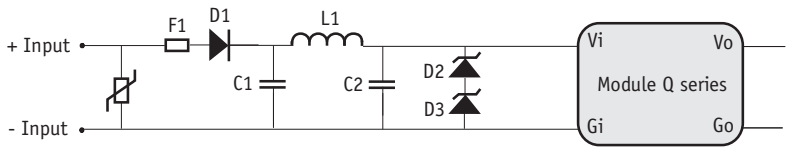
This solution is based on a single off-the-shelf product : GAIA Converter «limitor» module (LGDSI series).
Example of schematics is given hereafter.



Please consult LGDSI series datasheet for further details.

2-3-2 Using Discrete Components

This solution is based on discrete components to lay-out on the board.
Example of schematics is given hereafter.



Please consult EN50155 filter application note 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.

The description of the different requirements 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

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 solder and wiring of 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

6

5- Compliance with Temperature/Humidity Requirements

5-1 Temperature Requirements of EN50155 Standard

This is an important issue to be considered when specifying a DC/DC converter.
The EN50155 standard specifies 4 grades of operating temperature requirements according to the severity of the environment as shown is the following table.
The first column describes the temperature ranges inside the electronics cabinet. The second column describes the temperature range that is surrounding the electronics board.
It is this last temperature range that has to be considered as «theorical» ambient temperature for 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 the DC/DC converter specified by the manufacturer.

To cope with these requirements, 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 maximum 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	Internal cabinet temperature range	Ambient board temperature range	GAIA Converter modules temperature range	
T1	-25°C / +55°C	-25°C / +70°C	Industrial line :	-40°C / +71°C ambient
T2	-40°C / +55°C	-40°C / +70°C	Industrial line :	-40°C / +71°C ambient
T3	-25°C / +70°C	-25°C / +85°C	Hi-rel line :	-40°C / +85°C ambient -40°C / +105°C case
TX	-40°C / +70°	-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 Requirements

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	GAIA Converter modules performance
24 VDC	500Veff/50Hz/1min. or 707Vdc/1min.*	group A : 1.500Veff/1min.	2.000Veff/50Hz/1min.	Basic version : 1.500Vdc/1min.* Y version : 2.000Veff/50Hz/1min.
48 VDC	500Veff/50Hz/1min. or 707Vdc/1min.*	group A : 1.500Veff/1min.	2.000Veff/50Hz/1min.	Basic version : 1.500Vdc/1min.* Y version : 2.000Veff/50Hz/1min.
72 - 125 VDC	1.000Veff/50Hz/1min. or 1414Vdc/1min.*	group A : 1.500Veff/1min.	2.000Veff/50Hz/1min.	Basic version : 1.500Vdc/1min.* Y version : 2.000Veff/50Hz/1min.
125 - 315 V	1.500Veff/50Hz/1 min. or 2121Vdc/1min.*	group A : 1.500Veff/1min.	2.000Veff/50Hz/1min.	Basic version : 1.500Vdc/1min.* Y version : 2.000Veff/50Hz/1min.

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

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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