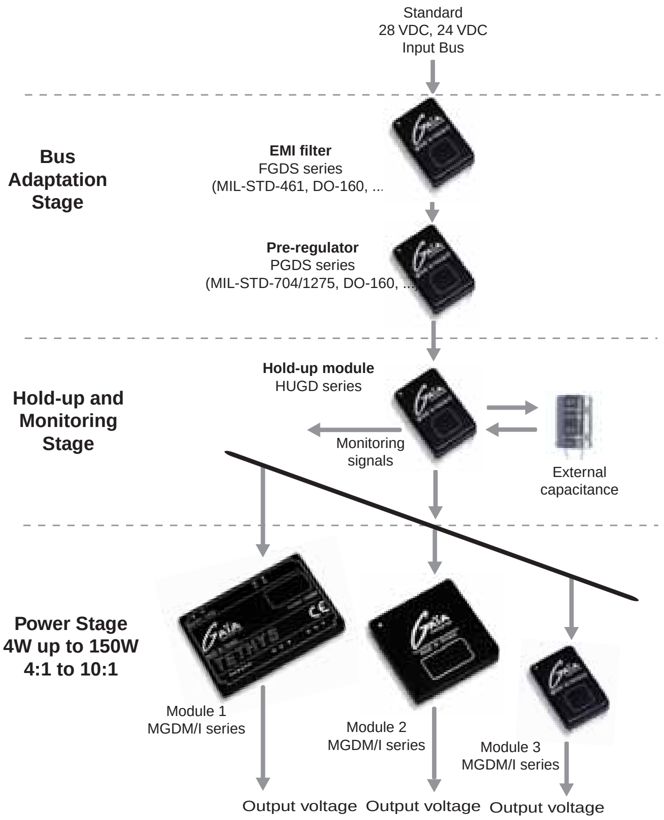
GAÏA CONVERTER

Modular Power Architecture Up to 50W for Avionics/Military Applications



1- General

1-1 Introduction

This application note describes how to use GAIA Converter DC/DC converters and front-end modules PGDS-50 and HUGD-50 to built a complete power supply that meets avionics/military standards. This modular power architecture is dedicated for 24V and 28V bus powered electronics up to 50W power.

1-2 Modular Power Architecture

The use of modular power architecture by using «ready-to-use» building block modules offer to designers a lot of positives. Development time is drastically shorter over a traditionnal custom approach. The use of standard building block modules «mass produced» is cost-effective over a custom design. It is a versatile and multi-applications oriented, qualification is facilitate by using already qualified building block.

1-3 28V Powered Avionics/Military Applications

The 28Vdc input bus is one of the most spread input voltage for low power and critical systems for :
- airborne applications
- groundborne applications

A lot of constrainsts around this input bus are existing including transients, spikes, recovery in power fail, electromagnetic interferences, crancking, ...
GAIA Converter has developped a standard easy-to-use and fully qualified modular power architecture to cover all these requirements.

The following sections will underline the different requirements to fulfill in the main area such as :
- Input voltage requirements,
- Electromagnetic interference requirements,
- Output noise requirements,
- Environmental conditions requirements,
- Thermal management.

2- Input Bus Voltage Requirements

2-1 General

Airborne or groundborne electronic systems powered directly from 28 VDC batteries bus or generator bus, shall sustain wide input excursions, including transients, spikes, crancking and shut down variations.
Those input variations are described in different standards, in which the most frequently used are as follows :

• For Airborne Applications :

- The US MIL-STD-704 standard : “Aircraft Electric Power Characteristics”.
- The International DO-160 standard : “Environmental Conditions and Test Procedures for Airborne Equipment”.
- The European En 2282 standard : “Characteristics of Aircraft Electrical Supply”.
- The British BSI 3G 100 : “Characteristics of Aircraft Electrical Power Supplies”.
- The Airbus ADB 100 chap. 8 standard : “Equipement Requirements for Suppliers, electric“

• For Groundborne Applications :

- The US MIL-STD-1275 standard : “Characteristics of 28 VDC Electrical Systems in Military Vehicles”.
- The British DEF STAN 61-5 Part 6 Electical Power Supply 28 VDC Electrical Systems in Military Vehicles.

There are different levels to sustain :

- The permanent input voltage range in normal, abnormal and emergency conditions,
- The brown-out and transient levels in normal and abnormal conditions,
- The spike levels,
- The start up voltage and crancking levels,
- The shut down (or transparency) levels.

The permanent input ranges are achieved by using standard GAIA Converter DC/DC modules without any additional devices.

The brown-out, transient and spikes are more aggressive and are achieved by using GAIA Converter front-end module designated “PGDS-50”. The PGDS-50 module is a transient protection module (see datasheet PGDS-50 for further details)

The minimum start up voltage during engine start is also achieved with the GAIA Converter PGDS series.

The shut down level is satisfied by an external hold up device (capacitance and/or a GAÏA Converter hold up module «HUGD-50» as exemple). The HUGD-50 module used in conjunction with an external capacitance is a hold-up charger and controller.
(see HUGD-50 datasheet for further details)

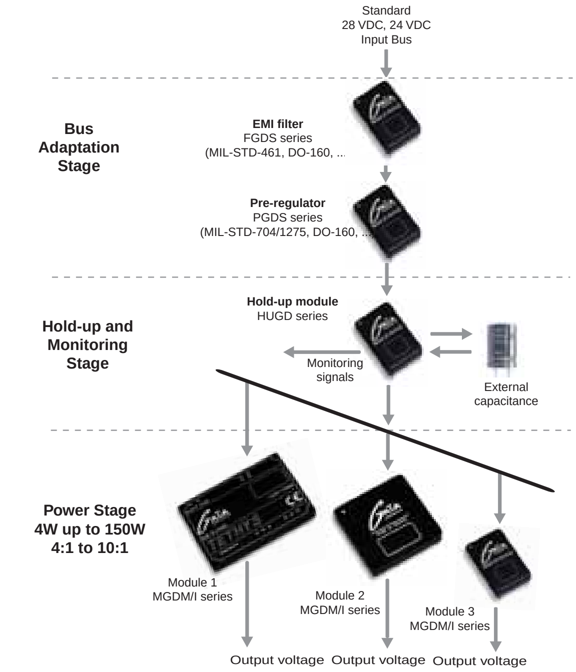
2-2 Modes of Operations

The typical architecture to cover all the requirements is shown in the figure herein.
This architecture includes :

- Front-end modules :
  - Pre-regulator module PGDS-50
  - Hold-Up module HUGD-50
- a complete range of DC/DC modules

The front-end modules cover the following operations depending on power bus input status :

Input Bus Status	Active Module	Operations
Transients & Spikes	PGDS-50	Transient & spike supressor
Normal	DC/DC	Generation of DC voltages
Low line	PGDS-50	Boost voltage for proper DC operation
Hold up	HUGD-50	used in conjunction with capacitance to provide energy



2- Input Bus Voltage Requirements (continued)

The following tables describe for airborne and groundborne applications the GAIA Converter modular power architecture compliance.

2-2 For Airborne Applications

Standards	<------------Steady State----------> Normal	Abnormal	Emergency	<--------------Transient-------------> Low Normal	High Abnormal	Interruption Abnormal	<-----Spikes----->	<---GAIA Converter DC/DC----> and Front-end Modules Compliance
MIL-STD-704A (cat. A)	25 - 28,5V	23,5 - 30V	17 - 24V	10V/50ms	80V/50ms	0V/0,05 to 7s	+/-600V/20µs	GAIA DC/DC range : 16 - 40V or 16-80V PGDS series : 10V/15s & 80V/100ms HUGD series : with capacitor PGDS series : 600V/20µs
MIL-STD-704D/E	22 - 29V	20 - 31,5V	16 - 29V	18V/15 ms	50V/45ms	0V/up to 7s	/	GAIA DC/DC range : 16 - 40V or 16-80V PGDS series : 10V/15s & 80V/100ms HUGD series : with capacitor
DO-160B/C (cat. A) spike cat. A	22 - 29,5V	20,5 - 32,2V	18V	10V/15s	46,3V/100ms	0V/ up to 7s	+/-600V/10µs/50 W	GAIA DC/DC range : 16 - 40V or 16-80V PGDS series : 10V/15s & 80V/100ms HUGD series : with capacitor PGDS series : 600V/20µs
DO-160D (cat. Z) spike cat.A	22 - 30,3V	20,5 - 32,2V	18V	10V/30s	80V/100ms	0V/up to 7s	+/-600V/2µs/50 W	GAIA DC/DC range : 16 - 40V or 16-80V PGDS series : 10V/15s & 80V/100ms HUGD series : with capacitor PGDS series : 600V/20µs
AIR2021E	24 - 29V	20,5 - 32,2V	17V	12V/50ms	60V/100ms	0V/ up to 5s	600V/50µs/50 W	GAIA DC/DC range : 16 - 40V or 16-80V PGDS series : 10V/15s & 80V/100ms HUGD series : with capacitor PGDS series : 600V/20µs

2-2 For Groundborne Applications

Standards	Steady State	Start Engine	Cranking	<-------Surges------> Low	High	Spikes	GAIA Converter DC/DC and Front-end Module Compliance
MIL-STD-1275B (generator + battery)	25 - 30V	6V/1s	16V/30s	18V/100ms	40V/50ms	+/-250V/50µs/15mJ	GAIA DC/DC range : 9 - 36V transient 40V/100ms or 9 - 45V PGDS series : 6V/1s PGDS series : 600V/20µs
MIL-STD-1275B (battery only)	20 - 27V	6V/1s	16V/30s	10V/500ms	100V/50ms	+/-250V/50µs/15mJ	GAIA DC/DC range : 9 - 36V or 9 - 45V PGDS series : 6V/1s & 100V/50ms PGDS series : 600V/20µs
MIL-STD-1275B (generator only)	23 - 33V	/	/	10V/500ms	100V/50ms	+/-250V/50µs/15mJ	GAIA DC/DC range : 9 - 36V or 9 - 45V PGDS series : 100V/50ms PGDS series : 600V/20µs
MIL-STD-1275D (generator +battery)	25 - 30V	6V/1s	16V/30s	18V/500ms	40V/50ms	+/-250V/70µs/15mJ	GAIA DC/DC range : 9 - 36V transient 40V/100ms or 9 - 45V PGDS series : 6V/1s PGDS series : 600V/20µs
MIL-STD-1275D (generator only)	23 - 33V	/	/	15V/500ms	100V/50ms	+/-250V/50µs/15mJ	GAIA DC/DC range : 9 - 36V or 9 - 45V PGDS series : 100V/50ms PGDS series : 600V/20µs
DEF STAN 61-5 (generator + battery)	25 - 30V	6V/1s	>15V	20V/500ms	40V/50ms	+130V/-100V/<10µs +90V/-60V/10µs +70V/-40V/5ms	GAIA DC/DC range : 9 - 36V or 9 - 45V PGDS series : 6V/1s PGDS series : 600V/20µs PGDS series : 600V/20µs PGDS series : 100V/50ms
DEF STAN 61-5 (battery only)	22 - 27V	1V/1s	>10V	20V/500ms	40V/50ms	+130V/-100V/<10µs +90V/-60V/10µs +70V/-40V/5ms	GAIA DC/DC range : 9 - 36V transient 40V/100ms or 9 - 45V External capacitance PGDS series : 600V/20µs PGDS series : 600V/20µs PGDS series : 100V/50ms
DEF STAN 61-5 (generator only)	15 - 40V	/	/	15V/500ms	80V/80ms	+280V/-220V<10µs +130V/-70V/10µs +110V/-50V/5ms	GAIA DC/DC range : 9 - 36V or 9 - 45V PGDS series : 80V/50ms PGDS series : 600V/20µs PGDS series : 600V/20µs PGDS series : 100V/50ms

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2- Input Bus Voltage Requirements (continued)

2-4 Input Bus Shut-Down Requirements

When input bus voltage shut-down the use of a storage energy device is necessary.
There are 2 ways to compy :
- the use of a stand(alone bulk capacitor
- the use of GAIA Converter HUGD-50 module together wxith a capacitor.

Both solutions are described thereafter.

2-4-1 Bulk Capacitor Solution

During bus power drop-out, avionics and military systems require a maintain of operation for saving data and controlling the shut-down. The duration of this shut-down operation is defined in different standards explained in previous table in section 2-2 and can go up to 7 secondes.

To maintain operation during this power drop-out, the traditional approach is the use of a bulk capacitor connected at the input of the converters to power them when power drops-out. The capacitor needed depends on the system specifications, the load and the efficiency of the DC/DC converters and the amount of capacitor for a given hold-up time is determined by the following formula :

$$C1 = \frac{(2 \times P \times Dt)}{\{ h \times (V1^2 - V2^2)\}}$$

where :
C : is the required capacitor (in farads)
P : is the power at the load (output of converter) (in watts)
h : is the efficiency of the converter at rated load
Dt : is the required hold up time (in seconds)
V1 : is the initial charged capacitor voltage (in volts)
V2 : is the low line voltage of DC/DC converter

For a typical hold-up time of 50 ms with 50W power (at the input of the DC/DC converter with 80% efficiency) plugged on a MIL-STD-704D 28V bus that can range down to 22V and considering the minimum permanent input voltage of GAIA Converter module at 16V, the required capacitance is a huge 18.000 µF/40V rated.

2-4-2 Hold Up Module Solution

To reduce drastically the size of this capacitor, GAIA Converter proposes a hold up module that will charge the capacitor at a much higher voltage (typically 38V).

Moroever this module allows a selection of the minimum threshold voltage at which the capacitance will begin to power the converters. In this case the amount of capacitance for a given hold up time is determined by the following formula :

$$C2 = \frac{2 \times P \times (Dt + 0.01)}{\{ h \times (38^2 - V2^2)\}}$$

where :
C : is the required capacitor (in farads)
P : is the power to the load (output of converter) (in watts)
h : is the efficiency of the converter at rated load
Dt : is the required hold up time (in seconds)
V2 : is the low line voltage of DC/DC converter (in volts).

For a typical hold-up time of 50 ms with 50W power (at the input of the DC/DC converter with 80% efficiency) plugged on a MIL-STD-704D 28V bus and using the hold up module the capacitance required will decrease down to 5.000 µF/40V rated.

Moroever this module provides monitoring signals of capacitor charge, discharge, power fail, and is able to drive complex avionics systems micro- shut-down, cold and hot start, ...

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2- Input Bus Voltage Requirements (continued)

2-5 Typical Schematics

To take into account the different constraints described in table of section 2-2, GAIA Converter recommends the following schematics integrating either the pre-regulator module PGDS-50 for transient, spike and low line operation together with the hold-up module HUGD-50 and a bulk capacitance for drop-out operation.

A typical schematic will be built with the following settings :

• For HUGD-50

- Setting of the «power fail threshold» Vth (adjustable between about 9V and 16V) which will determine the voltage limit underwhich the system will work in hold-up mode using only the capacitance energy. This setting is realized with a resistance Rth connected between the pin Vth and the G0 pin :
  - Rth : Vth unconnected will give a threshold of about 16V,
  - Rth : Vth connected to ground will give a threshold of about 9 V.
  If the PGDS-50 is used in conjunction with HUGD-50 module the pin Vth has to remain unconnected.

- Setting of the «charging current level» between 100 mA up to 2A will determine the charging time. A resistance Rcl connected between the pin Vcl and the pin G0 of 1K will give a charging time of 150µs/µF; a 2K will give about 475µs/µF.

Additionnal details on these settings are given in the HUGD-50 datasheet together with detailed operations.

• For PGDS-50

No settings are necessary, the PGDS-50 modules need just a voltage reference Vimes connected at a filtered input of the power bus.

Additionnal details on PGDS-50 is given in the PGDS technical datasheet.

- For bulk capacitance

The calculation is given by the following formula :

$$C = \frac{2 \times P \times (Dt+0.01)}{\{ h \times (38^2 - V2^2)\}}$$

where :

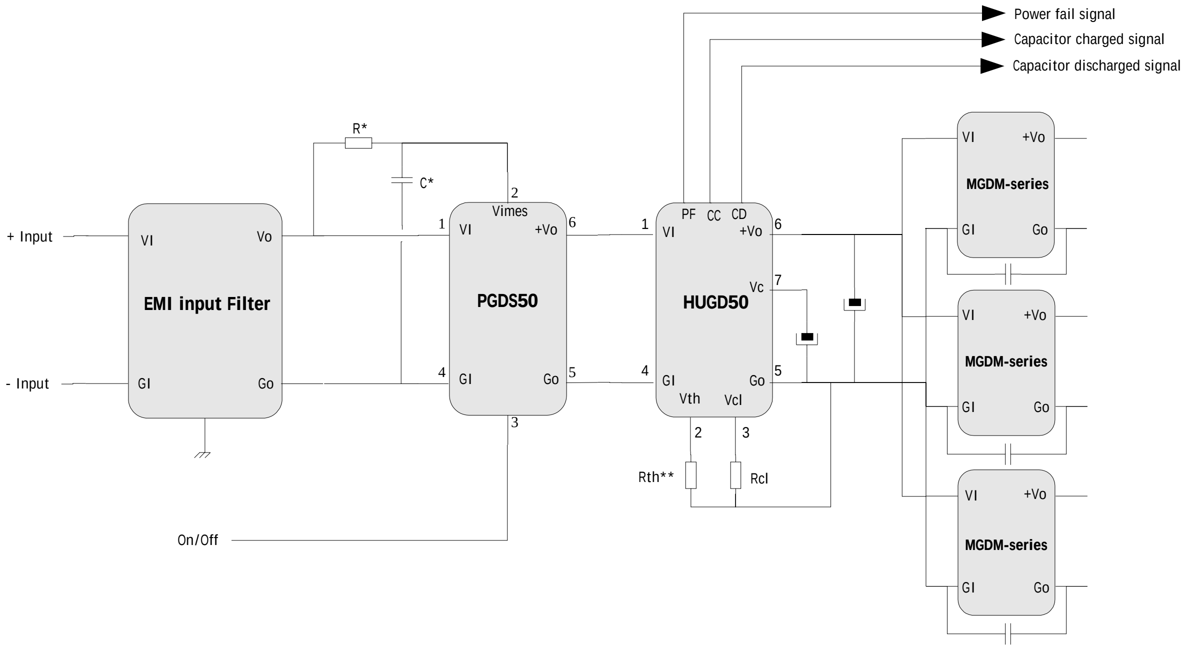
C : is the required capacitor (in farads)
P : is the power to the load (output of converter) (in watts)
h : is the efficiency of the converter
Dt : is the required hold up time (in seconds)
V2 : is the low line voltage of DC/DC converter

• Transition capacitor

To help transitionning the system in the different operating mode, GAIA Converter recommends the use of a transition capacitor. A 100µF electrolytic capacitor is recommended for 50W load and can be reduced for lower loads. Details are given in HUGD datasheet.

• EMI filter

To sustain EMI requirements a front filter is recommended. The following section 3 describes this filter.



*Note * : Due to possible oscillations caused by surges or fast transients at the input voltage level, it is recommended to implement a RC filter on the VIMES signal; several implementations as shown in the above figure can be tested to optimize the design. Typical values for the resistor R is 470 Ohm and for for the capacitance C is 1µF.*

*Note ** : When used in conjunction with PGDS-50 series, the resistance Rth of HUGD module has to be left unconnected.*

3- Electromagnetic Interference Compatibility Requirement

Airborne or groundborne electronic systems shall also sustain severe level of electromagnetic interference requirements.
Those interference levels are defined in different standards whereas the most popular are :

• The US MIL-STD-461C standard : "Electromagnetic Interferance Characteristics, Requirements for Equipment".

• The US MIL-STD-461D/E standards : «Requirements for the control of electromagnetic Interference Emissions and Susceptibility».

• The DO-160D standard : "Environmental Conditions and Test Procedures for Airborne Equipment".

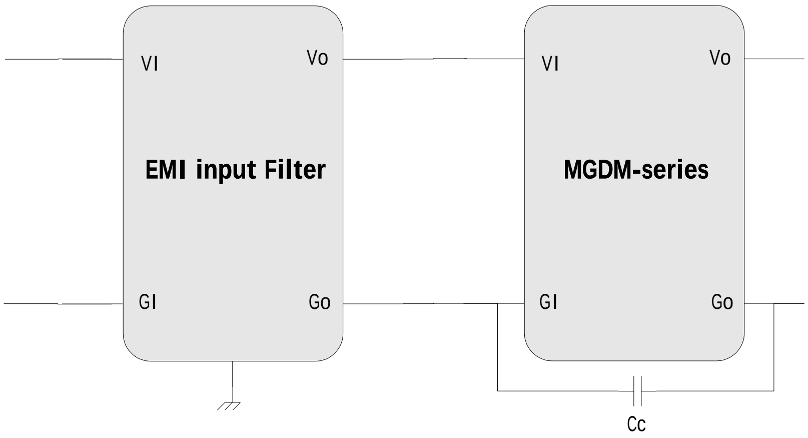
The requirements are divided into :
- Conducted emission (CE),
- Conducted susceptibility (CS),
- Radiated emission (RE),
- Radiated susceptibility (RS).

The following tables resume GAIA Converter products compliance with the requirements

Specifications	MIL-STD-461C	MIL-STD-461E	DO 160D	GAIA Converter module compliance
Conducted emission (CE) :				
Low frequency	CE 01	CE 101	Section 21	module compliant stand alone
High frequency	CE 03	CE 102	Section 21	module compliant with additional filter
Conducted susceptibility (CS) :				
Low frequency	CS 01	CS 101	Section 20	module compliant with additional filter
High frequency	CS 02	CS 114	Section 20	module compliant with additional filter
Radiated emission (RE) :				
Magnetic field	RE 01	RE 101	Section 21	module compliant stand alone
Electrical field	RE 02	RE 102	Section 21	module compliant stand alone
Radiated susceptibility (RS) :				
Magnetic field	RS 01	RS 101	Section 20	module compliant stand alone
Electrical field	RS 03	RS 103	Section 20	module compliant stand alone

3-1 Compliance with MIL-STD-461C/D/E Standards

To meet the latests US military standards MIL-STD-461C, MIL-STD-461D and MIL-STD-461E requirements and in particular CE03 and CE102 requirements, Gaïa Converter can propose a ready-to-use EMI filter module. Please consult EMI filter datasheet for further details.



4- Lay-out Recommendation

Good printed circuit board layout design is essential to achieve proper EMI performance. The two key areas to consider while laying-out a board are :

- Grounding design,
- Component and trace routing.

4-1 Grounding design

GAIA Converter recommend to use four layer boards. The two outer layers will be used for power and ground planes, and the two inner layers for low levels signals. Where necessary, extra planes to beef-up high current paths can be added on the inner layers.
We recommend that the top layer, located closest to the modules, be used for the ground planes and divided into two parts as follow :

- primary ground part, divided into two sub-parts (see EMI filter design note for further information)
- secondary ground parts,

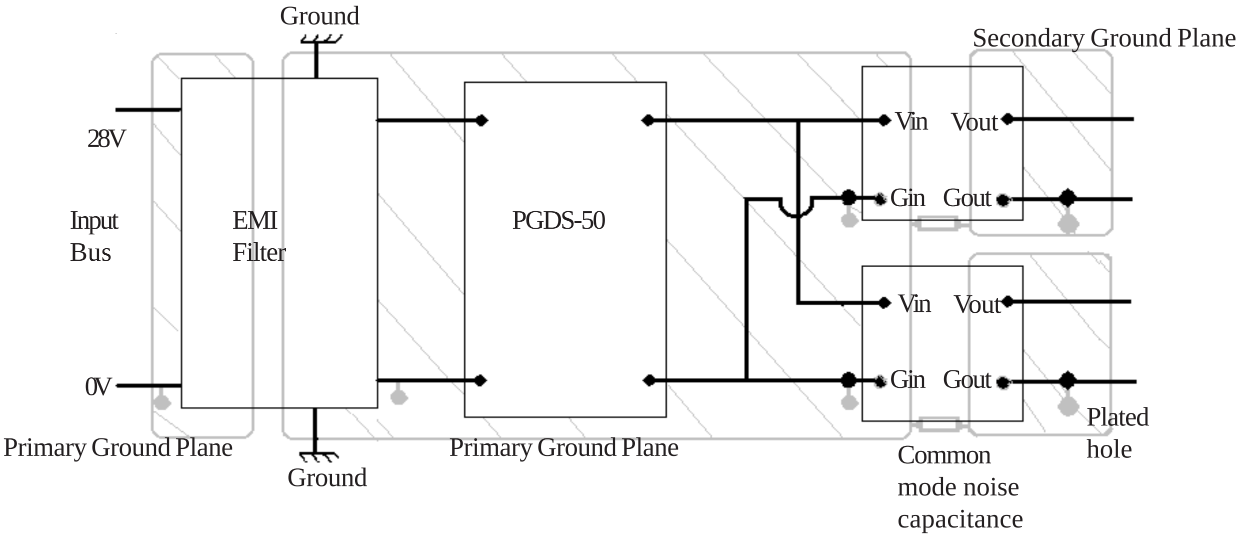
Both parts must be as large as possible and spread out over the entire surface of the board; a grid could be used to avoid a complete copper surface.
GAIA Converter recommend the use of a decoupling common mode noise capacitance (10nF) between primary and secondary ground planes. If more than one module is used, additionnal common mode noise capacitance are recommended.
The «case» pin of the modules (if available) can be connected either to primary or secondary ground plane and a 6 sides shielding can be achieved with the PCB ground plane.

4-2 Component and trace routing design

The component placement is also a key factor between a good result and a nightmare.

The first step in placing the component is to determine the power flow through the board. The most popular flow structure is from one side of the board to the other and avoiding cross-overs.
If more than one DC/DC modules is used it is recommended to place the modules side-by-side so that the power signals can be easily routed avoiding croos-overs. It is also recommended to leave 1/2 inch between each module to avoid that radiation from power stage of one module can affect the control stage of the adjacent module and cause cross-talk.

The second step is to place the EMI filter next and as close as possible to the modules minimizing trace lenghts to avoid «antenna» phenomenum and minimize loop areas and straight inductances that can limit the effectiveness of the filter. When placing theses components make sure to leave enough room for power carrying traces to run through. Please consult also EMI filter design note for additionnal routing information.



5- Output noise

Output noise measurements are difficult to make even under the best conditions. A GAIA Converter dedicated application note “Output ripple and noise” is available for complete information.

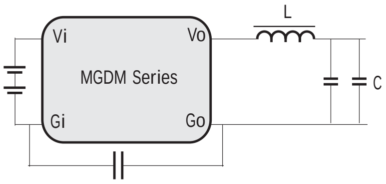
5-1 Output Noise with GAIA Converter Module Stand Alone

Gaia Converter DC/DC modules the have following maximum output noises.

Type of output	Output noise
3,3 and 5V output	40mVpp up to 20MHz Bandwidth
12V output	50mVpp up to 20MHz Bandwidth
15V output	60mVpp up to 20MHz Bandwidth

5-2 Output Noise with Additionnal External Filter

If the performance is not enough, GAIA Converter has qualified for each DC/DC converter a simple output LC and common mode filter as follow :



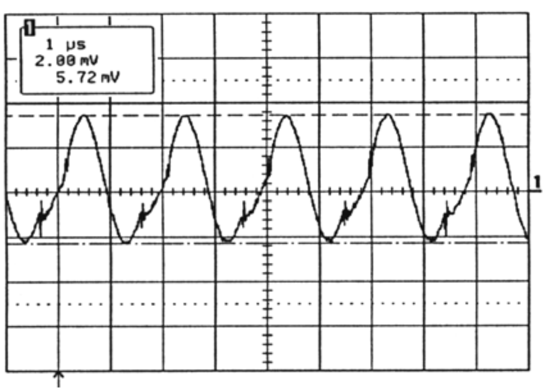
*Common mode noise capacitance C_C = 10nF

Output current	Less than 1A	1A to 2A	2A to 9A
Inductance L	4,7µH, DO1608C Coilcraft	1µH, DO1608 Coilcraft	1µH, DO3316 Coilcraft

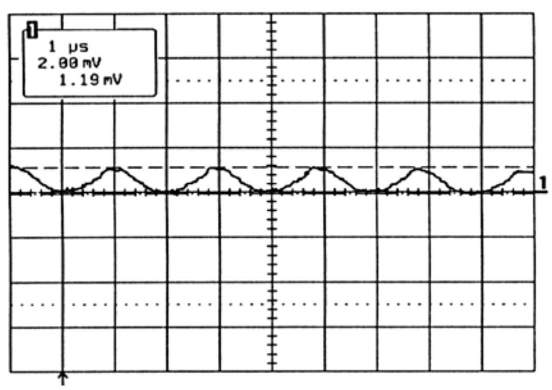
Output voltage	0 to 5V	12V	15V	24V
Capacitance C	47µF/10V tantalum 293D Series	22µF/20V tantalum 293D Series	10µF/35V tantalum 293D Series	10µF/35V tantalum 293D Series
Number of cpacitance	1 capacitor for each step of 2A	1 capacitor for each step of 1A	1 capacitor for each step of 0.7A	1 capacitor for each step of 0.7A

Such filter will reduce noises down to :

Type of output	Output noise with external filter
3,3 and 5V output	< 10mVpp up to 20 MHz Bandwidth
12V output	< 10mVpp up to 20 MHz Bandwidth
15V output	< 10mVpp up to 20 MHz Bandwidth



MGDB-04J-C with external filter



MGDB-10-J-C with external filter

6- Compliance with Environmental Condition Requirements

Avionics and military electronic systems shall sustain a high level of environmental conditions depending on their use/location.
The levels are defined in different standards, among which the most frequently used are :

• The RTCA/DO-160C standard : "Environmental Conditions and test Procedures for Airborne Equipment".

• The US MIL-STD-810 standard : "Environmental Test Method".

• The US MIL-STD-202 standard : "Environmental Test Method".

• The US MIL-STD-883 standard : "Screening Procedures".

• The French GAM-EG 13B standard : "Essais de comptabilité à l'environnement climatique, mécanique"

• The UK BS3G100 standard : "Environmental Conditions Test Method".

To verify the suitability of GAIA Converter modules, a complete qualification test program has been undertaking by an independent laboratory part of the French Defense Agency CELAR which includes :

Test parameter	Standards	GAIA Converter DC/DC module qualification
Life at high temperature	per MIL-STD-202G Method 108A	Operation : 1.000 hrs @ +105°C case Storage : 1.000 hrs @ +125°C ambient
Low temperature	per MIL-STD-810E Method 502.3	Storage : 1.000 hrs @ -55°C ambient
Temperature cycling	per MIL-STD-202A Method 102A	Number of cycles : 200 Temperature change : -40°C / +85°C Transfert time : 40 min. Steady state time : 20 min
Temperature shock	per MIL-STD-202G Method 107G	Number of shocks : 50 Temperature change : -55°C / +105°C Transfert time : < 10 sec Steady state time : 30 min
Low Pressure (Altitude)	per MIL-STD-810E Method 500.3	40.000ft, unit functioning 1.000ft/min to 70.000ft,unit functioning
Humidity (Cyclic)	per MIL-STD-810E Method 507.3	Damp heat : 60% to 88% relative humidity Cycle I : (31°C to 41°C) : 240Hrs
Humidity (Steady state)	per MIL-STD-202G Method 103B	Damp heat : 93¨% relative humidity Temperature : 40°C Duration : 56 days
Salt spray	per MIL-STD-810E Method 509.3	Temperature : 35°C Duration : 48 hrs
Vibration Frequency range Acceleration	per MIL-STD-810D Method 514.3	10 cycles in each axis frequency : 10 to 60Hz/60 to 2 KHz acceleration : 0.7mm/10g
Shock (Half sinus) Peak acceleration Duration	per MIL-STD-810D Method 516.3	3 shocks in each axis Peak acceleration : 100g duration : 6ms
Bumps	per MIL-STD-810D Method 516.3	2000 bumps in each direction duration : 6ms peak acceleration : 40g

7- Thermal Management

GAIA Converter modules are given for a maximum case temperature of 105°C. This case temperature corresponds to an internal component temperature far below (design derating) their maximum junction temperature.

Usually for designer, environment is explained with ambiant temperature. To rapidly check if this ambient condition is compliant with the maximum case temperature, the first step is to find the power dissipated in the converter, this value is calculated as follow :

$$P_{dissipation} = P_{out} / _{efficiency} - P_{out}$$

(Efficiency is given for each module in the technical datasheet)

GAIA Converter provides for each Hi-Rel converter the thermal resistance Rth case ambient by watt dissipated so the maximum ambient temperature is given with the formula :

$$T_{ambient} = 105°C - P_{diss} * R_{th}$$

Where Tambient is given in °C

An example is given with a MGDM-10 module, 10W converter, 86% efficiency used with 10W power and having 12°C/W of Rth in worst condition (still air) will be able to be used at :

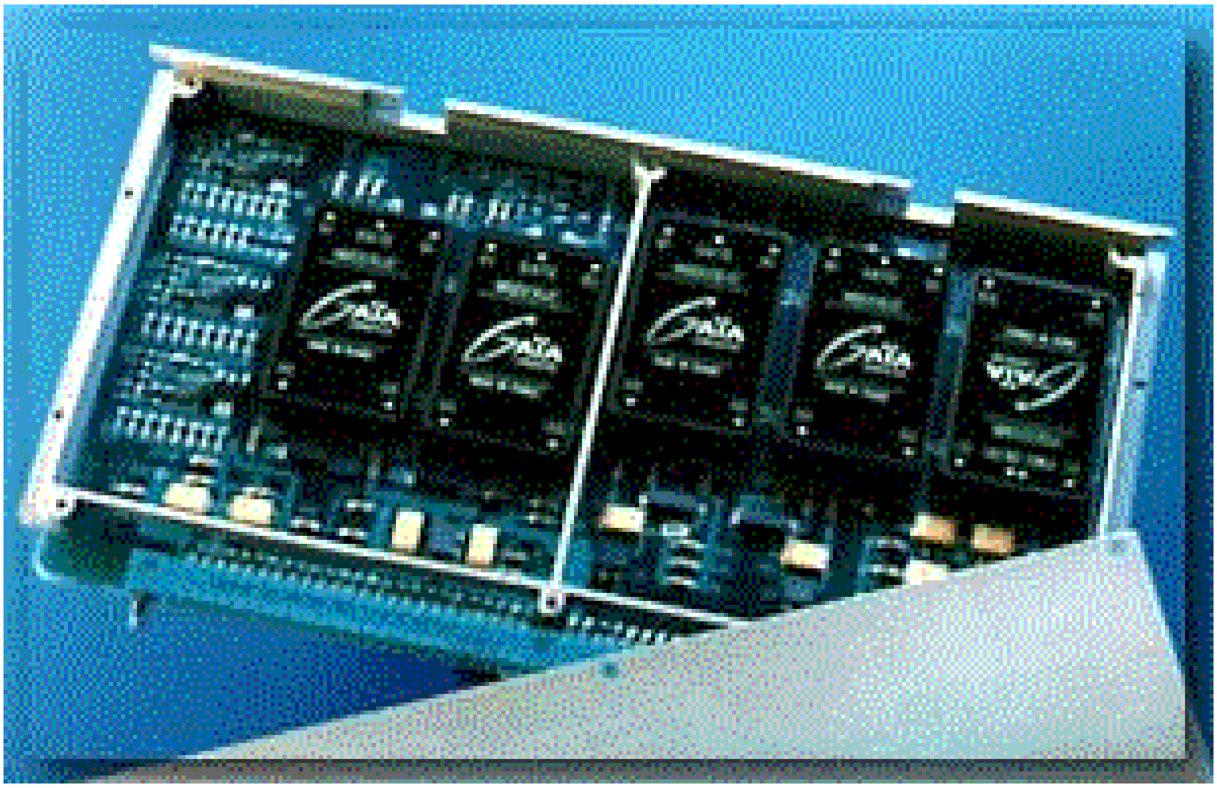
$$T_{ambient} = 105 - (10 / 86\% - 10) \times 12 = 85°C$$

If calculated ambient temperature is not compliant with the requirement an additional thermal path should be found to lower the thermal resistance with :

- Heat sink
- Forced air cooling
- Larger area of circuit board metallization.

A method of removing heat recommended by GAIA Converter is conductive heat sink through direct contact with the module case.

An example is given in the following application where heat sink is provided by the top case in conductive metal.



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