GAIA-CONVERTER

Modular Architectures in Military Power Supplies:

*The Roadmap for Customer Product Qualification*

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The power density race:

Miniaturization of power electronics has not stopped advancing over the past few decades. The progressive replacement of linear power supplies with switched-mode power supplies (SMPS) starting in the 1980s is the most efficient way to reduce the size of a power electronics system. One of the reasons for the SMPS's success lies with the fact that a switched-mode converter can convert an input voltage to an output voltage and drive a load with an 80% to 97% energy efficiency. This contrasts with a linear voltage regulator which usually rate from 50% to 70% efficient.

The fast-pace of SMPS miniaturization is due to several factors, the most important being switching transistor efficiency improvements. This results in less energy losses and permits higher power densities. With more efficient transistors the switching frequencies can also be increased. Higher switching frequencies allow the SMPS designer to reduce the coil size and associated coil losses. Reducing the overall losses reduces the dissipated heat allowing for a reduced heatsink size and area.

The emergence of specialized integrated Pulse Width Modulation (PWM) regulation ICs has simplified DC/DC converter circuitry while also improving the regulation accuracy. Regulation accuracy was perhaps the main shortcoming (along with generated noise) used by SMPS detractors. The new digital PWM ICs also further improve efficiency by adapting the switching regulator loop tuning over time.

Power Density Depends on Converter Functionality:

When you want to compare the power density of various SMPS you need to be sure they have the same level of functionality. Since high efficiency and power density go hand in hand, an isolated DC/DC converter will have a lower power density as compared to a non-isolated DC/DC converter because the isolation transformer is an additional source of losses. In the same manner, a DC/DC converter with a wide input voltage ratio capability will be less efficient (and have lower power density) than a DC/DC converter with a narrow input voltage range capability. It’s easier to maximize the power efficiency on converters with a narrow input voltage range. Many other functions such as the number of voltage outputs, switching frequency synchronization, internal filtering, and embedded protection circuits are all elements that create additional losses or a reduction in power density.

COTS DC/DC converters:

An engineer tasked with developing a military power supply will have his or her job greatly simplified by using small and
powerful fully integrated DC/DC power converters that were not available in the past. Leveraging the power of these commercial off-the-shelf (COTS) power converter components is the fastest way to develop a custom power supply design. The usage of COTS components in military applications has seen a phenomenal growth since the 1994 memo issued by former U.S. Secretary of Defense William Perry recommending that the U.S. DoD (Department of Defense) use COTS products wherever and whenever possible. Since the early 1990s, Gaia Converter has been part of an uninterrupted technological race to develop and manufacture high quality and high reliability COTS isolated DC/DC converters with continuously increasing performance and power densities.

Gaia Converter’s comprehensive range of board-mounted isolated DC/DC converters targets the defense and avionics markets. These markets demand parts with high performance, high reliability, small size and low weight. Leveraging Gaia’s full range of COTS power converters is the fastest and easiest way to develop a power supply with single or multiple outputs for four main reasons:

1. The converters are already qualified for various military standards.
2. Optimized power densities through many years of ongoing engineering research and development at Gaia Converter.
3. You can mix and match different Gaia parts with different functionalities giving the designer a great amount of flexibility that is almost the same as designing a custom power supply.
4. Developing a custom power supply design with discrete components would typically take far longer and cost much more than simply leveraging Gaia Converter’s COTS parts and making a plug-and-play customer-specific power supply.

<table>
<thead>
<tr>
<th>COTS in Modular Architecture:</th>
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<tbody>
<tr>
<td>In consumer electronics there are fewer design constraints. This allows the designer to use simpler and smaller DC/DC converters. Most battery-powered consumer or industrial equipment requires neither isolation nor transient protection; therefore a non-isolated converter is often the best design choice. The non-isolated DC/DC converter is more power efficient than its isolated counterpart, and therefore requires a smaller heatsink. In addition, battery buses or some industrial buses supply the DC/DC converter with an input voltage with a very narrow range of variations (e.g.: 23.4V to 25.3V for a 24VDC standard lead-acid battery). When the input voltage range is very narrow, the DC/DC efficiency can be optimized, thus reducing the heatsink size.</td>
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<td>COTS in modular Architecture for Harsh environments:</td>
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<td>When engineers are designing a power supply unit (PSU) for harsh electrical environments like in avionics and military systems, the bulk power source is provided by AC generators or by various standard battery voltages. Note that in these harsh environments the battery voltages can also be affected by voltage spikes, noise transients, and voltage drop-outs. In harsh environments like these, the DC/DC converter requires front-end components to condition the power input. These components can include spike limiters, pre-voltage regulators, EMI filters, inrush current limiters, and voltage hold-up modules. Therefore, a PSU design for harsh environments requires these front-end support components to comply with the various regulatory standards associated with harsh environments. Gaia Converter offers a full suite of these front-end components, so the designer can develop a full turn-key power supply design for avionics, military or other harsh environment applications. Note that for power supplies designed for harsh environments meeting the various regulatory compliances often takes priority over size and power density.</td>
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</table>

### Table: COTS DC/DC Performance

<table>
<thead>
<tr>
<th>Isolated COTS DC/DC Serie</th>
<th>Power Capability (Watt)</th>
<th>Power Density (Watt per In³)</th>
<th>Input Voltage Ratio (Vmin/Vmax)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MGD204</td>
<td>4</td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>MGD208</td>
<td>8</td>
<td>29</td>
<td>7</td>
</tr>
<tr>
<td>MGD210</td>
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<td>21</td>
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<td>72</td>
<td>5</td>
</tr>
<tr>
<td>MPG5145B</td>
<td>240W</td>
<td>900</td>
<td>7</td>
</tr>
</tbody>
</table>

**Figure 3:** Gaia-Converter Board mounted COTS by power density and input voltage ratio

**Figure 4:** Gaia-Converter typical architecture
Complying With Standards:

The electric power buses used in military and avionics equipment are characterized according by different standards. The MIL-STD-704 standard specifies the electrical power bus used on military aircraft. The MIL-STD-1275 specifies the electrical power bus used in military vehicles. For civilian aircraft the DO-160 standard specifies the electrical power bus. All military devices need to comply with EMC (Electro Magnetic Compliance) requirements that are defined in MIL-STD-461. The table and EMC graphs below show that power supplies in avionic systems or military vehicles need to be robust enough to sustain high level of constraints in voltage conditions. In addition to the requirement for wide input voltage ranges, the DC/DC converter also needs to resist over-voltage transients and fast high-voltage spikes. A typical stand-alone DC/DC converter cannot sustain these over-voltage conditions and transient voltage spikes.

Typical Application:

We can look at the power requirements for a hypothetical on-board navigation system for a military aircraft. It consists of a power supply unit, a processor module, an analog module, and an LCD display. The PSU board must provide a 12V 1.5A rail for the LCD display, a symmetric set of +/-12V rails at 0.4A per rail for the analog module, and a 5V25A rail for the processor module. The PSU must comply with Mil-STD-704F cat A. and Mil-STD-461G (environmental). The external power input to the navigation system is a 28VDC power bus supplied by the aircraft. The processor module has a requirement to continue operating during a 200 millisecond power bus interruption while the display and analog modules don’t have this requirement. In cases where the analog module fails, the LCD display must continue operating. The PSU will be assembled into a closed chassis with no fan. The chassis temperature limits can range between -55°C to 95°C. The fearless design engineer can choose to develop his or her own PSU from the ground up. They will first consider what system topologies to select, like fly-back, forward, or possibly a cascading design with a boost converter feeding several buck converters. Another option is to choose a “SEPIC” topology, where the output voltage can be greater than, less than, or equal to the input voltage. The engineer
will need to develop several voltage feedback loops to output the required voltages and keep them stable under varying load and temperature conditions. Once this step is completed, the design engineer will need to verify that their design passes internal testing and meets the required regulatory compliances.

The testing phase will likely highlight a certain number of design weaknesses that will require a redesign. Sometimes this process can lead to a never-ending looping between design corrections and improvements and qualification testing. By the time the final design is arrived at that passes all of the testing and regulatory compliances, a considerable amount of time and expense will have been invested into the PSU portion of the navigation system. This can lead to project delays and cost overruns for the entire system.

Gaia-Converter has invested more than 25 years in developing various sets of modules for PSU development using our modular architecture. Design engineers can use our COTS parts to speed-up the design and reduce the cost of PSU development in the true spirit of the William Perry directive.

**Modular Design for the Navigation System with COTS:**

In our navigation system, the LCD display needs to remain operational if the analog module fails. We also stated that the processor module must remain operational during an external power brown out. To meet these requirements, it is necessary to supply each module with power independently. For each component in the system to be immune to failures of other components, isolated DC/DC power sources need to be used.

For the processor module power supply, Gaia Converter has an MGDS Series part capable of outputting 150 watts of power (P/N: MGDS-155-O-C). This DC/DC converter can supply up to 30 amps of current at five volts, meeting the 25-amp requirement for the processor module. The input voltage capability of the converter is 16V to 80V which meets the 16V to 29V requirement for the Mil STD 704F specification.

To ensure the processor module will work during a 200-millisecond power bus interruption one option is to store energy in a large capacitor connected across the voltage input of the DC/DC converter. A quick calculation shows that you need a 111,000µF capacitor to do this. If you use a 50V 120,000 µf electrolytic capacitor, this is a large part that is almost 24 cubic inches in volume. In view of our desire for a high-density design, there are other more space-efficient ways to do this. Note in addition to the large electrolytic capacitor you also need two power diodes and one power resistor.

With the Gaia Converter hold-up module (P/N: HUGD-300) you can implement a brown-out protection circuit that offers considerable space savings. You can comply with the 200-millisecond power interruption requirement using an 80V 10,000µF capacitor. Note this capacitor is only 3.5 cubic inches in volume, which is much smaller than the 24 cubic inches required for the basic design.

For the LCD display power supply, Gaia Converter has an MGDD Series part capable of outputting 20 watts of power (P/N: MGDD-21-N-E). This DC/DC converter can supply up to 1.65 amps of current at 12 volts, meeting the 1.5-amp requirement for the LCD display. The input voltage capability
of the converter is 9V to 60V. The high input voltage range for this converter means that it can easily sustain a 50V 50-millisecond transient. The part can operate continuously when the input voltage is at the upper limit of 60VDC, and it can temporarily withstand input voltages up to 80VDC.

Note the same 20-watt MGDD Series converter can be used for powering the analog module because it is possible to configure the outputs as +12V and -12V with a common ground.

**EMI Considerations**

The MIL-STD-461G specification states that any AC ripple current superposed on the DC input current of a device should not be higher than certain limits defined over a certain frequency range. This AC “disturbance” current creates conducted emissions, in contrast to the radiated emissions which are the electromagnetic fields radiated by an electronic device.

Designing an input filter to reduce the conducted emissions with discrete components may appear to be relatively easy considering the large number of electrical filter schematics available in the existing technical literature. Most designers will think that a common mode inductor followed by an LC input filter to reduce conducted emissions is not a trivial matter. A faster and easier way to implement a successful filter design can be achieved by using a Gaia Converter FGDS Series modular filter. These properly-tuned filters are available in different current ratings and are qualified according to MIL-STD-461:

To meet radiated EMI emissions compliance, all of the DC/DC converters produced by Gaia-converter are encapsulated in a metallic casing. The conductive casing material provides the required shielding for the switching circuit in the converter that is the main source of EMI radiation. In addition, the PCB designer for the PSU must use good design practices to keep EMI emissions to a minimum.

With the proper PCB layout considerations and using Gaia Converter’s COTS DC/DC converters and filters, the design engineer can easily create a PSU meeting the required power, reliability, density, and EMI requirements.

**Final Design:**

The final schematic diagram is presented in figure 10. Thanks to the modular architecture used, only few discrete components are required. This simplifies not only the schematic but also the PCB layout. The Gaia Converter modules support a maximum case temperature of 105 °C.

Gaia Converter supplies efficiency curves for its converters as well as comprehensive thermal data and reliability data like MTBF as example. This information provides the design engineer with the required information to predict the PSU behavior over the full operating temperature range for our example of on-board navigation system.

The flexibility of the modular architecture allows the designer to easily reuse the existing power supply design for different projects. For example, you can replace the MGDD-21-N-E converter with another model in the MGDD series to deliver for example 5V instead of 12V while keeping the same footprint on the PCB. In the same way, the MGDS Series 150-watt part used for the logic module can be exchanged with a MGDS Series 75-watt part. So with the same PSU PCB the designer has some easy options for changing the output voltage levels and the power levels.

Another strategy for developers utilizing Gaia Converter’s “building blocks” approach would consist of building the front end on a separate board so that it can be reused as a universal “avionics frontend” for various “back end” designs supporting different power levels and voltages, etc.

**Useful Functions:**

Among the other advantages of using a modular architecture, is that the Gaia Converter modules themselves have numerous embedded functions that can greatly simplify the power supply designer’s tasks.

**System Protections:**

All Gaia-converter DC/DC converters have a built-in overcurrent protection function. This allows the PSU designer to secure the general operation of a given system and give it some immunity from load fault conditions. This protection function reduces the impact of a short-circuit or overcurrent load failure to an individual module and the affected Gaia module will not cause an excessive drain on the input power once it detects the excessive load or short-circuit condition. This means that other power converters in the system will not be affected and will continue to function properly.

**Synchronization:**

For certain applications that are sensitive to high frequency noise, even when this noise is at a very low level, it can be advantageous to slightly shift the synchronized switching frequency of each DC/DC converter to keep the switching frequency outside the noise-sensitive bandwidth of the application. This functionality is available in most of Gaia Converter’s products.

**Soft-start:**

To avoid high inrush currents when the input bus is powered on, all of our converters embed a “soft start” function. The internal pulse-with modulation (PWM) control circuit
progressively adjusts the pulse width during the startup sequence until the steady state operation level is reached. This function is particularly useful because it will limit the input current rise independent of the rise time of the supply voltage.

Sharable Remote On-off:
A PSU architecture using multiple DC/DC converters usually requires that all output voltages rise at the same time. In support of this Gaia Converter’s products incorporate an active-low output-disable remote control function pin. Using this method, it is very simple to synchronize the output voltage rise from multiple converters by connecting all output-disable control pins together. The remote-control pins can then be driven by any open-drain output device and can be activated in any desired sequence for an orderly startup of the system. This functionality can also be used to selectively shut down unused components in the system when not needed to reduce system power consumption.

Input Disturbance Immunity:
The DC/DC internal regulation circuit uses a current-mode regulation scheme that confers to the converter an outstanding accuracy with respect to the output voltage stability. In this regulation scheme, the switching regulator references not only the output voltage but also the output current. Any input voltage disturbance will not have any impact on the output voltage value, giving the DC/DC converter a very high immunity to input bus disturbances.

Enhanced Stability:
Switch-mode power supplies are organized around switching electronics and can sometimes encounter stability issues that are mainly linked to input impedance mismatching. To address this issue in the rare cases that it does occur, Gaia Converter has equipped its DC/DC converters with a pin called “VIF” that allows the designer to stabilize the circuit by connecting a small capacitor between the VIF pin and ground.

Qualification:
Passing the final qualification test is generally the ultimate step in the design, testing and verification process before going into mass production.

The final qualification test applies to the complete system. The systems considered to be an assembly of components and subsystems such that each individual component or subsystem must not fail in order for the complete system to successfully pass the final qualification testing.

Gaia Converter guarantees its parts will function properly in any final system qualification test. The Gaia-Converter DC/DC converters and front-end modules can be considered to be “qualification ready” parts. Our products have been designed and manufactured under the strictest quality processes and procedures. This allows for their use in military applications and gives the designer the confidence he or she needs to pass their final system qualification testing. Using Gaia Converter’s products allows the design team to bring a successful product to market faster knowing that the PSU component is being built with reliable parts that have been “pre-qualified” by Gaia Converter’s team of design and production engineers.

Conclusion:
Using the example of an on-board navigation system for military aircraft highlights the benefits of using Gaia Converter’s COTS modular architecture for quickly designing a reliable “pre-qualified” PSU component for the navigation system. Leveraging the skills that come from 25 years’ worth of design experience in the power converter industry, Gaia Converter and its COTS modular architecture demonstrates an easier, faster and more cost-effective solution for bringing a design to market. With a 9V to 80V input range and a -55°C to 105°C temperature range and innovative technology like the voltage hold-up module giving the designer high-density backup power, GAIA-Converter delivers a unique high-quality, high-reliability and pre-qualified solution to meet your aerospace, defense, naval or industrial power supply needs.