Applying COTS Power Supply Technology to Tactical Military Applications

COTS high-density DC/DC converter modules can be cost-effectively used in military applications, but designers must fully understand the system requirements, be prepared to modify COTS hardware, and beware that military standards still govern power conversion requirements.

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Power supplies abound in military applications. Prior to the last decade, military and commercial high-reliability power requirements were met in most part by discrete component, custom-designed, power supplies. But early in the last decade, COTS commercial high-density DC/DC converter modules were being accepted as valid solutions to commercial power supply requirements—an entire industry segment was taking hold and the military took notice. These High-Density Modules (HDMs) introduced a dramatic change to the traditional power supply design, essentially modularizing the power supply through self-contained power supply "bricks" that convert unregulated DC voltage to a regulated output voltage as shown in Figure 1.

Unfortunately, the generally accepted early belief was that HDMs would not meet the stringent requirements of tactical military applications, and that only custom designs could satisfy these needs. However, as HDM technology improved it was soon realized that within a certain framework COTS HDMs offered significant advantages over custom solutions, but only if they were adapted to meet the application's unique needs.

Considering COTS HDMs

There are lots of positives associated with using COTS HDMs in military applications. Namely: they use commercial parts and are mass-produced so they are inexpensive, they can be screened to military environments as an assembly, and they are versatile and can be configured in distributed or centralized power formats. Finally, design and development time may be shorter over a traditional custom approach because of the huge head start these off-the-shelf bricks offer.

However, just "dropping in" a COTS HDM rarely works in a tactical application. The lessons learned have shown that to be successful, like other system components, adapting commercial hardware to tactical military requirements is not trivial and requires extensive knowledge of military power systems.

The COTS philosophy directed military procurement to focus less on military specifications and more on application performance by stripping away all of the extraneous requirements that drive cost. The HDM, for the most part, does relieve the power system designer of the cost burden of using hermetically sealed semiconductors and microcircuits. However, several military standards have survived and continue to either prohibit the use of COTS HDMs or seek to make the design and development task

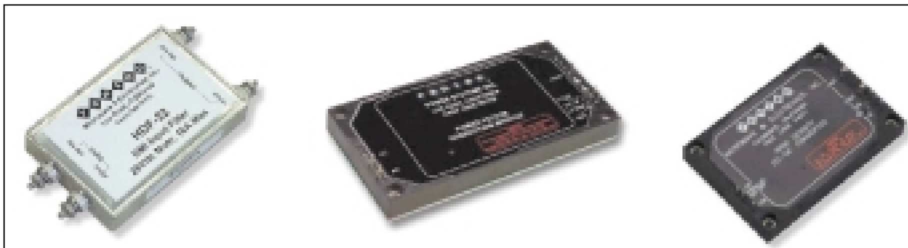

Figure 1

Examples of COTS power modules. Left to right: a MIL-STD-461 compliant filter which meets the conducted emissions requirement and prevents the noise from a PSU from affecting the line; a power factor correction module which produces a very low harmonic content (within MIL-STD-1399 guidelines of 3% for the first harmonic and 5% THD) and converts the unregulated AC to DC voltage; and a typical DC/DC HDM producing 250 W with a 270 VDC input and a 5 VDC output.

		28 VDC Steady State			270 VDC Steady State			60 Hz AC	400 Hz AC Steady State		
		Normal	Abnormal	Emergency	Normal	Abnormal	Emergency		Normal	Abnormal	Emergency
Aircraft Power Systems											
MIL-STD-704A	Cat A	25-28.5	23.5-30	17-24					110-118	104-124	106-122
(Note 1)	Cat B	24-28.5	22.5-30	16-24					108-118	102-124	104-122
	Cat C	23-28.5	21.5-30	15-24					104-118	98-124	100-122
MIL-STD-704B		22-29	20-31.5	18-29	250-280		240-290		108-118	100-125	102-124
MIL-STD-704C		22-29	20-31.5	16-30	250-280		240-290		108-118	100-125	104-122
MIL-STD-704D		22-29	20-31.5	16-29	250-280	245-285	240-290		108-118	100-125	104-122
MIL-STD-704E		22-29	20-31.5	18-29	250-280	240-290	250-280		108-118	100-125	108-122
Shipboard Power Systems											
MIL-STD-1399	Type I							440 or 115 +/- 5%			
(Note 2)	Type II								440 or 115 +/- 5%		
	Type III								440 or 115 +/- 2%		
28V Systems in Mil Vehicles		Normal	Gen. Only	Bat. Only							
MIL-STD-1275A(AT)		25-30	23-33	20-27							
Shipboard Power Systems		Normal	Abnormal	Emergency							
C-26-003-001/MS-001 (Canada) (Note 3)		22-29	18-32	18-29				440 or 115 +/- 5%			

Table 1

Although discouraged by the COTS initiative, military specifications still have utility in defining power supply performance as shown here. Many COTS HDMs need to be modified to meet many of these requirements, although many vendors specifically target military and aerospace applications with near-catalog products.

Note 1: For MIL-STD-704 A through E
- 'Normal' is normal operation.
- "Abnormal' is the condition when a malfunction or failure has occured and protection devices are operating to correct the malfunction.
- 'Emergency' is when the main generating equipment has failed and a limited, independent power system is powering vital systems.

more challenging for the power system engineer. These barriers are grouped into three categories:
- Input voltage conditions
- Environmental conditions
- Military-unique aspects

Therefore, how do we take advantage of the proven HDM topologies and state-of-the-art COTS HDMs, while meeting the tactical environments of military applications? The answer is to be aware of the application requirements and be prepared to modify HDMs where necessary. And even though COTS initiatives, for the most part got rid of military standards, some key standards are still required in order to characterize the application conditions.

Input Voltage Conditions

The input voltage conditions for tactical military applications cover two distinct areas: electromagnetic conformance (EMC) and input voltage. Power supply designers tend to lump EMC as an input rather than an environmental condition primarily due to the effects on an input line. EMC requirements are specified in MIL-STD-461 and are still in use today. Input voltages are unique to each service branch and are defined by: MIL-STD-704 (aircraft), MIL-STD-1275 (vehicles) and MIL-STD-1399 (shipboard).

Although most military power supply specifications have been modified so that they may now be considered performance specifications, the electromagnetic compatibility requirements remain, and are defined within MIL-STD-461. Without modification, the majority of COTS HDM modules will not meet MIL-STD-461. The conducted emissions requirement—the most commonly enforced requirement of MIL-STD-461 at the module level—typically requires 40 dB or more of attenuation from the HDM switching frequency all the way out to several megahertz.

Filters that are designed and qualified to FCC requirements typically are

Transient Limits

AC Transients				28 VDC				270 VDC				AC Power	DC Power
Voltage	Time	Voltage	Time	Voltage	Time	Voltage	Time	Voltage	Time	Voltage	Time	Interruption (max) Sec.	Interruption (max) Sec.
High		Low		High Transients		Low Transients		High Transients		Low Transients			
180	0.1	64	0.05	80	0.05	10	0.05					.05 -7.0	.05 -7.0
180	0.1	58	0.05	80	0.05	8	0.05					.05 -7.0	.05 -7.0
180	0.1	48	0.05	80	0.05	7	0.05					.05 -7.0	.05 -7.0
180	0.01	80	0.01	50	0.01	18	0.015	475	0.01	125	0.05	7.0	5.0- 7.0
180	0.01	80	0.01	50	0.01	18	0.015	475	0.01	125	0.05	7.0	5.0- 7.0
180	0.01	80	0.01	50	0.01	18	0.015	475	0.01	125	0.05	7.0	7.0
180	0.01	80	0.01	50	0.01	18	0.015	330	0.02	200	0.01	7.0	7.0
528/138	2	352/92	2									0.1	
528/138	2	352/92	2									0.1	
464/121	0.2	416/109	0.2									0.1	
				100	0.05	15	0.5						
120	0.03	80	0.07										

Note 2: For MIL-STD-1399
The harmonic distortion must be limited to not cause harmonic currents more than 3% of the rated load for the second through 32nd harmonic through 20kHz shall not exceed 100/n% of the full rated load (where n is the harmonic multiplier).

Note 3: For C-26-003-001/MS-001 (Canada)
- 'Normal' is normal operation.
- "Abnormal' is the condition when the battery is at top of charge.
- 'Emergency' is when the battery charger has ceased to function.

not considered adequate to manage the conducted and susceptibility requirements of the military tactical constraints. Custom filters from knowledgeable, military power supply or filter designers are required to meet MIL-STD-461. Unlike the commercial equivalent, external damping networks consisting of a single resistor and capacitor need to be placed at the EMI filter output to attenuate the conducted susceptibility ringing to a maximum of 6 dB. Each application needs to be approached individually for proper impedance matching and specification compliance.

Also, the primary input power for most military applications comes from alternating current sources. Therefore, some form of input power conditioning is required for the HDM to operate on DC alone. COTS HDMs, for the most part, come in three input voltages ranges: 28 VDC, 48 VDC (telecom) and 270 VDC. For this discussion we are interested in the 28 V and 270 V since these are the standard voltages that are either available or are derived on a military platform (Figure 2).

If direct current is not available there are two approaches to input power conditioning. First, the HDM module input voltage may be simplistically developed by direct-line rectifying the 208 volt, three-phase, 400 Hz prime power source of MIL-STD-704. Alternatively, 115 volt, single-phase voltage can be rectified in a doubler configuration, thus developing a nominal 270 VDC input for the HDM module. 28 V sources, such as those used in older avionics applications and military vehicles, are available via a transformer rectifier module. However, in all cases these voltages have an exceptionally wide range and require particular attention in order to meet the applicable input voltage standard over all conditions (Table 1).

One solution that takes advantage of single-phase inputs is a power factor correction module. Power factor correction (PFC) modules effectively rectify and boost the AC input voltage to a regulated DC voltage, taking care of the burden of a wide-ranging, unregulated, single-phase AC source. PFC modules also produce very low harmonic distortion. For shipboard applications above 1 kW, MlL-STD-1399's 3% single and 5% total harmonic distortion (THD) requirement can be particularly difficult to meet and may require large passive components plus the PFC module in order to be compliant.

Using a power factor correction module also provides a secondary feature. The standard-boost PFC produces a regulated 360-380 VDC output, although the typical 270 V input HDM will operate down to a minimum of 220 VDC. For applications where "hold-up" is required—a system-level requirement to maintain output for about 50 ms when the input supply dis-appears—the energy requirement imposed upon the hold-up capacitors is significantly reduced. This is because while the intermediate bus voltage output from the PFC may decay from 380 down to 220 VDC during line drop out, this is still enough voltage to feed the HDM and maintain an output at the final stage. This approach has been implemented often when MIL-STD-704 or shipboard hold-up requirements are imposed.

Meeting the full range of the input voltages of the MIL-STDs listed in Table 1 under all conditions requires the acceptance that the majority of commercial modules will not work "as is". Whether it is 28 V or 270 V input, the low-line capability of most commercial modules will shut off prior to reaching the low-line level of the military specifications. That is, the minimum accepted voltage is lower for military applications than it is for commercial applications. Experienced military power supply designers and manufactures have methods for meeting these requirements since they have spent their careers doing so. The result: the standard HDM is modified to perform by changing the turns ratio of the main switching transformer. This in effect changes the ideal performance of the HDM by trading maximum output current for a wider input voltage range.

High-line conditions, as shown in Table 1, present another set of problems for the commercial module. For both the 28 V and 270 V input options, the commercial module has a maximum rated line capability that is typically far less than the applicable MIL-STD. Unlike low-line, high-line conditions can damage the HDM if it is not protected. Military power supply designers and manufacturers have developed clipping and pre-regulating schemes that will limit the maximum voltage the HDM will see to prevent damage and allow it to reliably operate over the full input voltage range.

Environmental Conditions

Unlike commercial high-density modules, the tactical HDM module has a much more intense operational microenvironment. The tactical HDM needs to be qualified to Tri-Service requirements encompassing land mobile, airborne, surface and sub-surface naval conditions, which include shock and vibration, humidity, temperature and overall reliability metrics.

Environment-specific criteria are developed based on the platform and location of the HDM. Generally, the procedures of MIL-STD-810 are imposed. Shock requirements are particularly tough as defined within the constraint of MIL-S-901 or MIL-STD-810, and are severe compared to that which a module might experience in a typical commercial application. Naval applications in particular, will be exposed to high levels of humidity that often approach 100%, condensing. Finally, many applications still require HDMs to operate reliably over a wide temperature range of -40° to +85°C, and some -55°C requirements still exist.

Schemes have been developed for the "militarized" HDM that address these demanding requirements. The typical HDM is very low mass. Therefore, meeting shock and vibration may be as easy as encapsulating the module with RTV or epoxy. A lot of work has gone into enhancing the moisture tolerance of HDMs by military contractors. Since plastic encapsulated microcircuits (PEMs) and semiconductors are generally allowed, coating methods using parylene have proven to be effective.

Temperature, on the other hand, has not been as easily solved. The majority of the components available are not rated to -55°C. Most are considered high-reliability parts, but this is one area that the industry grapples with routinely. Component selection, testing and good design practices are key to meeting the temperature ranges outside rated levels. Since upscreening and derating are routinely practiced, to provide credibility relative to a specific HDM application the system integrator should insist on the manufacturer's qualification documentation supporting the HDM hardware for that application.

To further assure environmental capability and reliability, and to reduce infant mortality, it is recommended that both the HDM modules, as well as the entire power supply, undergo Environmental Stress Screening (ESS) prior to delivery to the systems integrator. A procedure delineating the ESS test procedure is detailed in the Navy's new power supply document "More Power for the Dollar", NAVSO P-3641A (see www.bmpcoe.org/pmws/download/knowhow.html).

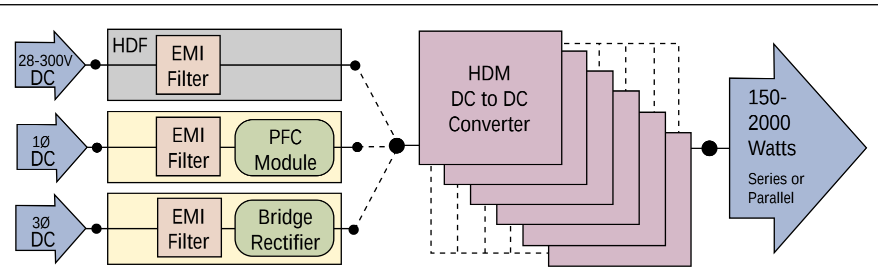

Figure 2

A variety of input voltages feed front-end modules, which in turn feed a variety of COTS DC/DC converters (called High-Density Modules, or HDMs).

Military-Unique Aspects

There are many other military-unique aspects revolving around the demands of each tactical military application. The majority of the military power supply designer's time during the development process is spent adding or masking the HDM's generic performance to meet the application. Table 2 lists typical examples of these modifications.

Overcurrent and overvoltage set points
Output filtering
Synchronization
Unique output voltages
Parts selection

Table 2

Typical military-unique aspects such as these deviate from pure COTS HDMs.

Overcurrent and Overvoltage Set Point

Overcurrent protection (OIP) and overvoltage protection (OVP) are features that are standard on HDMs. OIP is the function of limiting the amount of current a power supply will provide during a condition of high current demand. This function protects the power supply from damage during this condition. On the other hand, OVP is a limiting function that prevents the power supply from providing too high of an output voltage. Should the HDM lose regulation, OVP will shut-off or prevent the power supply form delivering voltage higher than a set level.

Typical trip ranges for OIP and OVP are 110-135% of the rated full load and 110-130% of the output voltage, respectively. However, many applications do not use the full rated load of the HDM and modified OIP is required for reduced levels. Often, standard OVP set points are set too high to provide the protection necessary to prevent downstream component damage should an overvoltage condition exist. If a lower limit is required, it should be specified to the HDM provider and the internal OIP and/or OVP limits adjusted accordingly. This protection is provided when modules are manufactured to a customer's specific requirements.

Output Filtering

One of the key advances that HDMs achieved was the relatively high switching frequency. This is the frequency at which the power supply operates in converting the DC source voltage. There are many proprietary and patented schemes developed for converting the unregulated input voltage to regulated voltage. For the most part, these schemes all involve a process of first switching the input voltage through a semiconductor switch, then through a primary isolation transformer, and finally rectifying and filtering the output of the secondary modules. Very simplistically, by modulating the duty cycle or operating frequency, output voltage regulation is achieved.

An HDM's outputs typically have ripple, noise and random deviation components from the switching, rectification and filtering process of 1-2% of the output voltage. Many military systems cannot tolerate this level of ripple and noise, therefore requiring external filtering to achieve under 0.5%. Also for stability, many HDM manufacturers suggest output capacitors. It is recommended that a low ESR tantalum capacitor of 10 mfd per load ampere be placed directly at the output of the HDM module. This capacitor should be paralleled with a 1 mfd ceramic capacitor as well as with a 0.1 mfd ceramic capacitor. This network of capacitance will attenuate the switching periodic and random deviation (PARD) and any dynamic load induced noise.

Synchronization

Synchronization is the function of operating more than one HDM at the same switching frequency. By having the converters operate at the same frequency, certain power system predictability and signature occurs. On the input line the current demand when the HDM power switch is in the "on" state occurs at the same time for all HDMs.

Although this produces a very large momentary input current draw during each "on" cycle, it is predictable and for many tactical military applications this is very important because systems must operate at a known EMI level in order to manage radiated emissions. The same effect occurs on the output voltage during output rectifier, filter conduction and main switching activity. The alternative of free running HDMs may produce on average a lower peak current draw on the input, but some systems cannot live with the unpredictability of the input and output conducted and emitted spectral content.

Figure 3

Rantec Patriot missile system power supply using three HDMs.

Unique Output Voltages

Standard output voltages such as 2.1, 3.3, 5, 12, 15, 24 and 28 volts are readily available; however, in addition to these, unique output voltages for military systems may also be required. For various reasons, voltages outside the available range are required for unique applications such as radars (voltages such as 8 and 9 VDC are required to compensate for some line loss characteristics). Most HDMs have a "trimming" function that allows the user to adjust the output voltage through an external resistor network.

However, these adjustments are intended for fine-tuning the output voltage and not for establishing a new output voltage for the converter. Their range is limited and some functions with set limits, such as OIP and OVP, do not change with trimming. Finally, an HDM's optimum performance is designed around the specified output voltage. Once the HDM is adjusted externally to another voltage, it is no longer operating in its optimized range. When a unique voltage is required the integrating activity should specify the output required, the overvoltage point, as well as the overcurrent limit. Some military HDM providers can accommodate non-standard output voltage.

Parts Selection

Parts selection covers a very wide area, but a key point of focus is overcoming restricted materials—in particular aluminum electrolytic capacitors. Tactical military requirements still exist that restrict the use of aluminum electrolytic capacitors. This is because of their propensity to leak and stop working after a period of many years, failing to achieve the life-cycle depot shelf-life for many types of military equipment.

Commercial applications do not have these restrictions; therefore, most COTS HDMs use aluminum electrolytic capacitors. Overcoming these restrictions when using COTS HDMs with aluminum electrolytic capacitors may require extensive design changes and additions of external capacitors to an HDM. The solution is to select HDMs designed with solid tantalum capacitors when this requirement is imposed.

Joint Military and Industry Efforts

Several efforts recently have been initiated to keep up with the changes in both the military and commercial power conversion world. The Navy, Army and IEEE have published or are working on guidelines pertaining to HDMs. The Navy's NAVMAT P-4855-1A, "Navy Power Supply Reliability, Design and Manufacturing Guidelines"—for a long time the guiding force behind power supply design practices for military applications—was superseded in October 1999 by NAVSO P-3641A, "More Power for the Dollar, Price vs. Value, A Technical Guide". The new publication is a reference tool for selecting the best power supply value, which is often not a pure commercial power supply, but something in between full military and commercial.

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The Army has published a report "Power Supplies High-Density Modules (HDM), Applying COTS Technology to Multiple Weapon Systems" (see: www.dsp.dla.mil/documents/HDM power.htm). This report addresses HDM use for specific Army weapons systems such as the Patriot missile system, Theater High Altitude Area Defense (THAAD), and National Missile Defense (NMD).

Lastly, the IEEE has established an industry consortium of primarily military power supply companies and military prime contractors to establish practices for HDM use. The document, IEEE -P1573 is in the draft stages and will go a long way in educating the user community on HDM use.

For its part, Rantec Power Systems has been solving tactical military requirements using HDMs for over ten years. Almost without exception, some form of modification was required to the HDM to meet the application. The company's 30 years of military power supply experience have allowed it to understand the rapidly changing military requirements that have occurred over the past 10 years. Moreover, the company's power supply knowledge gives its engineers the background to understand the commercial HDM design and knowledge of adapting them to customer applications. Rantec provides a full compliment of military HDMs and the accessories needed for tactical military applications, and designs custom power supplies using these same modules. Examples of Rantec Power Systems COTS HDM successes in military applications include the Patriot program (Figure 3), ADCAP torpedo and various NSSN applications. ▮

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