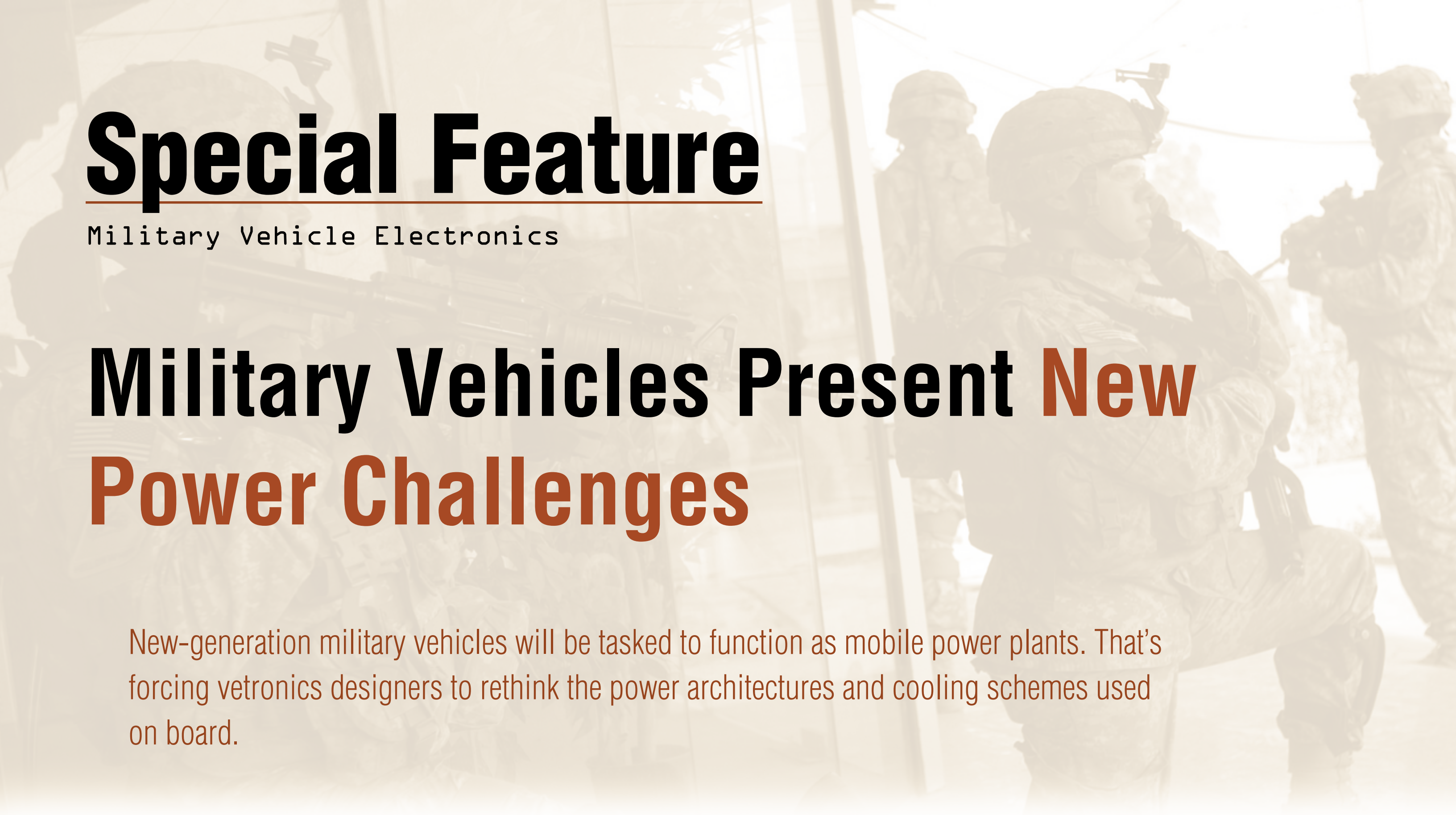

Special Feature

Military Vehicle Electronics

Military Vehicles Present New Power Challenges

New-generation military vehicles will be tasked to function as mobile power plants. That's forcing vetronics designers to rethink the power architectures and cooling schemes used on board.

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Next-generation military vehicles will be providing unprecedented levels of export power and standardization. Conventional design techniques will come up short in terms of power density, reliability and cost for these applications. System designers will need to seek out alternative equipment design and construction techniques for highly reliable power conversion that will provide these applications new levels of standardization and performance.

Present-generation deployable land-based systems (Figure 1) generally derive their power from vehicle engines or portable generators. These typically provide 120/240 VAC or 28 VDC at power levels from 10 kW up to 30 kW. Problems associated with the present practice include excessive audible noise, thermal signature and fuel usage. All of these lead to increased risk for the war fighter, as well as increased pressure on logistics. New-generation military vehicles that employ electric hybrid technology present an opportunity to significantly address these issues by providing "Export Power" that is sourced by the vehicles' onboard energy storage plant and provided to systems outside the vehicle.

On present-generation systems, more often than not export power is sourced from the vehicle's 28 VDC alternator. At the typical power levels being demanded by today's export power loads (many times significantly greater than 10 kW), operating currents can easily top 500A, presenting problems with expensive, large conductors and especially with the overload protection components required to break this much current.

Higher Voltage Storage Plants

New-generation vehicles will employ higher voltage energy storage plants such as Nickel-Metal Hydride or Lithium-Ion Batteries or Super Capacitors. These will typically operate at 300 VDC to optimize hybrid motor operation. Along with the ability to provide significant amounts of power with drastically reduced audible and thermal signatures, the availability of this higher voltage power presents some significant advantages to the export power conversion system. Distribution currents are reduced by 90%—for example from 500A to 50A—from the 28V case, and components within the power converter can be reduced in size due to reduced operating currents.

Military vehicles present challenges to power conversion assemblies due to the severe environment they must operate in, and the mission critical nature of their deployment. By their very nature, they will be operating in remote areas where maintenance may be limited and unanticipated failures catastrophic. More often than not export power converters will be located outside the crew space of a vehicle, fully exposed to the elements. Many times they can be located below the fording plane of the vehicle, requiring the assembly to be immersion compatible. Operating temperatures generally range from -46° to +54°C. Mechanical vibration and shock requirements are typically characterized by MIL-STD-810F, Methods 514.5 and 516.5.

A survey of required power conversion density requested by various vehicle manufacturers indicates a range from 3.4W/in^3 to as high as 10.3W/in^3. Typical cooling requirements call for either forced air cooling or liquid cooling. The choice of cooling methodology is absolutely critical in the successful deployment of this type of equipment.

Forced Air Cooling

In dealing with severe environments in both the commercial and military markets, TDI has a great deal of experience with both sealed and unsealed equipment solutions. The highest power conversion density is achieved through the use of direct fan cooling, circulating air throughout the inside of the power conversion assembly. However, this is only advisable if the unit is mounted in a protected location where relatively clean air is available. Otherwise, the solution is prone to dust and dirt buildup on internal components and the addition of moisture can form conductive "mud," which can precipitate failures. Given the tactical nature of these vehicles, under extreme conditions dust and dirt buildup will overcome even the extra protection measures.

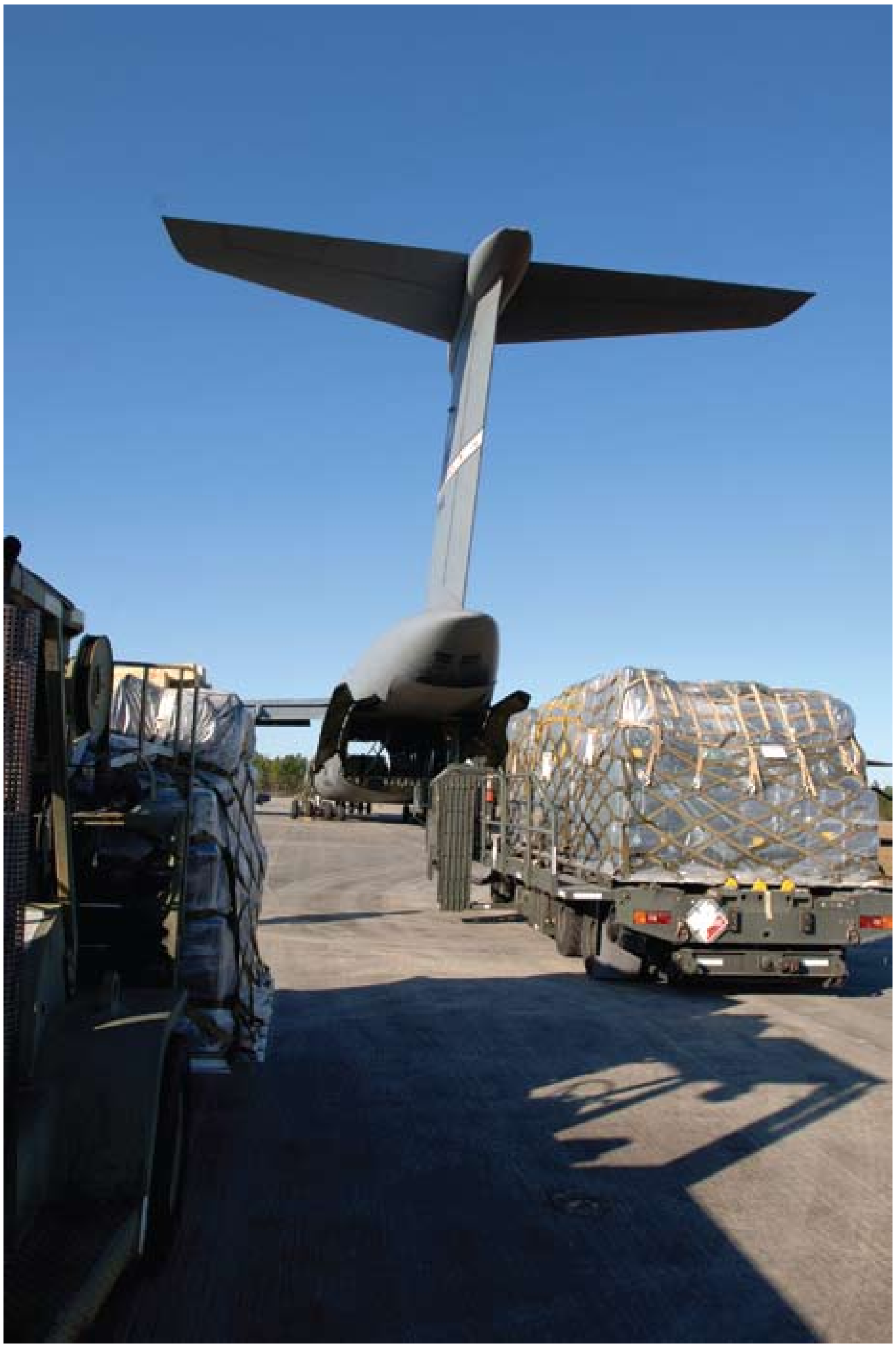

Figure 1

Present generation deployable land-based systems generally derive their power from vehicle engines or portable generators. Problems associated with the present practice include excessive audible noise, thermal signature and fuel usage. All of these lead to increased risk for the warfighter. Shown here, a truck loaded with deployable command and control components remains on standby for loading aboard a C-5 aircraft.

The best chance for success for an externally mounted, air-cooled converter in a military vehicle is an indirect system where there is no direct air impingement on internal components. This arrangement uses fans to cool heat sinks—usually referred to as a "wind tunnel" design—and allows the electronic components to be protected from the environment by locating them on the other side of the aluminum heat exchanger. While this approach offers more protection, it also results in a larger package. Figure 2 shows a typical wind tunnel design that has been deployed by TDI in both airborne and ground-based applications. The unit depicted there is a 10 kW DC-AC inverter that meets military requirements. Package size for the unit is 20 x 8.17 x 12 inches, and it delivers approximately 5W/in^3 at 10 kW from an input voltage of 360 VDC.

While the wind tunnel approach fully isolates electronic components from the external environment, there are some limitations associated with it. First, it requires a fan that is exposed to the environment. This is a wear out mechanism that has to be taken into account. If the air inlet or outlet is blocked, operation may be compromised. It's also not compatible with full immersion unless contained in an additional water-tight vessel. Moreover, designs tend to be fully customized, providing little opportunity to leverage solutions into different applications.

Liquid Cooling

The use of liquid cooling allows the electronics package to remain sealed, while also allowing the heat exchanger to be located in a potentially more convenient location, such as the front of the vehicle. Typically, the cooling liquid employed is either water or a mixture of water and ethylene glycol (antifreeze). The most common approach to liquid-cooled systems has all heat producing components mounted to a flat cold plate, which has liquid circulating through it. The liquid is then circulated through an external heat exchanger to cool it. Figure 3 shows a unit TDI has designed and deployed with this approach. This is an immersion-compatible, vehicle mounted converter that produces 21 kW of 28 VDC and 110 VAC power from a 300 VDC input, while being cooled with 80°C coolant delivered from the vehicle.

While this can be an efficient cooling system, it requires a large amount of engineering time to design, keeping all the heat producing components in contact with the cold plate as well as maintaining good electrical connections to a printed circuit board. One of the limitations of the cold plate approach is that it depends on flat shapes for heat transfer. Often times this results in an assembly that is spread out over a larger than ideal physical area, which can result in electromagnetic noise containment issues. Likewise, this type of assembly generally requires an excess of wiring, resulting in higher cost and potentially reduced reliability due to the increased number of interconnects.

Beyond a simple cold plate, more exotic and integrated liquid-cooling structural members can be deployed. Such units are available providing 7 kW of DC output power and using a central liquid-cooled extrusion that is highly customized to provide cooling for a number of both flat and irregularly shaped components. While this type of design addresses some of the limitations presented by a flat cold plate, it requires a higher level of engineering design, resulting in a completely customized unit that is not adaptable to other applications.

Next-Generation Liquid-Cooled Products

In determining a strategy to address new generation liquid cooling requirements and provide the best performance in vehicle applications, this technology must be able to meet the following objectives:

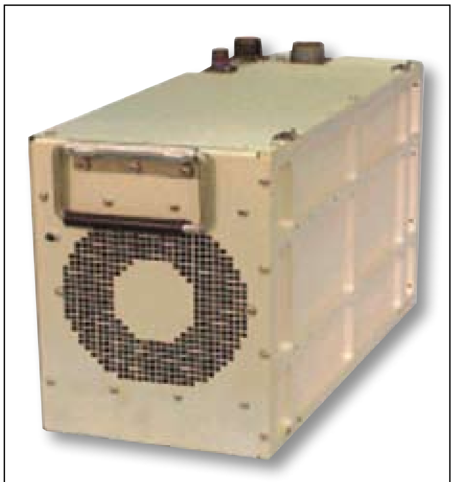

Figure 2

The best chance for success for an externally mounted, air-cooled converter in a military vehicle is an indirect system where there is no direct air impingement on internal components. Shown here is a typical "wind tunnel" design that has been deployed by TDI in both airborne and ground-based applications.

1. Meet the environmental requirements of vibration, mechanical shock and liquid immersion.
2. Work with coolant temperatures much higher than was dealt with in the past (up to 80°C in some instances).
3. Meet the EMC requirements of MIL-STD-461.
4. Provide solutions that are not so highly customized as to jeopardize development timelines or cost budgets.
5. Provide a good basis for reliability expectations.

Taken together, items 2 and 5 present a particularly challenging requirement. Analysis of existing units shows that while it is not too difficult to control the temperatures of components with the larger share of power losses, it is very difficult to control temperatures of components with relatively low losses, but which don't have a good connection to the heat transmission path. It is not unusual for the internal ambient air temperature inside water-cooled units to be 40°C, or higher, than the coolant temperature.

If the coolant is 80°C, then internal ambient air temperature can easily reach 120°C, or higher. This presents some real problems for certain component types. For example, integrated circuits contained in PC board-mounted SMT packages may dissipate a few hundred mW. These depend on the ambient air that surrounds them to carry this heat away, and with an effective ambient of over 120°C, reliability is compromised. Likewise, there are many passive components whose reliability quickly falls off as temperatures increase above 100°C.

Managing the Heat

Methods for controlling this effect include reducing the internal ambient temperature rise above coolant temperature, or improving the thermal path from the component to the coolant. Internal air temperature rise can be reduced by circulating air inside the box and employing an air-to-liquid heat exchanger. However, this generally takes up a significant amount of room and adds the reliability impact of a circulating fan.

Improvement of the thermal path can be achieved by surrounding the sensitive components with a thermally conductive compound that ultimately contacts with a liquid-cooled surface. While this method is effective, the design needs to comprehend this need from the very beginning, otherwise a short path from the component to the coolant might not be achievable. Given these considerations, TDI considers a modularized liquid-cooled approach as a good fit for military vehicle applications. The modularized liquid-cooled approach also presents some advantages with regard to design for electromagnetic compatibility. By partitioning assemblies, the EMI filter can be fully isolated and shielded from noise-generating assemblies, thereby simplifying filter design.

Non-Conventional Liquid-Cooling Technologies

TDI has developed a new technology that utilizes oil to encapsulate electronic components so as to provide a highly

Figure 3

The most common approach to liquid-cooled systems has all heat-producing components mounted to a flat cold plate, which has liquid circulating through it. The liquid is then circulated through an external heat exchanger to cool it. Shown here is a unit TDI has designed and deployed with this approach.

thermally conductive path between these components and the ultimate heat dissipater. The initial deployment of this technology is in convection-cooled, environmentally sealed products for commercial, industrial and military use.

The advantage of oil in these applications is that it is an insulator, so it can be used in direct contact with the electronic components. Complete circuit board assemblies are immersed in the oil, and this produces a relatively isothermal environment that greatly increases component reliability.

Recently this technology has been expanded to include heat dissipation through circulating oil. TDI has deployed this technique on commercial hybrid vehicle components such as battery chargers and DC/DC converters. The oil used is typically a UL-approved, environmentally friendly, vegetable-based transformer oil. However, hydrocarbon-based mineral oil has also been successfully tested and we believe that diesel fuel could also be used in this application. The advantage of diesel fuel would be that it is already used on the vehicle and is logistically an excellent choice.

Advantages of Direct Coolant Circulation

Advantages of circulating coolant directly to electronic components include the extreme protection from exterior environmental effects and buffering from shock and vibration effects. This approach allows you to use existing air-cooled assemblies with little or no changes. Perhaps the biggest advantage that can be achieved with this method of cooling is the reduction of overall operating temperatures. Since most liquid-cooling technologies that have been considered to date share the coolant loop with other heat sources, power electronic components end up operating at unusually high temperatures. These higher operating temperatures will ultimately have a deleterious effect on system reliability. By cooling the power electronics with a lower temperature coolant that comes in direct contact with the components, their operating temperature will be significantly reduced, resulting in a significant improvement in reliability.

Great opportunities for reduced design cycle time and improved performance are presented through the use of standardized cooling topologies that can be employed across various power conversion assemblies. Further, extremely significant gains can be made through the use of direct circulating coolant on component approach.

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