System Build and Custom Engineering to meet Rugged Military standards

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Abstract

While building systems to meet Rugged Military standards care has to be taken on certain crucial aspects during the design stage itself. If this is not done, the system may not meet the rugged requirement specs and hence not qualify for the rugged Military standards. This article addresses the top level details which need to be considered during the design stage, prior to building the system. The emphasis here is on the mechanical and electrical integration and not on specific hardware / software configuration.

Overview

Defense solutions these days demand the highest levels of technology. Combined with increased customer demands for short development cycles and lower cost, these demands pose a major challenge to system engineers. Building a system for defense applications involves high-reliability COTS products, custom hardware design, mechanical and electrical integration followed by qualification tests to ensure that they meet the required Military standards. While building systems to meet Rugged Military standards care has to be taken on certain crucial aspects during the design stage itself. If this is not done, the system may not meet the rugged requirement specs and hence not qualify for the rugged Military standards. This article addresses the top level details which need to be considered during the design stage, prior to building the system. The emphasis in this article is on the mechanical and electrical integration and not on specific hardware / software configuration.

System Architecture

The system architecture is drawn out based on the functional requirement specifications of the system. The key factors that come into consideration here is the platform the system is going to be based on, selection of the processor and the cooling mechanism. This decision is based on the end application of the system - whether it is signal processing, display or control application. For example, if the end application is signal processing, a PowerPC processor like MPC 7447A /7448 or MPC 8640 / 8641D from Freescale could be ideal choice as it provides high computational power and a variety of COTS modules with multiprocessor options are available in the market. The choice of the platform - a VME / VPX / CPCI based system would depends on a multitude of factors like the number of slots that are required, ruggedness, throughput and performance requirements. For example: if the data transfer rate required is more than 320Mbytes per second then VPX may be the ideal platform to go with as it can provide 6.25 Gbps per differential pair.

Once the processor and platform is selected, the next step would be to decide on the kind of cooling required for the system: whether its air cooled, conduction cooled or liquid cooled.

There are many global vendors that provide a wide range of COTS modules for rugged defense electronics. These modules are available for various categories like DSP & FPGA processing, Single Board Computers, Signal Acquisition, Video Graphics and Radar, Data Storage, Data Recorders, Displays, I/O and Communication etc.

After choosing the right COTS module, careful attention needs to be given for the system build in terms of chassis construction, power supply design, backplane design, backplane communication, fabric topology to used in backplanes, Ethernet connectivity, slot configuration, I/O routing, connectivity and connectors etc. to meet the end application / qualification requirements.

Backplane Design

While using VPX technology, the backplane has to be custom designed as per the application requirement. A standard VPX backplane is currently not available which can suit all applications. In order to make the system rugged, the I/Os needs to be routed to a rugged connector since the standard VPX connectors with wires or rear transition modules cannot meet the specifications required for rugged applications. The SRIO / PCIe fabric topology also needs to be properly selected: it may either be full mesh or half mesh or two half mesh or custom fabric connectivity. High end software such as 3D modeling and simulation tools need to be used and special attention needs to be given to signal integrity to ensure that the backplane operates at the rated data transfer speeds.

In VME 64X or other systems, if a COTS backplane is used, there may be situations when the signals from one board need to be transferred to another board at higher speeds. Under such conditions, a customized VME sandwich backplane may be designed to route all interconnectivity between the slots.

Enclosure construction material

The construction of the chassis or enclosure should be of a suitable alloy to meet the application that it is intended for. In case of airborne equipment, all the material used should be of airborne grade having very low weight. For the structural members, Aluminum 6024 is preferred due to its hardness. For the LRUs HE-30 or equivalent is preferred. In systems where bending of alloy is required, Al 5052-H32 is preferred as it is of airborne grade. For non-airborne or ground based applications, Al-5052 is good enough as it has excellent characteristics with high fatigue strength, and can be used for structures which are subject to excessive vibrations. As 5052 also has excellent corrosion resistance it can be also be used for naval applications.

Enclosure construction material

The construction of the chassis or enclosure should be of suitable alloy to meet the end applications for deployment in Land, Sea and airborne. The alloy should meet the environmental criterions, structural, safety and reliability requirements. Aluminum alloys like 2000 to 7000 series are used accordingly for different applications. High-end composite materials are used where strength and weight is a main constraint. Special material like alloy steel, titanium etc. can be used where the system is in direct contact with contaminated ambient.

Mechanical modeling

Mechanical modeling needs to be done to ensure all mechanical components and COTS boards can be mounted with ease to ensure zero error, good aesthetics and a cost & time advantage. CAD modeling gives shape to an idea, then to design and an extended link to the manufacturing process. The space taken for dust caps, back shells, Cable support, cable bending radius, cable thickness also need to be considered. Connector placements and their orientation are of significant importance from the assembly and maintenance perspective. CAD / CAM tools like Pro-E and Solidworks are the popular 3D modeling tools available.

Structural Analysis

Once the mechanical modeling is completed, the model needs to be analyzed for structural integrity. Structural Analysis has to be done keeping in mind the end requirements like vibration and shock specifications and over vibration frequency range. Maximum stress on the parts needs to be calculated on all three axis and the stress on the material for the specified vibration and shock loads should be lesser than the yield strength of the material used for construction. If the stress on the part is more the structure need to be further strengthened.

Vertical or Horizontal Orientation

In a VME or VPX system, the cards may be mounted in vertical or horizontal orientation. Horizontal orientation may suit well when there are fewer slots and height restrictions. Also while choosing the orientation, care should be taken to ensure sufficient space is provided for air inlet/ outlet in case of air-cooled systems.

Cooling Mechanism

Cooling of processors and other hot spots inside the unit is of utmost importance while designing the system. Inadequate cooling will result in failure of the expensive boards and components and the entire project / program may be at risk if it is not well taken care. The choice of cooling - conduction or air or liquid, decides the cost of the equipment and this choice needs to be made based on the budget available and the actual heat load.

Convection cooled systems provide a certain degree of flexibility in terms of changing fans if the heat load varies and hence a cost advantage. If the heat load is more in a particular slot, air bafflers can be provided to divert more air to that particular slot and regulate temperature. Though convection cooling provides flexibility at the same time if the heat density per square inch is more, it is difficult to cool down the system using this method. The selection of the fans is primarily based on the CFM requirements of the board to cool the hot spots. The other key parameters are the RPM and noise in dB. The system will be noisier with fans considering the high power required in current signal processing designs and the MTBF values drop down when multiple fans are used. For airborne systems where the equipment is required to operate at high altitude, convection cooling cannot be used as the air density will be low. If the system needs to be water proof and hermetically sealed, in such cases too, convection cooling method cannot be adopted.

Conduction cooled system provides more ruggedness, noiselessness and added benefits, but at the same time it is twice as expensive as air cooled systems. Here, care should be taken to perform thermal analysis using thermal simulation tools and to ensure that the system works well with the existing heat load.

If the heat density is too high and cannot be met by convection or conduction cooling methods, then liquid cooling or hybrid cooling techniques need to be incorporated.

Thermal Analysis

Irrespective of the cooling methods used in the system, thermal simulation of the system needs to be carried out. To start with, hot spots need to be identified based on the chip specifications and its heat dissipation needs to be calculated. Once all the hot spots and their heat dissipations are calculated, a computational fluid dynamic analysis needs to be conducted to evaluate the thermal performance. A thermal / CFD Analysis needs to be carried out over the operating temperature range in which system is required to operate.

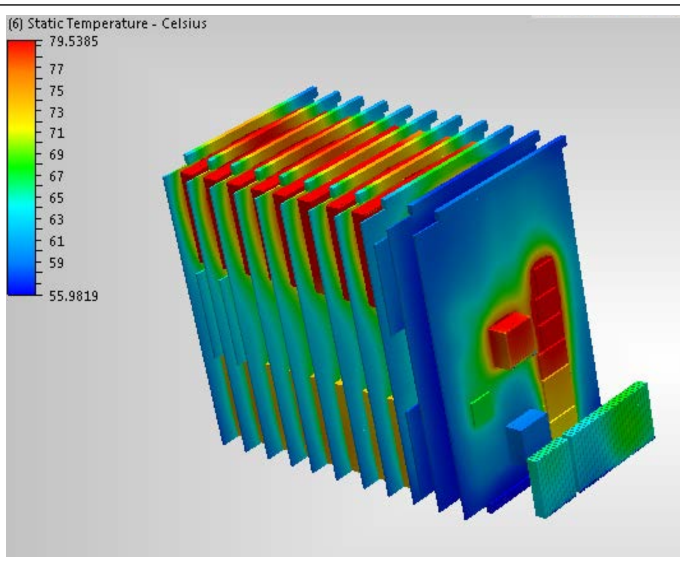

Image 1: Thermal Profiling of a system

Power Supply Design

The life of the system mainly depends upon the power supply and hence design of power supply is a critical factor. Power supply for the system needs to be designed based on the power requirements of the boards, fans and other active units housed in the system. Maximum current in Amperes required for each of the voltage rails need to be added for all the boards and it is recommended to provide a buffer for safety. The minimum features to be added while designing a power supply are short circuit protection, line and load regulation, thermal protection, isolation, and reverse polarity protection. Ripple / noise should be within the specified limits. Also the voltage levels should be within the tolerance specified as per the VME / VPX standards. The power supply designed should also comply with the MIL-STD-704D, MIL-STD-461E fro EMI/EMC and MIL-STD-810 for environmental specifications. A good power supply design can eliminate many EMI/ EMC issues that may be crop up later. The location of the power supply in the system also plays the major role. Preferably, the power supply should not be mounted too close to other electronics to ensure that noise and heat from power supply does not affect them. At the same time it shouldn't be too far, else it may result in voltage drop in the wires. The design should also take care of power supply efficiency and cooling.

Connector selection

The choice of connectors is another critical parameter. The primary criteria of connector selection depend upon the signal handling capacity. Some of the other parameters are ruggedness, space requirements and wires gauge / type supported. The connectors on the panel in rugged military applications are normally 38999 series III connectors. In that, there are multiple varieties like square flange, Jamnut or Square flange with clinch nuts. Jamnut connectors are normally used due to its ease of use. The Square flange types need to be mounted with four screws in the corners with nuts and washers on the other side. Square flange with clinch nuts ease connector mounting to some extent but are expensive and have high lead time. If blind mating is chosen, the mechanical design should be very precise, if not it leads to contact issues and connector or pin breakages.

EMI

Electromagnetic emissions can either be conducted or radiated. They can either be generated from the system to be designed or from other equipment around it to which the system being designed is susceptible. The best method to suppress the EMI noise is at the source level itself. Else, it could result in adding extra components and rework at a later stage leading to various compromises w.r.t. size, weight, increased cost or in the worst case, leading to redesigning of the complete system. The graph below depicts the cost advantage if the EMC shielding is taken care at the design stage itself.

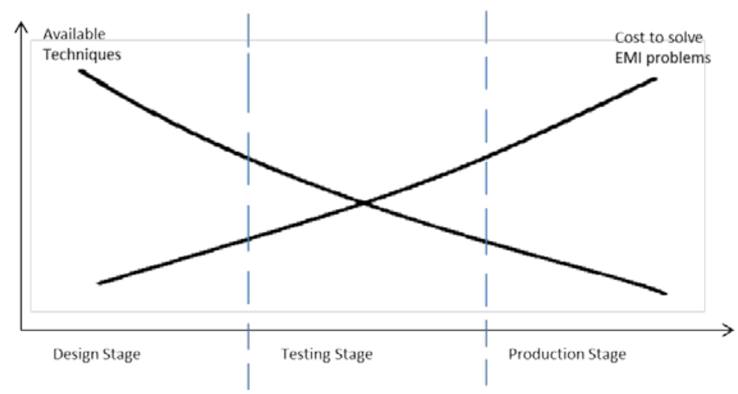

Image 2: Cost advantage of EMI/EMC shielding at design stage

Conducted emissions have to be suppressed by incorporating a good filter design at the input stage and the length of the wire from power entry point to the local power supply should be optimal.

Radiated emissions can be suppressed by providing good enclosure, PCB and harness design. The openings should be minimal and at all openings honeycomb filter should be incorporated. Conductive gaskets should be incorporated at all the joints. Double layer shielding by providing air gap or other non-magnetic conductive material is a more efficient method to block radiated emissions.

Braided harnesses should be used and the braid should be terminated to the body of the equipment completely by providing 360 degree protection. Back shells are available to provide this type of termination for EMI/EMC protection.

Earthing is required for the safety of the operator and the equipment and also to sink EMI noise. Either a single point grounding scheme or multi-point grounding scheme can be adopted, but care should be taken to ensure that it is bonded properly. The cable harnesses should be shielded and shields should be connected to ground. Pig-tails should be avoided while grounding the shields.

Health Monitoring

In a mission-critical system, it is important to keep monitoring the health of the unit to ensure that any errors are flagged. Some of the key parameters to be monitored are the fan health, high/low temperatures and power supply voltage levels. If these critical parameters are not in range the health monitoring unit should identify and indicate or flag it for corrective measures or the health monitoring unit should correct it automatically.

Noise reduction

In air cooled systems, at high temperatures the fan control circuitry would make the fan run at high speeds and hence generated high noise. This makes it difficult for human presence to operate and monitor the system, unless the system would be monitored remotely. Thus, while building air-cooled systems, the noise levels need to be controlled. If the heat dissipation is very high, noise is inevitable since high RPM fans having very high dB are incorporated. But, noise level in dB should be lesser than 70 dB so that operators can work with the systems for a longer duration.

Since the fans are selected based on system's highest operating temperature range [eg. 55^{o}C] and most of the time the system would be operating in normal ambient conditions [25-40^{o}C], fan control circuitry should be incorporated, to reduce the fan speed at normal ambient temperatures and hence produce less noise.

Testing and Maintenance

While choosing connectors, connector placements, wire routing and mechanical design care should be taken for easy maintenance, testing and trouble shooting.

Weight optimization

Weight optimization has to be considered in the initial stage. The material used for fabrication and the harness braids are the components that add up the weight. The cable harnesses inside the system should be optimal length and of appropriate gauge.

System Engineering Services by Mistral

Mistral has the experience required to take a concept / specifications to product and take it further to deployment. Mistral has built several systems proven to work in rugged Military environment.

Mistral has partnered with Curtiss Wright Controls Defense Solutions (CWCDS), a world leader in development of rugged electronics for defense applications provides wide range of these COTS

Mistral has successfully built several systems for defense market based on CWCDS products. Some of the widely used modules include:

- CHAMP AV6 with Four Freescale Power Architecture™ MPC8640/8641 dual-core CPUs at 1.0GHz
- CHAMP AV4 having Four PowerPC™ MPC7447A/7448 CPUs up to 1.25GHz
- SVME / DMV-1901 having Intel® Core™ Duo or Core™2 Duo 1 .5 or 1.67 GHz
- XF-05F- featuring quad fiber-optic transceivers with a user programmable Xilinx Virtex-5 FPGA
- VPX6-684- Managed Gigabit Ethernet switch

These COTS solutions are augmented by custom backplane and enclosure designs by Mistral's Engineering team. The systems built are compliant to MIL-STD-810E, MIL-STD-461E, MIL-STD-704D and MIL-STD-4172 for human engineering. The documentations and qualifications will be done as per the DGAQA and CEMILAC guidelines.

Following are some of the tests done on the systems developed in Mistral as per the MIL-STD-810E and MIL-STD-461E.

- Insulation and Isolation Resistance Test
- Bond Resistance
- High Temperature Storage Cum Operation Test
- Low Temperature Storage Cum Operation Test
- Low Pressure or Altitude Test
- Humidity Test
- Mould growth or Fungus Test
- Salt Corrosion
- Dust
- Shock Test
- Acceleration
- Transit Drop
- Bench Handling
- Fluid Contamination
- EMI/EMC Tests
  - CE-102/CS-101/ CS-114/ CS-115/ CS-116
  - RE-102 / RS-103

Mistral also provides training to customers on system deployment and usage and provides support and maintenance on the systems designed by them.

Below is a case study that showcases the system engineering of a Signal and Data Processing Rack (SDP) for a radar network by Mistral.

Case Study

The Signal and Data Processing Rack (SDP) is one of the sub-systems in the radar network which provides resources for radar signal processing, data capturing, data recording with other radar control functions.

<u>The Requirement</u>

The requirement was to design and integrate a solution to meets the overall functional and performance criteria; while adhering to the longevity, product lifecycle management and integration norms. This included:

- Mechanical design of the Signal and Data Processor Rack with structural and thermal analysis
  - The rack had to be housed in a sheltered space on a wheeled vehicle and designed for compliance with JSS 55555 and MIL – STD 461 E
  - The rack had to be mounted on shock mounts in an air conditioned shelter and an AC vent had to be provisioned on top of the SDP rack to allow circulation of conditioned air to the rack for cooling purposes
- Design and Fabrication of a hybrid backplane (VPX and VME)
- Generation of Wiring Charts, ICD (Inter Connection Document) and provide cable harnesses as per the ICD

Image 3: Signal and Data Processing Rack

- The rack had to be equipped with:
  - Quad Power PC and Intel based processing system
  - Quad channel sFPDP module mounted on VPX board capable of communication using sFPDP protocol
  - VPX based Gigabit Ethernet Switch
  - Provision of Redundant Power
  - Power Supplies to cater for the entire rack. Circuit breakers and protection circuitry to be provided to prevent damage to the electronics housed in the rack
- The rack had to be mounted with LEDs, to indicate the health of the power supplies and the fans
- The rack needed to comply with JSS 55555 and MIL-STD 461 E standards for EMI/EMC and Environmental specification.

<u>The Solution</u>

Mistral developed an air-cooled mechanical enclosure for the SDP rack comprising of the following components:

- Power PC based VPX processing cards
- Quad Channel sFPDP Module for sFPDP interface
- VPX based Data Recorder card
- VPX based Gigabit Ethernet Switch
- Intel Core 2 Duo based VME processing board
- Flash PMC module
- Two port Gigabit Ethernet PMC Module
- Custom Hybrid Backplane
- Serial to LAN converter
- Necessary Power Supplies
- Backplane Chassis

A custom 14-slot hybrid backplane was designed to accommodate 6U VPX cards and VME cards. The backplane has 12 VPX slots and 2 VME slots. The SRIO Fabric adopted was dual half mesh topology while maintaining high level of signal integrity.

System Design

System Study with report generation was provided to ensure that all the operational environmental conditions and performance requirements were met. This included the complete 3D computer modeling of the system, system power consumption calculations, system cooling calculations, system structural analysis, system thermal analysis and external/ internal cable harness.

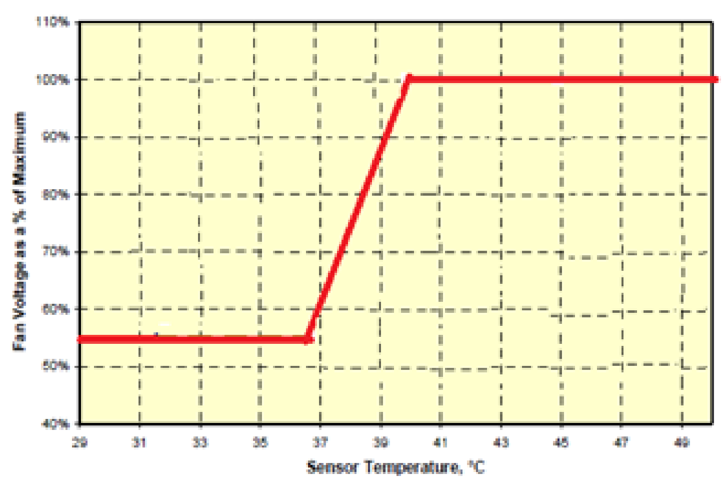

Image 4: Fan Voltage control based on Temperature

- Keeping the dB levels low in an air cooled rack having very high cooling requirements. This was done by controlling the fan voltage based on temperature as shown in graph in Image 4.

- Power ON sequencing and temperature monitoring and control inside the SDP Rack
- Establishing optical links for sFPDP and Fiber Channel and Gigabit Ethernet network for external and internal network.

Custom Hardware Design

- Rugged Air cooled Rack
- Hybrid Backplane having 12 VPX slots and 2 VME slots
- Redundant Power supplies
- Complete cable harness design
- Integration
  - Integration of all boards within the system; and establishing functional capabilities of base card, inter- and intra-system communication, GigE network establishment, Inter Processor Communication with inter- and intra-system dependencies.
  - Integration and testing of COTS and custom designed hardware.
  - Integration of drivers, BSP, DSP libraries.
- Verification and Validation
  - Design and validation of rack for a high-power application, with thermal management.
  - Rugged systems adherence to ground based application - All boards supplied cater to the requirements of JSS55555 and MILSTD461E.

Conclusion

Based on the complexity of the system, the system architecture and other criterions, the design process involves defining the hardware and software architecture, COTS components, modules and interfaces and connectors required to meet the customer's specification. While architecting a system that meets rugged Military standards, it's essential to design it in a way wherein it can be practically implemented and will be robust. The key to achieve this is to understand the environment in which the system has to operate in, and at the same time, ensure adherence to guidelines that are provided by standards worldwide.