

**Electronic Part Selection and Design Guidelines for
Low Criticality Space Flight Payloads**

**Prepared for:
The Payload Community**

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1.0 Introduction

This document provides a brief overview of several EEE parts selection and design related issues that are critical to successful development of reliable space hardware. Many part technologies have weaknesses that can lead to component failures if the part is subjected to the launch and orbital environments. Guidelines are furnished herein for the selection and application of electronic parts in order to enhance hardware reliability and to aid individuals who might be new to the space flight hardware development processes.

1.1 Scope

This document is intended to provide electronic component selection and design insight that is generally not found in other program materials. Reference materials listed in this text are among those considered as required reading for the hardware developer. The developer is encouraged to establish links to STS and ISS program personnel and to obtain materials referenced in this text as well as those recommended by program personnel, as this text is by no means a comprehensive coverage of flight hardware design considerations. For ISS payloads an excellent phasing document is SSP 57057 now approved as revision B. Key safety related policies and determinations are found in a collection identified as NSTS/ISS 18798 Revision B entitled Interpretations of NSTS/ISS Payload Safety Requirements.

Since this document does not impose requirements, the use of the words 'shall' and 'must' are avoided. However, the guidelines provided in this text are most often vital if not critical to payload mission success and failure to follow these guidelines greatly increases risk of premature hardware failure in many instances. Disregarding the advice provided by these guidelines particularly in the area of materials flammability can present a hazard to the crew. In addition, disregarding these guidelines could lead to advisories or requests for a change late in the design cycle or in the worst case a lack of approval for flight use when a noncompliance is discovered. SSP 30233 entitled Space Station Requirements for Materials and Processes is an excellent reference material on this topic.

Additional key references that should be reviewed include:

NSTS 21000 IDD MDK Middeck Interface Definition Document for the STS
NSTS 1700.7B Safety Policy and Requirements for Payloads Using the STS
NSTS 5300.4(1D-2) Safety, Reliability, Maintainability and Quality Provisions for the Space Shuttle Program
SSP 30213B Space Station Program Design Criteria and Practices (old JSCM 8080)
SSP 30312H Electrical, Electronic and Electromechanical (EEE) Parts Management and Implementation Plan for Space Station
SSP 30512 Space Station Ionizing Radiation Design Environment
JSC 27301D Materials Control Plan for JSC Flight Hardware
SSP 50005 ISS Flight Crew Integration Standard

SSP 30240 Space Station Grounding Requirements
SSP 30423 Space Station Approved Electrical, Electronic and Electromechanical Parts
SSP 30245 Space Station Electrical Bonding Requirements

Of particular value is a link to the payload web page:

<http://stationpayloads.jsc.nasa.gov/pd/>

and to the EV web page:

<http://www4.jsc.nasa.gov/org/Ev/ev5/index.html>

1.2 General Considerations for space flight hardware:

One valuable tool for the selection of parts is a participation in the Government Industries Data Exchange Program (GIDEP) where a search of their data base may turn up information that a part is going to be discontinued or that it has a history of failure.

Another valuable process is the act of subjecting a subassembly, prototype, protoflight or qualification hardware unit to radiation testing to determine its susceptibility to radiation that could jeopardize its operational capability in the cosmic radiation environment found in earth orbit. Susceptibilities found during these early phases of development are more easily corrected than they are when the flight units are complete.

Like ionizing radiation testing, some developers subject their designs to an earlier EMI test so that more time is available for the identification and correction of problems in the final flight units.

Intra-vehicular Activity (IVA)

Payload hardware intended for use in IVA habitats should be expected to function in uncommon conditions that are unique to flight hardware environments. A listing of key considerations follows:

- *There is no gravity to keep loose items and particulates moving predictably to the floor or to assure a crewman's footing as he performs operations at the payload front panel.
- *Particulates in the air can be ingested by payload fans and projected out into the cabin where a crewman's eye might be injured.
- *The unintended release of a fluid that is considered toxic or not compatible with eye contact is a serious condition.
- *Contained fluids may take on a turbid nature that is rich with micro-bubbles.
- *The surface tension of fluids becomes a stronger influence in the absence of gravity.
- *There is no convective heat transfer to facilitate the cooling of hardware components. This causes parts that are not actively cooled to get significantly hotter than they would in an earthbound application.

The environment present in space flight vehicles and the ISS assumes that the air that sustains life is refurbished and recycled. Contamination to the breathing mixture is a

very serious matter. Special attention must be applied to assure minimal off-gassing of materials and to take all reasonable measures necessary to minimize the likelihood that over stressed hardware components might release offensive and/or toxic odors.

Extra-vehicular Activity (EVA)

Additional reference materials must be understood for design of hardware in an EVA application.

Payloads mounted outside the crew volume can be exposed to extremes of temperature varying from – 100 C to + 125 C.

There is an elevated exposure to UV, cosmic energy, atomic oxygen and micrometeoroids.

The absence of air further reduces cooling options.

Risks to an EVA crewman are significantly elevated particularly since they require several minutes for reentry into their habitable volume. Hardware functionality must not place them in the position of a hasty return to an airlock.

2.0 Recommendations

2.1 Capacitors

2.1.1 Aluminum Electrolytic Capacitors

The use of aluminum electrolytic capacitors use is highly discouraged for space flight hardware. This is a very commonly used commercial capacitor that is frequently selected because of its very high capacitance per weight/volume.

Concerns:

- a. The part is non-hermetic and can leak acid in a vacuum environment or dry out in a terrestrial environment leading to a reduced capacitance.
- b. The voltage rating of the part eventually falls to the voltage at which it is being used where an operational boundary or memory is established.
- c. Nonuse of such capacitors will allow the oxide formation on the aluminum foil to dissolve into the electrolyte thereby diminishing its voltage rating
- d. For most parts the capacitance can decrease following exposures to extremes of temperature
- e. Useful life decreases with exposures to extremes of temperature and can decrease to as little as 6 months with operation of the part at its maximum rated temperature.
- f. Hydrogen, a flammable gas, can be vented from the part while in use

Main Failure Modes:

1. Leakage around the seal allows the part to dry out which in turn causes a decrease in capacitance.
2. Internal shorting across plates caused by voltage stresses on the part.
3. A lowering of the part's working voltage level caused by an oxide on the aluminum foil dissolving into the electrolyte during nonuse.

Recommendation:

Use of this aluminum electrolytic capacitor in non-critical hardware placed in an IVA environment is not acceptable unless each of the listed shortcomings are understood and accepted or addressed.

The design should expect and accommodate an inrush of current when power is once again restored to dormant parts.

Since the aluminum electrolytic capacitor is not reliable in an EVA environment where it may lose some of its electrolyte, capacitor alternatives are recommended such as a tantalum wet slug (CLR 79, 81, 91) or stacked ceramic capacitors.

If they must be used, insure sufficient derating.

2.1.2 Solid Tantalum capacitors

This is a very commonly used commercial capacitor that is very reliable if properly derated. Proper derating provides a very reliable performance of the solid tantalum capacitor which can enjoy a decreasing failure rate as operational time increases.

Military examples are MIL-C-39003 for solid electrolytic tantalum capacitors and MIL-C-55365 for tantalum chip capacitors.

These capacitors are intended mainly for use in filter, coupling, blocking and other low voltage applications (such as transistor circuits) where stability, size, weight and shelf life are important factors. The DC leakage and dissipation factor should be taken into consideration when designing transistor, timing, phase-shifting, and vacuum tube grid circuits. Operation of these capacitors in parallel increases the risk of DC surge current failures in low-impedance circuits.

Concerns:

Relatively high ESR leads to internal heating in the presence of high transient energy. This is the reason why they are not good for power supply filters or other high ripple applications.

Solid tantalum capacitors have inherent impurities in the dielectric that allow small leakage currents. Excessive voltage or overheating can cause the current at a defect site to dramatically increase causing very highly localized heating (400 to 500C). If there is an external series resistance in excess of one ohm/volt the conductive manganese dioxide converts to a less conductive MN_2O_3 that effectively caps the shorted site. These "self healing" events occur during equipment operation and are unknown to the user. If there is a value less than the one ohm/volt series resistance, a thermal runaway can occur with the possible outcome of a shorted capacitor.

Recommendation:

The use of solid tantalum capacitors is highly recommended if they are derated properly (50% voltage) and are surge tested by a test facility like the Receiving Inspection and Test Facility (RITF) or the manufacturer to MIL-C-39003/10A guidelines. Rescreening of commercial capacitors here at JSC after the manufacturer performed surge current testing resulted in an additional 5.6 percent fallout (54/971). JSC performed additional testing at cold (worst case) temperatures instead of just a hot temperature test as performed by the manufacturer. It is highly recommended that payloads be subjected to tests such as those above where they are evaluated at the temperature extremes of intended use.

Guidelines for use:

- a. Do not use parts in a circuit with less than 1 ohm/volt impedance
- b. Derate the applied voltage 50% against the capacitor rating.
- c. If parts must be used in low impedance applications, use of MIL-C-39003/10A screened parts is recommended.

2.1.3 Wet-Slug Tantalum capacitors - MIL-C-39006

These capacitors are limited to applications at 125 VDC or below. Their primary use is in low voltage power supply filtering circuits but also may be used in coupling and bypassing, circuit isolation, tuning, timing, power factor correction and phase shifting applications. Their low leakage current (lowest of all the tantalum types) is not appreciable below +85 deg C and at ordinary temperatures is comparable to good quality paper capacitors yet they are much smaller in size. These capacitors have the highest capacitance per size or volumetric efficiency of all capacitor dielectrics.

Concerns: Before the tantalum cased wet-slug capacitor the standard product was a silver cased wet-slug (CLR 65). If the silver cased devices are subjected to negative voltage over a long enough period, conductive dendrites will grow internally between the silver case and the tantalum anode. Designers should not select CLR 65 devices for use in flight hardware.

Recommendation:

When buying commercial wet slug capacitors, assure they are not silver cased. Non-hermetic commercial grade wet-slug tantalum capacitors are available but are not recommended. Instead, use of a tantalum cased wet-slug capacitor designated as CLR 79, CLR 81, CLR 90 and CLR 91 or their commercial equivalent is suggested. Perform the required derating.

2.2 Connectors

The fragile nature of connectors has not presented an overwhelming reliability problem with most NASA programs, but there are ongoing concerns. There have been numerous

quality issues like pins that are pushed back and bent or inserts that have been miss-locked. In general, the use of commercial or non-space rated connectors is acceptable. The following guidelines and application questions will aid in selection.

Guidelines for buying connectors:

- a. Do not use cadmium plated connectors without project and S&MA approval. Sublimation of cadmium in a high temperature (250F plus) environment creates a health hazard since the resulting vapor can attach to a person's lungs. Cadmium is typically gold or a military green color.
- b. Connector pins should have an under plate between the external gold plating and base material to prevent leaching. The preferred gold thickness is between .000050 to .000030 inches with a barrier metal under-flash to address leaching concerns. Nickel is a commonly used barrier metal.
- c. As a minimum, use environmentally sealed connectors anywhere condensation or a potential for a water leak might exist.
- d. The base material of a connector should be aluminum or stainless steel. Other materials should be carefully evaluated and tested against mission requirements.
- e. All unmated cables/connectors should have a protective cap for protection against electrostatic discharge, debris entry and physical damage. These caps must be tethered and the exposure of sharp strands on a wire cable must be prevented.
- f. All connector materials should be evaluated against outgassing requirements to determine the need for bake-out. Materials that outgas can be detrimental to optics such as cameras as well as to the crew.
- g. All contacts, even if they are not used within a connector offering environmental sealing, should be placed in the connector shell/housing if the seal is to be maintained. Alternatively, plugs may be used in place of the pins. In addition, retention forces such as at a header interface where there is no capturing mechanism are higher for mating connectors if all contacts are installed

Military Connector Selection Guide

MIL-DTL-5015 Circular threaded, AN type

MIL-C-24308 Rectangular, miniature polarized shell, rack & panel while some of these are cadmium plated.

MIL-C-26482 Circular miniature, quick disconnect receptacles and plugs, environment resisting - NASA approved part is 40M39569 (NB0-NB7)

MIL-C-38999 Circular, miniature, quick disconnect (bayonet, threaded), environment resistant. The military equivalent to a Will mate with SSP 21635 and the Shuttle 40M38277 (NLS) series II.
As an example: The military equivalent to the D38999/20GG39PN is the SSP 21635, NATC00T21N39PN. The ISS connector is available from G&H or Amphenol.

MIL-C-39012 Coaxial, RF

MIL-C-39029 Contacts, Electrical connector

MIL-C-83513 Micro-miniature D-Subminiature connector with .05 spacing, Cannon is type MDM,

Commercial Connector Guide

Consider derating and select the contact size for the applied current

Favor a crimped pin for power connectors particularly those with high currents

Select pins with gold plating

Insure the temperature range is matched to the intended application

Select parts with minimal flammability characteristics

ISS Connector Part Numbers :

SSP 21635 contains two primary types of connectors.

a. NZGL – NASA Zero-G Lever Lock Connectors have no commercial or military counterpart but uses the same inserts as the NATC. This is an EVA connector for ease of operation by a gloved astronaut.

b. NATC – NASA Threaded Coupling Connectors are derived from MIL-C-38000 Series III for shell sizes 9-25, odd shell sizes only.

SSQ 21636 Rack and Panel Rectangular Connector family (NRP) derived from MIL-C-83527 “ARINC” connectors used on airborne equipment. These are available in both crimp and solder contacts.

SSQ 21637 Umbilical Interface Electrical Connectors that are derived from GSFC specification GSFC-S-700-42. These are used as umbilical interface connectors in conjunction with mechanized (jackscrew or motor driven) mating device.

SSQ 22680 ORU Rectangular Connectors used to interconnect power and communications to Orbital Replacement Units (ORU) in an IVA or EVA environment. These are available in both crimp and solder contacts

SSQ 22681 rectangular Modular Connectors are used to interconnect the Remote Power Controller Modules (RPCM) in an IVA or EVA environment. These are available in both crimp and solder contacts.

SSQ 22698 for EVA/EVA compatible circular connectors. These are derived from the MIL-C-38999 circular breach-lock connector.

2.3 Relays and Switches

The use of flight proven switches and relays is highly recommended for all applications. A classic misapplication is the use of a 28 VDC or 125 VAC switch in a 120 VDC application. The inherent characteristics of commercial switches and relays may not be matched for operational use in the chosen space applications.

Concerns: Concerns associated with switch or relay use are primarily associated with misapplications.

Recommendation:

1. Select switches and relays so as to match their advertised voltage/current range for the application intended. Placement of high current contacts in low voltage or worst yet, a dry circuit application is a serious misapplication. A dry circuit is defined as one where current is less than about 1 ma such as in an audio, video or digital path. Gold contact surfaces are designed for a dry or near dry circuit application. Alternate materials used in this application can become resistive to the point that the switch will appear as an open to the load.
2. Select switch/relays that have a wiping action when their contacts are closed. This wiping action cleans debris and oxidation from the contacts that is particularly beneficial in low voltage/current applications.
3. Derate relay and switch contacts for their intended load. Inrush current for inductive loads at turn-on can be as much as 7-10 times the steady state current.
4. The high altitude reduced pressure environment (prespace) during launch and reentry reduces the dielectric strength of air. This reduction permits arcing across switching contacts at voltages greater than 50 VDC. Use of non-hermetic relays/switches in an EVA environment could be a serious misapplication.

2.4 Wire and Cable

Concerns:

Even Mil Spec wire can arrive with imperfections that can lead to hardware failures following use in a payload.

Careless selection of wire can result in over temperature conditions of the insulation that can release odors, jeopardize hardware performance and produce flammability concerns. The application of silver plating over a copper base material can encourage the establishment of a corrosion known as the red plague.

Recommendation:

To insure quality control of wire, the JSC Receiving Test and Inspection Facility (RITF) or the manufacturers test program should be applied according to JPG 8080 standard E-24.

The selection of wire and cable sizes and their circuit protection should be based on the derating guidelines of either SSP 30312 Appendix B, Electrical, Electronic, and

Electromechanical Parts Management and Implementation Plan for Space Station Program or TM102179, Selection of Wires and Circuit Protective Devices for STS Orbiter Vehicle Payload Electrical Circuits. The recommended wire is compliant with Mil-W-22759, Mil-C-27500 or Mil-C-17. Use of TM102179 does not provide a quick view for wire selection, it instead requires adherence to a selection process. The combination of wire and circuit protection sizes is selected for the sole purpose of protecting all interconnecting primary power wiring in the event of a worst-case or 'smart' short.

Definition: A smart short is defined as a sustained higher than nominal current flow that is under the threshold for current interruption by the protection device in a reasonable period of time.

Of the following 3 figures in TM102179, dated June 1991, associated with wire gauge, insulation temperatures and currents, only figures 4 & 5 are to be used for space flight hardware:

Figure 3 - single wire in 14.7 PSI for ground support equipment

Figure 4 - Single wire in a vacuum EVA application (200F ambient)

Figure 5 - Single wire in a pressurized IVA application (72F ambient)

An example of the maximum currents that are allowed by Figures 3 - 5 for a 22 American Wire Gauge (AWG) is:

Free air (Ground Use Only) - 23.0 amps

Payload Bay (EVA Only) - 9.5 amps

Cabin (IVA Only) - 10.4 amps

According to the wire selection process of TM102179, wire size selection must be performed in conjunction with the following variables:

- a. The type and value of circuit protection
- b. The maximum allowable insulation temperature rise
- c. The number of wires in a bundle
- d. The length of the wire dictates resistance and signal or voltage loss
- e. Assume circuit breakers/fuses will not trip/blow in a matter of minutes at 130 percent of their rated current and that "smart short" currents of at least 120 percent of the device rated value can be sustained. The design derating process must assure that wire insulation never exceeds its maximum rated temperature.

Conformal coating or solder tinning the ends of silver plated copper wire is required to prevent the red plague.

Where wire insulation is judged as unacceptable due to flammability considerations, an option may exist to fully over wrap the conductors with a flame proof tape like Kapton.

2.5 Fuses

The use of a fuse requires special attention. Its use implies more time to restore power, the need to handle small parts that can be released in microgravity and the necessity to access stowage areas. Like the circuit breaker, its function is to protect not just the load but also the downstream conductors. The quicker fuses are in general faster to respond than most circuit breakers.

The automatic reset capability of solid state devices forces the designer to consider the tradeoffs of an automatic and unobserved power restoration without an understanding of the overload condition vs. keeping the hardware in an unpowered state until some thoughtful intervention is provided or a person is present to observe events as power is restored.

Concerns:

Glass is a constituent of most fuses and a material that is prohibited on orbit unless it is suitably contained. The breakage of glass in a microgravity environment presents an acute hazard to the eyes of the crewmen.

Cartridge fuses leak to match the atmospheric pressure around them. Even hermetic fuses leak at a rate of as much as $10E5$ atmosphere/sec. Reduced pressure with the accompanying loss of oxygen and its quenching effect will permit an arc to be established across the gap of an open fuse so as to sustain current flow after an overload condition. For these reasons cartridge fuses cannot be used for applications at or above 50 V while in EVA.

Recommendation:

Consider all options other than the use of a glass envelope fuse including the use of ceramic fuses covered in heat shrink. One such option is a fuse compliant with Mil-PRF-23419.

Loss of convective cooling in microgravity requires that fuses be derated to 50% of their advertised current when in use on orbit. Fuses rated at values around or below 1/8 amp require still further derating to the level of 25%.

There is only one fuse that is approved for ISS 120 VDC use in a vacuum. This fuse, made by AEM, Inc., is physically large and somewhat expensive. Its part number is P600L.

At this time, the limited field of acceptable fuse types includes those compliant with Mil-PRF-23419. FM08 or FM12 fuses are permitted for vacuum or pressurized environments less than the nominal voltage of 28 VDC.

Call a EEE parts representative for consultation on all 120 VDC applications.

2.6 Circuit Breakers

Just as with wire and fuses, careful attention should be paid to selection of all types of circuit breakers. There are in general two types of circuit breakers, thermal and magnetic.

Thermal breakers utilize a bimetal strip that heats up and bends with applied current causing it to bend and trip the armature. Performance characteristics of these are altered by the surrounding temperature.

Magnetic breakers utilize a coil which trips the armature when the current or coil field is high enough. This technology will respond faster than thermal breakers for high currents and is far less susceptible to environmental temperatures.

Concerns:

Trip response curves can vary widely from one model to another and from one manufacturer to another. Given such variety, a circuit breaker selection can be made that allows the developer to match the device to its intended service. Inductive loads require use of a response curve that is that is relatively slower than the average response time to prevent false trips of the breaker, i.e. the device response should be delayed to accommodate the inrush condition of inductive loading. Since capacitors look like a short at the abrupt application of a voltage, there is an inrush of energy required to charge them to their applied voltage after which they store and release that energy as needed to maintain a voltage level. Inductors on the other hand store current and provide a release or kickback of this energy when their field collapses. Consideration of these traits will influence circuit breaker choice.

Circuit breakers may sustain their full rated current continuously at ambient temperature and even do so at current levels as high as 110% of rated current and possibly higher. However, the absence of convective cooling and the resultant elevated temperatures while on orbit will cause nuisance trips and drives a 50% derating of circuit breakers just as with wire.

Contact opening in the presence of DC voltages as high as the 120 VDC ISS voltage can produce an arc that can be very destructive to the device. For improperly chosen circuit breakers, sustained current flow may even exist across contacts that have opened following a trip condition.

Recommendations:

Do not use circuit breakers in 120 VDC applications that are not designed and tested specifically to that voltage level.

Consult relevant documents including TM102179 and its addendum letter TA-92-038, dated Feb. 22, 1993 for proper selection

Perform the required derating.

Call an EEE parts representative for consultation on all 120 VDC applications.

2.7 Batteries

Concern:

Batteries provide a source of energy and can become hazardous if a downstream component fails. The use of any battery and its charging protective circuitry draws attention from personnel associated with crew safety and such use must be approved by the JSC battery group.

Lithium batteries have particularly hazardous failure modes.

Recommendation:

Prepare to submit a full disclosure of the battery characteristics as well as any known history of prior use to the JSC battery group. Include in that disclosure all circuitry

associated with charging up to the primary voltage source, use of any protection diodes, current limiting devices in either charge and discharge paths as well as wire gauges in use. In addition, there should be a two fault tolerance where the threat of a catastrophic hazard exists and a single fault tolerance for a critical failure.

Avoid use of lithium batteries where there is any other alternative.

Reference JSC 20793 to find safety guidelines for payload batteries.

2.8 Power Supplies

Power supplies provide needed secondary voltages for circuitry while providing beneficial circuit ground isolation between primary and secondary voltages. In addition they can include over voltage and over current protection for downstream loads on the secondary voltages which complements the overload protection in primary power. Linear power supplies are larger in physical size, are much less efficient and have very little EMI production.

Other supplies known as DC/DC converters employ a chopper or oscillator and a transformer to change the incoming voltage to a lower or higher output voltage. These supplies are smaller, can have efficiencies over 85% and can produce significant amounts of EMI that may be filtered within the enclosure or left to the designer to find and cure.

Switching power supplies are functionally centered on a custom IC and may be packaged or even placed unpackaged on a PCB to elevate or decrease incoming voltage levels.

Concern:

Power supplies produce heat and can be one of the biggest reasons for using an enclosure fan.

The chopping nature of circuitry within these supplies can be at frequencies of several hundred KHz, producing transients that most always require filtering. Some DC/DC supplies are built with internal EMI filtering while others require external filters.

Sense lines connected to supply outputs right at the supply essentially defeat a good deal of regulation capability and establish the potential for low voltage circuitry to be operated outside of its voltage boundaries.

Connection of sense leads downstream of filter inductors or EMI filters should be avoided because it can permit the establishment of oscillations on the supply output.

Connection paths used for sense lines should not be interrupted while powered service is being performed. This can result in over voltage conditions on the load circuitry.

Soft start circuitry on the input of some supplies can jeopardize successful power up if their delay is too long.

Recommendation:

ISS applications do not allow the discharge of heat directly to the cabin air and any heat transfer to the cabin air can not exceed a limit. However, STS applications will allow this payload air discharge to the cabin air. Hardware to fly first on the STS and then be transferred to an ISS location needs to take both of these constraints into consideration.

Use of EMI filters that are external to the supply and produced by the supply manufacturer to fit their unique needs is highly recommended.

Power supplies or converters with exposed die on the inside should receive PIND just as with hybrid devices.

Supply output sense lines should be connected at the load particularly where excessive supply output wire lengths are involved and at the largest load where referencing is difficult or there exists a wide variance from light to heavy loads.

Apply thermal grease or other heat transfer aids to the mountings of these supplies
Perform the required derating.

2.9 Electrical Isolation and Bonding

Concern:

The integrity of vehicle and habitat power distributions systems can be compromised by wiring and selection of devices that do not maintain the required electrical isolation above structure (chassis) reference.

Poor and improper grounds for connector interfaces can allow the release of EMI, encourage intermittent hardware behavior and elevate hardware susceptibilities to otherwise tolerable disturbances. These conditions not only endanger hardware mission success but they can consume crew time due to operational irregularities thereby taking them from more productive endeavors.

Poor connections in power leads can cause appreciable heat production which creates not just a crew touch hazard but may elevate temperatures of materials leading to production of odors or worse.

Recommendation:

Adhere to program documentation such as NSTS 21000 IDD MDK for STS operation.
Adhere to program documentation for ISS operation such as SSP 30240 entitled Space Station Grounding Requirements and SSP 30245 entitled Space Station Electrical Bonding Requirements.

Ensure electrical isolation from the structure in excess of applicable values that depends on the intended hardware habitat and is never less than 1 Meg ohm.

Insure electrical bonding for ground interconnections that can be less but should never be more than 2.5 milliohm. Measurement of these levels requires use of a special instrument like that of a four point resistive measurement to cancel minute but contributing errors in instrument leads.

2.10 Edge Card Connectors

Edge card connectors should not be used. This connector type uses conductive fingers plated on the edge of a printed circuit board to pass signals to and from the PCB.

Concerns:

1. This connector interface is open to the environment and generally defies use of a conformal coating to cover exposed metal. There is no barrier to stop conductive debris from shorting between connector contacts.

2. This connector type cannot stop the ingress of moisture or prevent condensation from shorting between connector pins.
3. This connector is open to all conductors and could be susceptible to corona discharge in a low-pressure environment.

Recommendation:

The preferred replacement is a MIL-C 55302 edge connector or its commercial equivalent.

Selection and use of a pin header style of card connector interface is preferred.

Select connectors with materials immune to corrosion and flame resistant.

2.11 IC Sockets

Concerns:

There is an inherent vulnerability in the socketed part to moisture and conductive debris at the interface of pins and contacts.

Retention of the part in its socket can not be certain when exposed to a vibration environment.

The use of sockets brings with it the potential for galvanic corrosion due to metal dissimilarities between that of leaded parts and the socket conductors themselves. The selection and use of two materials that differ in potential by more than 0.25 volt according to SSP 30213B standard M/P-4 and Table I page 3-6 of SSQ 21678 or its form found elsewhere should not be placed in contact with one another.

The use of conformal coating to mitigate some of the threats above has a high probability of contaminating the socket to part interconnects.

Recommendation:

If a socket must be used, consider an application of a high consistency Room Temperature Vulcanization (RTV) staking. Measures must be taken to prevent RTV leaching into pin/socket interfaces. Be wary of thick applications as it may affect heat dissipation of the device.

Select sockets with gold plated leads where possible.

2.12 Material Plating

Several metallic materials are disallowed for use in flight hardware. With regard to electronic parts, pure tin, silver and cadmium are problematic.

Concerns:

Pure tin has an ability to grow dendrites or conductive whiskers capable of establishing a shorting path between conductors either as an attached or a floating entity. Tin plating may be applied within a component enclosure and not evident on the outside. The designer should investigate this possibility as these minute conductors may cause problems over time.

Pure silver can also grow dendrites but it is much less prevalent than that of tin. Silver plated copper wire is also associated with a condition called the red plague in the presence of moisture. This condition is a galvanic corrosion that is first established at the exposed junction of silver and copper and it initiates a serious degradation of the conductor. For this reason, soldered attachment of a pin or socket is always used over the crimped alternative.

Cadmium has the ability to sublime into a toxic gaseous state if its temperature is elevated at any time to 250 deg F (120 deg C). This temperature is well under the rated temperatures of approved wire insulations thereby reinforcing the need for a cadmium prohibition as today's wire gauge selections often take advantage of insulation temperature tolerances. Reduced pressure or EVA exposure may also accelerate this process.

Recommendation:

Consider soldering the unprotected ends of silver plated copper conductors.

Consider conformal coating or other exterior measures of protection to mitigate the presence of tin on an exterior surface. Consider the use of tin that has at least a 3% composition of lead to prevent dendrite growth.

Obtain program literature for material prohibitions such as NASA-STD-6001, JSC 27301D and JPG 8080.5 and adhere to them.

2.13 Audible Alarms

Concern:

Use of improper audible alarms for payload operations can confuse the crew and cause delayed responses to experiment operations or more vital station keeping and life support systems.

Recommendation:

Payloads must comply with the standards of SSP 50005C for use of tones and tone sequences. Some tones and tone sequences are prohibited as identified in SSP 50005C section 9.4.4.3.4.1. Hardware nominal or off-nominal processes that warrant an audible notification should be reviewed by safety and crew support personnel.

2.14 Colored Indicators

Concern:

Selection and use of displays with improper contrast, illumination or information can disrupt experiment operations or jeopardize its success by causing confusion and delaying responses. Off-nominal hardware processes that warrant a visual notification should be reviewed by safety and crew support personnel.

Recommendation:

Review the criteria of SSP 50005C the ISS Flight Crew Integration Standard for adherence to design requirements.

2.15 Ribbon Cable

Concerns:

Typical wire insulation on ribbon cables is flammable and is therefore prohibited in flight hardware.

Distributed capacitance along the length of a ribbon cable is a factor that can affect the shape of waveforms thereby compromising hardware performance.

Improper installation of Insulation Displacement Connectors (IDC) at the cable ends can either bridge adjacent circuits or make poor and intermittent connections.

Recommendations:

Identify a source of suitable cable, such as manufacturers of Teflon insulated ribbon cable.

Insist upon a full prototype evaluation to determine if signal transmission through ribbon cables is relatively uncompromised and free of unexplained anomalies.

Favor use of tools recommended for IDC connector installation.

2.16 EMI Filters

Selection of EMI filters should take into consideration the nature of the offending signal, currents involved, physical constraints as well as the source and load circuit impedances.

Concern:

Deployment of EMI filters can be very problematic if their need is discovered when the hardware is in its qualification configuration and has entered the formal and near final testing required to characterize its EMI. Payloads with cyclic or pulsing high current demands such as those characteristic of chopping motor controllers, DC/DC converters and Pulse Width Modulated (PWM) drivers can require aggressive use of filtering techniques including common mode chokes, LC filters, capacitor banks, or load balancing schemes.

Recommendation:

Prudent designers take the extra measures in early design to address the routine appearance of EMI issues. Transient absorption devices like ferrite beads, reverse biased diodes, semiconductor transient absorption devices, localized linear regulators, Metal Oxide Varistors (MOV), high speed transient voltage suppressors, neon bulbs, gas discharge tubes and liberal use of decoupling capacitors in the range of 0.1 to .01 uF are common solutions. Generally a combination of these corrective actions will provide the best solution particularly when placed right at the problem source and before it can be coupled into other circuitry.

Common mode chokes are widely available and highly recommended on the input lines as conducted noise is often differential in nature.

MOVs are about the most responsive device that can be applied to transients although they should be properly selected and fused. See a dedicated section in this guideline.

The three lead linear regulators are very inexpensive, relatively small and can offer very good transient and low frequency ripple control. A localized distribution of these will

help address EMI conditions and minimize the propagation of conductive interference from board to board.

Neon bulbs like gas discharge tubes provide clamping action and serve well to absorb strong pulsed transients. However, their response is not among the highest measures available.

The collapse of field energy within all inductors like relays, solenoids and even DC motors should be addressed by placing a properly sized silicon diode across the coil in the reverse direction of nominal current flow.

In all cases the use of twisted wires for power distribution is most highly recommended with the intent of twisting each voltage supply leg with its current return conductor. Plus and minus 12 or 15 VDC should be twisted with its common. Overall shielding around these conductors provides an additional measure of extreme importance. The practice of twisting and shielding should be applied to signal conductors as well.

Precautionary placement of decoupling capacitors are common practice and should be applied at each IC power pin. The values around 0.1 and .01 are considered optimal for low lead inductance, small size and reasonably high capacitance. Do not disregard use of these capacitors where recommended or found in application notes.

Perform the required derating.

Ferrite Beads & Toroid Cores

These devices have no known drawbacks but they do have some limitations. Much like a decoupling capacitor lowers transient energy at progressively higher frequencies, these beads and cores suppress transients with little to no weight and installation penalties. They can however saturate like an inductor at high current levels and lose some effectiveness. Prior to those levels, they provide significant attenuation for signals greater than about 10 MHz that are anticipated or found in EMI testing when time to hardware completion is minimal.

Some core mixes are conductive and most will break. They should then be protected against the vibration that might damage them and the freedom of movement that allows bridging between conductors.

Recommendation:

Although their core mix can be ideally selected for the offending frequencies, their deployment can be considered safe and highly recommended on power leads where low permeability is best and particularly on low frequency analog signal lines and control leads where high permeabilities are best. Do not place these on digital signal lines as they will compromise the waveform.

Caution should be exercised when using multiple cores and wrapping turns upon a core for an increased benefit as they do act like a series inductance. Extra inductance can encourage ringing with the right excitation.

Consider them as one of the least troublesome quick fixes.

2.17 Resistors

Concern:

Careless selection from among available resistor technologies may lead to undesired circuit variances and unexplained or misunderstood loss of functionality all of which can compromise payload mission success.

Resistors with exposed Nickel Chromium are subject to corrosion and loss of function.

Recommendation:

Select the proper resistor with regard to its intended application.

Perform the required derating.

Although **carbon resistors** enjoy the lowest cost, their temperature coefficients are relatively high for extended temperatures and they have the highest noise level.

Wire wound resistors offer the highest precision and can be found in three categories, high power, high accuracy and general purpose. Although the inductance of these devices must be considered when they are in use and their resistive range is somewhat limited, their characteristics can include high accuracy, relatively low temperature coefficients and long-term stability.

Metal film resistors are suitable for most demanding applications. They offer very low temperature coefficients, wide resistive range, the lowest resistance value, extremely low noise figures, popular power ratings, and excellent long-term stability.

Carbon film resistors uniquely offer for their low price very high resistance values and a negative temperature coefficient when needed. Surface contaminants on resistors above about 10 Meg ohms will affect their value.

Resistor arrays offer higher density packaging in a variety of configurations. Designers should note that the total package power dissipation is less than the sum of dissipation by the individual resistors within and that circuit isolation may be compromised due to the close proximity of resistive elements within that package.

Keep in mind that resistors are noisier at higher temperatures.

Perform the required derating.

2.18 Hybrid Devices

The relatively custom low volume production of some hybrid manufacturers suggests the potential for inattention to manufacturing cleanliness practices.

Concern:

There is a potential for release of conductive particulates within their enclosure.

Recommendation:

Consider use of a getter or potting of the contents.

Screening of these devices is recommended and PIND for the unspotted hybrids is a test that is highly recommended.

2.19 Metal Oxide Varistors (MOV)

MOVs are an inexpensive nonlinear resistive device that absorbs circuit transients. MOVs are particularly attractive where a fast response is needed.

Concern:

The resistance of an MOV decreases with increasing thermal or voltage stress such that more of the applied energy is absorbed as that stress increases. The primary failure mode with this characteristic is initially a short that can be followed by an open condition. This process may be accompanied by substantial smoke production.

Recommendation:

Selection should utilize a 10 to 25% derating rule of thumb above the applicable maximum DC or sinusoidal AC rating. If the device is to be applied across a non-sinusoidal AC waveform, the VAC rating of the selected device should be the next lowest rating found by dividing the RMS voltage of the applied waveform by a factor of 1.4. Some manufacturer's literature suggests a fuse be placed in series with the MOV to mitigate a potential failure. It is suggested that the value of this fuse can be a 0.5 amp slow blow device.

2.20 Fans

The absence of convective cooling on orbit can be addressed with the addition of fans.

Concern:

Fans without air filters in microgravity can easily ingest or discharge particulates and fluids at a crewman and into the habitable volume.

Unguarded fans can ingest larger items left to float about the cabin that can cause rotor lockup resulting in hardware overheating.

Unguarded fans can permit entry of a crewman's finger.

Fans are serious producers of acoustic noise and moderate producers of EMI.

Since the crew must work as well as sleep in an environment whose noise is determined by the accumulative affect of all hardware, each payload must comply with a maximum acoustic noise emission level.

Fans most always utilize wire insulation like Polyvinyl chloride (PVC) that is not approved due to its flammability characteristics. For that reason, this wire should be replaced with an approved wire at its point of attachment to the fan or as close to that point as is possible.

Designers are often unaware that fans must accommodate a locked rotor condition without creating a hazard.

Recommendation:

Use air filters for all fans to allow for periodic cleaning and provide protection against particulate entry.

Add fan guards to all fans mounted near accessible exterior surfaces. Conductive guards, grills or screens can not only prevent the ingestion of materials that might occlude airflow but they can help reduce EMI emissions from an otherwise open cavity. Use of brushless fans is preferred due to the production of EMI by fans that use brushes. To address the small but appreciable production of EMI by even brushless fans, a decoupling capacitor of around 0.1 uFd should be applied to its terminals.

Audible fan noise can be suppressed in several ways. Placement of the fan at right angles to the hardware front puts the noise production around a corner providing some suppression with little effect on airflow. Adding nonflammable noise abatement foam will further attenuate audible noise.

Intentionally selecting a fan somewhat larger than needed and then running it at a reduced voltage and hence a reduced speed will help with noise emission while maintaining the desired airflow. Using a fan speed controller with its sensor placed at heat production areas will provide cooling when it is needed and therefore fan noise only when the fan is running. These controllers are now available as ICs.

2.21 Cavity Devices

Cavity devices can include but are not limited to hybrids, EMI filters, crystals and crystal oscillators, transistors, switches, relays, circuit breakers, thermostats and some DC/DC converters.

Concern:

The manufacture of these devices have processes that can allow release of conductive and insulating particulates within the sealed enclosure that are free to float about to create shorts or open conditions. These can in turn compromise performance in a microgravity environment.

Recommendation:

Screening for particulates is called Particle Impact Noise Detection (PIND). Ground use of contaminated devices provides a false sense of security, as there is less particulate migration and a bit more predictability of particulate location. If available, the use of a getter material within the enclosure is a desirable option.

2.22 Semiconductor Heat Transfer

Semiconductors like power FETs, transistors operational amplifiers and diodes in a TO-264, TO-247, TO-220 or TO-3 package may dissipate significant levels of heat particularly if they operate in a linear region or support fast switching speeds. Heat produced at the device junctions must be effectively removed if the device is to operate at its rated power dissipation.

Concern:

Designers frequently overlook the need to transfer heat from semiconductors while they may be careful not to exceed the more obvious current and voltage boundaries.

Recommendation:

The use of approved thermal grease or wafers of mica and silicone are required to prevent failure of the device just as if it could be exposed to over voltage or over current conditions.

It is also recommended that the developer perform a thermal analysis of the assembled payload considering the absence of convective cooling and design in reasonable margins required for reliable performance.

2.23 Lead Based Solder

Although discussions are underway, and we are getting pressure from Europe and Japan, the tin lead composition solder is still permitted and preferred for production of flight hardware.

Alternative alloys being considered require more heat that can impart stresses on the parts.

3.0 Manufacturing Processes

Several NASA workmanship standards that are considered important to hardware fabrication should be made available to the manufacturer where they are applicable. Here is a list of the important ones:

- NASA-STD-8739.1 Workmanship Standard for Staking and Conformal Coating of Printed Wiring; Board and Electronic Assemblies
- NASA-STD-8739.2 Workmanship Standard for Surface Mount Technology
- NASA-STD-8739.3 Requirements for soldered Electrical Connections
- NASA-STD-8739.4 Crimping, Interconnecting Cables, Harnesses, and Wiring
- NASA-STD-8739.5 Fiber Optic Termination's, Cable Assemblies and Installation

Alternative IPC standards on workmanship are judged acceptable by NASA. The IPC categorization of Class 3 is the most stringent and best suited for space flight.

IPC - Interconnecting & Packaging Electronic Circuits 847 509-9700 in Illinois

- | | |
|----------------------------------|--|
| ANSI/IPC A-610B | Acceptability of Electronic Assemblies (a key reference providing detailed acceptance standards) |
| J-STD-001B | Requirements for Soldered Electrical and Electronic Assemblies (Classes of workmanship - class 3 denotes superior work, vs. class 1 which is lower grade.) |
| IPC-HDBK-001 | Guide to the Requirements for Soldering |
| Soldering Materials Specs | |
| J-STD-004 | Requirements for Solder fluxes |
| J-STD-005 | Requirements for Soldering Paste |

J-STD-006	Requirements for Electronic Grade Solder Alloys and Fluxed and Non-Fluxed Solid Solders for Electronic Soldering Applications
IPC/JEDEC-STD-020A	Moisture/reflow sensitivity classifications for nonhermetic solid-state surface mount devices
IPC-325	Drawings
Printed Circuit Board	
IPC-A-500	Guidelines for Acceptability of Printed Boards
IPC-2221	Generic Standard on PWB Design, March 1998
IPC-2222	Sectional Standard on Rigid PWB Design, March 1998
IPC-6011	Generic Performance Specification for Printed Boards, July 1996
IPC-6012	Qualification and Performance Spec. for Rigid Printed Boards, July 1996
IPC -6013	Qualification and Performance Specification for Flexible Printed Circuit Boards

3.1 Conformal Coating

Conformal coating is vital to space flight hardware for two main reasons. (1) Flight hardware can have conductive debris in them that will cause few concerns until we enter a zero-g environment. If printed circuit boards are not coated then the hardware is at risk that a short will occur. (2) Condensation will form on surfaces while on orbit. The formation of condensation on printed circuit boards of a payload will provide a conductive path and a stimulus for corrosion. For hardware used in a pressurized environment, JSC has used an RTV like the Dow Corning 3140 and 3145 with success. It is a silicone-based coating that can be applied by spraying, brushing or dipping and it is soft enough to remove when necessary. The ISS program also uses a lot of Polyurethane coatings. Polyurethane works well in an un-pressurized environment where EVA payloads may offgas more freely. A product called Para-Xylylene Dimer (Parylene) used for IVA applications also has favorable characteristics. This product requires a vapor deposition and is very resilient. Use of type ER - Epoxy coatings is discouraged because of removal difficulties and the risk of damage to fragile parts with varying coefficients of expansion.

3.2 Surface Mount Technology (SMT)

While SMT offers the tempting advantage of reduced size and weight, these powerful benefits do not come without a cost.

Concerns:

Miniaturization requires use of special equipment and training.

The application of heat provides thermal stresses to components with the associated reliability and performance degradation.

Contamination can jeopardize payload operations if not addressed during manufacture. Hand soldering of surface mount components is hazardous to the components themselves. Failure to provide preheating of the board as well as its components can induce mechanical stresses in small parts as they cool. Parts will expand slightly when heated and attached to a board. Contraction of this part on a board that did not receive similar heating can result in part failures that are not observed without visual aids.

Recommendation:

Personnel working with SMT should be trained to do so. Information on a training option is available in the next section.

Review and understand a readily available standard for (SMT), i.e. the IPC-A-610 or the earlier NASA STD 8739.2 entitled Workmanship Standard for Surface Mount Technology.

Exercise care during the application of heat for component installation.

Adopt practices that prevent contamination to the board surface.

Higher board yield will require use of the proper equipment and training.

3.3 Training for manufacturing skills

Building for hardware reliably is as critical as selecting the right parts. To build reliable hardware the team needs expertise in soldering, cable making, wire harnesses, conformal coating, and electrostatic discharge controls. The JSC S&MA organization teaches these classes without cost to any outside hardware builders who are on a JSC contract. The training coordinator is Kathleen Alaniz at (281) 483-0666. The available classes can be found at site: <http://wwwsrqa.jsc.nasa.gov/ritf/ritfhome.htm>. The cost to you would be the motel and transportation to get to JSC. Most of these classes last about a week.

There are also IPC training classes available around the country but there are training costs associated.

4.0 EMI Considerations

The EME team has a web page that contains lots of valuable information at - <http://www4.jsc.nasa.gov/org/ev/emc/analysis/index.html>

There are many ways to deal with EMI. The favored approach is to stop it at its source rather than to try to suppress its presence throughout the assembly. The twisting of wire pairs is a valuable solution that can be overlooked and be considered a rule for good hardware design. Next to the twisting of wire, the shielding of wire and preferably the use of both techniques, i.e. the twisted shielded wire will provide the best safeguards against what cannot be readily foreseen. These options prevent the coupling of EMI by a release from the source conductor as well as a receipt by the receiving conductor. High impedance circuit inputs or unbalanced unterminated conductors have the highest

susceptibility to coupled interference as the path to ground for sinking of all signals, intended and unintended, is a high impedance. Strategic placement of conductive barriers for partitioning within the assembly is an option.

In general, electrostatic and electromagnetic emissions both conducted and radiated are areas that will have to meet governing specifications. Conducted emissions provided to the payload from the power source may cause interference with the normal operation of a payload, potentially leading to loss of a payload's mission. Similarly, conducted emissions that are produced at the payload can be a disturbance to not only other nearby payloads but to more critical hardware sharing that power distribution source.

The susceptibility a payload has to the surrounding radiated and conducted interferences is not generally an area of concern to any entity other than the payload itself and its mission. However, intentional radiated emissions from other sources, such as Station communications or navigational systems, as well as from other payloads with or without RF communications functionality may interfere with operation of a payload.

Unintentional radiated or conducted emissions from a payload, if not in compliance with narrow and broadband limits, could cause interference with vital on-board communications or navigational equipment, as well as with other mission dependent hardware items or even other nearby payloads. Radiated emissions from a payload may be impressed on nearby conductors serving other hardware that have a particular susceptibility at those radiated frequencies. Conducted emissions from an offending payload may be impressed on power distribution conductors such that a nearby load or one sharing that power source is detrimentally affected.

The fast rise and fall times associated with the switching of digital circuitry can be a significant source of both radiated and conducted emissions. These emissions may be found at the fundamental switching frequency or at multiples of that frequency many decades away from the fundamental frequency. Due to the low currents involved, the disturbance is primarily of the electrostatic variety. Missing, improperly selected or improperly designed filters can allow the passage of undesirable frequencies from one subassembly to another or from one major rack assembly to another. The careless addition of an inductor in buss power filters can even produce a ringing condition on the supply voltage which receives its excitation from the alternating digital loading or switching power supplies. Like digital circuitry, DC/DC converters, particularly those supporting higher currents, add a significant electromagnetic component to the EMI offences. Proper positioning, shielding, wire twisting, filtering and grounding are the tools available to a developer to be used as insurance in early design to minimize the appearance of surprises when completed hardware is exposed to costly program required testing.

Often, unintentional radiated emissions are caused by a combination of poor shielding, poor enclosure design, and/or poor grounding or bonding practices. For example, designers should be wary of cable shield terminations that utilize a single conductor tied at the end of an over-wrapping cable shield. To realize the benefit of a cable shield, there must be a minimum of series inductance in the ground return path for this shield. Drain lead lengths and the number of metallic junctions for shield terminations must be

held at an absolute minimum to insure this objective. In addition, conductive paths with large surface areas are required to drain to ground the offending higher frequencies. For this reason the full contact benefit of metallic connector back shells and strain relief accessories are recommended over the use of a single wire drain. Should it be necessary, very short drain pigtailed from the shield to an adjacent screw on the strain relief clamshell may suffice if the designer cannot use the optimal approach above. However, weaknesses of this approach will not be known until the finished hardware enters the test chamber at a time when rework may not fit the schedule.

In general, simple capacitance applied to the ground reference, and simple bypass capacitances are not sufficient to pass EMI radiated and conducted test requirements. The differential and common mode form of conducted emissions is best addressed by EMI filters that are specifically designed to control both of these modes.

For a qualitative investigation of radiated EMI from cables and assemblies you can use a near field EMI probe and sources of them can be found with a search of the web. These hand held devices are made for band segments of electrostatic and electromagnetic emissions. They are connected by coax to a scope input where the user monitors relative values of coupled energies as he probes the equipment. A few sources include:

www.aratech-inc.com

www.bkprecision.com

www.com-power.com

www.electro-metrics.com

WWW.emctest.com

www.fischercc.com

Companies associated with EMI conditions include those identified at this location:

<http://www.emclab.umr.edu/products.html>

5.0 Design References and Safety

Although the entire standard Space Station Program Design Criteria and Practices, SSP 30213, is applicable to ISS hardware, the following highlighted standards represents those that receive frequent discussion. This list is not intended in any way to diminish the importance of standards not mentioned:

G-04	Protection of Spacecraft Electrical and Mechanical Systems from Debris
G-07	Intermittent Malfunctions-Prohibited Use of Equipment
G-09	Shatterable Material-Exclusion from Habitable Compartment
G-10	Control of Limited Life Components
G-21	Spacecraft Equipment-Moisture Protection
G-25	Thermal Design and Analysis-Thermal Parameters
G-27	Fire Control

G-33	Surface Temperatures
E-01	Mating Provisions for Electrical Connectors
E-03	Electrical and Electronic Devices-Protection from Reverse Polarity and/or Other Improper Electrical Inputs
E-04	Electrical Connectors-Moisture Protection
E-06	Corona Suppression
E-09	Electrical Circuits-De-energizing Requirement
E-11	Protective covers or Caps for Receptacles and Plugs-Electrical
E-12	Electrical Connectors-Disconnection for Troubleshooting and Bench Testing
E-14	Electrical Wire Harnesses-Dielectric Tests
E-15	Electrical Power Distribution Circuits-Overload Protection
E-17	Electrically Radiated and Conducted Interference
E-19	Potential Hazard of Relay/Contactor Remake
E-20	Control of ESD for Electronic Parts and Assemblies
E-21	Electrical Connectors
M/S-01	Equipment Containers-Design for Rapid Spacecraft Decompression
M/S-03	Wire Bundles-Protective Coating
M/S-05	Threaded Fittings-Restrictions on Release of Particles and Foreign Material
M/S-06	Exposed Sharp Surfaces or Protrusions
M/S-07	Windows and Glass Structure
F-14	Habitable Module Ventilating Fans-Protection from Debris
P-03	Wire Splicing
M/P-01	Material Selection, Review, and Drawing Signoff
M/P-02	Flammability of Wiring Material
M/P-03	Toxicity of Materials Used in Crew Compartments-Wire Insulation Ties, Identification Marks and Protective Covering
M/P-04	Metals and Metal Couples-Restriction on Use
M/P-06	Toxicity- Requirements for Nonmetallic materials Proposed for Use Within Crew Compartment
M/P-07	Material Detrimental to Electrical Connectors
M/P-10	Liquid Locking Compounds, Restrictions, and Controls
M/P-16	Restriction on Coatings for Areas Subject to Abrasion
M/P-18	Etching Fluorocarbon Insulated Electrical Wire

Additional Excerpts from Design Standards

Compliance with JSCM 8080 Standard E24 is highly recommended
SSP 50431 Space Station Program Requirements for Payloads

Additional Excerpts from Safety Standards

NSTS 1700.7B Safety Policy and Requirements
NSTS 5300.4 Safety Reliability, Maintainability and Quality Provisions for the Space Shuttle Program

6.0 Cable Fabrication Techniques

The developer should secure and follow the guidelines found in:
NASA-STD-8739.4 (formerly NHB 5300.4(3G-1)) Crimping, Interconnecting Cables,
Harnesses, and Wiring

NASA-STD-8739.3 (formerly NHB 5300.4(3A-2)) Soldered Electrical Connections

IPC/WHMA-A-620 Requirements and Acceptance for Cable and Wire Harness
Assemblies

See Appendix A for further information

7.0 Questions To Ask When Buying COTS Hardware

The purpose of this checklist is to provide guidelines when selecting Off-the-Shelf
(OTS) hardware.

1. Do the materials meet the outgassing and flammability requirements of the applicable program, ISS or STS. Reference materials include:
 - NASA-STD-6001 (old NHB 8060.1C) Flammability, Odor, Offgassing and Compatibility Requirements and Test Procedures for Materials in Environments that Support Combustion
 - NSTS 22648 Flammability Configuration Analysis for Spacecraft Applications
 - SSP 30233 Space Station Requirements for Materials and Processes
2. Ask about company quality control processes. Successful completion of government contracts, prior space flight hardware production and particularly compliance with Mil 9858A standards will be of interest.
 - a) Does the manufacturer have evidence of a quality system that provides repeatability, corrective actions and controls the purchase of materials and electrical parts?
 - b) Does the manufacturer require qualification of vendors or do they simply buy from the lowest bidder?
 - c) If multiple units are purchased, will all units have the same configuration? How is this controlled?
 - d) Beyond the procurement issues, how does the manufacturer maintain and use their manufacturing procedures and resolve concerns and materials issues during manufacturing.
3. Where a parts list is available with the COTS assembly, a review can be performed to determine the presence of problem parts. A Government Industries Data Exchange Program (GIDEP) search for the listed parts will determine if any should be changed OR if expanded testing is to be performed in conjunction with the retention of suspect parts. These findings will be dispositioned with the

- possible outcomes of acceptance, replacement, increased sparing, special screening or alternative considerations.
4. Have the manufacturer's "designed to" limits and safety margins been evaluated against the worst-case in-flight use and program safety requirements. Environmental differences including the lack of heat convection, extremes of temperature, atomic oxygen and cosmic radiation should be considered.
 5. Ask the manufacturer to provide a copy of the schematic diagram. Retain the schematic for the time when a failure is to be investigated and better understood.
 6. Ask the manufacturer to provide a failure history (field and in-house settings) showing a time-line of which components failed, when failures have occurred, circumstance regarding the failure, and the suspected cause. Seek the manufacturer's help to understand any trends that may indicate a concern needing resolution for the intended flight application.
 7. Ask for a copy of a flow diagram depicting the firmware or software coding or a functional block diagram of the firmware or software code. This material will facilitate the definition of a full functional check as well as the diagnosis of concern areas before and after a failure.
 8. Hardware procurement specifications must clearly describe all critical high and low level hardware functions so that receiving inspections or functional checkouts at the time of delivery can verify the item was proper on its arrival.
 9. Seek assurance that an evaluation has been performed on the design being purchased. Does the company use electrical and mechanical part derating guidelines that are a part of their design processes? If so, understand the guidelines/derating criteria used for that evaluation. Secure a copy of this material for the file as it will be a key factor in anomaly reviews. If an analysis of the parts derating surfaces troubling conditions, the options exist to exchange a part, subject the assembly to extensive testing or to withhold its approval for use. When required, additional tests will include an examination of its ionizing radiation susceptibility as well as a thermal cycle protocol. This later test must include multiple cycles varying within the temperature range of freezing to a level just below its maximum storage temperature. The hardware will be powered on and off at freezing temperatures as well as powered on and off at a level defined as its lowest known maximum component temperature less a guard band of approximately 15 deg F.
Is a copy of the manufacturers stress analysis available for review? If the manufacturer has performed similar tests, then portions of the testing described above may be waived.
 10. Determine if the manufacturer will make use of an in-line and acceptance test plan which details all the testing performed on the hardware and at what

- temperatures they were performed. Understand what, if any functions are not tested by the manufacturer prior to shipment. It is best to have the manufacturer perform as much testing as possible to detect concerns before the hardware is delivered.
11. Obtain a recognized software computational aid for reliability predictions, a copy of PRISM software or a field failure experience Mean-Time-Between-Failure (MTBF) evaluation or an MTBF based on a controlled system life test by the manufacturer. In the absence of an analysis performed by the manufacturer, one provided by the project may be warranted prior to hardware use.

A valuable link to designers aids:

<http://www.electronic-assemblies.com/electronic-assemblies/>

Acronyms:

AWG- American Wire Gauge
DC- Direct Current
DWV- Dielectric Withstanding Voltage
C- Celsius
COTS- Commercial Off The Shelf
EMI- Electro-Magnetic Interference
EVA- Extravehicular Activity
F- Fahrenheit
FET- Field Effect Transistors
GIDEP- Government Industries Data Exchange Program
IC- Integrated Circuit
IDC- Insulation Displacement Connectors
IPC- Institute for Interconnecting and Packaging Electronic Circuits
ISS- International Space Station
IVA- Intravehicular Activity
JEDEC- Joint Electron Device Engineering Council
JSC- Johnson Spacecraft Center
KHz- Kilo Hertz
LC- Inductance Capacitance
LCD- Liquid Crystal Display
MHz- Mega Hertz
MOV- Metal Oxide Varistors
MTBF- Mean Time Between Failure
NASA- National Aeronautics and Space Administration
NATC- NASA Threaded Coupling Connectors
NRP- NASA Resource Protection
ORU- Orbital Replacement Unit
OTS- Off The Shelf
PCB- Printed Circuit Board
PIND- Particle Impact Noise Detection
PSI- Pounds per Square Inch
PVC- Polyvinyl Chloride
PWM- Pulse Width Modulated
RITF- Receiving Inspection Test Facility
RPCM- Remote Power Controller Module
RTV- Room temp Vulcanization
SMT- Surface Mount Technology
S&MA- Safety, and Mission Assurance
STS- Space Transportation System
TM- Technical Memorandum
UV- Ultraviolet
VAC- Volts Alternating Current
VDC- Volt Direct current

APPENDIX A

**TERMINATION OF SHIELDED CABLE / HARNESSES
FOR USE IN HIGH-RELIABILITY AND SPACE FLIGHT APPLICATIONS**

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ABSTRACT

In applications where cables and harnesses are located in, or routed through, environments with high electromagnetic noise or interference levels, an electrically-neutral-referenced metallic shield structure is effective in providing noise isolation to the internal conductors. Typically supplied in the form of a braided wire sleeve or foil-mylar wrap tube which completely encircles and covers the conductors, the shield structure functions as a "Faraday cage" to protect the internal conductors from spurious signals and unwanted electrical / electromagnetic fields. Shields are not considered a structural strength component of a cable or harness, and for design and safety reasons are not allowed to be used as current-carrying conductors.

KEYWORDS

Braid, faraday-cage, floating, mylar-film, pick-off, shield

DISCUSSION

Cables and harnesses requiring protection from external electromagnetic noise or interference can be protected by the use of a simple metallic shield which is electrically connected to the system ground. Typically, this shield is in the form of a braided wire sleeve or foil-mylar wrap which completely encircles and covers the conductors, and may be supplied as an integral component of a manufactured cable (i.e.: 1 or more braided wire or mylar-film layers), or as an over-sleeve component (i.e.: braided wire) of a built-up harness / cable.

The shield primarily functions as a "Faraday cage" by completely enveloping a cable or harness's conductors in an electrically-common metallic structure, providing noise isolation and an effective means to distribute a unified ground reference through the entire system. The cable or harness system should be designed to prevent the introduction of ground effects (ground loops or current flow between dissimilar ground reference potentials) by bonding the shield to a single-point ground reference.

Whether terminated to a connector or as part of a hard-wired harness, the proper attention to detail in the design and termination of the shield will result in a robust cable or harness.

A. DESIGN CONSIDERATIONS

1. The cable-connector termination should be designed to provide sufficient stress protection to the individual conductors to prevent overstress to the conductors or to the terminations in the event the cable is subjected to an axial load stress (pull or kick load).
2. The conductor-connector termination shall be sized to ensure that each conductor fits in the corresponding termination pin without modification. Conductors and/or terminators shall not be modified to fit.
3. The termination of shielded cable systems shall prevent the introduction of ground effects (ground loops or current flow between dissimilar ground reference potentials). Shields should always be bonded to a single-point ground reference.
4. Shield structures (braid or mylar-film) are safety devices and shall not be used as current or signal carrying conductors.
5. Shield terminations should be designed to provide electrical continuity between the connector body and shield structure. The transition / pick lead should be as short as possible to reduce unwanted EMI, with the transition / pick lead located such that the mechanical transfer between the connector body and cable structure is not compromised.
6. Connectors should be assembled per engineering or manufacturer instructions.
7. The shield termination should be located as close to the end of the cable and connector as possible, but should not be located in a position that will result in it being crushed by the connector's cable clamp or compression fitting.
8. Cable clamps or compression fittings should be torqued to specification and should have no sharp edges or protruding hardware which could present a puncture or snagging concern.
9. Connectors should be sized to meet the current-carrying and use requirements.
10. Adjacent located connectors shall be color-coded, sized, or mechanically-keyed to prevent unintentional cross-connection or mating.
11. Multiple cable shield leads should be cluster-bonded to a single bond / ground point. Multiple cable shield leads shall not be daisy-chained.
12. Floating terminations should be dressed to produce a smooth profile that controls and prevents protruding shield strands from becoming a short circuit or sharp point / snagging concern.

B. SHIELD OPTIONS

Cable and harness shields are available in numerous styles, providing the design engineer with options to meet a specific application or requirement. For most multi-conductor cables, the shield is typically supplied as an integral component of the cable assembly, consisting of one or more layers of braided copper-wire sleeve or mylar-film wrap with an integral drain (ground) conductor, with effective coverage ratings of approximately 60 to 100 percent.

Braided Copper. Braided copper-wire construction has long been the primary method to provide shielding, while maximizing overall flexibility. The braided shield's effective coverage rating is dependant on the braid strand diameter, strand count, and

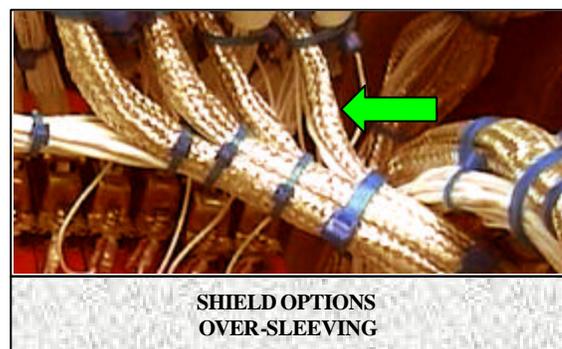
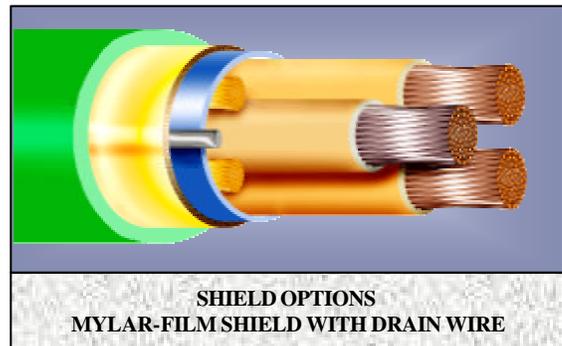
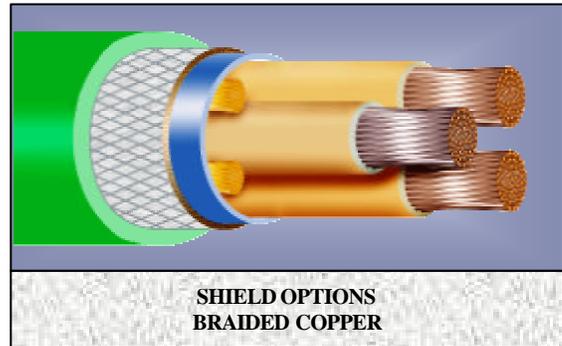
weave density, with braid stranding becoming extremely fine with high strand count and tight weave as the effective coverage approaches 100%. For extremely sensitive applications, cables with multiple braided sleeve layers are available. Electrical termination is typically accomplished by a crimp or solder termination to a separate ground lead (pick), as the braid's overall cross-sectional diameter is usually too large to provide a proper, reliable termination to a connector pin or bond.

Mylar-Film. The mylar-film design provides a higher effective coverage rating, with a reduction in overall cross-sectional area, weight, and slightly reduced flexibility. The drain wire in a mylar-film shield configuration is in electrical contact with the mylar's metallized surface the entire length of the cable, and is provided to facilitate the electrical termination by conventional solder or crimp process.

Over-Sleeving. For applications requiring additional shielding, or where shielding is shown to be required through test, a braided wire over-sleeve shield can be installed over a completed cable or harness, rather than redesigning and building an entire new assembly. These braided sleeves are supplied in two application forms; tinned-copper or nickel-plated copper for electrical isolation; and, beryllium-copper or stainless steel for mechanical protection / elevated temperature applications.

Over-sleeve constructions present the design engineer with additional safety and termination issues that must be adequately resolved to ensure reliability is not compromised and to minimize injury to personnel or damage to a spacesuit.

- Discrete wire harnesses with an over-sleeve shield should be designed with a non-conductive inner layer between the bundle and the shield, to protect the internal wiring from abrasion and possible cold-flow damage. The inner layer is especially beneficial when the wiring bundle conductors are Teflon[®] insulated, or in applications where the harness is expected to see flexure.



- Over-sleeve shields should exhibit a tight, smooth dress and profile, with even coverage and no broken or projecting strands. Assemblies may be insulated or uninsulated, depending on the application and safety concerns. Assemblies designed for applications where contact with personnel is a concern may require an external fabric or non-metallic jacket to prevent snagging, punctures, or unintended (sneak circuit / ground fault) electrical grounding.



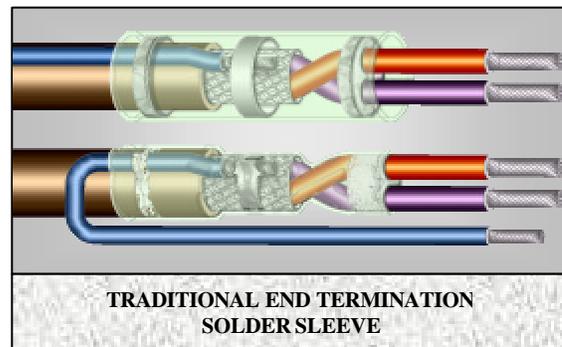
C. SHIELD TERMINATIONS

The proper termination of the shield in a shielded cable or harness can be a challenge to the design engineer. Electrical interference control (noise immunity), ground loop avoidance, and mechanical requirements (strain relief, physical size, location) often are in conflict with each other. The shield termination should be located as close to the end of the cable and connector as possible, but should not be located in a position that will result in it being crushed by the connector's cable clamp or compression fitting. Ideally, the shield termination should be located between the cable clamp and the connector pin insert body, protected by the backshell against physical damage, stress, and electromagnetic interference.

1. End Termination Styles

The two most often used configurations are the traditional termination, which is typically used for the electrical termination of the shield at the cable end; and, the inline termination which allows the shield to be terminated along its length, making it a desirable choice when used with connectors having short backshells and for connectors using a "flying lead" termination to the bulkhead.

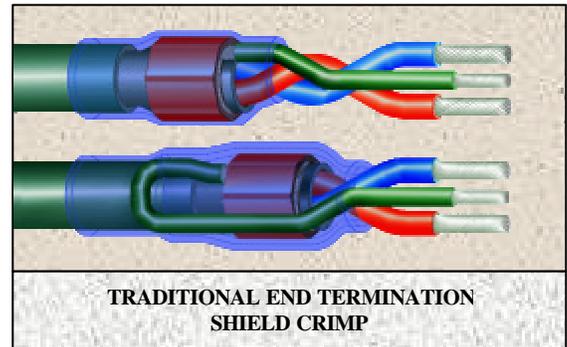
- Solder Sleeves.** Solder sleeves are often the first choice for the termination of ground leads to shields. Attachment of the ground (pick) lead may be in either direction, depending on the degree of stress relief desired and length of lead allowed by electrical noise / interference levels.



While the solder sleeve offers a unitized, environmentally sealed, "one-stop, one-step" termination, the designer must ensure that the processes used to complete the solder sleeve will not damage the other components in the cable or

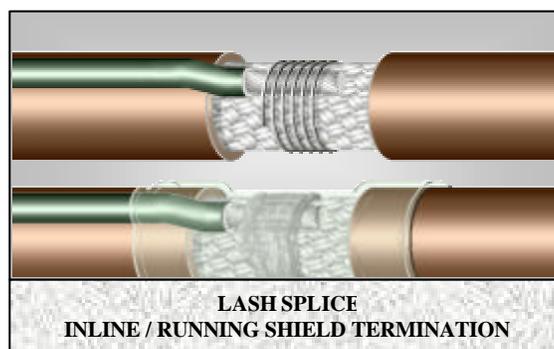
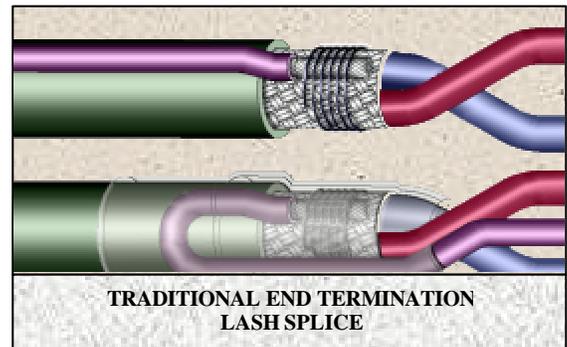
harness. The termination shall comply with all the requirements of NASA-STD-8739.4 for a solder sleeve termination.

- b) **Shield Crimps.** Shield crimps are the second most desirable choice for the termination of ground leads to shields, and are also used for floating shield terminations. Crimp terminations offer a “solderless” solution to the shield termination problem, and are often the only termination solution for the termination of nickel / nickel-plated shields or for the reliable termination of shields in high heat applications.



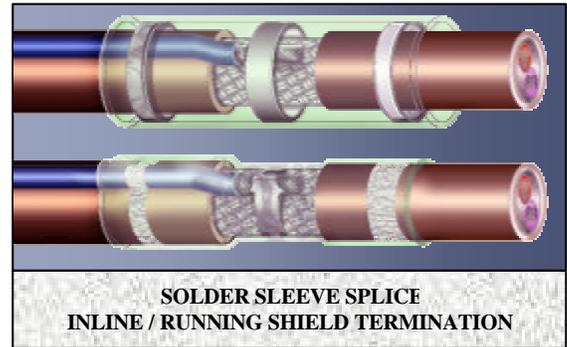
Shield crimps are a proven, robust, and easily inspectable termination, but tend to be bulky and may be a weight concern. The termination shall comply with all the requirements of NASA-STD-8739.4 for a shield crimp termination.

- c) **Lash Splice.** Ground leads may also be terminated to a shield using a lash winding when the design requires a soldered termination with good mechanical properties, small size, and low weight. For applications where the cable materials can withstand soldering temperatures, the termination can be soldered directly to the overlying shield structure. In a modified version of the shield termination, the shield is separated from the center conductor(s) and formed into a “conductor” to which the ground lead is spliced.



2. Inline Termination

The inline termination allows the shield to be terminated along its length, outside of the connector clamp zone, thereby making it a desirable choice when used with connectors having short backshells and for connectors using a “flying lead” termination to the bulkhead. The termination may be completed with a solder sleeve or lash splice, if the underlying conductor insulation materials are capable of withstanding typical soldering temperatures. Attachment of the ground (pick) lead may be in either direction, depending on the degree of stress relief desired and length of lead allowed by electrical noise / interference levels.

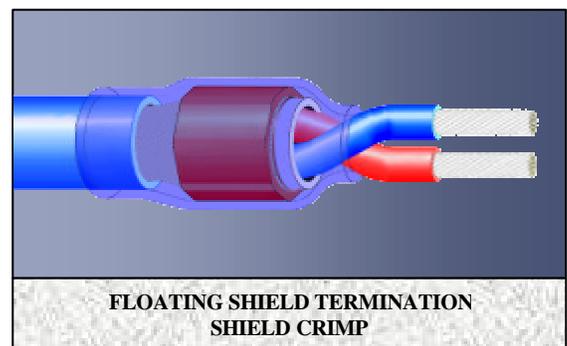
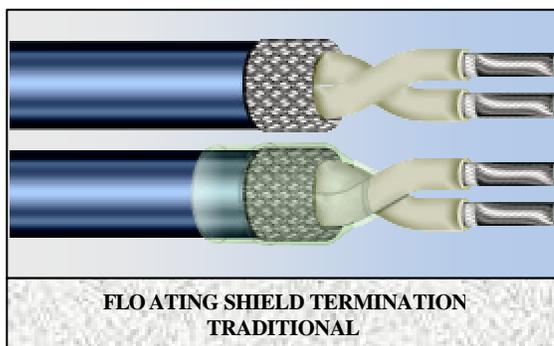


3. Floating Shield Termination

A non-conductive version of the shield termination, called a “floating shield termination” is used when the electrical termination of the shield is not desirable, but the cable end must be dressed. The termination is designed to ensure the shield is properly secured to prevent electrical contact with any conductive path and to control any protruding or loose shield strands that may cold-flow puncture the insulation of nearby conductors.

A traditional floating shield termination is constructed by dressing the cable shield out uniformly, folded back tightly over the cable’s outer jacket, and then trimmed to a uniform length. The shield termination is then sealed with a short length of transparent / translucent heat shrink tubing.

A crimped version of the floating shield termination offers the designer a proven, robust, and easily inspectable termination. While the crimp tends to be bulky, they are sometimes quicker to assemble and complete than the more traditional floating termination, and may be more reliable in high heat applications.

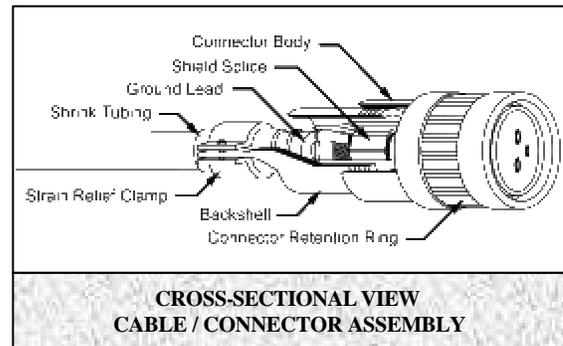


D. CONNECTORIZATION

The termination of a cable or harness with a connector is a decision the design engineer must consider carefully, as the addition of connectors introduces reliability concerns that must be addressed by the design engineer. The connector serves many roles simultaneously – allowing the cable / harness to become more functional by its ability to be mated, unmated, or relocated; providing an electrical circuit for electrical / electromagnetic noise immunity; and, providing strain relief to the cable / harness assembly.

1. Functionality

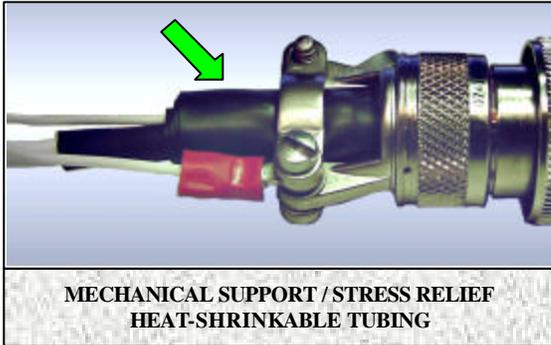
The functionality imparted by connectorization requires some design forethought, as the end-use application often defines the connector style chosen. For example, a micro-miniature plastic-bodied connector, while lightweight and small, would be unsuitable for an environment expected to see physical abuse or where the user is expected to normally wear bulky, pressurized gloves (a.k.a: a suited astronaut on EVA). Likewise, a bulky metal-shell connector may not be the best choice for use in a crewmember-worn instrumentation harness in a shirt-sleeve environment.



2. Mechanical Support / Stress Relief

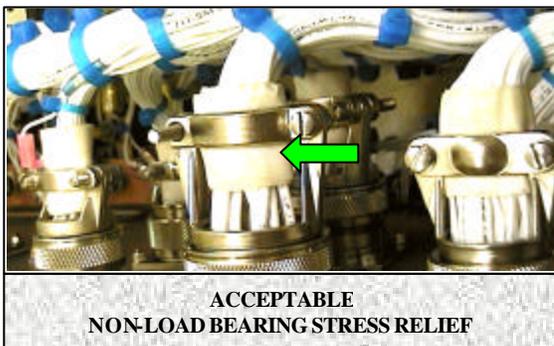
The connector provides mechanical support and stress relief to the cable's individual conductors, by transferring mechanical load from the connector shell to the cable body. In such applications, the connector backshell compression or clamp grips the cable or harness outer jacket, or terminates to the cable's strength member (if supplied). In situations where the cable's or harness' cross-sectional diameter is less than the minimum specified for the proper setting of the stress relief clamp or compression fitting, multiple overlapping sections of heat shrinkable tubing may be used to build-up the effective diameter. Adhesive-lined / meltable inner-jacket heatshrink tubing provides a positive non-slip mechanical grip and environmental seal on the cable, where single-wall shrink tubing may present a slippage concern. The "meltable" liner is typically a low-density polymer or heat-activated adhesive that

may present outgassing, flammability, or other safety concerns, and its use must be approved.



The use of adhesive-backed tape as a build-up media is an accepted alternative, especially in instances where the cable / harness has already been terminated to the connector, and installation of shrink tubing would require the disassembly or destruction of the terminations. The use of adhesive-backed tapes should be examined on a case-by-case basis, as anecdotal evidence suggests the tape may lose some of its physical properties over time and shrink in size – compromising the integrity and effectiveness of the stress relief clamp / compression.

In applications where the termination is non-load bearing, the stress relief requirements may be relaxed. Harness terminations in an electronic package are generally static and not typically subjected to pulling forces normally associated with external usage (i.e.: a crewmember tugging on an instrumentation cable as they float through an airlock). In internal applications, the sleeving / wrap provides sufficient stress relief to the wire terminations while protecting the harness conductors against abrasion and cold-flow from contact with the connector strain relief clamp / compression.



In no instances should the mechanical support / stress relief be applied directly to the individual conductors or harness if the installation is expected to be subjected to tensile stress loads, unless a strength member is incorporated in the design. Internal conductors are typically sized for current and voltage characteristics, not strength. Incorrect design and application of stress relief devices produces a cable / harness

assembly with insufficient mechanical strength and may result in terminal pull-out or conductor separation – possibly exposing personnel to live / hazardous voltages.

Strength members are typically only seen in hybrid (copper / fiber optic) cables, or are designed in as a separate component in harnesses, span the entire length of the cable or harness, and are mechanically terminated to the connector bodies or bulkhead. Strength members in harnesses may be separate non-current carrying high-strength conductors, aircraft cable, or non-metallic materials (i.e.: lacing or Kevlar[®] cord). Strength members in commercially supplied cables / cordage are typically a non-metallic yarn or Kevlar[®] cord, located at the approximate center of the cable diameter or supplied as a layer of individual fibers surrounding the conductor bundle (as in a fiber optic cable).

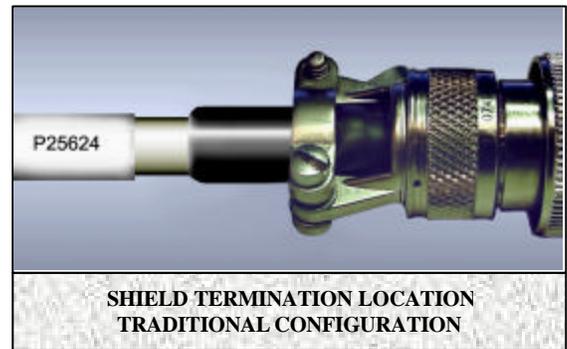
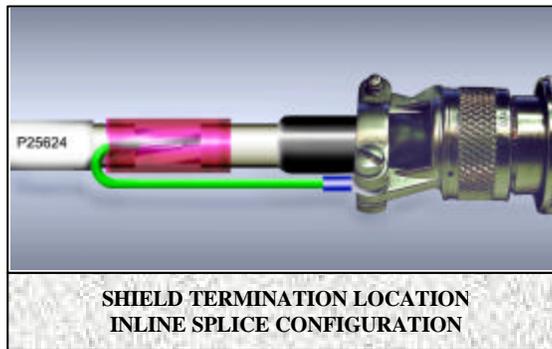
3. Electrical / Electromagnetic Shielding

The connector may also serve as the conductive link between the cable shield and the system ground in applications requiring electrical / electromagnetic interference shielding. Typically, this is accomplished by an electrical termination of the shield to one of the connector pins, or an external termination to the connector body or bulkhead.

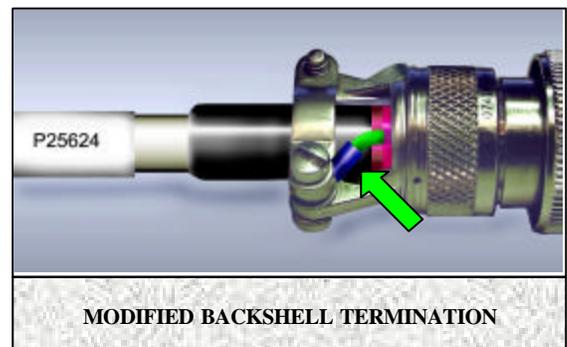
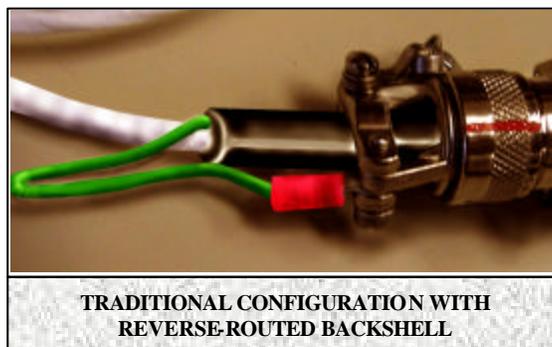
- a) **Shield Termination Location.** The location of the electrical and mechanical termination between the shield and the ground lead / pick-off is often poorly defined by the design engineer, and unfortunately (or fortunately depending on how the problem is viewed) the final design decisions may actually be left to the assembly technician. The actual electrical termination to the cable / harness shield may either be located outside of the stress relief clamp / compression (using an inline splice with termination to the connector body or bulkhead) or between the clamp and termination body (or within the backshell area) if space permits, using a traditional shield termination to either an internal pin, or routed back under the shrink tubing for termination to either the connector body or bulkhead.

The location is dependant on a number of interrelated performance and practical requirements:

- The splice should be located as close to the end of the cable / harness as practical to minimize electrical / electromagnetic interference.
- The splice should not be located in an area of high, repeated flexure, but its presence should not adversely impact required flexibility.
- The splice should not be located directly under the connector's stress relief clamp / compression fitting, with the preferred location being between the stress relief clamp / compression and the termination body, protected inside the backshell area.
- The splice should not adversely affect the mechanical strength between the connector and the cable / harness (i.e.: the splice location should not result in the cable's / harness' internal conductors being subjected to mechanical load in the event that the cable / harness is exposed to a tensile / pulling shock).

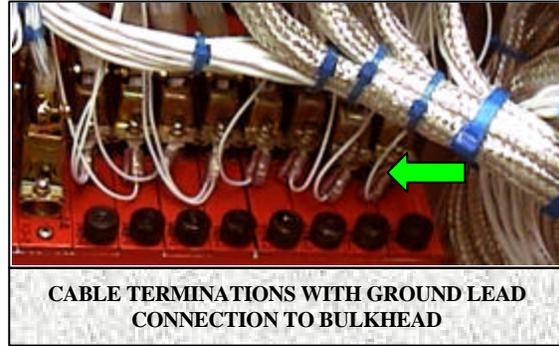


- b) Connector Body Terminations. Acceptable methods of electrically terminating the ground lead / pick-off include direct termination to the connector shell, or to the chassis mount / bond post. In these applications, the ground lead length should be kept as short as practical while still meeting bend radius and stress relief requirements. Termination to the connector's backshell results in a compact design where the ground connection is automatically completed as the connector is mated. In instances where the shield termination is a traditional shield termination located between the stress relief clamp and the connector body, the ground lead may be routed back under the shrink tubing and terminated to the clamp screw, or positioned to run between the clamp body openings and terminated to the clamp screw. This modified termination results in a ground termination with negligible exposed ground wire loop – an important consideration if users are prone to tugging on the ground loop to disconnect the cable (or are using it as a handheld).

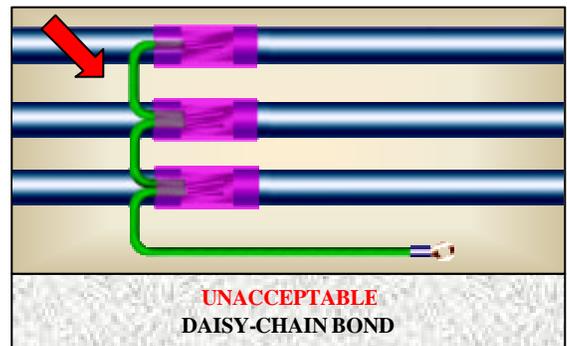
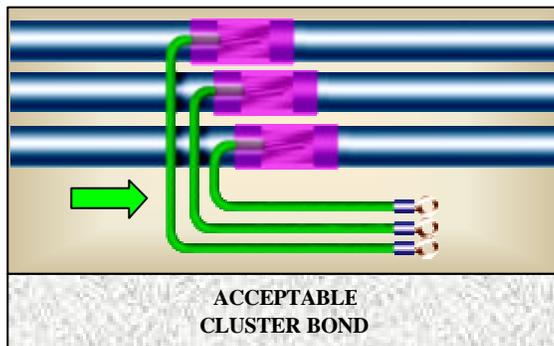


- c) Chassis / Bulkhead Termination. Ground lead termination to the connector chassis mount / bulkhead is also acceptable, provided the ground lead length is within design limits and the design meets usage requirements. This termination option limits the utility of the connector, as the harness is still mechanically attached (through the ground conductor) to the bulkhead when the connector is demated. This ensures that the ground connection is maintained even when the

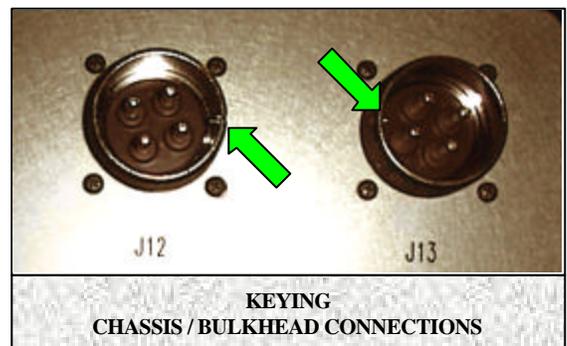
connector termination is broken, but may not be acceptable in applications where the connector is routinely repositioned in a patch panel, or where the cable is to be physically removed. The chassis / bulkhead termination also presents a possible safety concern that may limit the termination's use in applications where users may tug on, or become entangled in, the ground loop wiring – making this ground termination style more appropriate for use in enclosures, cabinets, or racks.



- d) Mass Termination Of Ground Leads. For applications involving the chassis-mount or bond-post mass termination of shield leads, the leads shall be grouped and terminated in clusters of four (4) leads maximum to a single bond terminal or bond lead. The cluster configuration assures that in the event one ground lead is broken or disconnected, the integrity of the remaining leads is not compromised. Connecting the grounds in a daisy-chain configuration is not recommended, as the termination is a single-point ground failure in the event of a conductor break or disconnection, and restricts the removal of a cable / harness within the interconnecting chain.



- e) Keying. In applications requiring the termination of multiple, identically-sized connectors, the design should ensure positive identification and elimination of unintentional cross-connection / mating that could result in circuit malfunction or hardware damage. Keying, polarity-specific pinning, or hard-wired circuit



interlocks are the preferred methods employed to mechanically control unintentional cross-connection / mating. Color coding and labeling have been shown to be somewhat useful, but mechanical methods are preferred when practical.

E. CONCLUSION

Connectorization is an accepted and reliable method to increase the functionality of cables and harnesses in applications where a “connect / disconnect / relocate / reroute” operation is required. A cable’s / harness’ form, fit, and function requirements dictate connector design and termination attributes that must be adequately addressed by the design engineer. The second most important design decision, after the selection of a connector that accommodates the required number of circuits, mechanical attributes, and human factors, is the design and implementation of the shield and conductor terminations. The decision on location of the shield termination splice directly impacts the electrical and mechanical performance of the entire connectorized assembly.

A connector selected to match the application’s form, fit, and function, coupled with a properly designed shield and conductor termination, will result in a cable / harness assembly that is robust, reliable, and safe.