Final Release Version, 1/23/2012

Improved Bonding and Grounding Methods for Electrical / Electronic Equipment

NSRP Electrical Technologies Panel Project Report

23 January 2012

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Executive Summary

Bonding and Grounding in accordance with MIL STD 1310, Shipboard Bonding and Grounding Methods for EMC and Safety, is time consuming and costly as currently applied. During new ship construction, going to "bright metal" requires removing paint or oxidation from new equipment and foundations. Existing methods are successful in that bonding and grounding are being accomplished with rare and isolated failures.

This project was conceived under the belief that less expensive methods for bonding and grounding may exist in either private industry or government shipbuilding. The goal of the project has been to investigate methods and provide the Technical Warrant Holder with recommendations on how those methods could be adopted throughout Navy shipbuilding.

A scientific approach was used to discover and review potential new methods. The most promising were explored further to determine their potential application to Naval shipbuilding.

The primary results are:

- It is recommended that the use of grounding washers in place of cleaning to "Bright Metal" be allowed in selected applications and under selected controls.
- For future ship designs, adding a separate grounding conductor, for individual electrical components should be evaluated for its overall cost benefits.
- It is recommended that each shipyard explore pre-masking grounding surfaces on electrical foundations and electrical equipment. No blanket statement was possible, but a cost savings may be achieved under certain circumstances.

Proposed changes to MIL-STD 1310H to accommodate these changes were developed and are presented in Attachment 4.

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Background

Bonding and grounding of electrical equipment installed aboard U. S. Navy Ships must be accomplished to the requirements of MIL-STD-1310, *Standard Practice for Shipboard Bonding, Grounding, and Other Techniques for Electromagnetic Compatibility and Safety*. These requirements are well established as an effective quality and workmanship standard. However, compliance is time and labor intensive. Because of the large number of bonding and grounding events on each ship, in the tens of thousands, bonding and grounding contributes significantly to overall ship construction costs.

The objective of this project was to examine the effectiveness and cost efficiency of alternate materials and installation methods.

The Class A bond was considered to offer limited opportunities for process improvement. Class B and C bonds are used in the majority of shipboard bonding applications and, were considered to offer the best opportunities to obtain cost savings through process changes. This study focuses on Class B and C bonds.

Definitions

Bonding - An electrical bond is a conductive path between two metallic surfaces established by welding, bolting/clamping, or addition of a bond strap. Bonding is the act of creating the bond.

Grounding - The process of bonding to ground potential.

Bond Classifications

Class A - Metallic surfaces bonded by welding or brazing.

Class B - Metallic surfaces bonded by bolting or clamping.

Class C - Metallic surfaces bonded by bridging them with a metallic (conductive) bond strap.

MIL-STD-1310 Section 3.

During new ship construction, going to “bright metal” requires removing paint or oxidation from new equipment and foundations. This is the most time consuming activity in bonding electrical equipment to its foundation. The goal of the project has been to investigate methods to reduce bonding and grounding costs while maintaining the functional requirements of MIL-STD 1310.

The process of a Class B Bond is summarized as follows:

At least one mounting bolt hole/mounting foot shall be prepared for electrical safety. All mounting feet/mating surfaces shall be prepared for C5ISR equipment operation and EMI/EMP mitigation bonding.

(1) Clean mating surfaces (e.g., sand, file, grind, brush, scrape, etc.) down to smooth, bright metal of item to be mounted. Clean the contact surface(s) on the mounting area (ground plane) ….

(2) Wipe down all surfaces to be mated.

(3) Apply a thin film of Antiseize zinc dust - Petrolatum (A-A-59313) to the cleaned areas of the mating surfaces and to the threads of all hardware (bolts and nuts) to be used.

(4) Bolt item to the mating surface and torque all bolts as specified/required.

(5) Seal and preserve the junction for installations located topside or in wet spaces.

(a) Apply Permatex Form-A-Gasket #2 (CAGE 01232; NSN 8030-00-849-0071) or equivalent around the perimeter of the mating surfaces and mounting hardware.

(b) Use finger or orangewood stick to contour and mold sealing compound to the edges of the material around the mating surfaces.

(c) Paint/repaint scraped and brushed areas.

Ref: MIL STD 1310 Rev H, September 17, 2009

This project focused on steps 1, 3, & 5 as areas where improvement could be achieved.

Project Goals and Objectives

1. Complete a survey of technology advances for bonding and grounding.
2. Each technology, tool or material will be examined against the MIL-STD 1310 requirements.
3. Recommend a set of technologies, tools and / or materials to be tested based on evaluation of their potential to achieve effective bonding and grounding at a lower cost.
4. Perform testing to determine which tools and / or materials meet the functional requirements in MIL STD 1310 for bonding and grounding.
5. Document findings in a combined test report.
6. Develop a recommended revision for MIL STD 1310, if necessary.

Study Participants

This study was conducted with the participation of team members from Huntington Ingalls Industries – Ingalls and Newport News, General Dynamics - Bath Iron Works, AVO Training Institute, Inc., and Panduit Corporation. A team member list with contact information is provided in Attachment 1.

Study Process

A disciplined project management approach has been applied. The project followed a detailed schedule and closely tracked budget throughout the execution.

Methods and Procedures

During the process of accomplishing the project goals and objectives, the following steps and methods were used:

- The scheduled activities "Identify Testing Controls, Conditions and Requirements" and "Identify and Approve the Testing Location" were completed prior to project start at no cost to the project. This was necessary for project estimating prior to project award. Testing locations that met MIL-STD-810 standards were identified and a down select was conducted.
- Interviews with private sector manufacturers of electrical equipment were conducted.
- Team members were briefed on MIL-STD 1310 as it relates to bonding and grounding. This gave each team member a common understanding of the requirements for bonding and grounding. The understanding of the dynamic nature of this standard and how its changes impacted shipbuilding was key to developing recommendations for new methods, technologies and tools. That briefing is provided in Attachment 2.
- A technology search was conducted.
- Potential methods, technologies, and tools to meet the requirements for bonding and grounding were collected and reviewed.
- A down select was conducted based on potential to provide a reliable bonding under a wide variety of conditions at a lower cost than today's methods.
    a. The primary method selected for testing was the use of grounding washers in place of cleaning to "Bright Metal". This method is being used by one shipbuilder of Navy non-combatant ships with the approval of the Navy. This technique was thought to have the greatest potential to reduce costs while still offering a high quality ground.
    b. A second method was researched which involved conductive sealants that would take the place of the existing sealants and the anti-seize zinc dust - petrolatum which serves as a conductive, anti-corrosive material. By having a material that met the substantive requirements of both products, it was believed it would be possible to eliminate a step in the process. A number of sealants were evaluated. This method did not result in finding a conductive sealant for this purpose. The evaluation is discussed in Attachment 3.
- Physical testing of grounding washers under a high corrosion environment was conducted at an external laboratory. After these results were received, physical testing of the amount of torque needed to achieve a ground with different kinds of washers was also completed. The process and results are discussed in the following sections.

- A final down-select determined which methods, technologies and tools are presented herein.
- Proposed changes to MIL-STD 1310 for bonding and grounding were developed and are presented in Attachment 4.
- The results of this research project will be presented and distributed to the participants of the NSRP Electrical Technologies Panel and will be made available through the NSRP web site.

Early in the project, it was concluded that electromagnetic interference (EMI) should be included in this study. The DC Resistance requirement was for EMI considerations in electronic equipment, which must be less than 2.5 mohms per MIL STD 461, DOD Interface Standard; Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment.

It was also decided that it will be necessary to preserve the junction to avoid corrosion after adequate bonding is established. A good bond could fail later if not preserved. The current processes uses anti-seize thread compound zinc dust (A-A-59313) at the connection point and then seals the junction after the connection is made.

Vendor Survey

A survey of electrical vendors was conducted. The vendors contacted are shown in Attachment 5. After follow-up discussions, the following key points were determined:

1. Grounding is done with direct contact (bolted and welded), grounding cable, and an independent wire. No other methods for bonding and grounding are being used.
2. Several vendors suggested that a separate grounding conductor in the power supply wire is a low cost alternative.
3. One vendor suggested a Euflex internal tooth washer and provided a sample for testing. This was the genesis of our discussions of grounding washers. Afterwards, other venders suggested washers for grounding and a search found additional available washers that might serve this purpose.

No new grounding breakthroughs were discovered with the vendor survey.

Review of Potential Improvements

Bonding and grounding methods were review for potential improvements in the following three general categories:

- Direct Contact, welded or bolted
- Bonding Straps
- Separate Grounding Conductor

> On metallic hull ships, the metal hull, when in contact with the water, shall establish and be designated as ground potential.
>
> *MIL-STD-1310 Section 5.1.1.1*

During this review, adding a separate grounding conductor was discussed but later discounted because of the added costs for modifying the existing designs of ships. New designs could include a separate grounding conductor, but the design and material costs and weight considerations may offset the benefits in grounding costs. However, a separate ground conductor is beneficial to "Plug-And-Play" electrical component connection that is being addressed in another NSRP project. A separate ground conductor for equipment isn't permitted by MIL-STD-1310 except that "A separate ground conductor in a power supply cable may be used in lieu of a separate ground wire connecting electrical or electronic equipment to associated connection boxes and switch boxes" is permitted for non-metallic hull ships.

Masking ground spots in advance of painting was suggested**.** This is an attractive alternative because it has the potential to reduce the amount of time for performing Class B and C bonds by reducing the amount of paint that needs to be removed. Concerning this idea, the shipyard may not know the location of the grounding before the item is sent to paint. Masking ahead of time is common to the telecommunications industry and may be of value for shipbuilding. It would be possible to pass masking the grounding area onto the vendors. The shipyards could require that the vendors supply an area near each bolting surface to be protected from corrosion but unpainted.

Bonding and grounding using washers to cut through paint instead of removing the paint to bare metal was proposed. There was concern that grounding washers provide a low cross section for current transfer. With the lower cross section, the ability to transmit current is reduced. This was considered before making the recommendations herein.

Using different types of "doping", the material used to maintain electrical contact and prevent corrosion, was proposed. This evolved into the study of conductive sealants.

A stud which would cut into the box by having teeth near the base was suggested. This type of stud doesn't exist in this form but could be specified. No further work on this concept was performed.

Because of limited time and resources, the grounding washer idea and the conductive sealant idea were selected for further study.

Grounding Washer Effectiveness and Corrosion Study

Grounding washers from numerous vendors were collected and physically evaluated by each team member. A down-select was performed to select five washers which represented a variety of the available alternatives. Those selected are shown in the following table. Lab specimens were prepared as detailed in Attachment 8. A test plan was developed and approved by the team (see Attachment 9).

#	Vendor	Model	Material	Type	Cost (each)	Country of Origin
1	Grainger	6FE71	A2 SS	External Serrated	$0.15	USA
2	Fastener Dimensions	MS35335-63	SS	External Serrated	$1.00	USA
3	Panduit	RGW-24-1Y	Zinc Plated SAE 1050-03 Steel	Internal Tooth	$1.00	USA
4	Askew	37NLITS	400 series SS	Internal Tooth	$0.12 or $0.28	Taiwan USA
5	Grainger	2DB84	Steel (not stainless) Zinc Plated	Internal External Tooth	$0.25	China

Figure 1 Washers Selected for Testing

The lab specimens were assembled using the five selected washers in three configurations. The laboratory testing was in accordance with MIL-STD-810. The selected vendor performed the required testing. Excerpts from their test report are provided in Attachment 10. Once the lab specimens were returned, they were checked for resistance between the plates and then disassembled to determine the performance of the washers. These results are shown in Attachment 11. Conclusions from this process are provided in the Study Findings section.

Conductive Sealant Study

Currently, conductive materials are used as a primary mechanism for bonding equipment frames to the hull structure for Navy programs. The equipment and structure must be properly prepared by removing any paint and corrosion along the interface. This is usually done by grinding and sanding just before the equipment is to be permanently installed to prevent corrosion during the time the equipment is in storage. Attachment 3 identifies multiple requirements listed in standards that characterize key performance criteria for sealants. Each standard calls for various characteristics of the sealant. Various conductive sealants were compared against the requirements of the relevant standards. The conclusions are provided in the Study Findings section below.

MIL-STD 1310G provides:

"A.5.1.3 Enhance conductivity, expel contaminants, retard corrosion. Apply a thin film of MIL-T-22361 antiseize compound to the cleaned areas of the mating surfaces and to the threads of all hardware (bolts and nuts) to be used.

> NOTE: Various conductive compounds and paints may be found to serve the same or similar purpose as MIL-T-22361 in this application. Some materials used, including conductive faying material (see A.5.2), might eliminate the need for sealant in accordance with A.5.1.4 and A.5.1.5. Nothing in this MIL-STD should be interpreted as preventing implementation of advancing technology or use of state-of-the-art materials for EMI and corrosion control, enhanced system operation and maintainability and personnel safety."

This note would allow for the use of other compounds. This note no longer appears in MIL-STD 1310H. Should a new sealant be identified, a change to MIL-STD 1310H would be required.

Study Findings

Grounding Washer Effectiveness and Corrosion Study

Grounding washers, under the conditions of this study, provide a high assurance of an acceptable ground for safety and EMI concerns. This study was limited to 3/8" bolts, the most common bolt used for mounting small electrical equipment, but could easily be extended to a wide variety of small bolt sizes, with low cost additional field testing (demonstration at each shipyard for additional sizes).

A variety of grounding washers were successful, however stainless steel is recommended for corrosion prevention. A carbon steel washer would be acceptable in a dry environment. It is not recommended that specific washers be identified; instead the characteristics of a successful washer should be specified with examples provided.

Attachment 13 provides a rough order of magnitude (ROM) cost estimate for the potential savings of using grounding washers in place of the class B bonds. The savings in hours varied between several thousand hours to more than 18 thousand hours per ship, depending on the number of grounds converted to the alternative method.

Conductive Sealant Study

Several different sealants were found to have acceptable properties for various applications. The sealants that were reviewed for applicability are shown. More in depth investigation is warranted to explore how the sealants perform, ease of application, and wear resistance. Much of the product information was not available because it is considered proprietary to the manufacturer. At this time, no change to currently accepted practices and sealants are recommended.

Pre-Masking Recommendation

Much of the time expended in bonding and ground is in cleaning the surfaces to “bright metal”. Removal of paint is time consuming, difficult work. Several of the team member suggested masking of the grounding spots prior to painting. This would work for a Class B (direct contact) or Class C (grounding strap) bond.

There are several practical considerations that make this recommendation less easy to implement than it would initially appear. The masking will need to be installed after surface preparation for paint. Surface preparation of foundations and electrical boxes is either through blasting or dipping in a corrosive substance. If the masking were installed prior to surface preparation, much of the masking would be lost. Providing specific directions to the paint craftsman to install the masking may be difficult. To have an Electrician install the masking after the surface preparation involves coordination.

During the removal of the masking, after paint, there is a concern that the masking tape will leave residue. There are many good products that can be used to overcome this concern.

Pre-masking of mating surfaces is recommended to reduce costs for bonding and grounding. Once the difficulties identified are overcome, a cost savings should result.

Torque Study

In order to understand better how to apply our knowledge of grounding washers, an understanding of the workers' ability to apply the needed torque was investigated. The documentation of this analysis is provided in Attachment 6.

The three washers that did not experience corrosion from the earlier study results were used. In this analysis, 3/8 inch bolts were used, this is the most common bolt size used for mounting small electrical boxes. Extension of this study to larger bolts is left for a later study.

#	Vendor	Model	Material	Type	Cost (each)	Country of Origin
1	Grainger	6FE71	A2 SS	External Serrated	$0.15	USA
2	Fastener Dimensions	MS35335-63	SS	External Serrated	$1.00	USA
4	Askew	37NLITS	400 series SS	Internal Tooth	$0.12 or $0.28	Taiwan or USA

Table 1 Washer Samples Being Tested in Torque Study

Torque Required to Penetrate Paint With Various Grounding Washers. (ft-lbs)									
Resistance (milliohms)	Torque:	8	10	12	14	16	18	20	22
	Sample 1	(1)	(1)	10.9	9.8	7.4	6.0	**2.3**	**1.7**
	Sample 1	8.7	7.2	6.5	4.8	3.8	2.9	2.8	**2.5**
	Sample 2	2.7	3.0	**2.0**	**1.5**	**1.3**	**1.3**	**1.1**	**1.0**
	Sample 2	**1.2**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Sample 4	**2.7**	**2.5**	**2.1**	**1.9**	**1.4**	**1.8**	**1.8**	**1.7**
	Sample 4	**6.6**	**1.5**	**1.3**	**1.2**	**1.2**	**1.1**	**1.1**	**<1**

Table 2 Test Results Showing Electrical Resistance at Various Torques

Some of the grounding washers tested had some permanent deformation after they were torque between two plates at 22 foot pounds (see Attachment 11). Because of this, we believe it would be prudent to require new grounding washers be used any time an electrical component is removed and then reinstalled to its foundation.

It was determined that a 3/8" bolt should be torque to 18 foot-pounds. This was selected because it is 150% of the torque which consistently provided a bonding of less than or equal to 2.5 milliohms for samples 2 and 4. This is the minimum resistance needed for all applications, Safety and EMI.

The Askew 37NLITS stainless steel washer performed very well overall. There were no signs of corrosion after accelerated corrosion testing and it pierced the paint in each test specimen. These were also the lowest cost washer tested. Reportedly, these are the washers that a shipbuilder is already using on non-combatant U.S. Navy ships. With these benefits, there would be no reason to use non-stainless washers, even in dry locations.

The following list of tools can be reliably used by most shipyard workers to produce the needed torque to provide bonding using two of the three tested grounding washers. For persons who could not achieve the desired torque of 18 foot pounds, a torque wrench with a long handle did not produce better results.

1. Open-end Wrench, 8 inch
2. Torque Wrench, 14 inch
3. Ratchet Wrench, 3/8 drive, 8 inches or longer
4. Crescent Wrench, 8 inches or longer
5. Torque-setting Drill, common commercial off the shelf model.

This finding is important in that requiring a torque wrench would add cost to the use of grounding washers that would off-set some of the benefits. For bolts larger than 3/8" diameter, the torque requirements will be larger and a torque wrench will probably be required.

Should tools other than a long handled torque wrench be allowed to install grounding washers, training with refresher training should be required. Each person should be qualified to assure they can reliably achieve the desired torque.

Current Carrying Capacity Study

After the end of testing, some team members voiced a concern about the smaller contact surface when grounding washers are substituted for a Class B bond. A current test was devised and is detailed in Attachment 12. It was demonstrated that the grounding washers have more than adequate current carrying capacity. The grounding washer contact points are able to carry more than enough current to trip a breaker or allow a ground to be detected.

Conclusions and Recommendations

It is recommended that the use of grounding washers in place of cleaning to “Bright Metal” be allowed in selected applications and under selected controls. Those limits include:

- Grounding washers must be 316 grade stainless steel unless another grade of stainless steel is approved in the ship specification.
- For 3/8” fasteners, a torque of at least 18 foot pounds is recommended to assure grounding washer piercing of paint/coatings. Each new application of fasteners and washer grounding design must be field tested under the conditions it will be applied using a torque wrench to determine the minimum torque and a micro-ohm meter to verify that the minimum desired ground has been achieved. Once the application is proven to provide a reliable ground, the use of the selected washer and methods can be continued.
- The use of anti-seize thread compound zinc dust (A-A-59313) or equivalent is still required on all contact points, which now includes where the grounding washer will pierce the paint/coatings.
- If tools other than a calibrated torque wrench are allowed, each worker using alternate tools will require annual training to assure they are achieving the desired torque for that application. Common hand tools were found to develop the required torque for a 3/8” fasteners for a wide variety of shipyard workers.
- When a bonded electrical component is removed, new grounding washers are required for re-installation.

Allowing the use of grounding washers as an alternative method for grounding will require a change to MIL-STD 1310.

Adding a separate grounding conductor, for individual electrical components should be considered in substitution for other grounding methods. The benefit is reduced time for grounding and a better opportunity for using plugs for connecting electrical components. The potential negative impacts are added costs and weight for the cables because of the additional conductor. Allowing for using a separate grounding conductor will require changes to MIL-STD 1310.

It is recommended that each shipyard explore pre-masking grounding surfaces on electrical foundations and electrical equipment. Although there are potential cost benefits, the complications discussed herein make this a complex decision. This recommendation requires no change to MIL-STD 1310.

No change to existing requirements for conductive sealants is recommended. Additional study using the criteria discussed in Attachment 3 could result in new products, however none were discovered during this limited study.

Proposed changes to MIL-STD 1310 for bonding and grounding were developed and are presented in Attachment 4.

Attachment 1: Team Member Contact Information

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Attachment 2: MIL STD 1310 Version G and H Comparison

Section: Forward

1310 G: To provide for shipboard EM compatibility (EMC) and safe operation, this revision of MIL-STD-1310 has been expanded to provide additional requirements and guidance for EMI prevention and safe operation in the following EM environmental effects (E^3) areas of concern.

6. The ship's common ground plane
7. Hull-generated EMI control
8. Hull-penetration EMI
9. Cable and case penetration/radiation EMI
10. Superstructure blockage/reflections, EM signature reduction
11. Equipment-generated EMI prevention
12. Electrical safety ground

1310 H: MIL-STD-464 establishes electromagnetic environmental effects (E3) interface requirements and verification criteria for airborne, sea, space, and ground systems, including associated ordnance. This includes intra-ship and inter-ship electromagnetic compatibility (EMC), electromagnetic pulse (EMP), inter-modulation interference (IMI), and electromagnetic radiation hazards to personnel, fuels, and ordnance.

1310 H **NEW**: This revision of MIL-STD-1310 has been expanded to include procedures for Electromagnetic Pulse (EMP) hardening. It also provides procedures and guidance to more easily address MIL-STD-464 requirements in relationship to intra- and inter-ship EMC, hull-generated IMI, lifecycle E3 hardness, EMP, and electrical bonding. However, adherence to the procedures contained herein does not relieve the contractor from meeting the applicable ships operational performance requirements specified in the contract.

1310 G Index	1310 H Index	Comments
1 Scope		
1.1 Scope	1.1 Scope	1310 G specifies performance requirements for shipboard bonding, grounding and shielding, identifies requirements for EMI control and specifies requirements for protection of personnel from electrical shock. 1301 H specifies standard practices to facilitate achievement of the intra-ship and inter-ship EMC, EMP, bonding and IMI requirements of MIL-STD-464.
1.2 Application	1.2 Application	No change
1.3 Tailoring	1.3 Tailoring	1310 G gives conditions where requirements may be tailored. 1310 H tailoring only with NAVSEA 05H3, Navy technical warrant authority approval.
N/A	1.4 New materials and technology	Encourages use of new materials and technology
2. APPLICABLE DOCUMENTS		
N/A	2.1 General	Disclaimer stating that users of the document are required to met the requirements of documents listed in section 3, 4 or 5 whether they are listed in section 2 or not.
2.1 Government documents	2.2 Government Documents	No change
2.1.1 Specifications, standards, and handbooks	2.2.1 Specifications, standards, and handbooks	Several changes in referenced documents, most notable is addition of MIL-STD-2169 (CLASSIFIED) - High-Altitude Electromagnetic Pulse (HEMP) Environment
2.1.2 Other Government documents, drawings and publications	2.2.2 Other Government documents, drawings and publications	All Navy drawings listed in REV G removed, NCS TIB 85-10 Volume I, 0910-LP-003-9770, Navy Installation & Maintenance Book, added and S9407-AB-HBK-010 Handbook of Shipboard EM Shielding Practices moved from 2.2.1 to 2.2.2
2.2 Non-Government publications	2.3 Non-Government publications	ASTM STDS A666, A312, A580 & B152 and NFPA NEC Handbook deleted, ANSI/IEEE C63.14 Dictionary of EMC including E3 and SAE-AS85049 Connector Accessories added.
2.3 Order of precedence	2.4 Order of precedence	Some change in wording

1310 G Index	1310 H Index	Comments
3 Definitions		
3.1 Acronyms used in this standard	3.1 Acronyms used in this standard	Some changes
N/A	3.2 Below deck areas	An area in ships that is surrounded by a metallic structure…
3.2 Bond-Bonding (electrical)	3.3 Bond-bonding (electrical)	No change
3.3 Bond classification	3.4 Bond classification	Adds (bright metal) to Class B and Class C bond definitions. Class B – Metallic surfaces (bright metal) bonded by bolting or clamping. Class C – Metallic surfaces (bright metal) bonded by bridging them with a metallic (conductive) bond strap.
3.4 Bond strap	3.5 Bond strap	Defines Standard bond straps as being constructed in accordance with MIL-DTL-24749. Type I bond strap – no change: Type II – adds 1x5 width to length ratio to definition: Type III – adds 1x5 width to length ration to definition: Type IV – adds minimum 1" width to definition.
N/A	3.5.1 Type V bond strap	New Type V bond strap defined: A modified MIL-DTL-24749 Type or uniquely constructed bond strap for unique and specific application (i.e., grounding of wire rope rigging).
3.5 Bright metal	3.6 Bright metal	No change
3.6 Broadband noise (BBN)	3.7 Broadband noise (BBN)	No change
3.7 Commercial-off-the-shelf (COTS)	3.8 Commercial-off-the-shelf (COTS)	No change
3.8 Computer ground system	3.9 Computer ground system	Rev H removes reference to MIL-STD-1399-406 and specifies it to be a hardwired ground system installed in accordance with system ICD's. Also reference to see electrical surge suppressor.
3.9 Conduit	3.10 Conduit	Changes reference to MIL-PRF-24758
3.10 Electrical surge suppressor, marine type	3.11 Electrical surge suppressor, marine type	Rev H modified to address ICD's, but very similar.
3.11 Electromagnetic compatibility (EMC)	3.12 Electromagnetic compatibility (EMC)	No change
3.12 Electromagnetic	3.13 Electromagnetic	No change

1310 G Index	1310 H Index	Comments
environmental effects (EME)	environment (EME)	
3.13 Electromagnetic interference (EMI)	3.14 Electromagnetic interference (EMI)	Rev H expands the definition of EMI.
3.14 Electromagnetic pulse (EMP)	3.15 Electromagnetic pulse (EMP)	Expands the definition of EMP.
3.15 Ground (ground potential)	3.16 Ground (ground potential)	No change
N/A	3.17 Grounding	The process of bonding a metallic item to ground potential.
N/A	3.18 Grounding effectiveness	The effectiveness of metallic penetrations bonded at the ship's hull to direct currents induced on these penetrations by topside EMI and EMP to the ship's ground. These metallic penetrations include pipes, waveguides, cables and metal tubing.
3.16 Ground loop	3.19 Ground loop	No change
3.17 Ground, personnel safety	3.20 Ground, personnel/electrical safety	Adds statement that an electrical safety ground does not necessarily meet the requirements for EMC/RF ground.
3.18 Ground, radio frequency (RF)	3.21 Ground, radio frequency (RF)	Adds reference to ICDs
3.19 Ground, 360 degrees (peripheral)	3.22 Ground, 360 degrees (peripheral)	No change
3.20 Grounding	N/A	The process of bonding a metallic item to ground potential.
3.21 Intermodulation interference (IMI)	3.23 Intermodulation interference (IMI)	No change
3.22 Maintenance related EMI	3.24 Maintenance-related EMI	No change
3.23 Mobile-transportable electrical equipment	3.25 Mobile-transportable electrical equipment	No change in content only formatting of paragraph.
3.24 Nonlinear junction	3.27 Nonlinear junction	No change.
3.25 Non-developmental item (NDI)	3.26 Non-developmental item (NDI)	No change.

1310 G Index	1310 H Index	Comments
3.26 Non-topside areas	N/A	Areas inside the hull or superstructure of a ship, a deck mounted shelter, or an enclosure not exposed to weather.
3.27 Portable equipment	3.28 Portable equipment	No change
3.28 Shield	3.29 Shield	No change
3.29 Shielded area	3.30 Shielded area	No change
3.30 Terminal protection device (TPD)	3.31 Terminal protection device (TPD)	No change
3.31 Topside areas	3.32 Topside areas	No change
3.32 Trunk, wireway	3.33 Trunk, wireway	No change
4. GENERAL REQUIREMENTS		
4.1 Performance requirements	N/A	Statement deleted in Rev H
4.1.1 Grounding; ship's ground potential	4.1 Ground potential and ships ground plane	Rev H adds requirement that Class A bonding will be used to maintain the ship's ground plane.
4.1.1.1 Common reference ground plane	N/A	Deletes statement that any metallic item class A bonded to ground potential shall be designated as an element of the ship's ground plane. This includes sheet metal, flat stock, stranded or solid conductor cable, etc.
4.1.1.2 Class B and class C bonding and grounding for EMC	4.2 Class B and/or C bonding	Relaxes requirement, WAS: "Electrical and electronic equipment shall be class B or class C bonded to the ground plane." IS: Class B and C bonding shall be used only as required for electrical safety, equipment operation, EMI mitigation, or EMP effects control
4.1.1.2.1 Metal-to-metal contact at bonded junction(s)	N/A	Deleted
4.1.1.2.2 Preservation of bolted mating surfaces	N/A	Deleted
4.1.1.2.3 Bond strap installation	N/A	Deleted
4.1.2 Hull-generated EMI	N/A	Deleted

1310 G Index	1310 H Index	Comments
4.1.2.1 General requirements for hull-generated EMI control	N/A	Deleted
4.1.2.2 Corrective action for hull-generated EMI	N/A	Deleted
4.1.3 Hull and cable penetration EMI	N/A	Deleted
4.1.3.1 Cable shielding	N/A	Deleted
4.1.3.2 Hull penetrations	N/A	Deleted
4.1.4 Superstructure blockage and reflections	N/A	Deleted
4.1.5 Equipment-generated EMI prevention	N/A	Deleted
4.1.5.1 Equipment-generated IMI	N/A	Deleted
4.1.5.2 BBN suppression; portable electrical tools	N/A	Deleted
4.1.6 Electrical safety; personnel shock hazard prevention	N/A	Deleted
4.2 Performance demonstration	N/A	Deleted
4.2.1 Ground plane and hull-generated EMI control	N/A	Deleted
4.2.2 Hull-penetration EMI	N/A	Deleted
4.2.3 Cable and case penetration/radiation EMI	N/A	Deleted
4.2.4 Superstructure blockage/reflections, EM	N/A	Deleted

1310 G Index	1310 H Index	Comments
signature reduction		
4.2.5 Equipment-generated IMI prevention	N/A	Deleted
N/A	4.3 EMP effects	Adds requirement for EMP protection in accordance with 5.4.
4.2.6 Electrical safety ground	4.4 Electrical safety	Requirement for grounding of equipment with a 30V or greater power source and replaced with “All non-current-carrying metallic parts of electrical equipment shall be effectively grounded by one of the following methods:”
N/A	4.5 Bonding and grounding of composite structures	Requires a Project Peculiar Document developed by the cognizant program manager be prepared for each composite structure developed for shipboard installation and that the PPD be approved by the technical authority for this standard.
N/A	4.6 Introduction of new technology	Encourages introduction of new technology and innovation, but requires its approval by the Technical Warrant Authority before being implemented.
N/A	4.7 Quality assurance inspection	A quality assurance in-process inspection shall be performed as specified (see 6.2)
5. DETAILED REQUIREMENTS		
5.1 Ground potential and ship's ground plane(s)	5.1 Ground potential and ship’s ground plane(s)	Title only, no change
5.1.1 Ground potential	5.1.1 Ground potential	Title only, no change
5.1.1.1 Ground potential for metallic hull ships	5.1.1.1 Ground potential for metallic hull ships	Adds requirement that when removed from the water, cognizant authority is responsible to ensure an appropriate ground is established and maintained.
5.1.1.2 Ground potential for nonmetallic hull ships	5.1.1.2 Ground potential for nonmetallic hull ships	Adds statement addressing when vessel is removed from the water as in 5.1.1.1
5.1.1.2.1 Ground plate location	N/A	Included in 5.1.1.2
5.1.1.2.2 Connection of the cable ground system	N/A	Included in 5.1.1.2
5.1.2 Ground plane(s)	5.1.2 Ground plane(s)	No change

1310 G Index	1310 H Index	Comments
5.1.2.1 Elements of the ground plane	5.1.2.1 Elements of the ground plane	Changes should be to shall be bonded to ground potential to form elements of the ground plane.
5.1.2.1.1 Superstructure, equipment foundations and racks	5.1.2.1.1 Superstructure, equipment foundations and racks	Removes (not shock mounted) from the section.
5.1.2.1.2 Cable grounding system's branches	5.1.2.1.2 Cable grounding system's branches	Changes should be to shall be Class A bonded.
5.1.2.1.3 Shielded room(s)	5.1.2.1.3 Shielded room(s)	Changes should be to shall be Class A bonded.
5.1.2.1.4 Computer ground system	5.1.2.1.4 Computer ground system	Removes requirement for computer ground system in accordance with MIL-STD-1399-406 and specifies computer ground systems shall be installed in accordance with applicable computer system ICD's.
5.1.2.2 Grounded items	5.1.2.2 Grounded items	No change.
5.1.2.2.1 Equipment cabinets and hardware items	5.1.2.2.1 Equipment cabinets and hardware items	Changes should be to shall be Class B or Class C bonded to ground.
5.1.2.2.2 Shock-mounted	5.1.2.2.2 Shock-mounted	Changes should be Class B or Class C bonded to shall be Class C bonded to ground.
5.1.2.2.3 Large hardware items	5.1.2.2.3 Large/long hardware items	Changes should be to shall be.
N/A	5.1.2.2.4 Bond strap and grounding wire routing	"… shall be directly routed and as short as practical. Only one bond strap shall be connected to each stud or boss."
N/A	5.1.2.2.5 Joiner/false/honeycomb bulkhead mounted equipment	Requires a separate green ground wire, or conductor identified with a wire label/tag as the ground wire, which connects to ship's ground plane. The current carrying capacity of the ground wire/conductor shall be equal or greater than the source conductor.
5.1.3 Class B and class C bonding and grounding	5.1.3 Class B and class C bonding and grounding preparations	Title only, no change
5.1.3.1 Class B and C bond	5.1.3.1 Class B and C bond	Removes discretion of the installing activity and gives detailed instructions for

1310 G Index	1310 H Index	Comments
installation	installation	preparing Class B and Class C bonds.
5.1.3.2 Hardware for Class B and C bonding	5.1.3.2 Hardware for class B and C bonding	Removes reference to MIL-DTL-24749 for class B bonds and states it shall be CRES 316 unless otherwise specified in an ICD or ship specification.
5.1.3.3 Class C bond straps	5.1.3.3 Class C bonding/bond straps	Added note to the following 5.1.3.3.b Unless removal and reinstallation is required in the course of production, still functional bond straps previously approved shall not be removed or replaced. Note: this does not apply for new construction ships.
5.1.3.3.1 Type I bond strap	5.1.3.3.1 Type I bond strap	Adds for electrical safety equipment operation, EMP effects control to previous requirement to bond metal-to-metal junctions identified as hull-generated EMI sources.
5.1.3.3.2 Type II bond strap	5.1.3.3.2 Type II bond strap	Adds figure 10 for reference of antenna tuner or coupler installation.
5.1.3.3.3 Type III bond strap	5.1.3.3.3 Type III bond strap	Changes non-topside areas to below deck areas.
5.1.3.3.4 Type IV bond strap	5.1.3.3.4 Type IV bond strap	No change
N/A	5.1.3.3.5 Type V bond strap	Added new bond strap. "Type V bond straps shall be designed as required for unusual situations when a standard bond strap constructed in accordance with MIL-DTL-24749 is not practical. Type V bond straps shall be approved by the Technical Warrant Authority of this standard only for use in special/specific applications."
N/A	5.1.3.3.6 Bond strap attachment methods	Adds figure 11 which shall be used for attachment of bond straps.
N/A	5.1.4 Submarine equipment grounding	Adds requirement for Type IV ground straps on sound isolated floating platforms, decks and bedplates to ground to the hull.
5.2 Hull-generated EMI prevention	5.2 Hull-generated EMI prevention	No change.
5.2.1 Nonmetallic topside material	5.2.1 Nonmetallic topside material	Removes sub-paragraphs on Implementation of advancing technology and Performance Requirements.
5.2.2 Topside stowage	5.2.2 Topside stowage	Deck stowage for metallic material not required for use topside should shall be avoided.
5.2.2.1 Portable and	5.2.2.1 Portable and	Changes should be stowed to shall be stowed

1310 G Index	1310 H Index	Comments
removable metallic deck hardware	removable metallic deck hardware	
5.2.2.2 Other metallic material	5.2.2.2 Other metallic material	Changes should be to shall
5.2.3 Insulate topside metal-to-metal contact junctions	5.2.3 Insulate topside metal-to-metal contact junctions	No change.
5.2.4 Bond topside metal-to-metal contact junctions	5.2.4 Bond topside metal-to-metal contact junctions	Modifies requirements and usage of Class A, B & C bonds. Eliminates paragraph on bonding not recommended.
5.3 Cable and hull penetration EMI control	5.3 Cable and hull penetration EMI control	Title only, no change.
5.3.1 Topside cable installations	5.3.1 Topside cable installations	Condition that cable be subject to illumination by high power EM energy is removed, all topside cable is subject to EMI control.
5.3.1.1 Shielded cable	5.3.1.1 Shielded cable	Now addresses conduit and specifies EMI backshells shall be in accordance with SAE-AS85049 or equivalent.
5.3.1.2 Unshielded cable	5.3.1.2 Unshielded cable	Should replaced with shall, rigid conduit preferred to flexible metal conduit where practical.
5.3.1.3 Wireway trunks	5.3.1.3 Wireway trunks	Should replaced with shall.
5.3.2 Hull penetration EMI	5.3.2 Hull penetration EMI control	Title only, no change.
5.3.2.1 Bonding metallic hull-penetrators	5.3.2.1 Bonding metallic hull-penetrators	No change.
5.3.2.1.1 Rigid conduit	5.3.2.1.1 Rigid conduit	Should replaced with shall.
5.3.2.1.2 Flexible conduit	5.3.2.1.2 Flexible metal conduit	Changed reference to MIL-PRF-24758.
5.3.2.1.3 Waveguides, pipes, tubing, and exhaust stacks	5.3.2.1.3 Waveguides, pipes, tubing, and exhaust stacks	Change should be to shall be.
5.3.2.2 Shielding effectiveness (SE)	N/A	Paragraph deleted.
5.3.2.3 Signal cables	N/A	Paragraph deleted.

1310 G Index	1310 H Index	Comments
penetrating the hull		
5.3.3 Below decks cable installations	5.3.3 Below decks cable and flexible metal conduit installations	Added requirement for below decks flexible conduit shall be in accordance with NAVSEA S9407-AB-HBK-010
N/A	5.3.3.1 Below deck flexible metal conduit bonding and grounding methods	Defines bonding requirements for flexible conduit, single and multipoint using Type V bond straps.
N/A	5.3.3.2 Termination and coupling of Type 2 conduit	Type 2 conduit required to be grounded at a single point only, methods of grounding provided.
N/A	5.3.3.3 Shielded multi-conductor cables	Requires use of EMI backshells assembled in accordance with MIL-STD-2003-5.
N/A	5.4 EMP protection	When invoked, take precedence over EMI reduction requirements in 5.3 but does not obviate the responsibility of meeting the EMC requirements of MIL-STD-464. Grounding effectiveness of the connector/backshell/cable shield system shall not be less than 60dB over freq. range of 100KHz to 100MHz.
N/A	5.4.1 Cables	
		Unshielded cables routed internal to the ship shall not be routed within 12 inches of weather doorways, hatchways, and windows unless the cables are routed within shielding conduit or wireway trunks. Cables that terminate at these openings, such as windshield wiper cables, window de-icing cables, and door alarm cables, shall be shielded and grounded as close as practicable to the end fitting. Cables shall not be routed within 10 feet of helicopter or aircraft hangar bay doors or well deck access doors unless they are shielded or routed in conduit or wireway trunk.
N/A	5.4.2 Cable shielding performance	
		The installing activity shall be responsible for ensuring the topside cables specified in ICDs or OEM guidance associated with government furnished equipment and contractor furnished equipment will not degrade the required level of EMP hardness of the ship. …

1310 G Index	1310 H Index	Comments
N/A	5.4.3 Wireway trunks	
		Wireway trunks shall be constructed to provide 60 dB shielding effectiveness. A typical wireway trunk is shown in figure 2.
N/A	5.4.4 Waveguides, pipes, tubing, and exhaust stacks	
		Waveguides, pipes, tubing, and exhaust stacks grounded as specified in 5.3.2.1.3 are properly grounded for EMP requirements.
N/A	5.4.5 Terminal protection device	
		TPDs shall be installed on all HF, VHF, and UHF antennas serving mission critical systems. The TPDs shall be procured that meet the test methods specified in NCS TIB 85-10 or the classified EMP environment referenced in MIL-STD-464 and defined in MIL-STD-2169.
N/A	5.4.6 EMP protection, composite structure	
		When EMP requirements are called out for composite ships or structures, a PPD to address the general EMP requirements shall be developed. If it cannot be shown by analysis or test that the composite structure meets EMP requirements, the interior of the structure shall be treated as being in a topside environment for electromagnetic considerations.
5.4 Superstructure blockage and reflections	5.5 Superstructure blockage and reflections	Replaced should be with shall be.
5.4.1 Topside configuration drawings	5.5.1 Topside configuration drawings	No change.
5.4.2 Flat and reflective surfaces	5.5.2 Flat and reflective surfaces	Replace should be with shall be in the following:
		a. Round stock and pipe. To diffuse and scatter reflections, round stock and pipe shall be used as a general rule in the design and fabrication of mast stanchions, supports and equipment foundations that will be illuminated by the main beam of a directional transmit antenna.
		b. Tilted/angled installation. Antenna mounting base(s) or foundation(s) shall be fabricated to offset, angle or tilt the antenna as necessary to minimize coupling

1310 G Index	1310 H Index	Comments
		between nearby antennas; to isolate antennas from nearby metallic structure; and to enhance antenna radiation and reception patterns.
		c. Radar-absorbent material (RAM). RAM shall be installed where necessary to control harmful EM reflections.
5.5 Equipment-generated IMI prevention	5.6 Equipment-generated EMI prevention	Replaced should be with shall be in statement
5.5.1 Wideband receiver front-end stages	N/A	Requirements now part of section 5.6 and sub-paragraphs.
5.5.2 RF-tuned receiver front-end stages	5.6.1 RF tuned receiver front-end stages	No additional protection should be required… replaced with No additional protection shall be required…
5.5.3 LF-MF receiver(s) but no in-band transmitter(s)	5.6.2 LF-MF receiver(s), but no in-band transmitter(s)	No change.
5.5.4 Active wideband receiver coupler systems	N/A	Paragraph deleted.
N/A	5.6.3 BBN suppression; portable electrical tools	
		Arc suppression filters shall be provided across the commutator/brushes of all electric motors
5.6 Electrical safety; personnel shock hazard prevention	5.7 Electrical safety; personnel shock hazard prevention	Removed note concerning EMC.
5.6.1 Portable and mobile-transportable electrically-powered equipment	5.7.1 Portable and mobile-transportable electrically-powered equipment	No change.
5.6.1.1 Electrical equipment with a conductive case	5.7.1.1 Electrical equipment with a conductive case	No change.
5.6.1.2 Electrical equipment with a non-conductive case	5.7.1.2 Electrical equipment with a non-conductive case	No change
5.6.2 Fixed-installed, electrically-powered	5.7.2 Fixed-installed, electrically-powered	No change.

1310 G Index	1310 H Index	Comments
equipment	equipment	
N/A	5.7.3 Fixed rack mounted or enclosure mounted electrically powered equipment	
		Shock hazard protection for equipment, including COTS and NDI equipment, installed in a rack mount or internal to an equipment enclosure shall be provided through one of the grounding methods or combinations of methods stated in 5.7.1 or 5.7.2.
6. NOTES	6. NOTES	Information is General or Explanatory in nature that may be helpful, but is not mandatory.
6.1 Intended use	6.1 Intended use	
6.2 Issue of DODISS	N/A	
	6.2 Acquisition requirements	
6.3 Subject term (key word) listing	N/A	
N/A	6.3 Quality assurance provisions	
N/A	6.3.1 In-progress inspection	
N/A	6.3.2 Final inspection	
N/A	6.3.3 Inspection responsibility	
N/A	6.3.4 Inspector certification	
N/A	6.3.5 Government verification	
6.4 RF impedance measurement	6.4 RF impedance measurement	
N/A	6.5 Subject term (key word) listing	
6.5 Changes from previous issue	6.6 Changes from previous issue	

Attachment 3: Review of Conductive Sealants

Currently, conductive materials are used as a primary mechanism for bonding equipment frames to the hull structure for Navy programs. The equipment and structure must be properly prepared by removing any paint and corrosion along the interface. This is usually done by grinding and sanding just before the equipment is to be permanently installed to prevent corrosion during the time the equipment is in storage. Once the interfacing surfaces are properly prepared and the environmental conditions warrant application (proper temperature and humidity, minimal airborne contaminants present, etc.), equipment is shimmed for level and the sealant material is applied. The materials are somewhat messy. Any excess material that makes its way beyond the boundaries of the interface must be removed and those surfaces cleaned. The material must then dry and cure, generally over a 24 hour period. Once the bond is generated and done properly, the equipment is effectively sealed and grounded. It is important to allow the mounting hardware to be free in the event the hardware must be removed or tightened.

The following section identifies multiple requirements listed in standards that characterize key performance criteria for sealants. Coupled to MIL-STD-1310, one can determine the effectiveness of a particular application or product. Many standards exist, such as MIL-S-81733C and MIL-A-46106A that address general sealant performance characteristics. Listed are three standards for the use of sealants. The sealants are in broad categories, indicating lubricating sealants, conductive sealants and water resistant sealants. This study focuses on standard electrical sealants. Some of these have lubrication properties as well, but the primary purpose of the sealant is to provide good bonding between the equipment and the ship hull, for both personal protection and the protection of the circuits.

Several different sealants were found to have acceptable properties for various applications. The sealants that were reviewed for applicability are shown below. The properties are similar to what is used today. The performance, ease of use and special accommodation (i.e., toxic materials safety precautions) were not compared. There is little difference in electrical characteristics between those researched, although there were some differences between performance characteristics, such as temperature ratings and curing time.

More in depth investigation would be warranted to explore how the sealants perform, how easy they are to apply and install, and how well they resist wear. Much of the product information is considered proprietary to the product manufacturers and was not available.

Spec & Type	Require-ment / Ref Number	Characteristic	Value	UOM	Notes
Product Notes					
General Items		Resistivity		ohm	
		Cure Time		days	
		Storage Life		days	
		Shear Strength		psi	
		Service Temperature		deg C	
MIL-PRF-81733D	SEALING AND COATING COMPOUND, CORROSION INHIBITIVE				Much of this standard is mechanical in nature; a few items of interest include actual material used (has a certain electrical characteristic) and how it is applied (together with the volotility and to toxicity) These are only a selection of all requirements listed
Type	1.2.1	Type I - For brush or dip application			
		Type II - For extrusion application, gun or spatula			
		Type III - For spray gun application			
		Type IV - For faying surface application, gun or spatula			
Class	1.2.2	Class 1 - Polysulfide rubber base material			
		Class 2 - Polythioether rubber base material			
Grade	1.2.3	Grade A - Contains chromate corrosion inhibitors			
		Grade B - Contains nonchromate corrosion inhibitors			
	3.3.1.3	C1, T1 (nonvolatile content)	84	%	
		C1, T2 (nonvolatile content)	92	%	
		C1, T3 (nonvolatile content)	65	%	
		C1, T4 (nonvolatile content)	90	%	
		C2, T1 (nonvolatile content)	84	%	
		C2, T2 (nonvolatile content)	92	%	
		C2, T3 (nonvolatile content)	65	%	

Spec & Type	Require-ment / Ref Number	Characteristic	Value	UOM	Notes
		C2, T4 (nonvolatile content)	95	%	
	3.3.1.5.1	T1 viscosity	100-500	poises	
		T2 viscosity	6,000–16,000	poises	
		T3 viscosity	50–150	poises	
		T4 viscosity	1,000–4,000	poises	
	3.3.2.1	T1 hardness	35	Shore A-2 Hardness	
		T2 hardness	35		
		T3 hardness	35		
		T4 hardness	30		
	3.3.2.2	C1 specific gravity	1.65	g/cc	
		C2 specific gravity	1.5		
	4.8.10	Low temp. flexibility			
	3.3.2.6	C1 T2 tensile stress	200	psi	
		C2 T2 tensile stress	250	psi	
	3.3.2.7	C1 T2 elongation	150	%	
		C2 T2 elongation	250	%	
	3.3.2.8	C1 T2 peel strength	15	per inch width	tested with a variety of contaminants
		C2 T2 peel strength	20		
	6.5	Toxicity	none		
MIL-A-46106B	ADHESIVE-SEALANTS, SILICONE, RTV, ONE-COMPONENT				vulcanizing compound
	1.2.1	Group I - General purpose			
		Group II - High strength			
		Group III - High temperature			

Spec & Type	Require-ment / Ref Number	Characteristic	Value	UOM	Notes
	1.2.2	Type I - Thixotropic paste			sometimes fluid, sometimes gel, depending on nature of cure and application
		Type II - Self-leveling liquid			
	3.3.2.1	Group 1 T1 viscosity			
		Group 1 T2 viscosity	150-550	per inch width	
		Group 3 T1 viscosity	N/A		
		Group 4 T2 viscosity	150-550	per inch width	
		G1, T1 hardness	20	Shore A min	
		G1, T2 hardness	20		
		G2, T1 hardness	22		
		G3, T1 hardness	20		
		G3, T2 hardness	15		
		G1, T1 tensile strength	220	psi min	
		G1, T2 tensile strength	150		
		G2, T1 tensile strength	500		
		G3, T1 tensile strength	220		
		G3, T2 tensile strength	150		
		G1, T1 elongation	350	% min	
		G1, T2 elongation	150		
		G2, T1 elongation	500		
		G3, T1 elongation	350		
		G3, T2 elongation	150		
		G3, T1 volume resistivity	10^{13}	ohm/cm	
		G1, T1 volume resistivity	10^{13}		
		G1, T2 volume resistivity	10^{13}		

Spec & Type	Require-ment / Ref Number	Characteristic	Value	UOM	Notes
		G2, T1 volume resistivity	10^{13}		
		G3, T2 volume resistivity	10^{13}		
		G3, T1 dielectric constant	3.5	max	
		G1, T1 dielectric constant	3.5		
		G1, T2 dielectric constant	3.5		
		G2, T1 dielectric constant	3.5		
		G3, T1 dielectric constant	3.5		
		G3, T1 dissipation factor	0.02	max	
		G1, T1 dissipation factor	0.02		
		G1, T2 dissipation factor	0.02		
		G2, T1 dissipation factor	0.02		
		G3, T1 dissipation factor	0.02		
		G3, T1 dielectric strength	300	v/mil min	
		G1, T1 dielectric strength	301		
		G1, T2 dielectric strength	302		
		G2, T1 dielectric strength	303		
		G3, T1 dielectric strength	304		
	3.3.2.2.1	heat resistance: table Iia,b			look these values up as necessary: withstand elongation, tensile strength, hardness testing for certain exposure

Spec & Type	Require-ment / Ref Number	Characteristic	Value	UOM	Notes
	3.5	Toxicity	none		
A-A-59313	Thread Compound, Anti Seize Compound				The fundamental use for this type of compound is for antiseize, not bonding; however, the properties augment bonding
	3	Zinc dust compound (table I)	41-43	% by weight	
		Petrolatum	57-59		
		stability	5	ml separatio n	
MIL-S-45180D	Sealing Compound, Gasket, HydroCarbon Fluid and Water Resistent				
	1.2	Type I: Hardening			
		Type II: Non hardening			
		Type III: Non hardening, low viscosity			
	3.1	Solubility shown in table I	100	%	
	3.2	Type I: Torque Release	70		
		Type II: Torque Release	40		
		Type III: Torque Release			
	3.3	Type I: Volatile	15	%	plus or minus 3,2,3
		Type II: Volatile	13		
		Type III: Volatile	24		
	3.4	Flow test	<=.25	in	
	3.5	Type I: Viscosity	4-20k	poises	
		Type II: Viscosity	4-20k		
		Type III: Viscosity	30-680		
	3.7	Water solubility	<= 2	%	
	3.8	Table III: Corrosion			
	3.9	Flash Point	>=10	deg C	

Spec & Type	Require-ment / Ref Number	Characteristic	Value	UOM	Notes
	3.1	Type II: Flexibility	-34	deg C	shall not crack when bent at this temperature
	4.1	Type III: Flexibility	-33	deg C	shall not crack when bent at this temperature
	3.12	Toxicity	none		

Sealants and Adhesives Reviewed Against The Above Standards

Shielding Express RTV

Can be found at http://www.shielding.com/13.%20Conductive%20Caulking%20&%20Adhesives.htm

SPG (silver plated glass)

SPC (silver plated copper)

NP (nickel particle)

Shielding Solutions

CEP SC001 - Silicone elastimer with silver plater copper particles; can be found at http://www.rfi-shielding.com/ downloads.shtml

CEP NC001 – Same as CEP SC001 with nickel plated graphite particles

CEP SA001 - Same as CEP SC001 with silver plated aluminum particles

ECA-SS001 - Electrically conductive adhesive with silver particles

ECA NCS - Electrically conductive adhesive with nickel particles

ECA SCS 001 - Electrically conductive adhesive with silver plated copper particles

Chomerics

CHO-SHIELD® 1086 Silicone Adhesive Primer - Acts in tandem with sealant or adhesive products

CHO-BOND 360-20 - Silver copper epoxy

CHO-BOND 1035 - Silicone silver glass sealant

CHO-BOND 4660 - Polyisobutylene silver copper sealant

Dow Corning 736 Heat Resistant/ Sealant

SSP Products (http://sspinc.com/ssp_store/):

Nickel coated graphite filled silicone compounds

SSP502-30

SSP502-40

SSP502-55

SSP502-65

SSP502-75

Silver plated glass filled silicone compound

SSP416-65

Silver plated copper filled silicone compound

SSP547-65

Silver plated aluminum filled silicone compound.

SSP548-65

Silver plated aluminum filled fluorosilicone compound.

SSP550-45

SSP550-70

Conductive one part RTV compounds.

SSP779-SPA

SSP779-SPG

SSP779-SPC

SSP779-S

SSP779-SPN

SSP779-NG(LV)

AI Technology Inc. (http://www.aitechnology.com/uploads/pdf/products/emishielding/pis9006t.pdf)

Conductive Caulk-Sealant

PIS9006

More information on the above and other products can be found at the following:

http://www.shielding.com/13.%20Conductive%20Caulking%20&%20Adhesives.htm

http://www.rfi-shielding.com/pages/products/caulk.shtml

http://www.rfi-shielding.com/downloads.shtml

http://www.globalspec.com/industrial-directory/conductive_caulk

http://www.matweb.com/search/datasheet.aspx?MatGUID=16897d8dcc15473eb028e50473c5f13b

http://www.darcoid.com/images/uploads/pdfs/G%20-%20Conductive%20Systems.pdf

http://www.asaptec.com/adchom2.htm

http://www.skygeek.com/rtv738-3oz.html (Dow product)

http://sealscience.com/pdf/EMI_RFI_ESD_022007.pdf#zoom=100

http://www.aitechnology.com/uploads/pdf/products/emishielding/pis9006t.pdf

http://www.teckniteurope.com/pages/caulk.html

http://www.sspinc.com/products_and_services/EMI_Conductive_Silicone_Compounds

Attachment 4: Proposed Change to MIL STD 1310H

To allow for the use of grounding washers in Class B bonds, after the following quote:

"5.1.3.1 Class B and C bond installation

b. Class B bonding procedure. At least one mounting bolt hole/mounting foot shall be prepared for electrical safety. All mounting feet/mating surfaces shall be prepared for C5ISR equipment operation and EMI/EMP mitigation bonding (see 4.2).

(1) Clean mating surfaces (e.g., sand, file, grind, brush, scrape, etc.) down to smooth, bright metal of item to be mounted. Use care not to gouge deep pits or grooves in the mating surfaces. Clean the contact surface(s) on the mounting area (ground plane) approximately ¼ inch larger than the mounting foot such that complete bright-metal contact is achieved when they are mated."

Insert the following text:

As an alternative to cleaning mating surfaces down to smooth, bright metal, a grounding washer may be placed between the item to be mounted and its foundation on every mounting fastener. If grounding washers are used, the following requirements are added:

1. Grounding washers must be 316 grade stainless steel unless another grade of is approved in the ship specification
2. A torque as specified on NavSea Drawing OD32382 Table 1 shall be applied to each mounting fastener.
3. Each new application of fastener size and grounding washer design must be tested under the conditions it will be applied using a micro-ohm meter to verify that the minimum desired ground has been achieved. Once the application is proven to provide a reliable ground, the use of the selected washer and methods can be continued.
4. If tools other than a calibrated torque wrench will be used to apply the specified torque, each worker using alternate tools will undergo annual training to assure they are achieving the desired torque with the tool used for that application.
5. New grounding washers will be applied each time an electrical component is removed and re-installed.

To allow for the use of grounding washers in Class C bonds, **after the following quote**:

"5.1.3.1 Class B and C bond installation

c. Class C bonding procedure.

(1) Clean (e.g., sand, file, grind, brush, scrape, etc. down to smooth, bright metal) the surfaces/areas where the bond strap is to be mounted approximately ¼ inch larger than the bond strap end lug, or boss if installing a Type I bond strap topside. Use care not to gouge deep pits or grooves in the mating surfaces. The distance between the mounting points shall be as short as practical to minimize impedance of the strap. Weld bosses in place for Type I bond strap installations topside. Repaint areas disturbed by welding (see 5.1.3.3.d and figure 11)."

Insert the following text:

As an alternative to cleaning surfaces/areas down to smooth, bright metal where the bond strap is to be mounted, a grounding washer may be placed between the ground strap and the surface/areas on the foundation. If grounding washers are used, the following requirements are added:

1. Grounding washers must be 316 grade stainless steel unless another grade of stainless steel is approved in the ship specification.
2. A torque as specified on NavSea Drawing OD32382 Table 1 shall be applied to each mounting bolt.
3. Each new application of fastener size and grounding washer design must be tested under the conditions it will be applied using a micro-ohm meter to verify that the minimum desired ground has been achieved. Once the application is proven to provide a reliable ground, the use of the selected washer and methods can be continued.
4. If tools other than a calibrated torque wrench will be used to apply the specified torque, each worker using alternate tools will undergo annual training to assure they are achieving the desired torque with the tool used for that application.
5. New grounding washers will be applied each time a grounding strap is removed and re-installed.

In order to allow for the use of a separate grounding conductor in place of a Class B or Class C bond, insert or modify the following text as indicated:

Modify "4.2 Class B and/or C bonding. Class B and C bonding shall be used only as required for electrical safety, equipment operation, EMI mitigation, or EMP effects control."

To read: 4.2 Class B, Class C, and/or Class D bonding. Class B, Class C or Class D bonding shall be used only as required for electrical safety, equipment operation, EMI mitigation, or EMP effects control.

Modify "5.1.3 Class B and class C bonding and grounding preparations.

5.1.3.1 Class B and C bond installation. The following procedures shall be used to ensure effective Class B and Class C bonds."

To Read: "5.1.3 Class B, Class C, and Class D bonding and grounding preparations.

5.1.3.1 Class B, Class C, and Class D bond installation. The following procedures shall be used to ensure effective Class B and Class C bonds."

Add section 5.1.3.1.d as follows:

d. Class D bonding procedure. A separate ground wire / conductor which connects to ship's ground plane. The current carrying capacity of the ground wire/conductor shall be equal or greater than the source conductor. The ground wire may be separate or included inside of the power supply cable. In either case, it shall have a green colored insulation, if practical.

(1) Clean (e.g., sand, file, grind, brush, scrape, etc. down to smooth, bright metal) the surface/area where the ground wire / conductor is to be mounted. This surface / area may be either inside or outside the item being grounded.

(2) Assure the ground wire / conductor is long enough to assure it will not be placed under strain at any time.

(3) Wipe down the surface / area where the ground wire / conductor is to be mounted with MIL-C-81302 non-residue type cleaning solvent to ensure they are clean and free of paint chips, metal filings and other residue.

(4) Apply a thin film of Antiseize zinc dust - Petrolatum (A-A-59313) or equivalent to the cleaned surface / area and to the threads of all hardware (bolt and/or nut) to be used.

(5) Bolt ground wire / conductor in place and torque bolt to 25 foot-pounds. (5) Seal and preserve the junction for ground wire / conductors installed topside or in wet spaces.

(6) Seal and preserve the junction for ground wire / conductors installed topside or in wet spaces. This is only required for junctions that may be exposed to wet conditions and is not required for connections inside of sealed components.

(a) Apply Permatex Form-A-Gasket #2 (CAGE 01232; NSN 8030-00-849-0071) or equivalent non-acidic sealing compound around the perimeter of the mating surfaces and mounting hardware.

(b) Use finger or orangewood stick to contour and mold sealing compound to the edges of the material around the mating surfaces.

(c) Paint/repaint scraped and brushed areas."

Note: A connector may be used to provide power and ground to equipment only under the condition that, should there be more than one power supply, each power supply will include a ground wire/conductor meeting the above requirements. The ground connection shall be made prior to any other connection.

Modify "5.1.3.2 Hardware for class B and C bonding. All hardware (e.g., straps, bosses, bolts, nuts, and washers) used for new or replacement shipboard Class C bonding shall conform to MIL-DTL-24749 requirements. Unless otherwise specified in an installation control drawing (ICD) or ship specification, hardware for equipment and metallic items requiring Class B bonding shall be CRES 316."

To Read "5.1.3.2 Hardware for class B, class C, and class D bonding. All hardware (e.g., straps, bosses, bolts, nuts, and washers) used for new or replacement shipboard Class C bonding shall conform to MIL-DTL-24749 requirements. Unless otherwise specified in an installation control drawing (ICD) or ship specification, hardware for equipment and metallic items requiring Class B or Class D bonding shall be CRES 316 unless another grade of is approved in the ship specification."

Attachment 5: Commercial Contacts

Each of these electrical equipment manufacturers was contacted at the 2010 International Workboat Show in New Orleans, LA to discuss the potential for improved bonding and grounding. Although many more vendors were contacted, these were the contacts who indicated interest in and/or knowledge of bonding and grounding.

Crawford Electric Supply Crawford Electric
Derek Robetson, (504) 731-0480
Address:
200 L & A RDMetairie LA 70001 United States
www.cescoltd.com

WAGO Corporation
Sunny Goomber, Senior Sales and Applications Engineer for South Central US (832) 886-0146.
Tim Williams, Regional Sales Manager, (985) 893-3093.
Address:
N120 W19129 Freistadt Road, Germantown WI 53022 United States www.wago.us

Key Electronic Solutions
Gary Lyvers, (504) 734 0641
Address:
623 Distributors Row
Suite D New Orleans LA 70123 United States
www.keyelectronics.net

Summit Electric Supply, Marine Division
Ed Dowey, Marine Division Director, (504) 535 2600
Address:
621 Time Saver Ave.
New Orleans LA 70123 United States
www.summit.com/marine

Seacoast Electric Company, Inc.
Tom Artinian, Director of Marine, Oil, and Gas (281) 265 0036
Address: 4000 Greenbriar Drive, Suite 150Stafford TX 77477 United States
www.seacoastusa.com

PYI, Inc.
Daniel Schalk (425) 355-3669
Address: 12532 Beverly Park Road Lynnwood WA 98020 United States www.pyiinc.com

Newmar
Jim "Kap" Kaplan, Applications and Sales Manager (310) 266-0561
Address:
2911 West Garry Avenue
PO Box 1306 Santa Ana CA 92704 United States
www.newmarpower.com

Integrated Power & Controls
Keith Hubble, Department Manager, (757) 312-0574
Address: 912 Ventures Way
Chesapeake VA 23320 United States www.earl-ind.com

Baton Rouge Marine Electrical Service, Inc.
Dick Brown, President (225) 642-3328
Address:
865 Highway 30Saint Gabriel LA 70776-5014 United States
www.brmes.com

Industrial Power Systems, Inc.
Glenn Beaupre (904) 731-8844 ext 15.
Address:
3010 Powers Avenue
Building 16 Jacksonville FL 32207-8038 United States
www.ipsswitchgear.com

L-3 Communications
Aurelie (Possum) Ponvillian, Field Service Engineer.
Michael Portier – Michael.portier@L-3com.com
Address:
901 E. Ball RoadAnaheim CA 92805 United States
www.L-3com.com/MPS

Eutex International (Sub divisions) Eutex Singapore, Calgary
Wayne Mayo (713) 862-0088
Address:
3409 BrinkmanHouston TX 77018 United States
www.eutexinternational.com

Walther Electric, Inc.
Walter Pecherek Jr., National Sales Manager (800) 925-8437, wpecherek@waltherelectic.com
Address:
12 World's Fair Drive
Unit F Somerset NJ 08873 United States
www.waltherelectric.com

Attachment 6 Torque Study

In order to understand better how to apply our knowledge of grounding washers, an understanding of the workers' ability to apply the needed torque was investigated. First, it was important to know how much torque would be needed to pierce the paint and provide good contact between the two metal plates. The following table shows the torque requirements to pierce the paint on the samples used for the earlier study. The three washers that did not experience corrosion from the earlier study results were used. In this analysis, 3/8 inch bolts were used, this is the most common bolt size used for mounting small electrical boxes. Extension of this study to larger bolts is left for a later study.

Table 3 Washer Samples Being Tested in Torque Study

#	Vendor	Model	Material	Type	Cost (each)	Country of Origin
1	Grainger	6FE71	A2 SS	External Serrated	$0.15	USA
2	Fastener Dimensions	MS35335-63	SS	External Serrated	$1.00	USA
4	Askew	37NLITS	400 series SS	Internal Tooth	$0.12 or $0.28	Taiwan or USA

Table 4 Test Results Showing Electrical Resistance at Various Torques

Torque Required to Penetrate Paint With Various Grounding Washers. (ft-lbs)									
Resistance (milliohms)	Torque:	8	10	12	14	16	18	20	22
	Sample 1	(1)	(1)	10.9	9.8	7.4	6.0	2.3	1.7
	Sample 1	8.7	7.2	6.5	4.8	3.8	2.9	2.8	2.5
	Sample 2	2.7	3.0	2.0	1.5	1.3	1.3	1.1	1.0
	Sample 2	1.2	<1	<1	<1	<1	<1	<1	<1
	Sample 4	2.7	2.5	2.1	1.9	1.4	1.8	1.8	1.7
	Sample 4	6.6	1.5	1.3	1.2	1.2	1.1	1.1	<1

Note 1: The first run of Sample 1 at below 12 foot pounds was not tested. Because piercing of the paint appeared to occur at a lower torque than expected, we expanded the torque range on the other samples.

Note 2: Many of the grounding washers tested had some permanent deformation after they were torque between two plates at 22 foot pounds. Because of this, we believe it would be prudent to require new grounding washers be used any time an electrical component is removed and then reinstalled to its foundation.

The team was concerned about the need for a torque wrench. It is not currently a common practice for installation teams to have a torque wrench. In this analysis, we took a sampling of employees from the electrical shop at Huntington Ingalls Shipbuilding – Ingalls to determine if common tools could achieve the necessary torque for a 3/8 inch bolt, as determined by the above analysis. The required torque was 18 foot-pounds. This was selected because it is 150% of the torque which consistently provided a bonding of less than or equal to 2.5 milliohms for samples 2 and 4. This is the minimum resistance needed for all applications, Safety and EMI.

"The 5th to 95th percentile is an anthropometric range employed by ergonomists and designers to try to accommodate the largest range of the population. Essentially the 5th to 95th percentile encompasses the 5'0" female to the 6'2" male. For reference the 50th percentile male (average male height) is 5'9" and a 50th percentile female is 5'4"".[1] For our study, we found a small female and a large male who nearly met the profile for the 5th to 95th percentile and others within this range.

Table 5 Profile of Participants

		Gender	Height	Weight	Age
Person	1	Male	6'0"	245	52
	2	Male	5'9"	175	35
	3	Female	5'10"	190	43
	4	Female	5'4"	130	54
	5	Female	5'5"	170	47
	6	Female	5'7"	190	48
	7	Female	5'2"	190	59
	8	Male	5'10"	232	33
	9	Male	5'7"	180	65
	10	Male	5'10"	180	56

[1] The Human Solution: Design for Human Use, Downloaded from http://blog.thehumansolution.com/index.php/faq/question/what_is_the_5th_to_95th_percentile/ on 8/23/2011

Table 6 Minimum Required Torque Produced by Participants

Tool	Person									
Tool Being Tested	1	2	3	4	5	6	7	8	9	10
Open-end Wrench	Y	Y	Y	N	N	Y	Y	Y	Y	Y
Torque Wrench & Socket	Y	Y	Y	N	N	Y	Y	Y	Y	Y
Ratchet Wrench & Socket	Y	Y	Y	N	N	Y	Y	Y	N	Y
Crescent Wrench (force against integrated jaw)	Y	Y	Y	N	N	Y	Y	Y	Y	Y
Crescent Wrench (force against movable jaw)	Y	Y	Y	N	Y	Y	Y	Y	Y	Y
Torque-setting Drill	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

The torque setting drill was shown to be a reliable means of producing the desired torque. The drill used was an off-the-shelf item. Setting the torque required a torque wrench to verify the setting. The accomplishment of the minimum desired torque was reliably set

Figure 2 R.Lee Flowers Performs Torque Testing to Develop Testing Protocol

We determined that the following list of tools can be reliably used by most shipyard workers to produce the needed torque to provide bonding using two of the three tested grounding washers. For persons who could not achieve the desired torque of 18 foot pounds, a torque wrench with a long handle did not produce better results.

1. Open-end Wrench, 8 inch
2. Torque Wrench, 14 inch
3. Ratchet Wrench, 3/8 drive, 8 inches or longer
4. Crescent Wrench, 8 inches or longer
5. Torque-setting Drill, common commercial off the shelf model.

This finding is important in that requiring a torque wrench would add cost to the use of grounding washers that would off-set some of the benefits. For bolts larger than 3/8" diameter, the torque requirements will be larger and a torque wrench will probably be required.

However, 18 foot pounds required a significant effort with all of the tools except the long torque wrench and the torque setting drill. Should other tools be allowed to install grounding washers, training with refresher training will be required. Each person should be qualified to assure they can reliably achieve the desired torque.

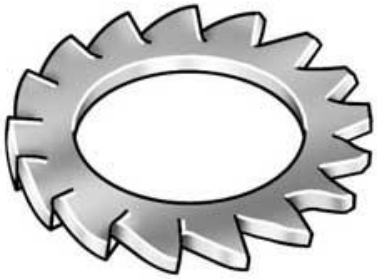
Attachment 7: Washers Selected For Testing

#	Vendor	Model	Material	Type	Cost (each)	Country of Origin
1	Grainger	6FE71	A2 SS	External Serrated	$0.15	USA
2	Fastener Dimensions	MS35335-63	SS	External Serrated	$1.00	USA
3	Panduit	RGW-24-1Y	Zinc Plated SAE 1050-03 Steel	Internal Tooth	$1.00	USA
4	Askew	37NLITS	400 series SS	Internal Tooth	$0.12 or $0.28	Taiwan USA
5	Grainger	2DB84	Zinc Plated Steel (not stainless)	Internal External Tooth	$0.25	China

Lock Washer, Ext, 10.5mm ID, PK 50 - Granger

Grainger Item #	6FE71
Price (pk.)	$7.61
Package Qty.	50
Brand	APPROVED VENDOR
Mfr. Model #	6FE71
Ship Weight (lbs.)	0.13

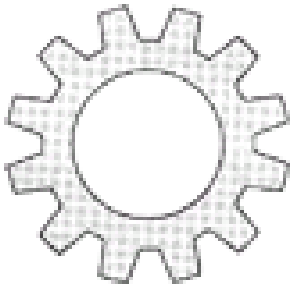
Item	Lock Washer
Type	External Serrated
Material	A2 Stainless (Comparable to 18-8 Stainless Steel)
Finish	Plain
Fits Bolt Sizes	M10
Inside Dia.	10.5mm
Outside Dia.	18mm
Thickness	0.9 to 2.7mm
Application	General Purpose
Meets/Exceeds	DIN 6798 Standard
Package Quantity	50



Angled outer teeth absorb vibrations and maintain fastener tension. Thickness is a range.

Fastener Dimensions, Inc.

http://www.fastenerdimensions.com/prod10.ht...



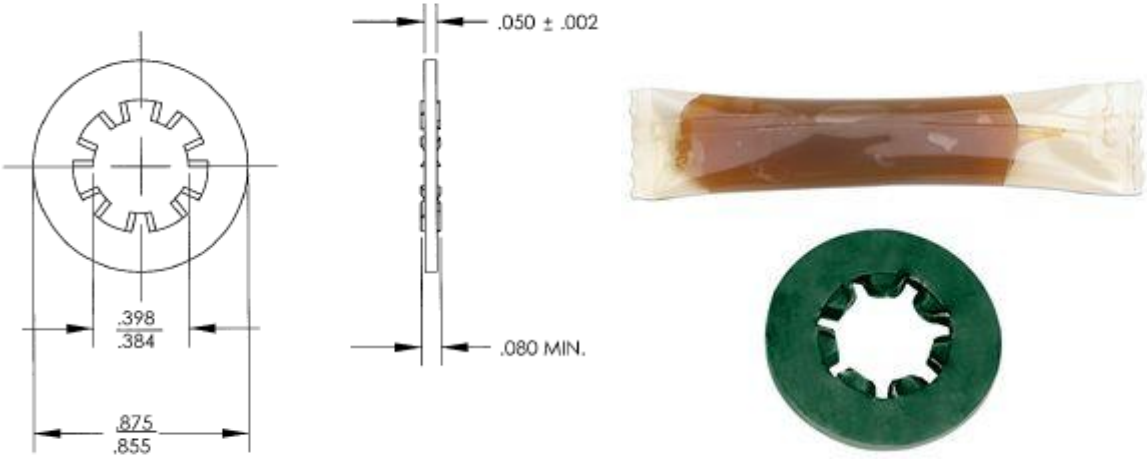
Distributor, Manufacturer, Custom Manufacturer
Company Profile: Hardened & ground washers. Fasteners; AN, AS, MS, NA, NASM, ordinance, military spec. aerospace, aircraft & commercial components, hardware & fasteners; bolts, screws, nuts, inserts, in every materials, size & length, standards & specials to spec, CAD drawings on-line, ISO 9001:2000 certified, Lockheed, ... Douglas, Boeing, Sikorsky & U.S. government approved. Fastener screws & bolts component machining & assembly.
External Tooth Lock Washers Brand Names: AMATOM, Bell, Camloc, ESNA, Helicoil, Huck, Kaynar, Lockheed, Raytheon, Rexnord, Rosan, SPS,...

Fastener Dimensions Inc, 94-03 104th Street, Ozone Park, New York 11416
Tel: 718-847-6321 • Fax: 718-847-8414 • www.FASTDIM.com • privacy policy • info@fastdim.com

The Panduit Internal Tooth "B" Twist Washer.

Samples received. Right now, they are only available in 3/8 inch size but Panduit may be able to get them made in other sizes.

List cost is $1.00 each by 100 box which is similar to other washers being looked at.



ASKEW Industrial Corporation

400 Series Stainless Steel (harder than 316 stainless steel)

3/8 Internal Tooth Lock Washer

Being used for grounding purposes on non-combatant classes of Navy ships.

Part # 37NLITS

Lock Washer, Internal/External Tooth, 0.398 ID, PK100 - Granger

Grainger Item #	2DB84
Price (pk.)	$25.30
Package Qty.	100
Brand	APPROVED VENDOR
Mfr. Model #	2DB84
Ship Weight (lbs.)	0.5
Country of Origin (Country of Origin is subject to change.)	China

Material	Steel
Finish	Zinc
Fits Bolt Sizes	3/8"
Inside Dia.	0.398"
Outside Dia.	0.985"
Thickness	0.045"
Rockwell Hardness	C40 to C50
Meets/Exceeds	ASME B18.21.1

Meet ASME B18.21.1 standards. Zinc-plated steel

Note: Bulk quantities of some sizes are available on Grainger.com®.

Attachment 8: Preparation of Lab Specimens

Cutting and Drilling of Test Specimens

The test specimens were made of materials commonly available in the shipyard. The steel and brass bars were 1" x 4". The steel bar was 3/8" thick and the brass bar was 1/8" thick. Each bar was drilled with three each 3/8" holes spaced 1" apart.

Blast and Paint Test Specimens

Twenty each small (1" x 4") steel and brass plates shall be blasted and painted.

Brass Bars:

A light blasting on both faces

Clean with solvent

Paint with 1 coat of 150 green primer

Paint on all surfaces with 1 coat of 111 dove gray. This is the paint schedule for small electrical cabinets.

Steel Bars:

Blast to remove rust and contaminants

Clean with a solvent to remove blast dust

Paint with 1 coat of 156 red paint

Paint with 1 coat of 156 red paint

This is the same paint schedule used on a machinery foundation in the bilge on a Navy ship.

The Coatings Department at Huntington Ingalls Industries – Ingalls painted the steel bars with the same paint and thicknesses as they would a steel foundation for an electrical panel. They painted the brass bars with the same paint and thicknesses as they would a small electrical panel.

Attachment 9: Test Plan for Bonding and Grounding

Revision 2, 5/25/2011

The 20 each specimens to be tested will be of a common steel bar approximately 4" long x 1" x 3/8" bolted to a brass or brass plate 4" long x 1" x 1/8". The bolts will be stainless steel and 3/8 diameter. There will be 3 bolts 1½ to 2 inches long. Where the paint is not intact, the stainless steel bolt may be replaced with a non-conductive nylon bolt.

All stainless bolts will be torque to 22 foot pounds (per NavSea Drawing OD32382 Table 1) and the nylon bolts will be tightened to hand tight. During assembly, all test items will be coated with zinc compound at the junction where paint may be removed or pierced. No sealant will be used on any sample to amplify the effects of the corrosion testing. The 20 specimens will be numbered and consist of the following items:

1&2 Assembled as per MIL-STD-1310G Class 2 Ground. (Current Practice) The bolting order will be Bolt Head, Flat Washer, Steel Bar, (removed paint), zinc compound, (removed paint), Brass Bar, Flat Washer, Lock Washer, Nut.

3&4 Test Item 1, The bolting order will be Bolt Head, Flat Washer, Steel Bar, zinc compound, Test Item 1, zinc compound, Brass Bar, Flat Washer, Lock Washer, Nut.

5&6 Test Item 2, The bolting order will be Bolt Head, Flat Washer, Steel Bar, zinc compound, Test Item 2, zinc compound Brass Bar, Flat Washer, Lock Washer, Nut.

7&8 Test Item 3, The bolting order will be Bolt Head, Flat Washer, Steel Bar, zinc compound, Test Item 3, zinc compound, Brass Bar, Flat Washer, Lock Washer, Nut.

9&10 Test Item 4, The bolting order will be Bolt Head, Flat Washer, Steel Bar, zinc compound, Test Item 4, zinc compound, Brass Bar, Flat Washer, Lock Washer, Nut.

11&12 Test Item 5, The bolting order will be Bolt Head, Flat Washer, Steel Bar, zinc compound, Test Item 5, zinc compound, Brass Bar, Flat Washer, Lock Washer, Nut.

The remaining tests are identical to the first ones except that two lock washers are used per connection instead of one. The lock washers and flat washers are placed as indicated below.

13 Test Item 1, The bolting order will be Bolt Head, Test Item 1, zinc compound, Steel Bar, Brass Bar, zinc compound, Test Item 1, Nut.

14 Test Item 1, The bolting order will be Bolt Head, Test Item 1, zinc compound, Steel Bar, Brass Bar, zinc compound, Test Item 1, Flat washer, Nut.

15 Test Item 2, The bolting order will be Bolt Head, Test Item 2, zinc compound, Steel Bar, Brass Bar, zinc compound, Test Item 2, Nut.

16 Test Item 2, The bolting order will be Bolt Head, Test Item 2, zinc compound, Steel Bar, Brass Bar, zinc compound, Test Item 2, Flat Washer, Nut.

17 Test Item 3, The bolting order will be Bolt Head, Test Item 3, zinc compound, Steel Bar, Brass Bar, zinc compound, Test Item 3, Nut.

18 Test Item 3, The bolting order will be Bolt Head, Test Item 3, zinc compound, Steel Bar, Brass Bar, zinc compound, Test Item 3, Flat washer, Nut.

19 Test Item 4, The bolting order will be Bolt Head, Test Item 4, zinc compound, Steel Bar, Brass Bar, zinc compound, Test Item 4, Nut.

20 Test Item 4, The bolting order will be Bolt Head, Test Item 4, zinc compound, Steel Bar, Brass Bar, zinc compound, Test Item 4, Flat washer, Nut.

Table 7 Selected Test Items

#	Vendor	Model	Material	Type	Cost (each)	Country of Origin
1	Grainger	6FE71	A2 SS	External Serrated	$0.15	USA
2	Fastener Dimensions	MS35335-63	SS	External Serrated	$1.00	USA
3	Panduit	RGW-24-1Y	Zinc Plated SAE 1050-03 Steel	Internal Tooth	$1.00	USA
4	Askew	37NLITS	400 series SS	Internal Tooth	$0.12 or $0.28	Taiwan USA
5	Grainger	2DB84	Steel (not stainless) Zinc Plated	Internal External Tooth	$0.25	China

Testing will be conducted in accordance with MIL-STD-810G and consist of the following steps:

6. Huntington Ingalls Shipbuilding will Measure the resistance between a test point on the steel bar and a test point on the brass bar. The test points will be cleared of paint and corrosion before measurement.
7. Huntington Ingalls Shipbuilding will photograph the samples before shipping.

Steps 3-8 will be performed by Detroit Testing Laboratory (DTL). DTL will take digital photographs of the samples during each step of the process.

8. Measure and record resistance between the brass bar and the steel bar with a calibrated ohm meter. Record resistance for all samples. DTL will clean off one spot on the brass plate and one spot on the steel bar with sand paper as test points prior to testing resistance.
9. Humidity Testing using MIL-STD-810G Method 507.5, Humidity, Procedure II, Aggravated for a duration of 21 days. Use Figure 507.5-7 and Table 507-5-IX from MIL-STD-810G for the required temperature and humidity profile.

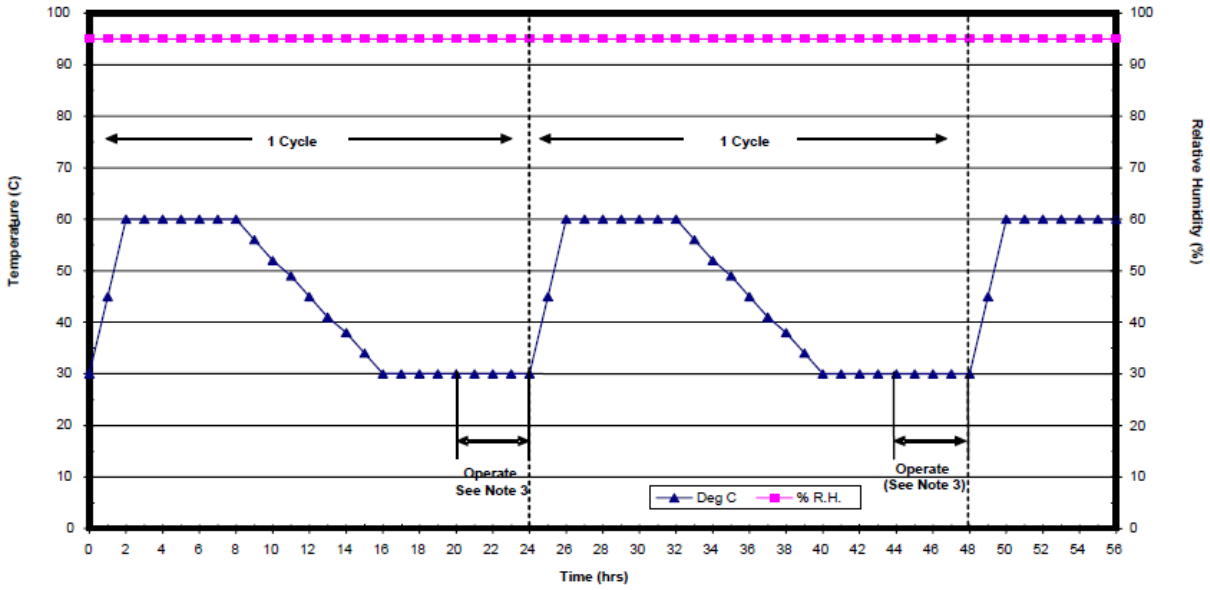


Figure 507.5-7. Aggravated temperature-humidity cycle.

NOTES:

1. Maintain the relative humidity at 95 ±4 percent at all times except that during the descending temperature periods the relative humidity may drop to as low as 85 percent.
2. A cycle is 24 hours.
3. Perform operational checks near the end of the fifth and tenth cycles.

Table 507.5-IX. Aggravated Cycle

Time	Temp. RH		
	oF	oC	%
0000	86	30	
0200	140	60	
0800	140	60	
1600	86	30	
2400	86	30	
0200	140	60	
0800	140	60	
1600	86	30	
2400	86	30	

10. Measure and record resistance between the brass bar and the steel bar with a calibrated ohm meter. Record resistance for all samples. DTL will clean off one spot on the brass plate and one spot on the steel bar with sand paper as test points prior to testing resistance.
11. Salt Fog testing in accordance with MIL-STD-810G Method 509.5, Salt Fog, for a duration of 8 days (48 hours wet / 48 hours dry cycles). Use the standard salt solution (5% +-1%) and temperature (35 degrees C +- 2 degrees C) as specified in the procedure.
12. Measure and record resistance between the brass bar and the steel bar with a calibrated ohm meter. Record resistance for all samples. DTL will clean off one spot on the brass plate and one spot on the steel bar with sand paper as test points prior to testing resistance.
13. Return Samples to:

Huntington Ingalls Industries

Attention: John Layman, Mail Stop T499-01

1000 Jerry St. Pe Highway

Pascagoula, MS, 39564.

14. Assure Package is insured and has a tracking number. Send test report and digital photos to John.Layman@hii-ingalls.com. Include paper copies of test report with samples being returned.
15.

Once the samples are returned to Huntington Ingalls, we will photograph the samples and take a resistance check on them.

At Huntington Ingalls, we will use Megger model DLR010HD Low Resistance (micro-ohm) Ohmmeter for resistance checks. The serial number and calibration information are recorded below.

The following tables will be used to record resistance readings:

(This table has been completed with the resistance readings recorded before the samples were sent to the testing laboratory.)

	Before Torqueing (mOhm)							After Torqueing to 22 Foot Pounds (mOhm)						
Sample #	Bolt 1 to Steel Plate	Bolt 1 to Brass Plate	Bolt 2 to Steel Plate	Bolt 2 to Brass Plate	Bolt 3 to Steel Plate	Bolt 3 to Brass plate	Plate to Plate	Bolt 1 to Steel Plate	Bolt 1 to Brass Plate	Bolt 2 to Steel Plate	Bolt 2 to Brass Plate	Bolt 3 to Steel Plate	Bolt 3 to Brass plate	Plate to Plate
1							0.1							0.0
2							0.5							0.1
3	Nylon	Nylon	Nylon	Nylon	Open	Open	Open	Nylon	Nylon	Nylon	Nylon	19.1	20.5	14.5
4	Nylon	Nylon	Open	Open	Open	Open	Open	Nylon	Nylon	6.7	5.6	6.0	6.8	9.0
5	Nylon	Nylon	Nylon	Nylon	Open	4.2	Open	Nylon	Nylon	Nylon	Nylon	3.5	3.3	0.5
6	Nylon	Nylon	Open	Open	Open	Open	Open	Nylon	Nylon	0.9	0.6	5.0	5.2	0.3
7	Open	Open	Open	Open	Open	Open	Open	3.1	2.8	4.4	4.0	3.5	3.4	0.0
8	Nylon	Nylon	Open	Open	Open	Open	Open	Nylon	Nylon	2.2	1.9	1.3	1.0	0.2
9	Nylon	Nylon	Open	5,300	Open	908	Open	Nylon	Nylon	2.3	2.2	7.7	7.0	0.5
10	Nylon	Nylon	3.2	Open	Open	Open	Open	Nylon	Nylon	6.4	7.2	7.6	8.2	0.8
11	Nylon	Nylon	Open	2.6	Open	139	Open	Nylon	Nylon	0.9	0.4	1.6	1.2	0.4
12	Open	Open	Nylon	Nylon	Open	Open	Open	24.5	26.5	Nylon	Nylon	29.0	31.0	0.1
13	Open	9.9	Open	Open	Nylon	Nylon	Open	Nylon	Nylon	32.7	0.9	Nylon	Nylon	33.3
14	Open	Open	Open	Open	Open	Open	Open	4.0	1.3	2.3	0.8	3.7	0.8	2.8
15	Nylon	Nylon	Open	2.5	Open	3.8	Open	Nylon	Nylon	0.5	0.3	0.5	0.3	0.7
16	Nylon	Nylon	Open	Open	Open	Open	Open	Nylon	Nylon	0.5	0.4	0.6	0.5	0.8
17	Nylon	Nylon	Open	Open	Open	Open	Open	Nylon	Nylon	0.2	0.2	0.2	0.3	0.5
18	Nylon	Nylon	Open	Open	Open	Open	Open	Nylon	Nylon	0.5	0.3	0.4	0.3	0.5
19	Nylon	Nylon	Open	Open	Open	Open	Open	Nylon	Nylon	0.4	0.6	0.5	0.5	0.7
20	Nylon	Nylon	Open	Open	Open	Open	Open	Nylon	Nylon	0.4	0.3	1.0	0.6	0.8

Torque Wrench Information: Snap-On 3/8 Drive Torque Wrench; 20 - 100 foot pounds range, Serial Number LSSMH171; 1005380313; NGSB GC 7LS Calibrated - ID - MH171; Date 02-17-11; Due 07-17-11

Resistance Measurements used Megger model DLR010HD Low Resistance (micro-ohm) Ohmmeter ID M18559 Calibration was performed on 5-18-2010 and is due 5-17-2013.

- The nylon bolts were inserted in place of steel bolts where there were obvious paths to ground.
- For sample specimen 13, a nylon bolt was added in the first position because of the path between this bolt and the brass plate.
- The nylon bolts would twist off at much less than 22 foot pounds. They served as place keepers only.
- On sample 15, all three of the bolts were grounded to the brass plate. It wasn't possible to replace all the bolts with nylon so bolts 2 & 3 were left as steel. This sample may have an unintended path from plate to plate. Similar condition exists on sample specimens 5, 10, and results from these samples will be discounted.

Specimen 13 had a relatively high resistance. It appears that the grounding washer pierced the paint to the brass plate but inadequately pierced the paint to the steel plate

Table 2 Detroit Testing Lab Resistance Testing Results with Calibrated Ohm Meter

Sample #	Plate to Plate before Testing Begins	Plate to Plate after Humidity Testing	Plate to Plate after Salt Fog Testing
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			

Note, this information was completed by the testing laboratory and the results are presented in Attachment 10.

Table 3 Huntington Ingalls Post-Test Resistance Testing Results

Sample #	Plate to Plate After Moisture Testing Complete (milli-ohms)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

Note, this information was completed and the results are presented in Attachment 11.

Attachment 10: Vendor Lab Report Findings (excerpts only)

DETROIT TESTING LABORATORY, INC.

PREPARED FOR
HUNTINGTON INGALLS INDUSTRIES
P.O. BOX 149, MAIL STOP T499-01
PASCAGOULA MS 39568-0149

ATTENTION
HOWARD WESTFAUL

CUSTOMER PURCHASE ORDER NUMBER
654840/1

REPORT DATE
JULY 13, 2011

Detroit Testing Laboratory, Inc.
7852 Ellis Road
Melbourne, Florida 32904 USA
Phone: 321.327.8985
Fax: 321.327.8986
www.dtl-inc.com

TEST SEQUENCE

Humidity testing was performed from 06/02/11 through 06/26/11.

SAMPLE DESCRIPTION

A total of twenty (20) Brackets were presented for testing. Sample numbers, for the test samples, as received, were 1 through 20.

Results

The samples showed mild corrosion. See Appendix B for resistance measurements.

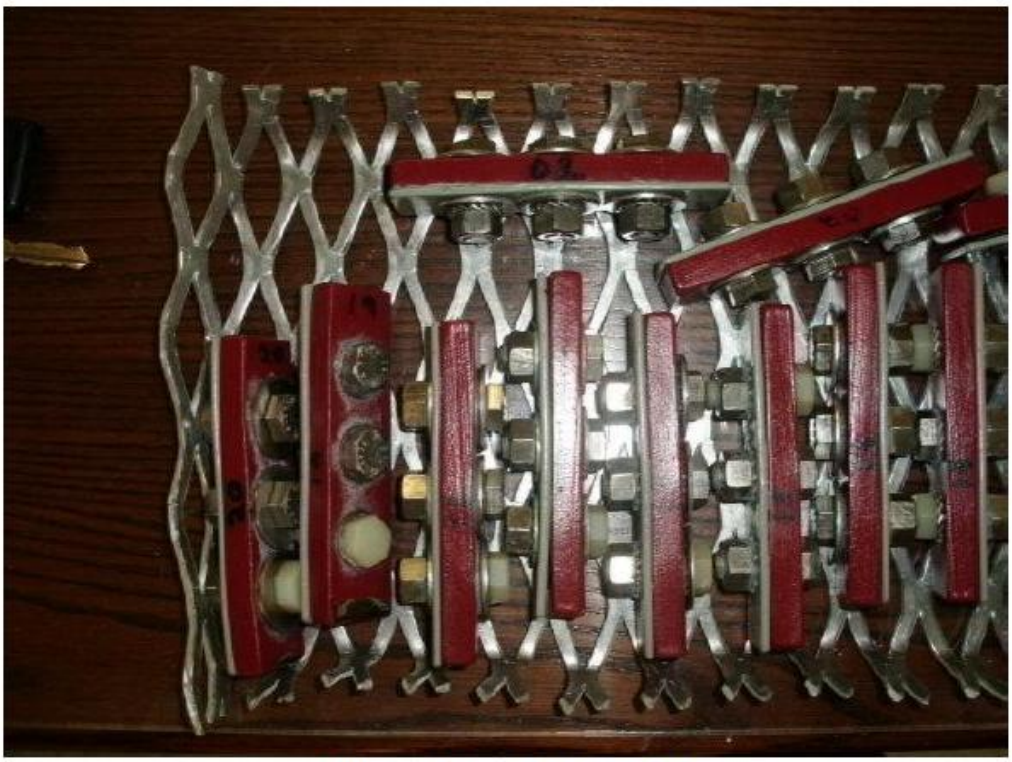
TEST EQUIPMENT

Detroit Testing Laboratory, Inc.'s calibration system meets the requirements of ISO 17025:2005.

DTL ID	Description	Manufacturer	Model	Calibration Due
13690	Digital Multimeter	Fluke	179	04/12
EC506	Environmental Chamber	Thermotron	M-64-CHM-705-810C	12/11
EC509	Environmental Chamber	Thermotron	F-40-CHMV705-2-705	05/12

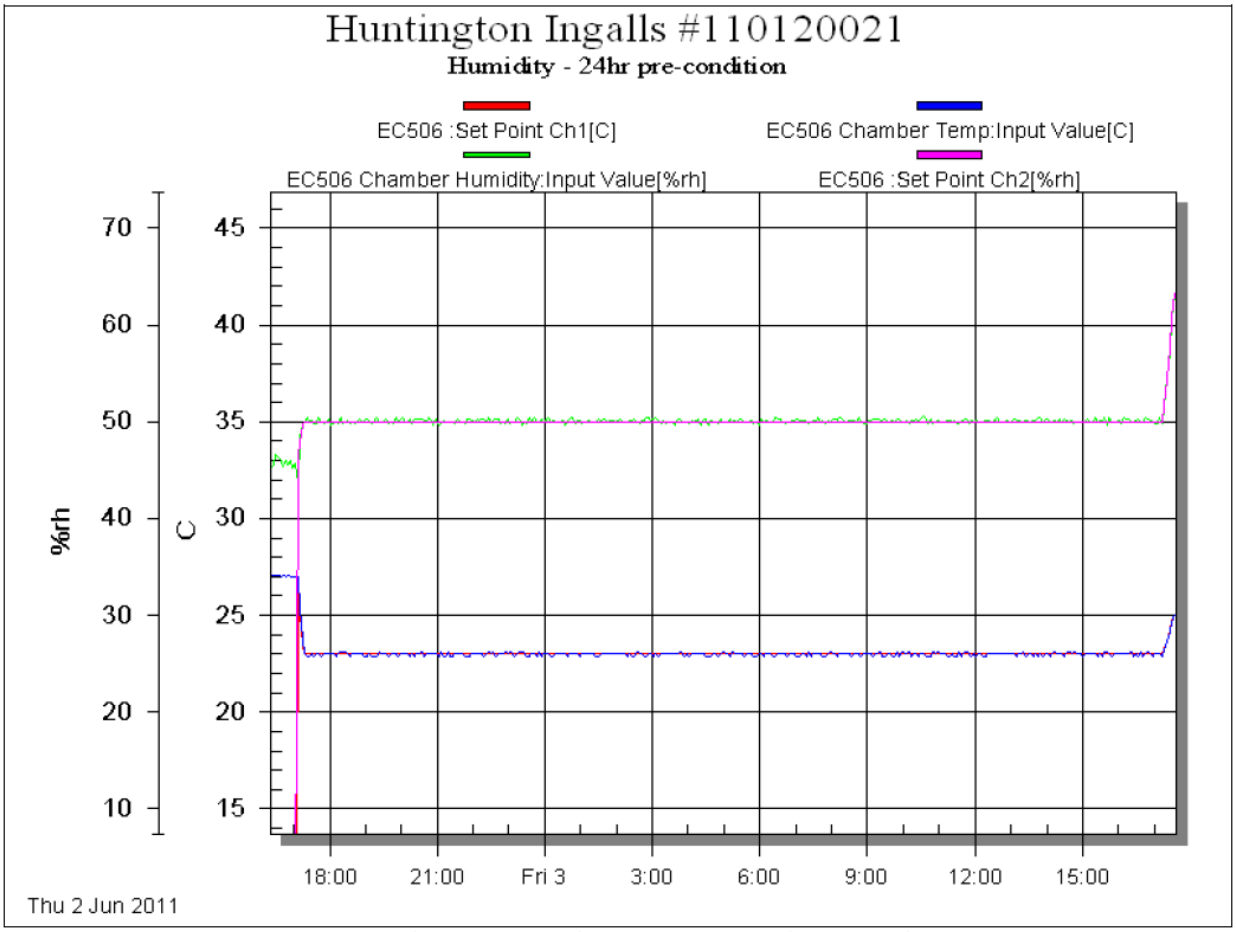
Humidity, Pre-Test

Humidity, Post 10 Cycles (Testing in Progress)

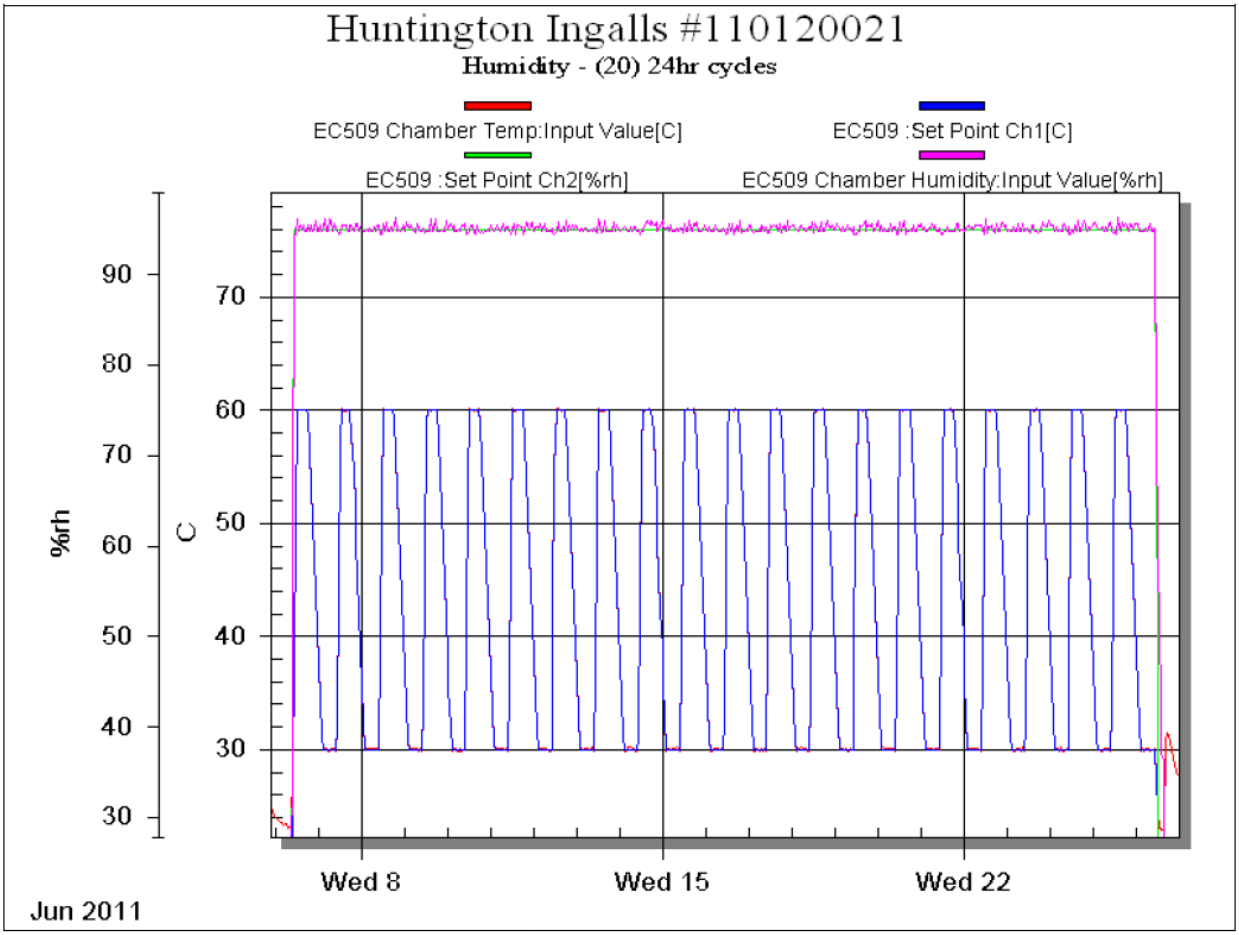


Humidity, Post-Test

Humidity, Post-Test



Humidity, Pre-Conditioning, Temperature Chart



Humidity, Temperature Chart

Table 2 Detroit Testing Lab Resistance Testing Results with Calibrated Ohm Meter

Sample #	Plate to Plate before Testing Begins	Plate to Plate after Humidity Testing	Plate to Plate after Salt Fog Testing
1	0.2	0.2	0.2
2	0.1	0.2	0.2
3	0.2	0.2	0.2
4	0.2	0.2	0.3
5	0.3	0.2	0.2
6	0.1	0.2	0.1
7	0.2	0.2	0.2
8	0.1	0.2	0.2
9	0.2	0.2	0.2
10	0.2	0.2	0.3
11	0.2	0.2	0.2
12	0.1	0.2	0.2
13	0.2	0.2	0.3
14	0.1	0.2	0.2
15	0.1	0.2	0.2
16	0.2	0.2	0.2
17	0.1	0.1	0.2
18	0.2	0.2	0.2
19	0.1	0.2	0.2
20	0.1	0.2	0.2

Plate to Plate Resistance Readings

TEST SEQUENCE

Salt Fog testing was performed from 06/26/11 through 07/04/11.

SAMPLE DESCRIPTION

A total of twenty (20) Brackets were presented for testing. Sample numbers, for the test samples, as received, were 1 through 20.

Results

No visible damage was noted to any of the samples. See Appendix B for resistance measurements.

TEST EQUIPMENT

Detroit Testing Laboratory, Inc.'s calibration system meets the requirements of ISO 17025:2005.

DTL ID	Description	Manufacturer	Model	Calibration Due
13690	Digital Multimeter	Fluke	179	04/12
EC502	Environmental Chamber	Thermotron	SM-32C	05/12
EC504	Salt Fog Chamber	Englehard	GL-41684	12/11

Salt Fog, Post First 48 Hour Wet Soak (Continued)

Salt Fog, Post First 48 Hour Dry Time

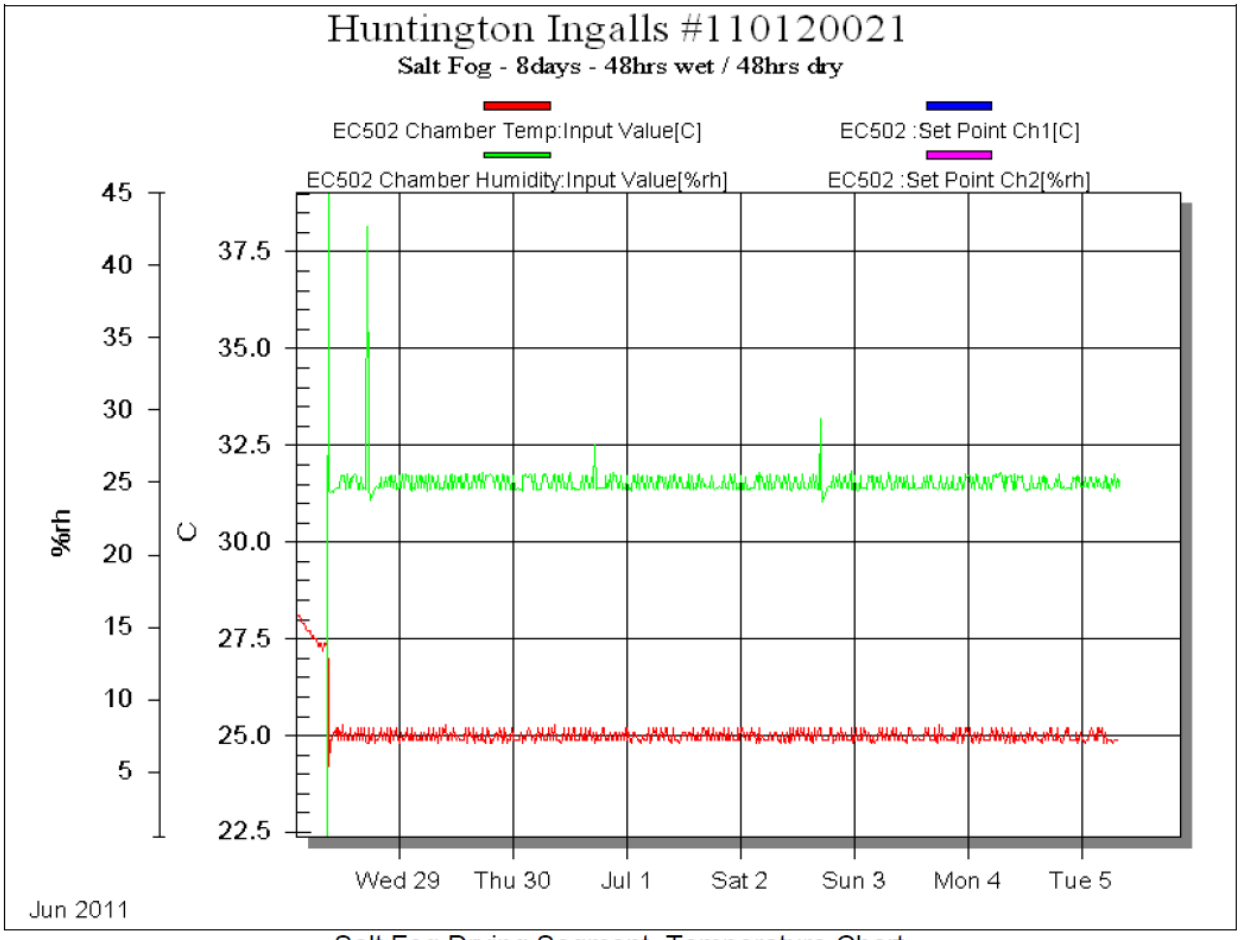
Salt Fog, Post First 48 Hour Dry Time (Continued)

Salt Fog, Post Second 48 Hour Wet Soak

Salt Fog, Post Second 48 Hour Wet Soak (Continued)

Salt Fog, Post Second 48 Hour Dry Time

Salt Fog, Post Second 48 Hour Dry Time (Continued)



Salt Fog Drying Segment, Temperature Chart

Table 2 Detroit Testing Lab Resistance Testing Results with Calibrated Ohm Meter

Sample #	Plate to Plate before Testing Begins	Plate to Plate after Humidity Testing	Plate to Plate after Salt Fog Testing
1	0.2	0.2	0.2
2	0.1	0.2	0.2
3	0.2	0.2	0.2
4	0.2	0.2	0.3
5	0.3	0.2	0.2
6	0.1	0.2	0.1
7	0.2	0.2	0.2
8	0.1	0.2	0.2
9	0.2	0.2	0.2
10	0.2	0.2	0.3
11	0.2	0.2	0.2
12	0.1	0.2	0.2
13	0.2	0.2	0.3
14	0.1	0.2	0.2
15	0.1	0.2	0.2
16	0.2	0.2	0.2
17	0.1	0.1	0.2
18	0.2	0.2	0.2
19	0.1	0.2	0.2
20	0.1	0.2	0.2

Plate to Plate Resistance Readings

Attachment 11: Test Sample Bonding Resistance and Notes and Observations from Samples after Testing

The following table shows resistance readings before torquing the bolts, after torquing the bolts, and after the salt spray corrosion testing was completed at the vendor facility. ,

	Before Torqueing (milli-ohms)							After Torqueing to 22 Foot Pounds (milli-ohms)							After Salt Spray Corrosion Testing (milli-ohms)						
Sample #	Bolt 1 to Steel Plate	Bolt 1 to Brass Plate	Bolt 2 to Steel Plate	Bolt 2 to Brass Plate	Bolt 3 to Steel Plate	Bolt 3 to Brass plate	Plate to Plate	Bolt 1 to Steel Plate	Bolt 1 to Brass Plate	Bolt 2 to Steel Plate	Bolt 2 to Brass Plate	Bolt 3 to Steel Plate	Bolt 3 to Brass plate	Plate to Plate	Bolt 1 to Steel Plate	Bolt 1 to Brass Plate	Bolt 2 to Steel Plate	Bolt 2 to Brass Plate	Bolt 3 to Steel Plate	Bolt 3 to Brass plate	Plate to Plate
1							0.1							0.0							0.0
2							0.5							0.1							0.0
3	Nylon	Nylon	Nylon	Nylon	Open	Open	Open	Nylon	Nylon	Nylon	Nylon	19.1	20.5	14.5	Nylon	Nylon	Nylon	Nylon	13.6	9.1	7.5
4	Nylon	Nylon	Open	Open	Open	Open	Open	Nylon	Nylon	6.7	5.6	6	6.8	9	Nylon	Nylon	15.0	11.8	10.6	8.3	6.8
5	Nylon	Nylon	Nylon	Nylon	Open	**4.2**	Open	Nylon	Nylon	Nylon	Nylon	3.5	3.3	0.5	Nylon	Nylon	Nylon	Nylon	6.2	6.0	0.6
6	Nylon	Nylon	Open	Open	Open	Open	Open	Nylon	Nylon	0.9	0.6	5	5.2	0.3	Nylon	Nylon	1.0	0.7	10.7	10.8	0.3
7	Open	Open	Open	Open	Open	Open	Open	3.1	2.8	4.4	4	3.5	3.4	0	3.6	3.1	7.1	6.7	84.0	83.7	0.4
8	Nylon	Nylon	Open	Open	Open	Open	Open	Nylon	Nylon	2.2	1.9	1.3	1	0.2	Nylon	Nylon	1.2	0.6	1.2	0.7	0.5
9	Nylon	Nylon	Open	5,300	Open	908	Open	Nylon	Nylon	2.3	2.2	7.7	7	0.5	Nylon	Nylon	2.0	2.0	7.1	7.6	0.6
10	Nylon	Nylon	**3.2**	Open	Open	Open	Open	Nylon	Nylon	6.4	7.2	7.6	8.2	0.8	Nylon	Nylon	10.3	10.1	13.7	14.0	1.0
11	Nylon	Nylon	Open	**2.6**	Open	**139**	Open	Nylon	Nylon	0.9	0.4	1.6	1.2	0.4	Nylon	Nylon	1.8	0.4	2.5	1.2	1.3
12	Open	Open	Nylon	Nylon	Open	Open	Open	24.5	26.5	Nylon	Nylon	29	31	0.1	12.1	12.1	Nylon	Nylon	12.0	16.6	0.2
13	Open	9.9	Open	Open	Nylon	Nylon	Open	Nylon	Nylon	32.7	0.9	Nylon	Nylon	33.3	Nylon	Nylon	33.7	0.6	Nylon	Nylon	34.5
14	Open	Open	Open	Open	Open	Open	Open	4.0	1.3	2.3	0.8	3.7	0.8	2.8	3.2	0.5	2.0	0.6	2.9	0.7	2.2
15	Nylon	Nylon	Open	**2.5**	Open	3.8	Open	Nylon	Nylon	0.5	0.3	0.5	0.3	0.7	Nylon	Nylon	0.6	0.4	0.6	0.4	0.7
16	Nylon	Nylon	Open	Open	Open	Open	Open	Nylon	Nylon	0.5	0.4	0.6	0.5	0.8	Nylon	Nylon	0.5	0.4	0.7	0.6	0.8
17	Nylon	Nylon	Open	Open	Open	Open	Open	Nylon	Nylon	0.2	0.2	0.2	0.3	0.5	Nylon	Nylon	0.3	0.3	0.4	0.4	0.5
18	Nylon	Nylon	Open	Open	Open	Open	Open	Nylon	Nylon	0.5	0.3	0.4	0.3	0.5	Nylon	Nylon	0.5	0.4	1.1	0.5	0.7
19	Nylon	Nylon	Open	Open	Open	Open	Open	Nylon	Nylon	0.4	0.6	0.5	0.5	0.7	Nylon	Nylon	0.5	0.5	0.8	0.4	0.9
20	Nylon	Nylon	Open	Open	Open	Open	Open	Nylon	Nylon	0.4	0.3	1	0.6	0.8	Nylon	Nylon	0.6	0.4	1.1	0.7	3.8

Torque Wrench Information: Snap-On 3/8 Drive Torque Wrench; 20 - 100 foot pounds range, Serial Number LSSMH171; 1005380313; NGSB GC 7LS Calibrated - ID - MH171; Date 02-17-11; Due 07-17-11
Resistance Measurements used Megger model DLR010HD Low Resistance (micro-ohm) Ohmmeter ID M18559 Calibration was performed on 5-18-2010 and is due 5-17-2013.

All samples were disassembled and photographed. All components were numbered and retained for later examination. Recall that the nylon bolts were used in some holes as place keepers in holes that showed grounding between the bolt and one or both of the plates before the test started. The nylon bolts did not allow for adequate torque to allow for penetration of the paint.

Sample #	Test Item	Observations And Conclusions	Corrosion	Piercing	Defor-mation*
1&2	n/a	Good contact between plates with minimal corrosion. Existing MIL-STD 1310 practice works well to assure bonding and grounding.	N	n/a	n/a
3&4	1	Piercing of paint on all plates. One steel plate had only a few small points of piercing on the steel plate.	N	Y	Y
5&6	2	Improved penetration over 3&4. Smaller number of teeth cuts through paint better.	N	Y	N
7&8	3	Excellent penetration. This thicker washer with sharp teeth was well designed for this application.	N	Y	N
9&10	4	The interior teeth washer worked well on a hole just larger than the bolt.	N	Y	N
11&12	5	Although there was electrical bonding, the piercing of the paint was good on the brass bar but only minor piercing on the steel bar. This style washer should be rejected.	Y	N	N
13&14	1	Very little paint piercing on the steel plate. Sample 13 did not have an acceptable electrical bond. It's possible that the ground on the sample 14 was through the bolt threads and not the washer.	N	N	N
15&16	2	One point where the washer penetrated to the steel plate had some corrosion. One point where the washer penetrated the brass plate also had some corrosion. Both of these corrosion spots were on sample 15.	Y	Y	N
17&18	3	Good penetration into the brass plates. Lesser penetration into the steel plates, but some points on each washer did penetrate into the steel. On areas where the washers were exposed, there was corrosion on the washers. Even between the washer and the surface of the bars, where the zinc compound was liberally applied, corrosion was proceeding along the surface.	Y	Y	N
19&20	4	Good penetration into the brass plates. Lesser penetration into the steel plates, but some points on each washer did penetrate into the steel. No visible corrosion. Some of the washers show deformation (crushing).	N	Y	Y

*This was a subjective evaluation. Only obvious deformation was noted.

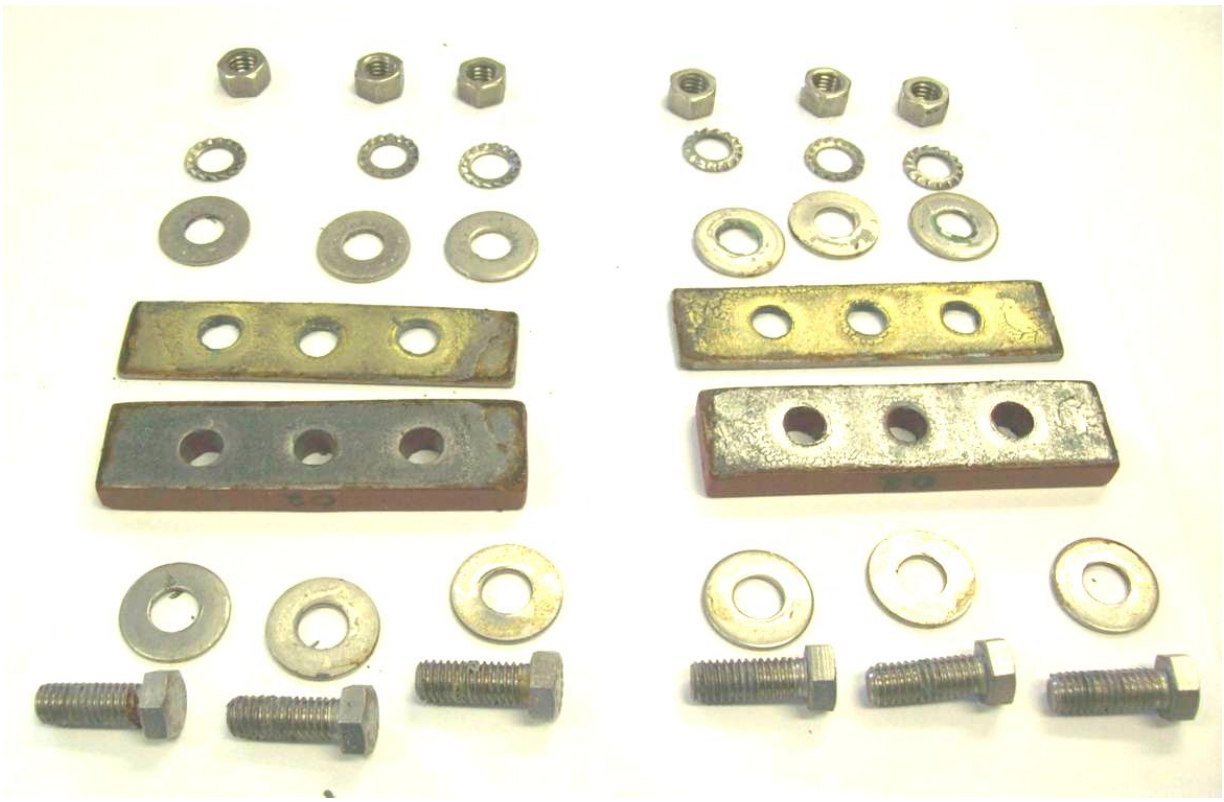


Figure 3 Specimen 1 & 2 Order of Assembly

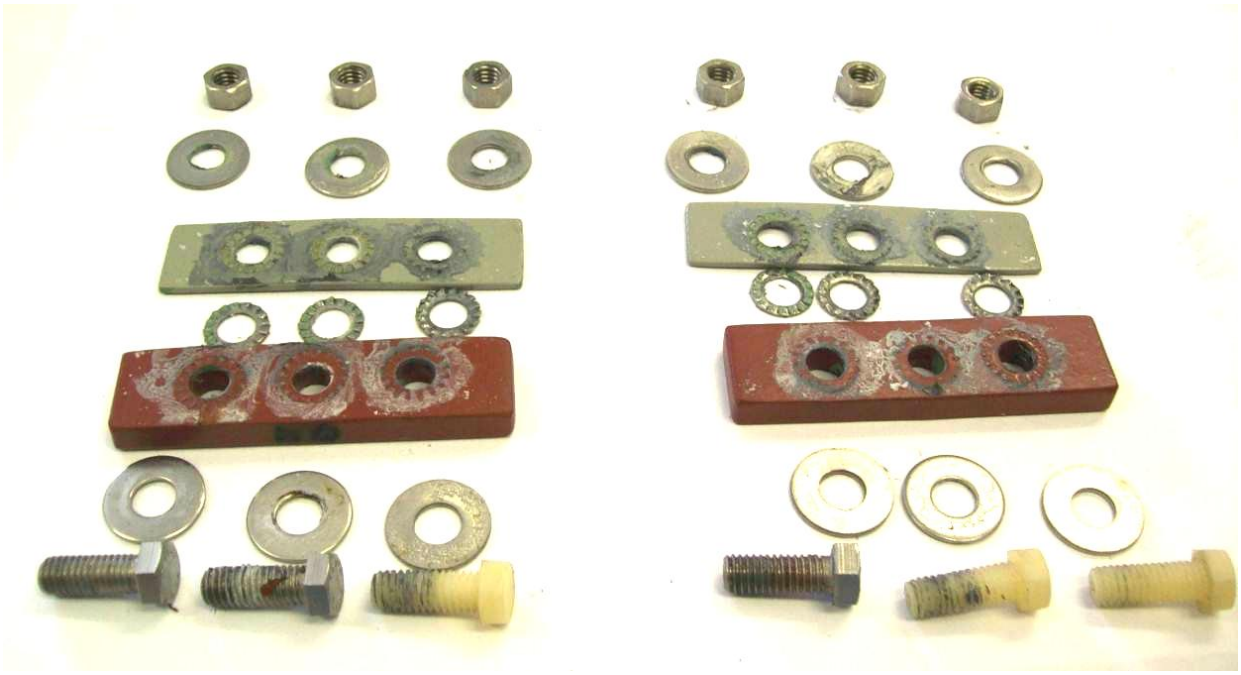


Figure 4 Specimens 3-12 Order of Assembly

Figure 5 These non-stainless washers showed significant corrosion

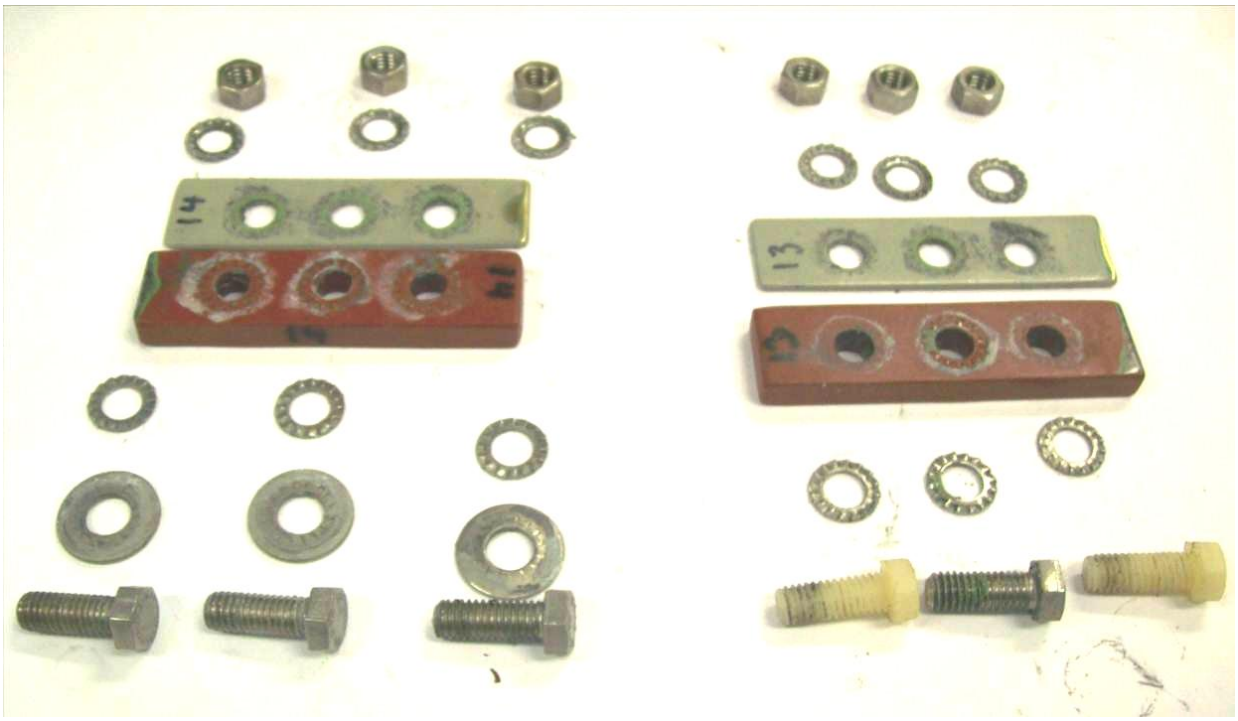


Figure 6 Samples 13, 15, 17, & 19 were assembled as shown on the left. Samples 14, 16, 18, & 20 were assembled as shown on the right

Attachment 12: Current Testing

After the completion of the original scope of this project, questions arose about the current carrying capacity of the grounding washers. The contact surface area is less than with a traditional Class B bond.

Four samples were prepared from the previous samples. Materials were chosen that were the least damaged.

Figure 7 Order of Assembly for Test Samples

Figure 8 Four Test Samples After Assembly

Figure 9 Assembled Test Sample

Figure 10 To prepare the samples, a small area on each end had the paint removed.

After assembly but before the bolts were torqued down, the resistance between the bolts and the steel plate and between the plates was checked to verify that there were no unexpected paths between the plates. After torquing to 22 foot pounds, the resistance was verified again to assure that a low resistance bond had been achieved.

	Before Torquing Bolts (Ohms)			After Torquing Bolts (mOhms)
Sample #	Bolt 1 to Steel Plate	Bolt 2 to Steel Plate	Plate to Plate	Plate to Plate
7	Open	Open	Open	0.49
16	0.41	0.13	Open	0.56
17	Open	Open	Open	0.40
18	Open	Open	Open	0.15

Figure 11 A Miller TIG Welding Machine, Syncrowave 350 LX was used to create the current.

Figure 12 Ingalls Welding Engineer, Bennie Porter, verifies the current output with a Fluke 337 Clamp meter

Figure 13 The voltage to current ratio confirms a resistance of 11 mOhm or less

V=I * R

0.6 = 55 * R

R = 0.6 / 55 = 0.011 ohms = 11 mohms

Each of the samples were tested for 5 minutes at 55 amps followed by 5 minutes at 110 amps.

Sample #	55 Amps	110 Amps
7	√	√
16	√	√
17	√	√
18	√	√

All samples allowed the passage of current with no change in resistance as shown by the voltage required to maintain the current. This indicates no degradation of the bonding due to the current passing.

After the end of the test, the last sample, number 18, was subjected to 250 amps of current for 10 minutes. After the test was secured, the sample was allowed to cool and was then disassembled. No signs of burn marks or other damage was seen on the mating surfaces including the washer tips. The reason the sample heated was the resistance between the clamps and the sample. The bonded surface had a lower resistance.

Also, Sample 16 was disassembled and inspected for signs of damage. None were identified.

Figure 14 Sample 16 after testing. No damage at mating surfaces.

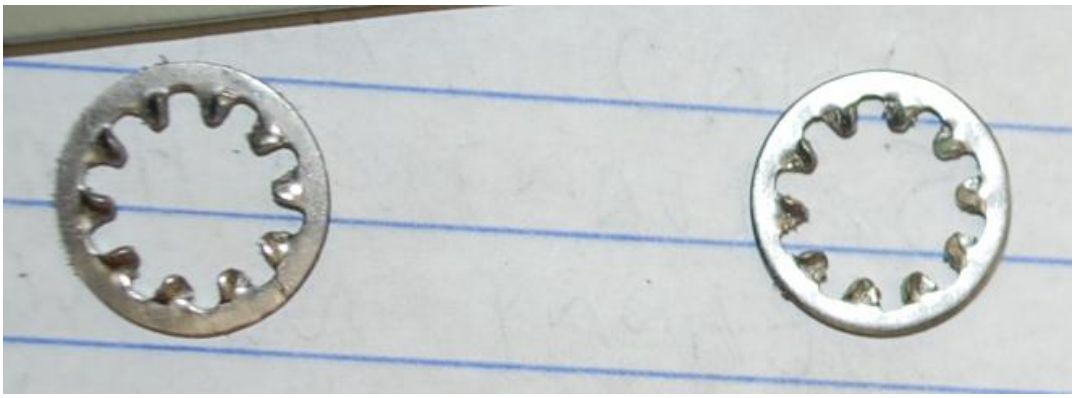


Figure 15 Close-up of Sample 16 Washers After Testing

A Megger brand model DLR010HD Low Resistance (micro-ohm) Ohmmeter was used for the resistance checks. The serial number and calibration information are as follows: ID M18559 Calibration was performed on 5-18-2010 and is due 5-17-2013.

Attachment 13: Rough Order of Magnitude (ROM) Cost Estimate

As an alternative to the Class B Bond of cleaning mating surfaces down to bright metal, a grounding washer may be placed between the item to be mounted and its foundation on every mounting fastener.

A database was queried to produce a list of every item of electrical equipment on each of the 4 ship classes produced at the Ingalls shipyard. The list for one class of ships was sorted to determine that 83 percent of the items were mounted with Class B bonds.

The standard for performing a Class B bond was compared to the estimated time for using grounding washers.

Ship Class	NSC	LHA	LPD	DDG
Estimated Savings (% of man-hrs)	76%	79%	80%	80%

These results indicate a significant cost savings if the shipyards were allowed the alternative method of using grounding washers as recommended in this document.