wiley

WEEB® Washer Guide

A complete guide to WEEB® washer solutions for the electrical bonding and grounding professional

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Why the Need to Bond and Ground?

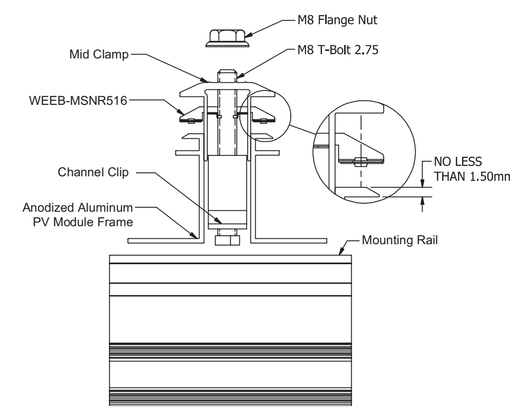
Strong, reliable infrastructure supports the smooth execution of business every day. Common practice and a crucial part of the National Electrical Code (NEC) require conductive equipment and systems to be properly bonded and grounded to protect workers and civilians from electric shock. Connections that do not last for the lifetime of the system or are not replaced in a timely manner can result in an unbonded system, putting people and equipment at risk.

There are countless avenues that engineers and installers can utilize to meet grounding and bonding requirements, but the resilience and quality of these methods are not always equal. Burndy has developed a line of products to ensure grounding and bonding connections stay fast no matter the environment, protecting both life and investments.

Best Practices

The following best practices include general rules of thumb that should be considered in bonding and grounding. Although every installation is unique, adhering to these guidelines promotes system longevity and protection from failure in the event of a fault or other electrical event where non-energized components become energized.

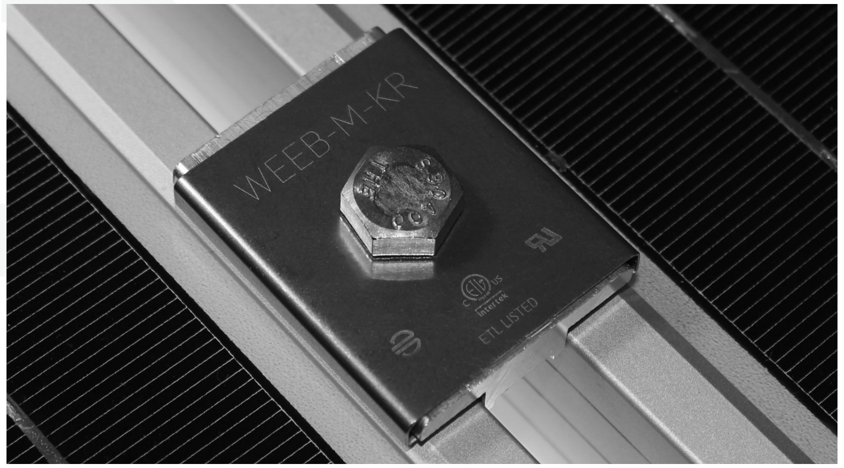
WEEB® washer technology fulfills all these practices, creating dense contact points while penetrating through coated surfaces to make connections that withstand the conductors' current load capacity.

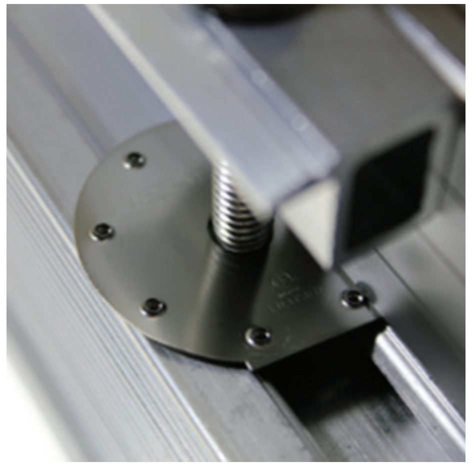


1. Metal structures and enclosures are bonded through connections to other metal components. The denser the contact point, the stronger the connection.

2. Non-conductive surface treatment or coatings must be removed before connectors can be installed. (Unless a WEEB washer designed specifically to create an electrical bond is used.)

3. Connection points must handle, without damage, faults at current levels and durations based on the conductor's current-carrying capacity. To do so, the connection resistance must be at a level conducive to the unimpeded flow of power.





Standards and Requirements

Similar to most aspects of an installation, codes and standards define requirements for bonding and grounding. This is viewed as so important that the NEC specifically states that products must be listed for their intended application. Meeting these requirements are essential for products to guarantee compatibility with defined applications and ensure the safety of an installation. The two main standards the WEEB technology is listed to are UL467 and UL2703.

UL467

The UL467 Standard applies to grounding and bonding connectors or devices used to make electrical connections between grounding conductors, equipment, and structures.

UL2703

UL 2703 Standard covers rack mounting systems, mounting grounding/bonding components, and clamping retention devices for specific (Manufacturer/model designation) flat-plate photovoltaic modules and panels intended for installation on or integral with buildings, or to be freestanding (i.e., not attached to buildings), in accordance with the National Electrical Code, ANSI/NFPA 70 and Model Building Codes.

In the Information and Communication Technology sector, the two main standards that grounding and bonding products may be listed to include ANSI/TIA-607-C and ANSI/NECA/BICSI 607-211.

The **ANSI/TIA-607-C** standard covers Generic Telecommunications Bonding and Grounding for Customer Premises.

The **ANSI/NECA/BICSI 607-211** standard covers telecommunications bonding and grounding planning and installation methods for commercial buildings.

> NEC specifically states that products must be listed for their intended application.

There are three NEC Articles that apply to bonding and grounding: Article 250, the main article covering bonding and grounding, Article 690 which covers PV systems, and Article 110.14(D) which directs Torque requirements for correct installation.

NEC Article 250 contains the following grounding and bonding requirements:

1. What systems and equipment are required to be grounded.
2. Location of grounding connections.
3. Types of electrodes and sizes of grounding and bonding conductors.
4. Methods of grounding and bonding.

NEC Article 690 applies to photovoltaic (PV) electrical energy systems, array circuits, inverters, and charge controllers for PV systems, which may be interactive with other electrical power sources (electric utility) or stand-alone with or without energy storage (batteries).

NEC 110.14(D) refers to situations where a tightening torque is indicated as a numeric value on equipment or in installation instructions provided by the manufacturer. It directs that a calibrated torque tool shall be used to achieve the indicated torque value unless the equipment manufacturer has provided installation instructions for an alternative method of achieving the required torque.

Each of the standards listed above subject WEEB washers to rigorous testing sequences that simulate the harshest conditions an installer is likely to encounter in the field. These washers are investigated from a variety of aspects, spanning from strength ratings to flame resistance. We ensure all WEEB washers meet standard requirements to give our customers peace of mind that they are using some of the highest quality components available in the marketplace.

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Material

The material used to manufacture a product can make the difference between a temporary product intended to last a couple of years and a long-term solution able to endure in all environments for decades. Stainless Steel is often looked at as a material guaranteed to last the life of an installation. It is important to note, however, that the grade of Stainless Steel can have significant impact on product longevity in corrosive environments.

304 Stainless Steel is the premier choice for products installed in conditions that can lead to corrosion. Significant testing has shown that 304 stainless steel demonstrates superior corrosion resistance and can endure harsh conditions, such as those seen in the most difficult solar installation environments. Products manufactured from 304 stainless steel are the optimal choice for applications intended to last the life of a system, even in harsh environmental conditions.

316 Stainless Steel offers maximum corrosion resistance in the harshest environments. It is known as "Marine Grade" Stainless Steel. It can endure temperatures up to 1600 degrees Fahrenheit, resist sulfuric acids and is often used for floating oil rigs and oil refinery piping. It is also the most costly option.

400 Stainless Steel products offer a good lower cost option when corrosion and movement is not a concern, such as inert indoor environments. They also offer a good choice for temporary applications where long-term stability and corrosion resistance are not key factors in product success.

Galvanized and Zinc-Plated Steel products are produced with a coating to provide a corrosion barrier. Typically, zinc plated refers to electroplating, with a very thin zinc coating. Zinc plated steel is not recommended for outdoor use. Galvanizing can either be electroplated (at varying thicknesses depending on corrosion resistance needed) or dipped for small components. Hot dipped galvanized is usually the thickest coating and thus the highest cost and corrosion resistance. Galvanizing to a G90 thickness is the standard baseline for most solar installs, but thicker coatings are routinely used in more corrosive environments. G90 is a typical galvanized coating thickness utilized in solar applications such as steel purlins.

> The entire WEEB washer product portfolio is manufactured in 304 Stainless Steel, providing excellent resistance to corrosion and cost effectiveness.

Types of WEEB® Washers

Wiley recognizes the need for quick and reliable bonding solutions. Our WEEB washers offer a simple, low-cost method to bond any non-conductive coated surfaces together reducing time, labor costs and the amount of copper wiring. The teeth on the washer pierce through most non-conductive coatings (e.g. anodization, powder coating, or painted surfaces) and embed into the underlying metal, creating a bonding connection between the mounting surface and coated metal component that it is installed on or between. The result is excellent conductivity without oxidation!

With many geometries available to mate with standard lugs or other hardware, WEEB washers can be used for bonding and grounding in various applications like, but not limited to, Solar Photovoltaic (PV) Frame and Racking systems, Unistrut systems, Telecom and Data Center Equipment and fencing enclosures.

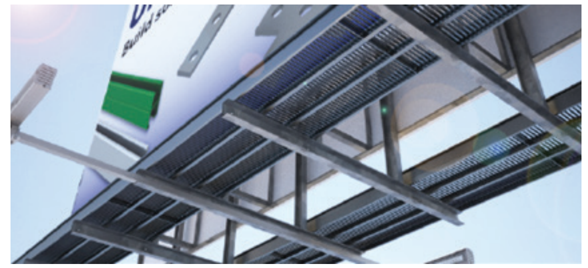
Solar PV Applications
When bonding Photovoltaic (PV) module frames with metal racking structures, WEEB clamp washers easily snap or slide into place for quick installation. Essentially, the module and rail become a singular piece, creating an electrical path to the ground. Integrated bonding clamps, and top and bottom mount washer configurations provide a perfect fit for most manufacturers.

Types of WEEB® Washers

GENERIC APPLICATIONS

Unistrut / Racking Systems WEEB Washers

Top and bottom configuration WEEB washers also provide excellent solutions for grounding and bonding Unistrut and racking systems, such as those seen in building frames or any type of metal racking configuration which may be subject to electrical charges.



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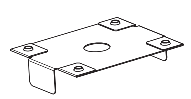
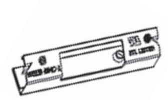
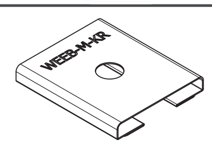
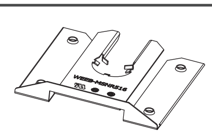
	**WEEB-WMC**	1.63 [41.30]	1.31 [33.50]	0.34 [8.61]	0.31 [7.94]	Rigid

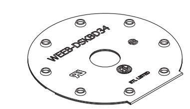
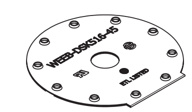
INTEGRATED BONDING APPLICATIONS

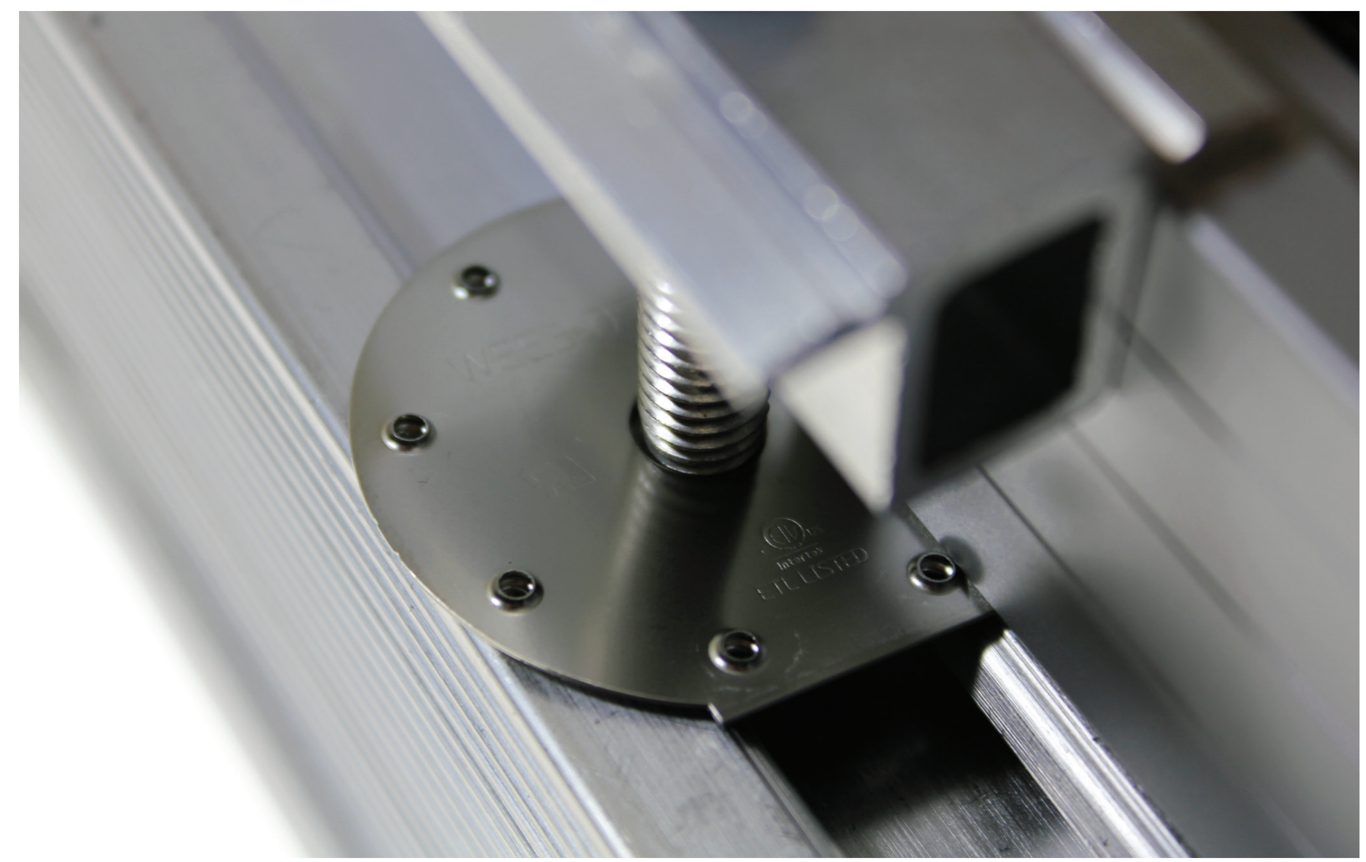
Integrated Bonding WEEB washers can snap or slide onto an existing mid- and/or end-clamp for easy installation in Solar PV applications.

Line Image	Catalog Number	Length inch [mm]	Width inch [mm]	Height inch [mm]	Hole Size inch [mm]	Type
	**WEEB-BMC-1**	1.57 [40.00]	.30 [7.60]	0.19 [4.83]	N/A	Clip On
	**WEEB-M-KR**	1.65 [41.90]	1.40 [35.80]	0.22 [5.50]	0.33 [8.38]	Slide On
	**WEEB-MSNR516**	1.50 [38.00]	1.57 [40.00]	0.25 [6.40]	0.43 [11.00]	Slide On

TOP CLAMP APPLICATIONS

Universal WEEB Washers bond PV modules to the mounting structure at mid-clamp locations. The disk shaped washers allow for a range of compatibility across various racking systems and applications.

Line Image	Catalog Number	Length inch [mm]	Width inch [mm]	Height inch [mm]	Hole Size inch [mm]	Type
	**WEEB-DSKBD34**	1.57 [40.00]	1.57 [40.0]	0.07 [1.75]	0.32 [8.10]	Disk
	**WEEB-DSK516-45**	1.77 [45.00]	1.77 [45.00]	0.07 [1.75]	0.32 [8.10]	Disk



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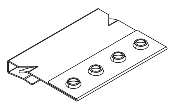
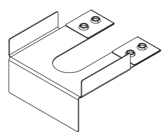
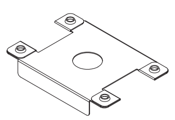
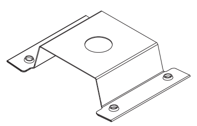
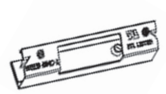
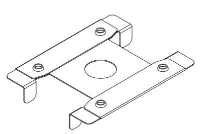
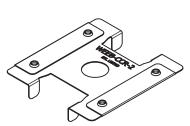
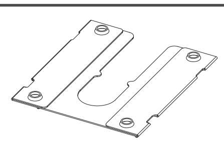
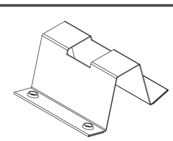
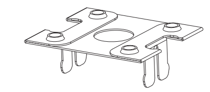
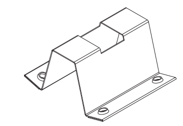
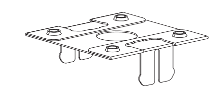
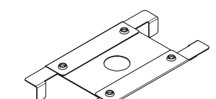
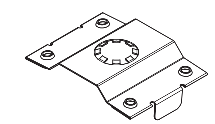
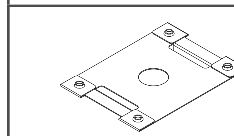
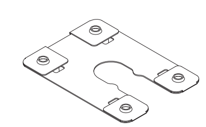
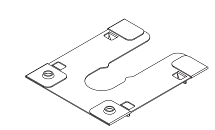
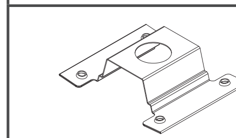
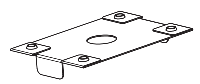
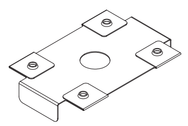
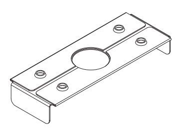
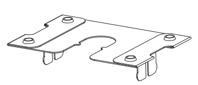
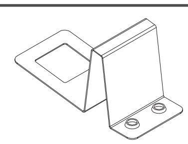
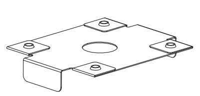
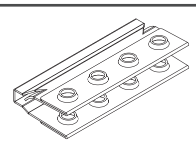
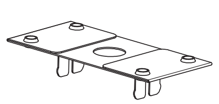
Top Clamp mounting WEEB® washers bond PV modules to the mounting system at mid-clamp locations. They may be pre-installed or slid onto mid-clamp hardware prior to the securement of modules and can be applied to applications outside of solar.

Line Image	Catalog Number	Length inch [mm]	Width inch [mm]	Height inch [mm]	Hole Size inch [mm]	Type
	**WEEB-ADC**	0.94 [24.00]	0.73 [18.66]	0.15 [3.75]	N/A	Clip On
	**WEEB-ADR**	1.34 [34.00]	1.18 [30.00]	0.72 [18.25]	0.38 [9.75]	Rigid
	**WEEB-ASR**	1.51 [38.40]	1.00 [25.50]	0.24 [6.12]	0.32 [8.14]	Rigid
	**WEEB-ATF**	1.68 [42.66]	1.26 [32.00]	0.40 [10.11]	0.31 [7.94]	Flexible
	**WEEB-BMC-1**	1.49 [38.00]	0.30 [7.60]	0.12 [2.97]	N/A	Clip On
	**WEEB-CCR**	1.59 [40.33]	1.26 [32.00]	0.24 [6.05]	0.33 [8.43]	Rigid
	**WEEB-CCR-2**	1.59 [40.33]	1.49 [38.00]	0.24 [6.05]	0.33 [8.43]	Rigid
	**WEEB-CMC**	1.28 [32.50]	1.15 [29.10]	0.19 [4.83]	0.31 [8.00]	Slotted
	**WEEB-DHF**	1.06 [27.00]	1.13 28.60]	0.60 [15.09]	0.30 [7.69]	Flexible

TOP CLAMP APPLICATIONS

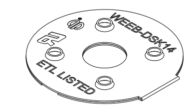
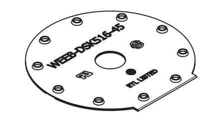
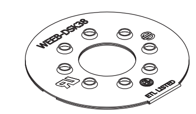
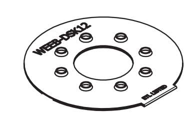
Line Image	Catalog Number	Length inch [mm]	Width inch [mm]	Height inch [mm]	Hole Size inch [mm]	Type
	**WEEB-DMC**	0.86 [22.04]	0.71 [18.00]	0.30 [7.62]	0.25 [6.35]	Rigid
	**WEEB-DPF**	1.06 [27.00]	1.13 [28.60]	0.59 [15.09]	0.30 [7.69]	Flexible
	**WEEB-DPR**	1.00 [25.41]	0.98 [25.00]	0.98 [25.00]	0.31 [8.00]	Rigid
	**WEEB-ECR**	2.16 [55.00]	1.17 [29.70]	0.28 [7.09]	0.33 [8.43]	Rigid
	**WEEB-JJR**	1.25 [31.75]	0.91 [23.00]	0.33 [8.51]	0.37 [9.40]	Flexible
	**WEEB-KMC**	1.67 [42.42]	1.22 [31.00]	0.18 [4.70]	0.37 [9.40]	Rigid
	**WEEB-KSR**	1.39 [35.26]	0.99 [25.20]	0.10 [2.55]	0.31 [8.00]	Slotted
	**WEEB-OCR**	1.36 [34.50]	1.16 [29.50]	0.12 [3.17]	0.33 [8.38]	Slotted
	**WEEB-OSF**	1.48 [37.70]	1.26 [32.00]	0.39 [10.03]	0.37 [9.58]	Flexible

TOP CLAMP APPLICATIONS

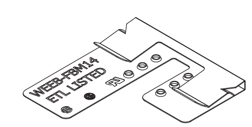
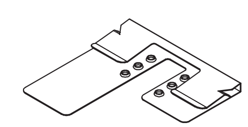
Line Image	Catalog Number	Length inch [mm]	Width inch [mm]	Height inch [mm]	Hole Size inch [mm]	Type
	**WEEB-PMC**	1.58 [40.11]	1.10 [28.00]	0.25 [6.37]	0.31 [7.94]	Rigid
	**WEEB-RPR**	1.47 [37.41]	1.14 [28.85]	0.27 [6.88]	0.32 [8.20]	Rigid
	**WEEB-SCR**	1.72 [43.70]	0.65 [16.51]	0.28 [7.11]	0.37 [9.53]	Rigid
	**WEEB-SMC-2**	1.50 [38.10]	0.98 [25.00]	0.33 [8.38]	0.32 [8.20]	Slotted
	**WEEB-SSF**	1.33 [33.86]	0.59 [15.00]	0.67 [16.94]	0.34 [8.48]	Flexible
	**WEEB-SSR**	1.70 [40.20]	1.35 [34.30]	0.27 [6.86]	0.37 [9.53]	Rigid
	**WEEB-STC**	0.94 [24.00]	0.42 [10.58]	0.17 [4.42]	N/A	Rigid
	**WEEB-UMC**	1.49 [37.91]	0.71 [18.00]	0.29 [7.34]	0.25 [6.35]	Rigid

BOTTOM MOUNT APPLICATIONS

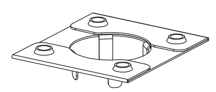
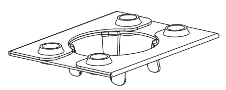
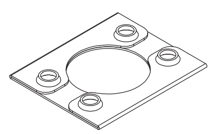
Universal WEEB® disk washers are typically installed between the solar PV module frames and the mounting surface at the module securement location.

Line Image	Catalog Number	Length inch [mm]	Width inch [mm]	Height inch [mm]	Hole Size inch [mm]	Type
	**WEEB-DSK14**	0.94 [24.10]	0.94 [24.10]	0.07 [1.75]	0.26 [6.75]	Disk
	**WEEB-DSK516**	1.01 [25.75]	1.01 [25.75]	0.07 [1.75]	0.32 [8.10]	Disk
	**WEEB-DSK38**	1.18 [30.88]	1.18 [30.88]	0.07 [1.75]	0.39 [9.80]	Disk
	**WEEB-DSK12**	1.39 [35.38]	1.39 [35.38]	0.07 [1.75]	0.51 [13.10]	Disk

Universal Frame WEEB washers clip onto the solar PV module frame at the module securement location to create a connection between the module and galvanized steel structure.

Line Image	Catalog Number	Length inch [mm]	Width inch [mm]	Height inch [mm]	Hole Size inch [mm]	Type
	**WEEB-FBM14**	1.78 [42.25]	1.67 [42.50]	0.12 [3.20]	0.26 [6.75]	Clip On
	**WEEB-FBM516**	1.81 [46.00]	1.78 [45.25]	0.12 [3.20]	0.32 [8.10]	Clip On

Bottom mount WEEB® washers bond PV modules to the mounting structure at the module mounting holes. May have features that can be applied to applications outside of solar and secure the WEEB washer at holes, slot, or directly to module frames prior to installation.

Line Image	Catalog Number	Length inch [mm]	Width inch [mm]	Height inch [mm]	Hole Size inch [mm]	Type
	**WEEB-11.5**	0.87 [22.10]	0.79 [20.20]	0.15 [4.00]	0.47 [12.00]	Rigid
	**WEEB-9.5**	0.71 [18.00]	0.59 [15.10]	0.12 [3.15]	0.39 [10.00]	Rigid
	**WEEB-9.5NL**	0.71 [18.00]	0.59 [15.10]	0.07 [1.74]	0.39 [10.00]	Rigid

GROUNDING LUGS

For a continuous ground path on roof or ground mounted solar systems the WEEB-LUG is designed and manufactured to meet and exceed industry standards and to deliver maximum reliability.

WEEB-LUGs have a low profile and consist of tin plated copper lugs and 304 stainless steel WEEB® washers available in various sizes, mounting hardware options and offered assembled or as a package component. They are UL467 Listed and UL2703 Recognized.

<table>
<tr><th colspan="7">WEEB® Grounding Lug</th></tr>
<tr><td colspan="7">Utilizes proven WEEB® washer technology to bite through most non-conductive coatings.</td></tr>
<tr><th>Catalog Number</th><th>Length inch [mm]</th><th>Width inch [mm]</th><th>Height inch [mm]</th><th>Hole Size inch [mm]</th><th>Mounting Hardware</th><th>Assembled</th></tr>
<tr><td>WEEB-LUG-6.7</td><td rowspan="8">1.57 [40.00]</td><td rowspan="2">0.71 [18.00]</td><td rowspan="8">0.47 [12.00]</td><td rowspan="2">0.27 [6.76]</td><td rowspan="2">1/4" hardware included</td><td>N</td></tr>
<tr><td>WEEB-LUG-6.7AS</td><td>Y</td></tr>
<tr><td>WEEB-LUG-8.0</td><td rowspan="3">0.86 [22.00]</td><td rowspan="5">0.32 [8.20]</td><td>M8 or 5/16" hardware NOT included</td><td>N</td></tr>
<tr><td>WEEB-LUG-8.0AS</td><td rowspan="2">5/16" hardware included</td><td>Y</td></tr>
<tr><td>WEEB-LUG-8.0UN</td><td>N</td></tr>
<tr><td>WEEB-LUG-15.8</td><td rowspan="2">0.71 [18.00]</td><td rowspan="2">M8 or 5/16" hardware NOT included</td><td>N</td></tr>
<tr><td>WEEB-LUG-8.2</td><td>N</td></tr>
<tr><td>WEEB-LUG-10.3</td><td>0.86 [22.00]</td><td>0.41 [10.30]</td><td>M10 or 5/16" hardware NOT included</td><td>N</td></tr>
</table>

<table>
<tr><th colspan="7">Wiley Grounding Lug</th></tr>
<tr><td colspan="7">Perfect for galvanized steel applications or anywhere a WEEB® washer is not required.</td></tr>
<tr><th>Catalog Number</th><th>Length inch [mm]</th><th>Width inch [mm]</th><th>Height inch [mm]</th><th>Hole Size inch [mm]</th><th>Mounting Hardware</th><th>Assembled</th></tr>
<tr><td>WILEYLUG6.7</td><td rowspan="4">1.57 [40.00]</td><td>0.71 [18.00]</td><td rowspan="4">0.47 [12.00]</td><td>0.27 [6.76]</td><td>1/4" hardware NOT included</td><td rowspan="4">N</td></tr>
<tr><td>WILEYLUG8.0</td><td>0.86 [22.00]</td><td rowspan="3">0.32 [8.20]</td><td rowspan="3">M8 or 5/16" hardware NOT included</td></tr>
<tr><td>WILEYLUG8.2</td><td rowspan="2">0.709 [18.00]</td></tr>
<tr><td>WILEYLUG15.8</td></tr>
</table>

Jumper Applications

WEEB Bonding Jumpers and WEEB Rope Lay Jumpers offer an excellent solution to maintain electrical continuity over long spans or air gaps between metal structures. Both include the WEEB washer's patented WEEB washer teeth which pierce through most non-conductive coatings and embed into the underlying metal component that it is installed onto and both are UL 467 and UL 270. Listed.

WEEB Bonding Jumpers (WEEB-BNDJMP) are constructed of corrosion resistant, tin-plated braided copper.

WEEB® Bonding Jumpers	*Utilizes proven WEEB® washer technology to bite through any non-conductive coatings.*						
Catalog Number	**Length inch [mm]**	**Width inch [mm]**	**Height inch [mm]**	**Hole Size inch [mm]**	**Gauge**	**Hardware**	**Assembled**
WEEB-BNDJMP6.7	9.00 [228.60]	0.71 [18.00]	0.08 [2.03]	0.26 [6.53]	6 AWG	WEEB® washer included; 1/4" mounting hardware NOT included	N
WEEB-BNDJMP6.7AS						WEEB® washer included; 1/4" mounting hardware included	Y
WEEB-BNDJMP8.0	6.00 [152.40]	0.87 [22.00]	10.0 [2.54]	0.32 [8.20]		WEEB® washer included; M8 or 5/16" mounting hardware NOT included	N
WEEB-BNDJMP8.0AS						WEEB® washer included; M8 or 5/16" mounting hardware included	Y
WEEB-BNDJMP8.2	10.00 [254.0]	0.71 [18.00]	0.08 [2.03]	0.32 [8.20]		WEEB® washer included; M8 or 5/16" mounting hardware NOT included	N
WEEB-BNDJMP8.2MS						WEEB® washer included; M8 flat washer included	N
WEEB-BNDJMP9	9.00 [228.60]	0.71 [18.00]	0.08 [2.03]	0.26 [6.53]		WEEB® washer included; 1/4" mounting hardware NOT included	N
WEEB-BNDJMP12	12.00 [304.80]	0.71 [18.00]	0.08 [2.03]	0.26 [6.53]		WEEB® washer included; 1/4" mounting hardware NOT included	N
WEEB-BNDJMP12AS						WEEB® washer included; 1/4" mounting hardware included	Y
WEEB-BNDJMP18	18.00 [457.20]	0.71 [18.00]	0.08 [2.03]	0.26 [6.53]		WEEB® washer included; 1/4" mounting hardware NOT included	N
WEEB-BNDJMP18AS						WEEB® washer included; 1/4" mounting hardware included	Y
WEEB-BNDJMP24	24.00 [609.80]	0.71 [18.00]	0.08 [2.03]	0.26 [6.53]		WEEB® washer included; 1/4" mounting hardware NOT included	N
WEEB-BNDJMP24AS						WEEB® washer included; 1/4" mounting hardware included	Y
WEEB-BNDJMP36	36.00 [914.84]	0.71 [18.00]	0.08 [2.03]	0.26 [6.53]		WEEB® washer included; 1/4" mounting hardware NOT included	N
WEEB-BNDJMP36AS						WEEB® washer included; 1/4" mounting hardware included	Y

WEEB Rope Lay Jumpers (WEEB-RLJ) are made from tin plated copper stranding and crimped into a high quality Burndy Lug.

Catalog Number	AWG Size	Length	Mounting Hole Diameter	Hardware Equivalent
WEEB-RL-J6C6-14	#6	6" / 152 mm	.27" / 6.8 mm	1/4"
WEEB-RL-J6C12-14	#6	12" / 305 mm	.27" / 6.8 mm	1/4"
WEEB-RL-J6C18-14	#6	18" / 457 mm	.27" / 6.8 mm	1/4"
WEEB-RL-J6C6-516	#6	6" / 152 mm	.33" / 8.4 mm	5/16"
WEEB-RL-J6C12-516	#6	12" / 305 mm	.33" / 8.4 mm	5/16"
WEEB-RL-J6C18-516	#6	18" / 457 mm	.33" / 8.4 mm	5/16"
WEEB-RL-J6C6-38	#6	6" / 152 mm	.39" / 9.9 mm	3/8"
WEEB-RL-J6C12-38	#6	12" / 305 mm	.39" / 9.9 mm	3/8"
WEEB-RL-J6C18-38	#6	18" / 457 mm	.39" / 9.9 mm	3/8"

Data Center and Telecom

Single and Two-Hole WEEB washer lugs are powder coat and paint penetrating contact enhancing washers used between connectors and equipment frames, cabinets, and other painted metallic surfaces to be bonded. They eliminate the need for surface preparation, saving time and providing a cleaner work environment. The penetrating teeth limit corrosion points and provide anti-rotation properties delivering consistent and tested connections for data center and telecom equipment.

WEEB® Washer	Compatible 1-Hole HYLUG™ Family	Conductor		Hex Head Bolt		Installation Tooling
		Wire Type	Wire Range	Size	Torque (in-lbs)	
	YA-TC14	Code	#14-#6 AWG			
	YA-L-TC14	Code	#14-#6 AWG			
	YAZ-TC14	Code	#14-#6 AWG			
WEEB-TC14	YAZV-TC14	Code	#14-#6 AWG			
	YGA-TC14	Code	#8-#6 AWG	1/4"	100	BTW30150
	YA-L-TC14-FX	Flex	#8-#6 AWG			
	YAV-L-TC14-FX	Flex	#8-#6 AWG			
	YAZ-TC14-FX	Flex	#8-#6 AWG			
	YAZV-TC14-FX	Flex	#8-#6 AWG			
	YA-TC38	Code	#14-#6 AWG			
	YA-L-TC38	Code	#14-#6 AWG			
	YAZ-TC38	Code	#14-#6 AWG			
	YAZV-TC38	Code	#14-#6 AWG			
WEEB-TC38	YGA-TC38	Code	#8-#6 AWG	3/8"	240	BTW150750
	YA-L-TC38-FX	Flex	#8-#6 AWG			
	YAV-L-TC38-FX	Flex	#8-#6 AWG			
	YAZ-TC38-FX	Flex	#8-#6 AWG			
	YAZV-TC38-FX	Flex	#8-#6 AWG			

Two-Hole Telecom WEEB® Washer

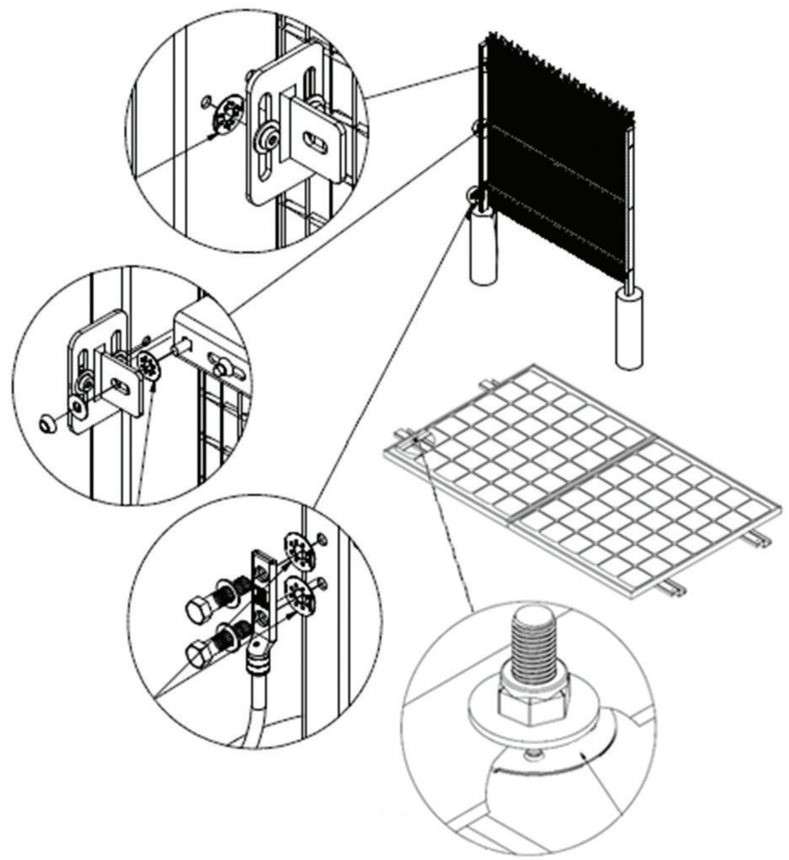
Catalog #	Compatible TWO-Hole HYLUG™ Family	Conductor		Hex Head Bolt		Stud Hole Spacing
		Wire Type	Wire Range	Size	Torque (in-lbs)	
	YA-2TC14					
	YA-L-2TC14		#14-2 AWG			
	YAZ-TC14	Code				
	YAZV-TC14					
WEEB-2TC14	YGA-TC14			1/4	100	5/8"
	YA-L-2TC14-FX					
	YAV-L-2TC14-FX	Flex	#8-2 AWG			
	YAZ-2TC14-FX					
	YAZV-2TC14-FX					
	YA-2TC38					
	YA-L-2TC38		#14-2 AWG			
	YAZ-2TC38	Code				
	YAZV-2TC38					
WEEB-2TC38	YGA-2TC38			3/8	240	1"
	YA-L-2TC38-FX					
	YAV-L-2TC38-FX	Flex	#8-2 AWG			
	YAZ-2TC38-FX					
	YAZV-2TC38-FX					

Stainless Steel Hardware Kits (TMH-SS) - Sold Separately*

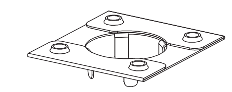
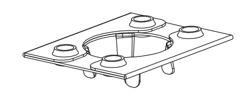
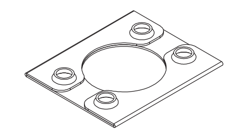
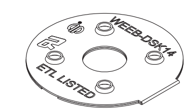
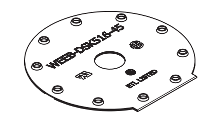
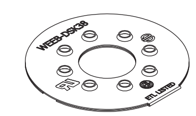
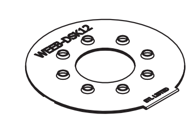
Catalog #	Bolt			Flat Washer	Split Washer	Hex Nut	Working Range	Installation Torque (in-lbs)
	Size	Length	Qty					
TMH-262SS		0.75					0.09-0.34	
TMH-263SS		1.00					0.34-0.59	
TMH-264SS	1/4-20"	1.25					0.59-0.84	100
TMH-265SS		1.50	2	4	2	2	0.84-1.09	
TMH-267SS		1.00					0.19-0.44	
TMH-268SS		1.25					0.44-0.69	
TMH-269SS	3/8-16"	1.50					0.69-0.94	240
TMH-270SS		1.75					0.94-1.19	
TMH-271SS		2.00					1.19-1.44	

Fencing

NEC regulations dictate that areas around electrified equipment or under transmission lines are required to be secured with grounded fencing. Wiley's WEEB washers provide a solution to bond coated or painted fencing panels together and connect to the grounded grid.



FENCE BONDING APPLICATIONS

Line Image	Catalog Number	Length inch [mm]	Width inch [mm]	Height inch [mm]	Hole Size inch [mm]	Type
	**WEEB-11.5**	0.87 [22.10]	0.79 [20.20]	0.15 [4.00]	0.47 [12.00]	Rigid
	**WEEB-9.5**	0.71 [18.00]	0.59 [15.10]	0.12 [3.15]	0.39 [10.00]	Rigid
	**WEEB-9.5NL**	0.71 [18.00]	0.59 [15.10]	0.07 [1.74]	0.39 [10.00]	Rigid
	**WEEB-DSK14**	0.94 [24.10]	0.94 [24.10]	0.07 [1.75]	0.26 [6.75]	Disk
	**WEEB-DSK516**	1.01 [25.75]	1.01 [25.75]	0.07 [1.75]	0.32 [8.10]	Disk
	**WEEB-DSK38**	1.18 [30.88]	1.18 [30.88]	0.07 [1.75]	0.39 [9.80]	Disk
	**WEEB-DSK12**	1.39 [35.38]	1.39 [35.38]	0.07 [1.75]	0.51 [13.10]	Disk

WILEY WEEB® Washer Guide | 1-800-346-4175 | www.hubbell.com/wiley

Washer, Electrical Equipment Bond

Generic WEEB® Washer Installation Instructions

NOTICE
PLEASE READ CAREFULLY BEFORE INSTALLING

Products are tested to UL 467, CAN/CSA-C22.2 No. 41
UL recognized to 2703US/Canadian standards for safety grounding and bonding equipment

The WEEB® washer family of products can be used to bond anodized aluminum, galvanized steel, steel and other electrically conductive metal structures. All installations shall be in accordance with NEC requirements in the USA and with CSA C22.1 in Canada. The WEEB® washers are for use with modules that have a maximum series fuse rating of less than 25A.

Installation Procedure:

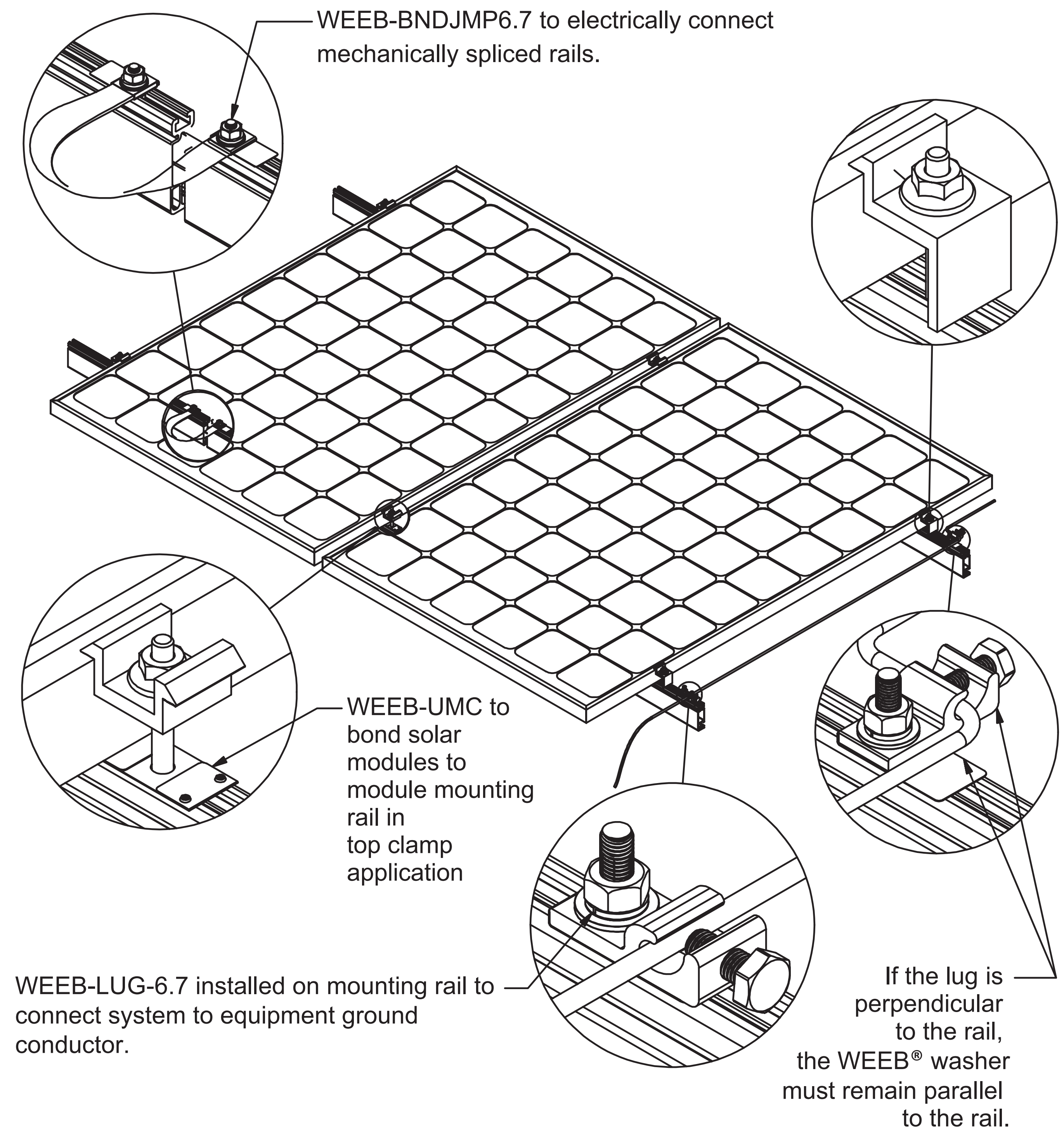
1. Inspect each module frame used with a WEEB® washer to ensure that the bottom mounting face of the frame is flat, and that there are no hindrances to embedding WEEB® washer teeth. WEEB® washers should not be used with a module frame that prevents the WEEB® washer teeth from embedding fully.
2. Apply general purpose anti-seize compound on fastener threads prior to installing WEEB® washers.
3. Align the WEEB® washer as prescribed in the mounting system-specific installation instructions. Refer to WEEB® washer compatibility page for illustrations. Visually check that WEEB® washers are properly positioned.
4. Once placement of modules is finalized, torque fasteners to specification as indicated in the BURNDY installation manual for your PV mounting system.

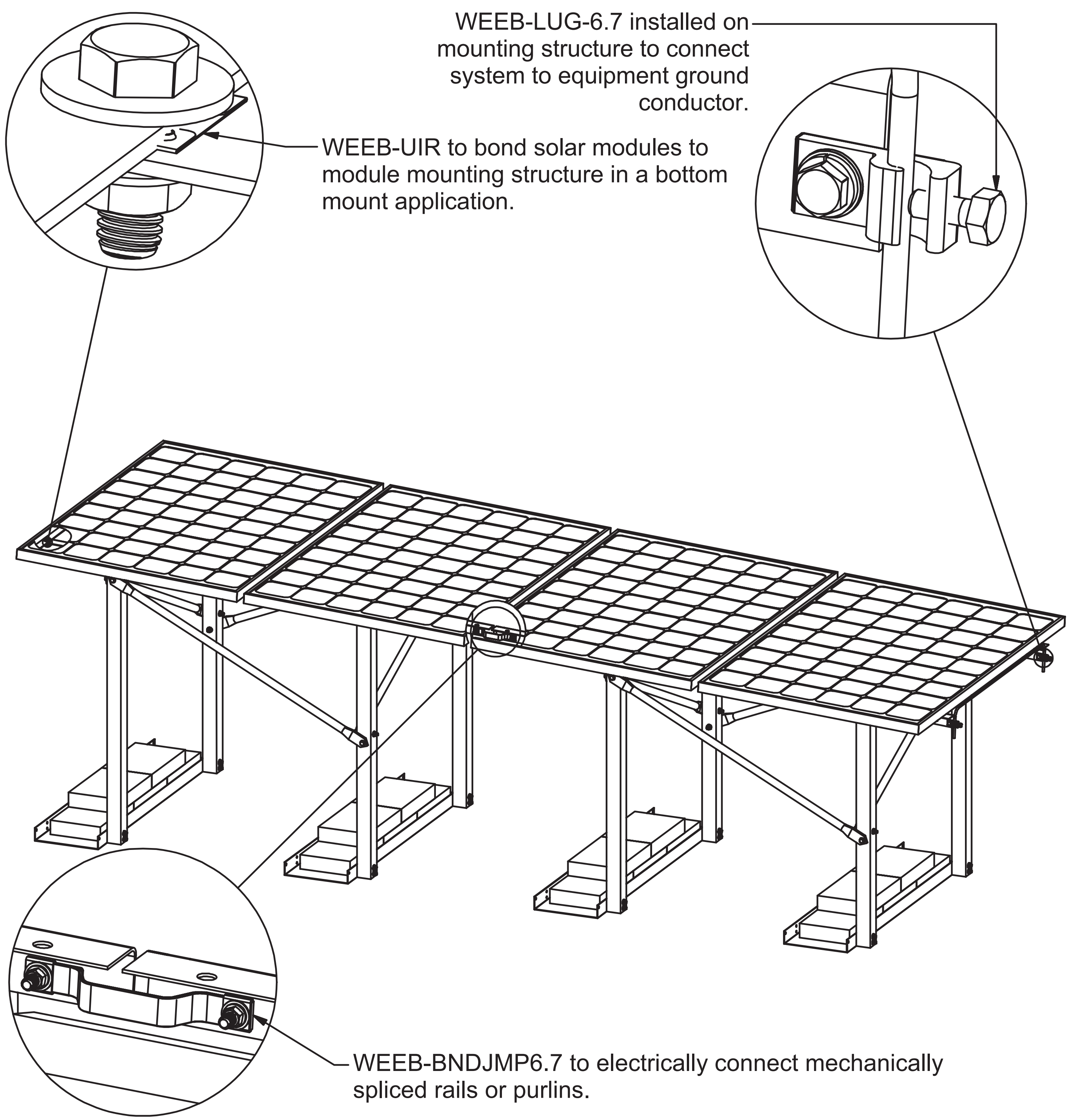
Important notes:

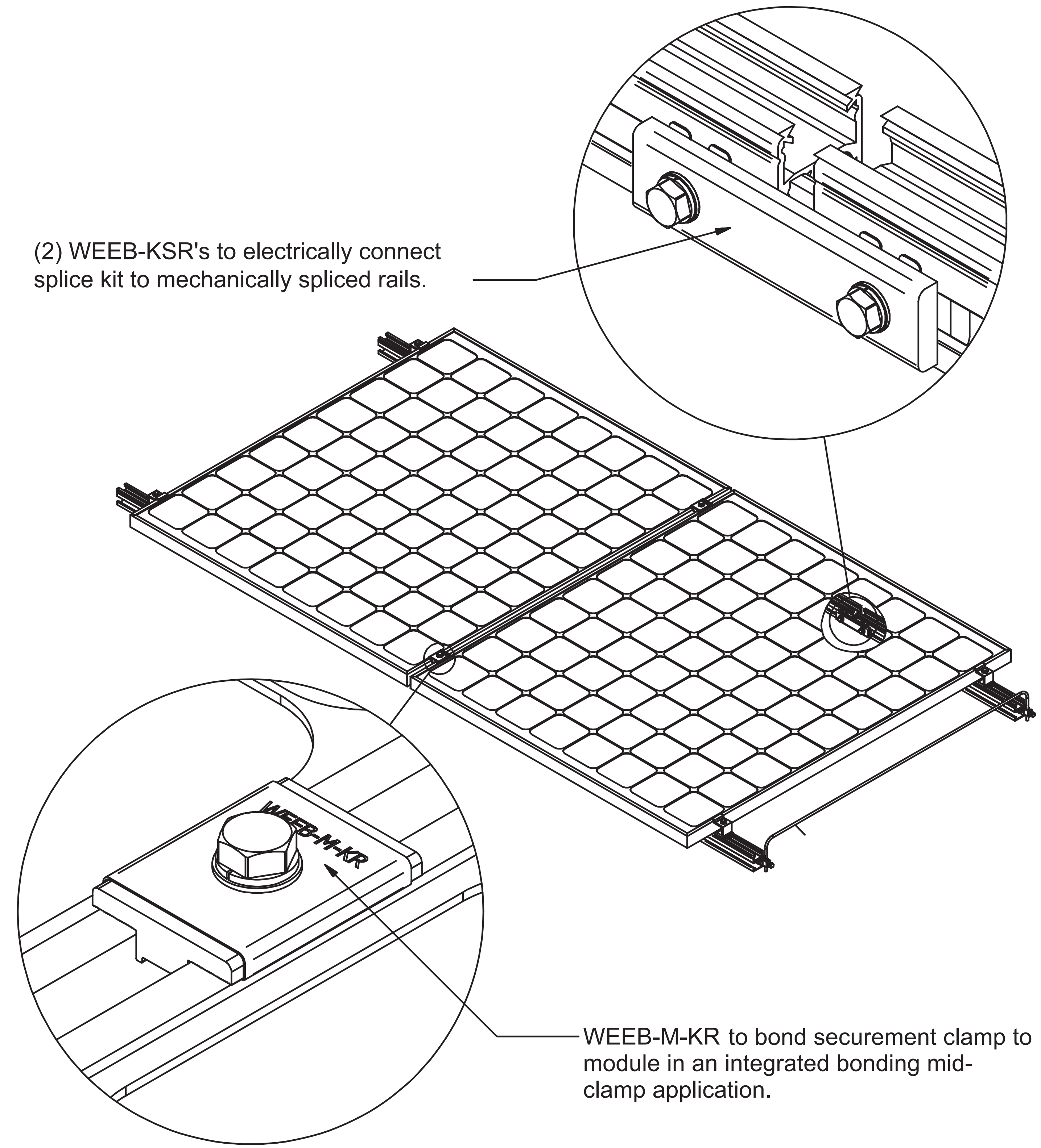
1. The NEC section 690.43 states, "Exposed non-current carrying metal parts of module frames, equipment, and conductor enclosures shall be grounded in accordance with 250.134 or 250.136(A) regardless of voltage."
2. When replacing a single faulty module, also remove the adjacent modules which are in contact with the same WEEB® washers as the faulty module. This will ensure that there are never ungrounded modules in the array.

Intertek
4004188

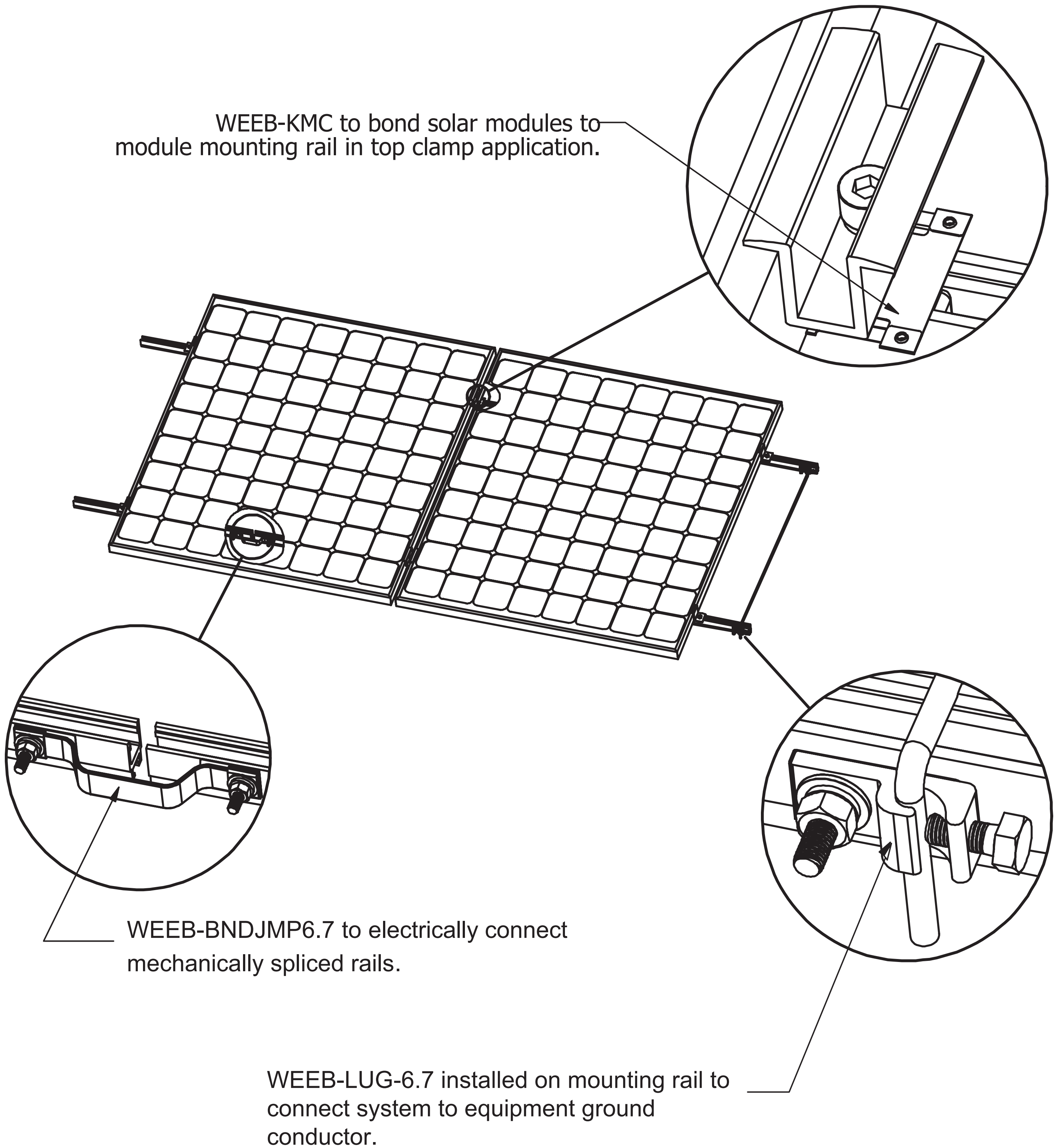
Application Examples



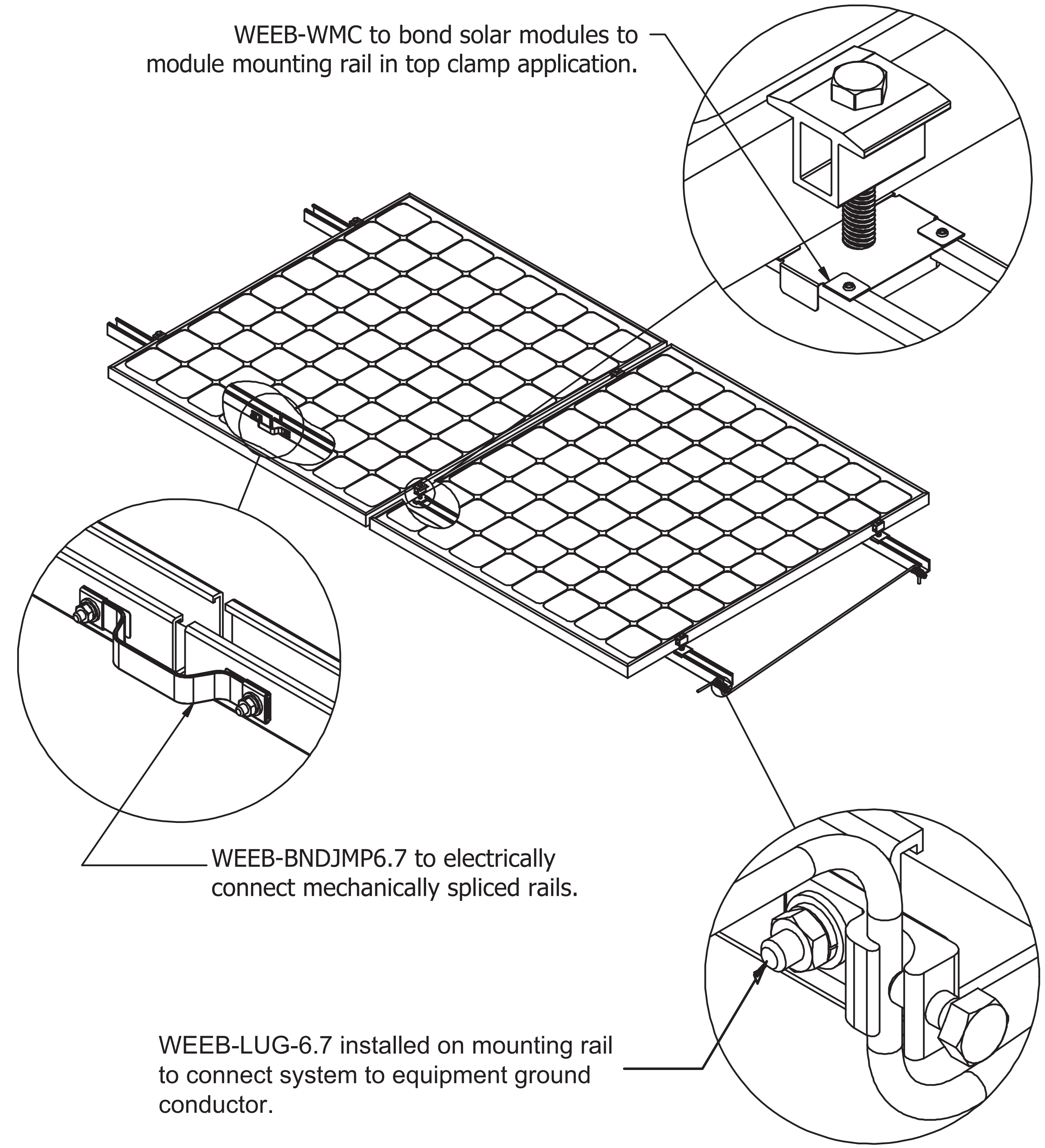

WEEB-LUG-6.7 installed on mounting structure to connect system to equipment ground conductor.
WEEB-UIR to bond solar modules to module mounting structure in a bottom mount application.
WEEB-BNDJMP6.7 to electrically connect mechanically spliced rails or purlins.


(2) WEEB-KSR's to electrically connect splice kit to mechanically spliced rails.
WEEB-M-KR
WEEB-M-KR to bond securement clamp to module in an integrated bonding mid-clamp application.

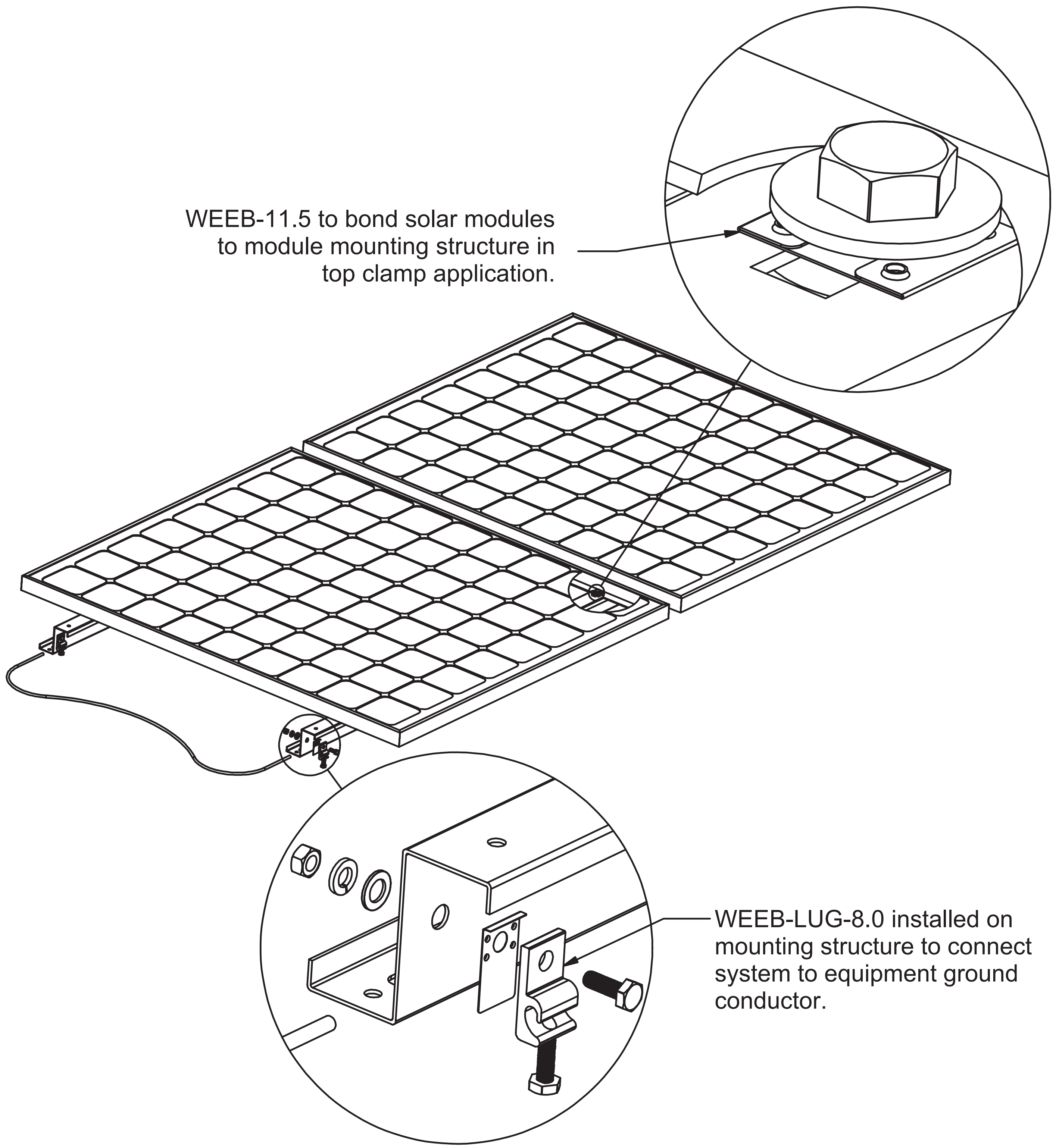
APPLICATION



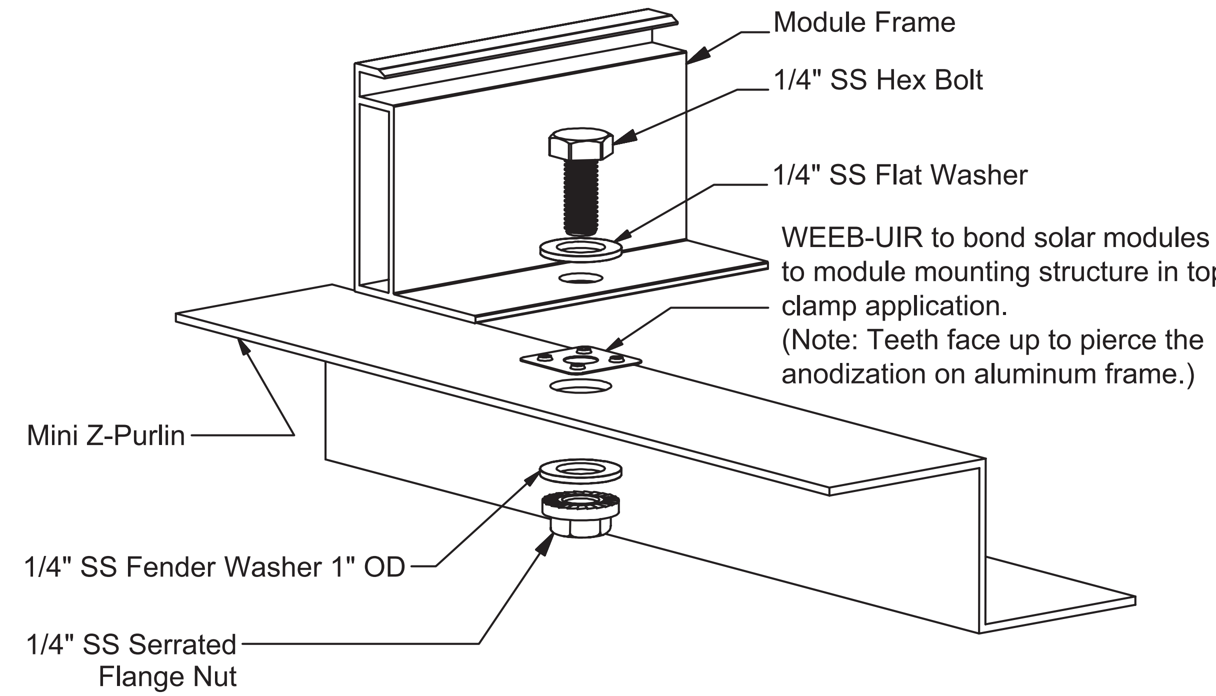
APPLICATION

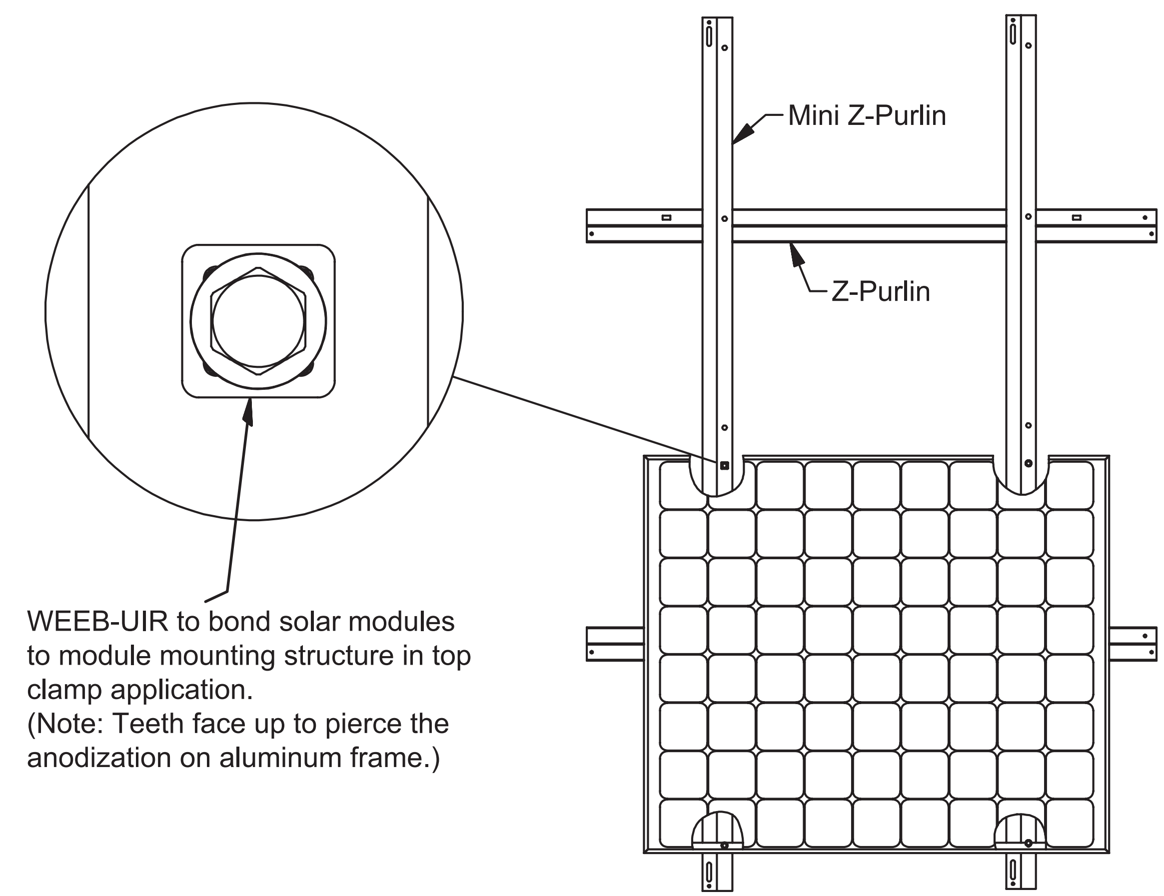


APPLICATION



APPLICATION





wiley

WEEB® Washer Theory

A study on the performance and resilience of technologies used to bond systems through non-conductive coatings.

Author:
Kurt Naugler

Editor:
Melissa Dailey Hartwick
Business Development
Renewable Market Specialist

HUBBELL® | BURNDY®

Abstract

Strong, reliable infrastructure supports the smooth execution of business every day. Common practice and a crucial part of the National Electrical Code (NEC) require conductive equipment and systems to be properly bonded and grounded, to protect workers and civilians from electric shock. Connections that do not last for the lifetime of the system or are not replaced in a timely manner can result in an unbonded system, putting people and equipment at risk.

There are countless avenues that engineers and installers can utilize to meet grounding and bonding requirements, but the resilience and quality of these methods are not always equal. Burndy has developed a line of products to ensure grounding and bonding connections stay fast no matter the environment, protecting both life and investments.

Table of Contents

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Introduction

It is common practice and a crucial part of the National Electrical Code (NEC) that conductive equipment and systems must be properly bonded and grounded to ensure worker and civilian safety from electric shock. There are countless avenues that engineers and installers can utilize to meet grounding and bonding requirements, but the resilience and quality of these methods are not always equal. Connections that do not last for the lifetime of the system or are not replaced in a timely manner can result in an unbonded system, putting people and equipment at risk. There is limited long-term data available to determine the quality of bonding mechanisms vital to the safety of all systems susceptible to electrical events.

To combat this lack of long-term data, extensive testing has been conducted to evaluate bonding methods and aid in material and product selection to ensure the longevity and the continued safety of an installation. Testing results include product reaction to electrical, mechanical, and environmental stress, and are developed from both industry standard procedures as well as innovative testing sequences applied to different products commonly used as bonding mechanisms. Results provided will aid in informed decision making in both system design and on system maintenance scheduling.

This study looks at bonding products used to form a conductive path by piercing through non-conductive surface coatings or finishes and embedding in the underlying conductive substrate. The primary materials and coatings examined include anodized aluminum and powder coated steel. These materials were chosen based on their frequent use in electrically sensitive installations ranging from renewable generating installations to energy storage systems and even in data centers. Grounding and bonding in these systems are extremely important given the potential for short circuits and the extensive damage that could occur if equipment and structures are not properly bonded. When done correctly, grounding and bonding effectively guide electrical noise paths in sensitive electronic equipment. The study explores technologies that industry professionals are familiar with and provides data that can assist in knowledgeable system design and product selection.

Ensuring that the longevity and continuing safety of an installation, extensive testing should be conducted.

Bonding in Practice

The NEC defines Bonded or Bonding as something that is connected to establish electrical continuity and conductivity (NFPA 70, 2017). In practice, bonding is used (and required) as a mechanism to protect people and equipment from electrical damage in the event of a fault or other electrical event where usually non-energized components become energized. Metal structures and enclosures are bonded through connections to other metal components which are eventually connected to the grounding system. These connections carry current like any other component. Additional information about standard connections can be found in ***Connector Theory and Application*** (Di Trioa, Woo, & Zahlman, 2010).

Current bonding applications often require the removal of a non-conductive surface treatment or coating before connectors can be installed. The technologies presented in this study are intended to eliminate the need for this time consuming and imperfect process. By piercing through a nonconductive layer, these connectors form contact points with the underlying conductive substrate. The theory behind aggressive, piercing contact points is that the embedment into a substrate will increase the density of contact points, or A-spots, in each embedment location.

The high density of A-spots allows the smaller embedment areas to carry the necessary current generally spread across the bottom of a connector pad. Figure 1 shows a depiction of the microscopic view of the contact surface between two sides of a connection and the concentration of current at the connection to the 3 A-spots shown.

Two technologies commonly used to pierce non-conductive coatings include WEEB® (Washer, Electrical Equipment Bonds) washers and star washers (external tooth lock washers). These two technologies have piercing members that are intended to penetrate the non-conductive layer during installation and form concentrated A-spots in each embedment location within the substrate material. This embedment location must be sufficient to carry needed current and must be reliable in order to last the intended life of an installation. These technologies have been subjected to extensive electrical, mechanical and environmental testing to determine the capabilities and limitations of each method.

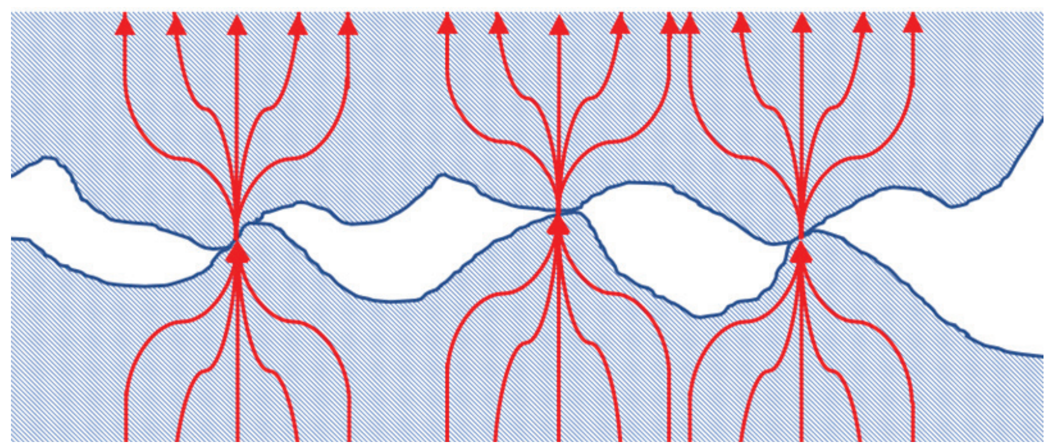

Figure 1: Microscopic view of connection points (A-Spots); adapted from 'Connector Theory and Application' (Di Trioa, Woo, & Zahlman, 2010)

Electrical Considerations

Based on the primary function of bonding devices, electrical properties should be considered of paramount importance in evaluating different products. These connection points must handle, without damage, faults at current levels and durations based on the conductor's current-carrying capacity, as defined by industry standards. In order to sustain these currents without damage, connection resistance must be at a level conducive to the unimpeded flow of power. A lower resistance connection is one sign indicative of a high-quality connection.

Short-time Current Testing
To test products for connection resiliency compared to the rating of the system and connection, short-time current testing is one of the harshest test sequences. This is due to the fact that test values are based on the upper limitations of the conductor size being used. The different connection types were evaluated using durations and currents from UL467: Standard for Safety Grounding and Bonding Equipment.

The energy applied to the connection in each of the test sequences performed is designed to simulate a fault current just below the fuse rating of the conductor for which the connection is rated. Using the ratings for #6 wire, testing was completed with WEEB® washers and star washers installed on substrates of anodized aluminum and powder coated steel and paired with zinc-plated copper lugs of similar ratings and size.

WEEB washer and star washer testing was also conducted with oxide inhibiting compounds Burndy® Penetrox™ E (Pen-E) and Sanchem NO-OX-ID® (No-Ox). These compounds are intended to aid and protect the connection from corrosive environments without a negative impact on the electrical integrity of the connection. Oxide inhibiting compounds accomplish this through the sealing of the connection from moisture to prevent galvanic corrosion (Di Trioa, Woo, & Zahlman, 2010). The images in Figure 2 show both a passing result of a connection that was able to pass the specified current for the duration of the test (left), as well as a graph from a test where the connection failed to pass the specified current. It is worth noting that I2t conversions were utilized in the testing methods performed.

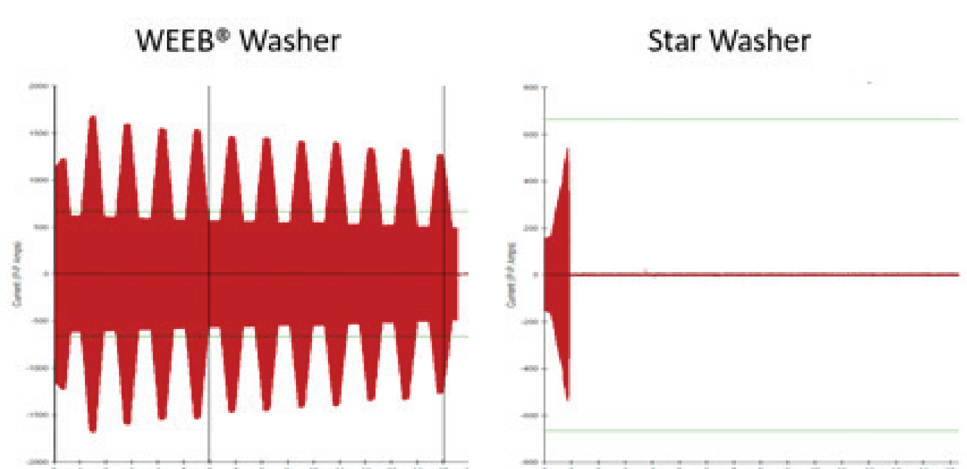

Figure 2: *Left* - Passing test result; *Right* - Failure to carry current

When looking at the results from testing three samples from each test group (WEEB washer and star washer, each bare, with Pen-E and with No-Ox), most samples achieved passing results. While all WEEB washer samples passed testing, two of the three star washer samples with No-Ox failed to carry the current. Of the samples that failed, one sample failed to generate continuity before the test and both samples showed no continuity through the connection following testing.

Resistance of Short-time Current Samples
In addition to the pass/fail criteria available from the short-time current testing, resistance readings were taken on each sample before and after the testing was performed. With the understanding that low resistance is associated with a good connection, the initial resistance readings give insight into the quality of the connection when it is first installed, but the resistance readings following the application of electrical stress through testing give insight into the reliability of the connection following an electrical event.

Figure 3 shows the average resistance readings from each sample group before and after the samples were subjected to electrical stress in the short-time current testing. The increase in resistance, measured in microhms (µΩ), through the test sequence is depicted by the line and quantified on the secondary vertical axis. It is worth noting that the star washer samples that failed to exhibit continuity before and after testing were treated as outliers and omitted in the calculation of average resistance.

When looking at the resistances on a comparative basis between like groups of WEEB washers and star washers, it is apparent that each WEEB washer group showed lower average resistances than the respective star washer group. The one comparison that does not fit with this pattern is the comparative resistances of the Pen-E groups after electrical testing. In this instance, the WEEB washer average resistance was higher than the star washer group. The relative difference was so slight it was deemed insignificant.

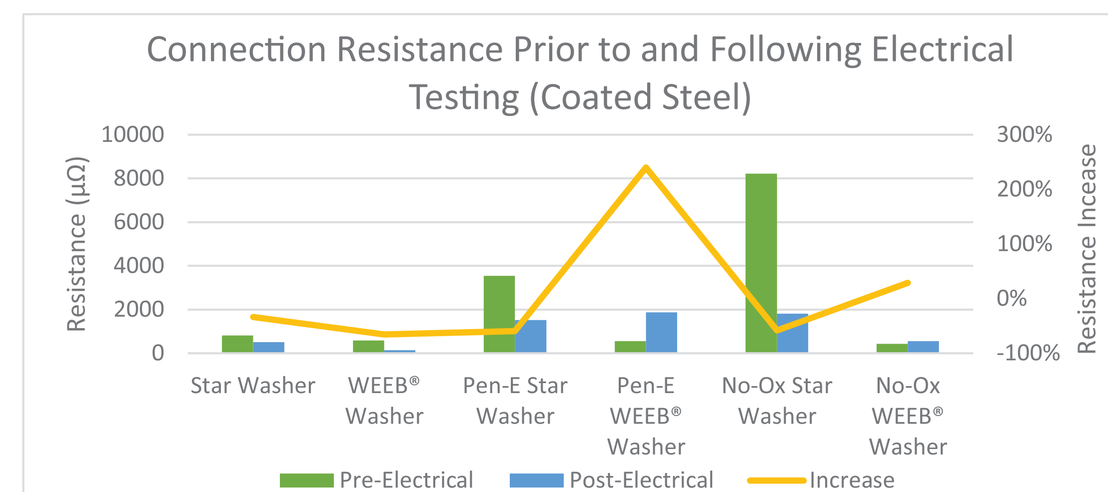

Figure 3: Resistance measurements from short-time current testing on coated steel

Figure 4 depicts the same resistance measurements as Figure 3, but with the test group connections made to anodized aluminum. Due to the fact that module frames and solar racking are commonly made from anodized aluminum, this test setup is representative of bonding connections made in many solar installations, but is not limited to this application.

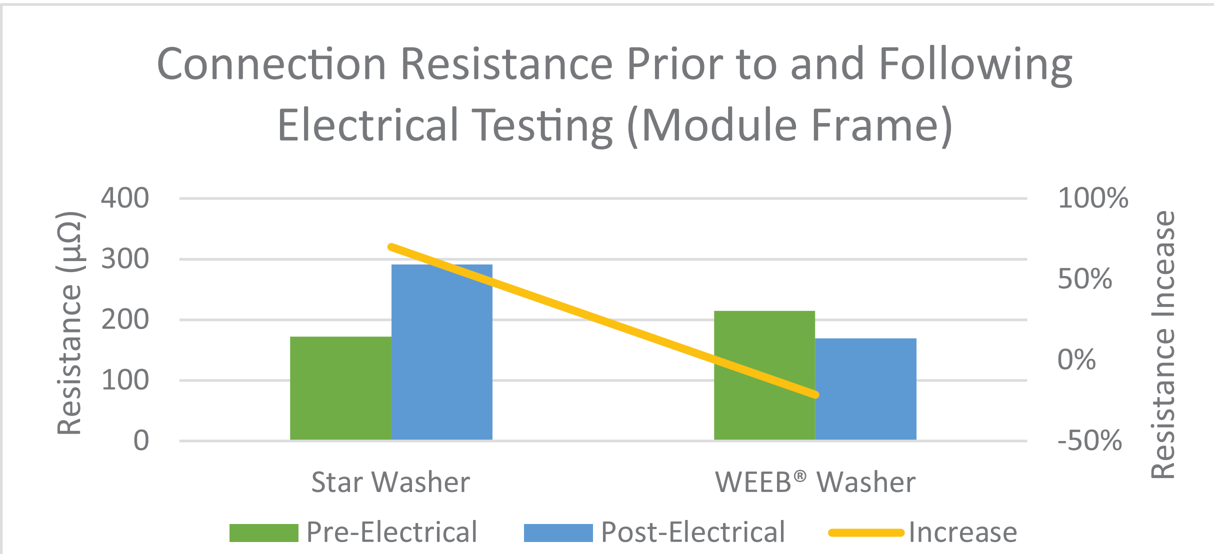

Figure 4: Resistance measurements from short-time current testing on anodized aluminum

The average measurements in these test setups showed the comparable initial resistance of each test group. However, the resilience to electrical stress shown by the post-electrical measurements is where there was significant differentiation. While the star washer group exhibited a significant increase in resistance following the testing, the WEEB washer group's average resistance measurements decreased. This decrease in resistance is indicative of a connection able to stand up to significant electrical stress.

Resistance in Corrosive Environments

Additional resistance readings were taken on similar groups of samples during salt fog testing of the products. Salt fog was applied in accordance with the procedure outlined in ASTM B117 for a total of 1000 hours. Resistance readings were taken on each group of samples prior to the salt fog sequence and every 250 hours up to 1000 hours. These resistance measurements give good insight into how the connections will hold up when installed in highly corrosive environments.

Figure 5 and Figure 6 show the progression of resistance readings on each group of samples through the 1000 hours of the salt fog exposure. As one would assume, all sample groups showed an increase in resistance of the connections as time in the corrosive environment increased. While an increase in resistance is generally expected, the relative increase compared to initial resistance readings as well as rate and consistency of increase, are indicative of the rate of degradation of the connection.

The steady resistance readings seen in all WEEB washer samples show that the connection points are degrading at a predictable pace and the lifetime of connections in corrosive environments can be planned for. The relatively volatile resistance readings of the star washer samples make planning for consistent connection maintenance difficult. The results noted in the figures 5 and 6 also omit the failure of a star washer sample mounted to an anodized aluminum substrate. The omission begins in the 750-hour resistance calculations and causes the average resistance of this group to be largely understated in the figure. When compared to an absence of failures in the WEEB washer test groups, this data point adds to the inconsistency of the star washer connection in this test.

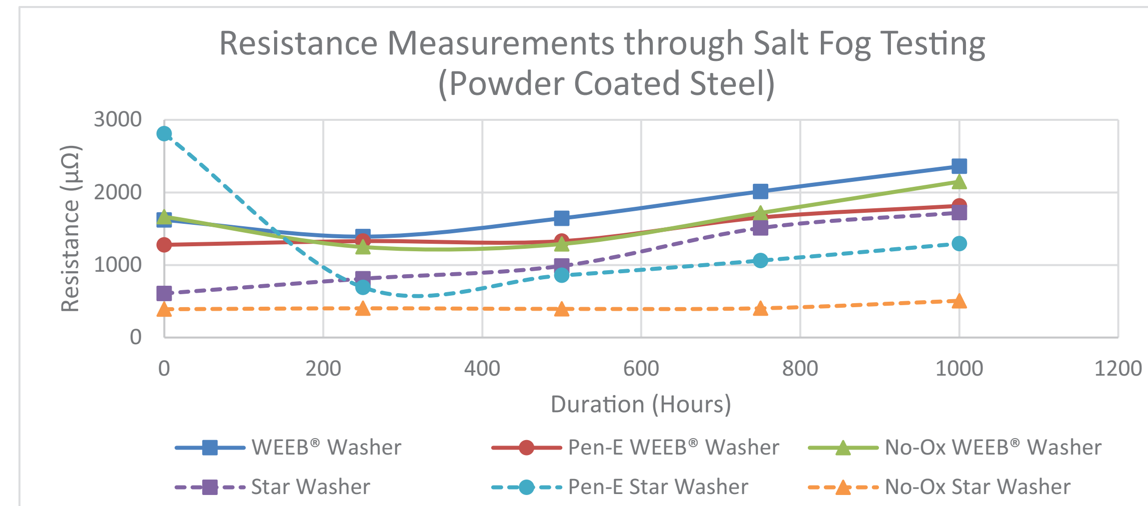

Figure 5: Resistance measurements through salt fog testing, coated steel samples

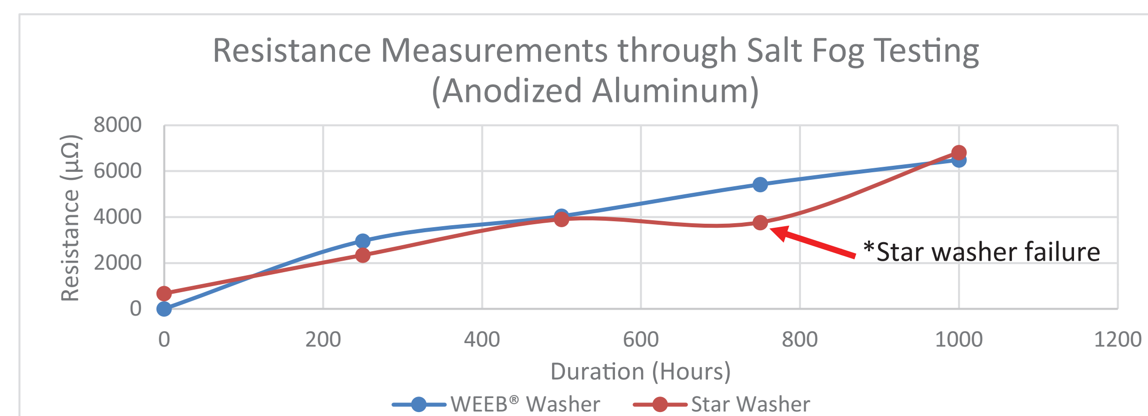

Figure 6: Resistance measurements through salt fog testing, anodized aluminum samples

Mechanical Considerations

In addition to the primary function of electrically connecting parts of an assembly, connectors must exhibit strong mechanical properties to ensure the longevity of the connection and continued safety of an installation. To evaluate the mechanical properties provided by WEEB washer and star washer bonding methods, the strength of each connection was tested in addition to an analysis of the connection geometries.

Anti-rotation Testing

Bonding connectors can serve mechanical functions as well as carrying electrical current in some applications. An installation-critical, mechanical function of washer style connectors lies in their ability to minimize rotation in relation to the substrate. Anti-rotation properties can extend the longevity of an installation that may be subject to varying external forces such as vibration, wind or those caused by cyclical motion which can cause damage.

A test fixture, shown in Figure 7, was developed to directly test and measure an assembly's ability to prevent rotation. WEEB washers and star washers mounted on coated steel were tested against a control group mounted on plain steel. Moment force was applied until the fixture rotated at least 10° from the original position or the substrate bent. The torque-displacement curves of each of the sample groups are illustrated in Figure 8.

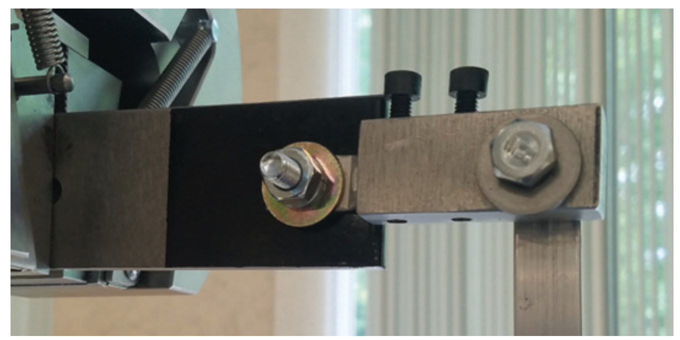

Figure 7: Anti-rotation test fixture

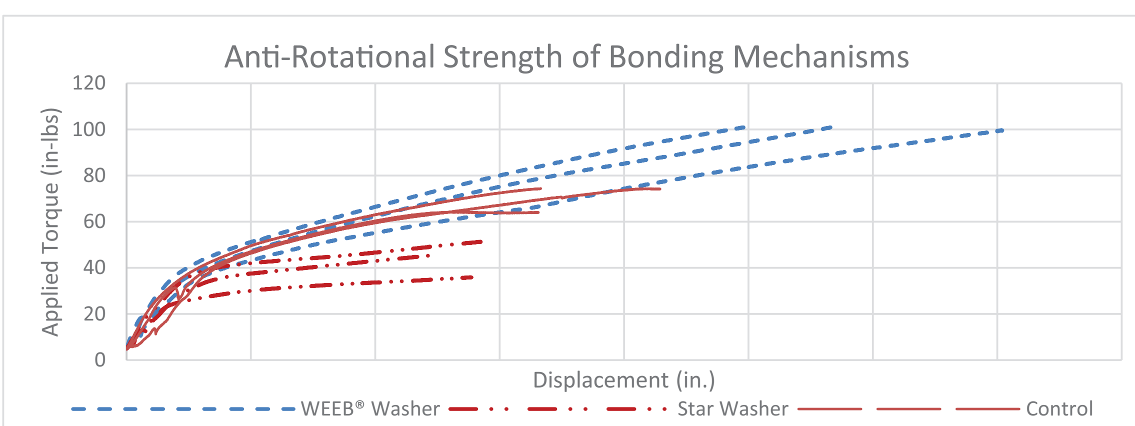

Figure 8: Torque-displacement curves: anti-rotation testing

Geometry of Connection Points

To explain the differences noted in mechanical strength observed between WEEB and star washers, microscopic analysis of the connection points was completed. The left image in Figure 9 shows a graded mesh of a WEEB washer connection point installed on powder coated steel, while the right image is the 3D microscopic view of the same connection. Figure 10 shows the same images from a star washer installation.

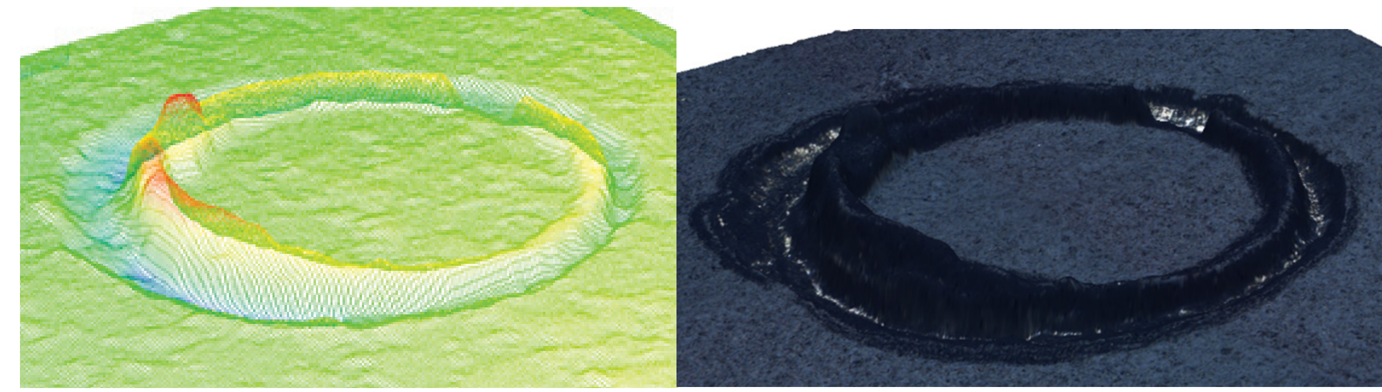

Figure 9: 3D Microscopic views WEEB washer embedment

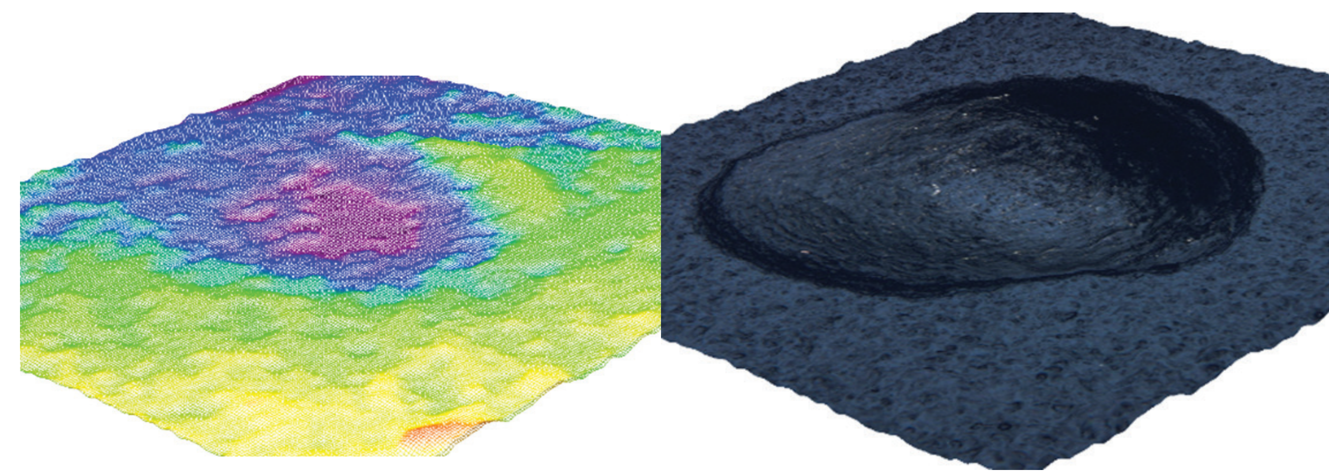

Figure 10: 3D Microscopic views of star washer embedment

It is clear from the data and embedment images why the WEEB washer showed greater resistance to rotation of the connection when compared to the star washer. The penetration of the powder coat and indentation into the steel substrate detected at each WEEB washer embedment point not only provides a good electrical connection but also transfers moment force from the anti-rotation fixture into shear force at each embedment. This means that the mechanical strength of the connection is not simply from friction between the surfaces. For rotation to occur, deformation of the steel substrate or stainless steel WEEB washer must also occur.

In stark contrast to the clear embedment seen in the WEEB washer images, the star washer embedment shows a minor depression into the powder coat surface finish. This small depression in the powder coat may slightly increase the coefficient of friction between the two surfaces. However, in testing the mechanical strength of the connection was not improved.

Figure 11 shows the same microscopic analysis as described above but the substrate analyzed is anodized aluminum as opposed to powder coated steel. Similar conclusions can be drawn for the aluminum substrates based on the same reasoning of deep embedment by the WEEB washer contact points and limited embedment by the star washer.

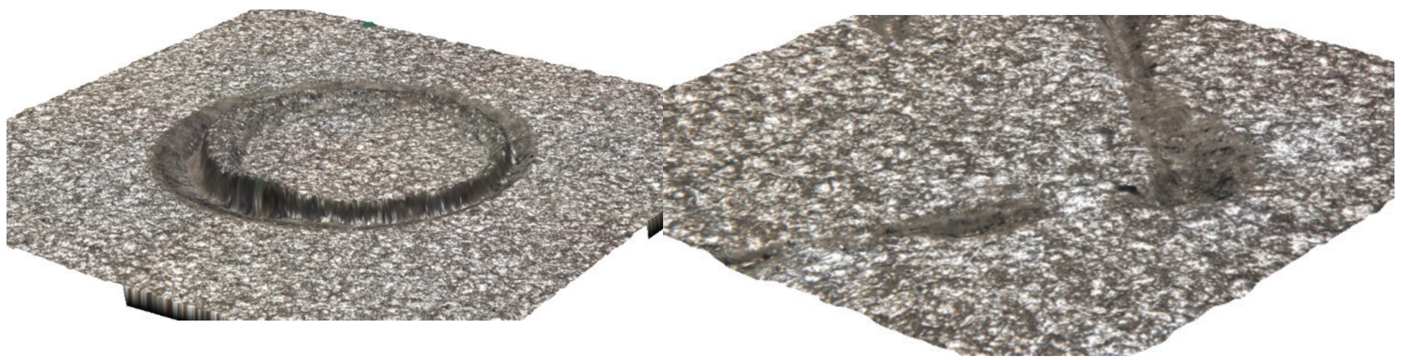

Figure 11: *Left* - WEEB washer embedment in anodized aluminum; *Right* - Star washer contact point with anodized aluminum

Environmental Considerations

While the industry has come a long way in understanding the role that corrosion plays in determining the lifespan of installations, there is still room for improvement in predicting how components will react to the fluctuating environmental conditions of the real world. To combat this, testing in varying environments as well as in highly corrosive salt spray was completed.

Multi-stress Degradation Resistance

To evaluate the materials used in WEEB washers and star washers, multiple standards across industries have been evaluated with the goal of encompassing many of the environmental stressors encountered by real-world installations.

One of the harsher test methods comes from the transmission insulator standard IEC 61109. This standard submits products to cycles of UV radiation, salt fog, rain, heat, and humidity with new cycles starting every 24 hours. The 24-hour cycle as defined in the standard is shown in Figure 12.

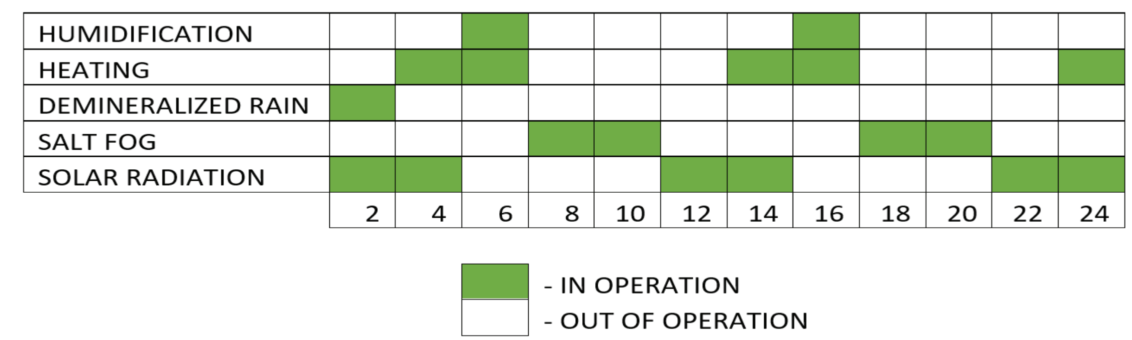

Figure 12: 24 Hour cycle per IEC 61109

As the materials progressed through the testing sequence, parts were periodically inspected for signs of degradation. Material degradation could come in the form of corrosion, discoloration, or loss of function of the part. Samples were inspected every 500 hours through the full test sequence which spanned over 1500 hours.

The high-grade, stainless, 300 series alloy used in WEEB washers showed no signs of significant corrosion throughout the entirety of the test sequence. Although Figure 13 shows the connection accumulating salt from the salt fog portions of the sequence, there was no corrosion as a result of the salt deposition on the connection or substrate.

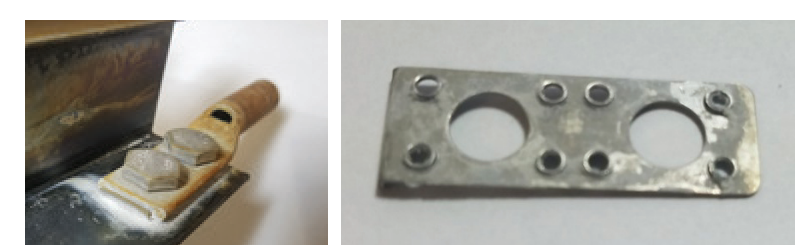

Figure 13: Lack of corrosion in WEEB washer samples

On the other hand, Figure 14 shows significant corrosion that occurred in the lower grade materials tested. These materials are representative of star washers and other low-grade bonding connectors. The degradation of the material caused by corrosion shows that these connectors will not exhibit the longevity required in a real-world installation.

Figure 14: Corrosion of lower grade materials used in standard star washer connections

Salt Fog Corrosion Resistance

In addition to the IEC 61109 multi-stress sequence, samples that were subjected to salt fog testing per ASTM B117 were analyzed for corrosion at the connection points. This analysis was completed because corrosion in connection points can drastically reduce the size, quantity, and quality of the A-spots in connections. Any negative impact on the A-spots will result in rapid deterioration of the electrical properties of the connection.

The severity of testing can be seen in the corrosion of the substrate material around the connections shown in Figure 15. The image on the left is a test sample with powder coated steel substrate and the image on the right is an identical sample mounted on anodized aluminum.

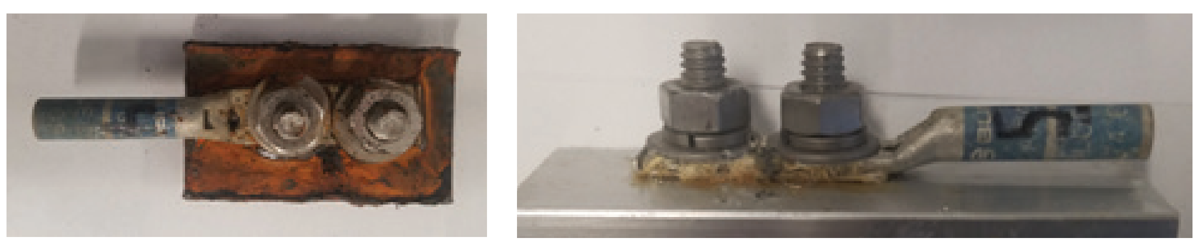

Figure 15: Samples following ASTM B117 test sequence

While there is significant corrosion of the substrate and material around the connection, the true indicator of the quality of connection should be analyzed at the connection points. To accomplish this analysis, cross sections were taken of each test group with a focus on the embedment locations of the WEEB washer and star washer samples.

The images in Figure 16 are microscopic views of cross sections taken at connection points of WEEB washer and star washer samples installed on powder coated steel substrates. The top two images are WEEB washer embedment points and the lower images are star washer connection points. The left images are samples that were not subjected to salt fog testing and the right images are samples following 1000 hours of salt fog.

It was observed that there was minimal corrosion of either sample type at the connection points through the duration of the test sequence. This shows that both connection types at the actual connection point should be resistant to corrosion in a purely salt rich environment. While this is contradictory to the corrosion that occurred in the lower grade materials through the multi-stress sequence, it supports the finding that WEEB washer connections are resistant to corrosion in harsh environments. It is also worth noting that the microscopic analysis of the cross section shows remaining powder coat material between the star washer contact points and the steel substrate. This supports the analysis of connection points described in the 3D analysis of contact points available in the mechanical considerations section.

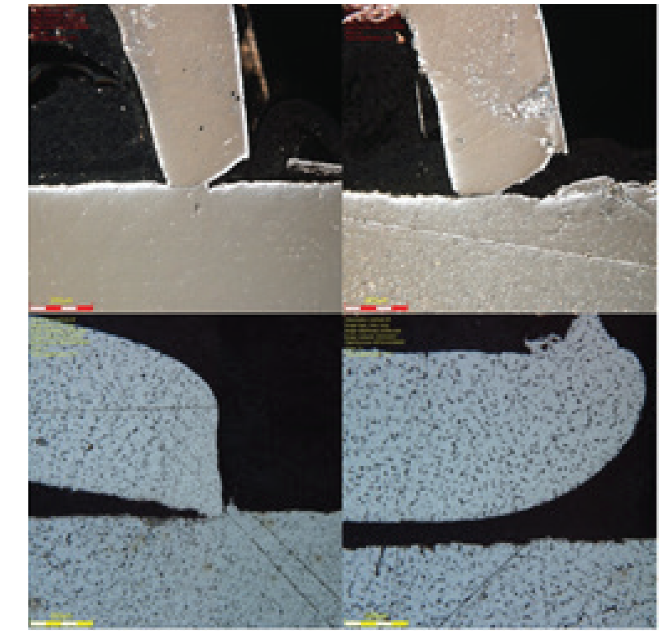

Figure 16: WEEB washer (top) and star washer (bottom) samples from salt fog testing

When the results in Figure 16 are compared to the control samples shown in Figure 17, it shows that the combination of powder coat and a penetrating device is superior to connections made at locations where the protective surface treatment is removed to make the electrical connection. Figure 17 depicts a cross section of the connection between a tin-plated lug and aluminum substrate before (left) and after (right) salt spray testing.

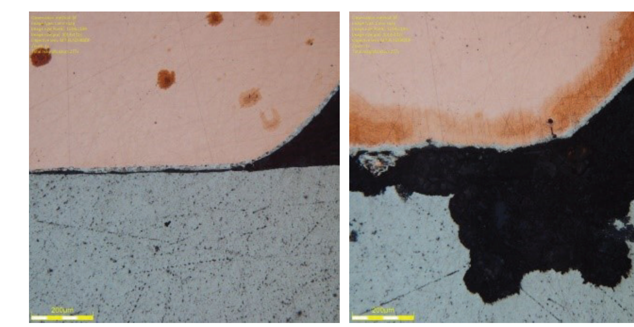

Figure 17: Control sample from salt fog testing

The heavy corrosion observed in the control sample following 1000 hours of salt fog testing support the use of penetrating devices to retain the integrity of a protective coat in an installation. While the direct connection without penetrating devices had low initial resistances, the substantial corrosion of the substrate material shows that over time this connection will deteriorate significantly.

WEEB washer connections are resistant to corrosion in harsh environments.

Mechanical Considerations

WEEB washers showed superior performance in essentially all electrical, mechanical, and environmental evaluation. Additional insight has been gained that aids in the understanding of the quality of these connections. In analyzing the electrical integrity of these connections, short-time current testing as well as resistance readings through electrical and environmental stress were completed. Mechanical considerations included the integrity of connections through anti-rotation testing and a microscopic 3D evaluation of the geometry of the connection points. Environmental factors were assessed through accelerated aging in a multi-stress sequence and through an analysis of connection points throughout the salt fog testing.

With zero failures in short-time current testing and consistent resistance readings before and after electrical testing, WEEB washers outperformed star washers. In many cases, the WEEB washer samples showed lower resistances both before and after testing when compared to the star washer test groups. Consistency of resistance readings in salt fog testing is supported by the environmental considerations in the analysis of corrosion of connection points.

When it came to mechanical performance, the WEEB washer samples impeded rotation of the connections while the star washer samples actually decreased the anti-rotation properties of the connection. This is supported in the 3D images of connection points that were gathered. The WEEB washer embedment geometry enables a purely friction-based reaction to transition to shear forces at each connection. This significantly increased the mechanical strength. In the star washer analysis, it was observed that the connection merely depressed the powder coat slightly at each connection point and decreased the force required to rotate the sample connections.

In environmental analysis, the WEEB washer samples showed minimal signs of corrosion through both the multi-stress sequence and the salt fog testing. Analysis of the connection points following salt fog testing show that both the WEEB washer and star washer samples had limited corrosion at the interface between the connector and substrate material. This is a stark contrast to the significant corrosion seen in the control sample and supports the use of penetrating devices to prevent corrosion of a substrate material.
With all the testing considered and evaluation of WEEB washer and star washer penetrating devices used in connections, it is clear that the utilization of a bonding device to penetrate a non-conductive surface coating is superior to making a connection by removing the coating completely. The resilience of these devices tends to suggest that their use will increase the lifetime and durability of a bonding connector. When comparing the quality of the different penetrating devices, the WEEB washer showed superior performance when compared to star washer connections. Robust and consistent electrical performance combined with superior mechanical properties and high-grade, corrosion-resistant materials makes the WEEB washer bonding device the optimal choice for system performance and connection resilience.

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Di Trioa, G., Woo, K., & Zahlman, G. (2010). Connector Theory and Application: *A Guide to Connection Design and Specification*. Burndy LLC.

NFPA 70. (2017). In *National Electrical Code*. National Fire Protection Association.

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