TEGAM Application Note 109

Testing Aircraft Electrical Bonds Ensures Safety and Reliability, Improves System Performance

Fixed and rotary-wing aircrafts are complex assemblies consisting of various electrical and mechanical components, which are all connected to form a sound mechanical structure. While mechanical integrity is the primary concern of aircraft manufacturers and maintenance teams, sound electrical bonding is critical to ensuring that all control and communications systems operate reliably.

A bond is an electrically conductive joint and the bond test determines whether an effective electrical ground has been established between two points. **Electrical bonding of aircraft structures is important for many reasons and should always be checked when building or maintaining an aircraft.** Proper electrical bonds:

- Protect aircraft passengers and electronic systems from lightning discharges.
- Prevent the buildup of static charges and protect passengers and systems from electrostatic discharges.
- Minimize RF potentials on electronic enclosures.
- Provide low-impedance signal paths for electronic equipment, thereby improving system reliability and performance in harsh electromagnetic environments.
- Prevent fuel ignition hazards from electrical fault currents.

Ensuring that electrical bonds in the aircraft are of the highest quality requires the use of a Test & Measurement instrument specifically designed to accurately measure very low resistances in demanding environments, such as the **TEGAM Model 710A Bond Meter**. The Model 710A is a handheld, auto-ranging, low-resistance **bonding** meter with simple controls for use by an operator not familiar with Ohm's law. It has a resolution of 1µΩ and an accuracy of ±0.2% of reading + 0.02% of range. Operating temperature range is -10 to 55 C. The TEGAM Model 720A (coming soon) offers the same specifications and features as the Model 710A but is intrinsically safe.

Classes of Aircraft Electrical Bonds

MIL-STD-464-C (1 December 2010), *Electromagnetic Environmental Effects Requirements for Systems*, gives engineers some guidance regarding electrical bonding. It notes that historically there have been six different classes of electrical bonds: A, C, H, L, R, and S.

- **Class A bonds** are the bonds in antenna installations. Class A bonds should provide a short, low-impedance path from the appropriate metal portion of the antenna to the ground plane of the aircraft over the operating frequency range of the antenna.

  Poor Class A bonds can seriously affect communication system performance. A poor bond could cause an impedance mismatch which reduces the signal radiated by the antenna or alter an antenna's radiation pattern. At best, the communication will perform poorly, and at worst, fail altogether.

- **Class C bonds** are used for current path returns. This class of bond ensures that current path returns can adequately handle the power drawn by electronic equipment without excessive voltage drop. Excessive voltage drops in the current return path can cause electronic equipment to malfunction by decreasing the power supply voltage. For 28 VDC systems, the voltage drop for power returned through the structure should be less than 1 V. For 115 VAC systems, voltage drop should be less than 4 VAC.

  In addition, special fault current bonding is required at joints where fuel or gas may be present to prevent them from exploding due to heating or arcing from fault current flow. **This is a critical safety issue.** Figure 1 shows the allowable bond resistance for the expected maximum fault current. These levels are approximately 0.74 mΩ at 100 amps of fault current and 0.074 mΩ at 1000 amps.

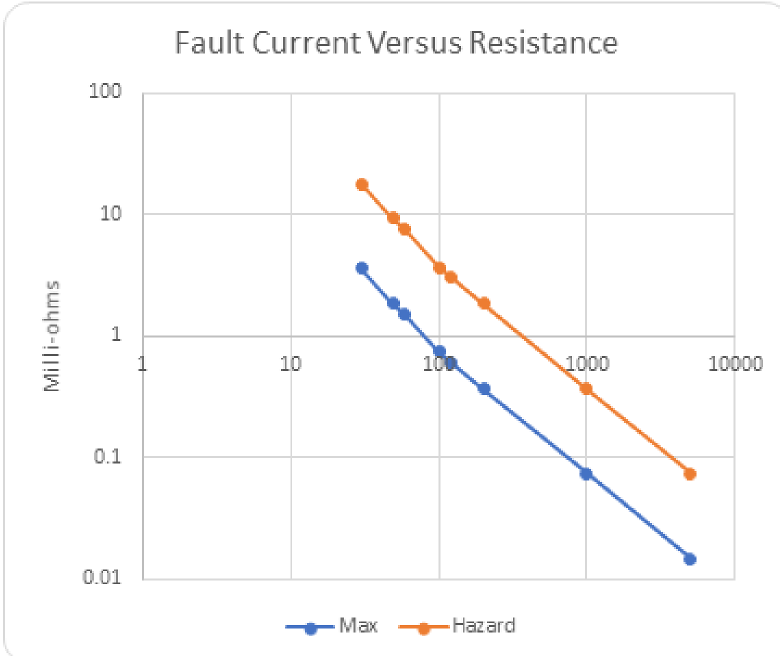

Figure 1: Use this chart to determine the maximum bond resistance for an estimated fault current.

- **Class H bonds** are used to prevent shock hazards and are also critical for ensuring personnel safety. Conduits carrying electrical wiring and exposed conducting frames or electronic parts and equipment must be bonded properly so that should a fault occur circuit-protection devices will operate properly. Personnel must be prevented from encountering any hazardous voltages. MIL-STD-464 sets the resistance of this type of bond at 100 m**Ω** or less.
- **Class L bonds** provide lightning protection. Without proper bonding, lightning surges can produce voltages which can shock personnel, ignite fuel through arcing and sparking, ignite or dud ordnance, and upset or damage electronics. They are used at all points where lightning might enter an aircraft. These entry points include, but are not limited to, navigation lights, fuel filler caps, fuel gage covers, refueling booms, fuel vents, radomes, and canopies. MIL-STD-464C says that Class L bonds should control internal vehicle voltages to maximum of 500 V.
- **Class R bonds** provide protection from electromagnetic interference (EMI). One of the biggest ways that EMI can cause problems is by coupling into data cables and causing data errors. This can degrade performance of an avionics system or cause it to fail completely. To prevent EMI from causing system malfunctions, you should make sure that shielded cables are bonded properly.

  MIL-STD-464C notes, "While specific bonding levels needed to obtain required performance are system-dependent, 2.5 milliohms has long been recognized as an indication of a good bond across a metallic interface, particularly aluminum." It goes on to note that, "There is no technical evidence that this number must be strictly met to avoid problems. However, higher numbers tend to indicate that a quality assurance problem may be present and bonding may be degrading or not under proper control."

- **Class S bonds** prevent the buildup of potentially hazardous electrostatic charges caused by precipitation static effects, fluid flow, air flow, exhaust gas flow, personnel charging, and other charge-generating mechanisms. These charges can build up to thousands of volts and their sudden discharge can ignite fuel and damage or degrade the performance of electronic systems. **Many integrated circuits, for example, are easily damaged by electrostatic discharges.**

  Class S bonds should measure less than 1 **Ω**, but MIL-STD-464C notes, "Relatively poor electrical connections (much greater than the specified one ohm) are adequate to dissipate static charge. However, controls must be imposed which indicate that a reasonable metal-to-metal connection is present. Allowing values greater than 1.0 ohm could result in questionable or erratic connections being considered adequate."

Bond testing

According to MIL-STD-464C, the resistance across a bonding or grounding jumper must be 0.1 **Ω** or less. For some bonds, such as Class L and Class R bonds, you may want to ensure that the bond resistance is lower than 0.1 **Ω**. Class S bonds should measure 1 **Ω** or less.

For Class C bonds, you must consider the maximum fault current that may pass through the bond. Figure 1 shows the relationship between the fault current and the maximum bond resistance required to keep the voltage across the bond to a safe level. Fault current is the maximum current delivered when an internal power to ground short occurs. Fault currents are defined for different electrical distribution circuit segments, such as a main panel or branch circuit.

Since bonding itself cannot eliminate all possible sources of ignition, the equipment itself must be so designed to minimize or eliminate them as well. The resistance between the equipment case and the structure shall not exceed those shown in Figure 1 above.

You measure the resistance between the cleaned areas of the object and the structure after the mechanical connection is completed. To test bonds such as those described above, an instrument capable of measuring very low resistances, such as the TEGAM Model 710A Bond Meter needs to be used. The Model 710A is a digital milli-ohmmeter/bond meter with a full scale reading of 100 **Ω**. Resolution is 1μΩ and accuracy is ±0.2% of reading + 0.02% of range. The Model 710A uses a four-wire method of measurement to determine the resistance of an electrical bond. This method allows you to measure low resistance very accurately despite the resistance present in the connection leads.

Making Accurate Resistance Measurements

In a four-wire configuration, two wires supply the test current to the bond under test, while the other two wires are connected to a sensitive voltmeter built inside the ohmmeter. Because the voltmeter has very high input impedance, very little current flows through these wires, making the voltage drop across these wires negligible when compared to the voltage across the bond under test. Once the Model 710A makes the voltage measurement, it calculates resistance of the bond by dividing the voltage measured by the value of the test current.

In addition, the Model 710A minimizes the effect of thermal contact potentials. These occur whenever two dissimilar metals contact one another. Normally, these thermal contact potentials are low enough to not affect a resistance measurement, but when measuring very low resistances such as bond resistance, they can totally throw off the measurement.

Let's look at an example. In Figure 2, the resistance we're trying to measure is 100 μΩ, and our test current, I_S is 100 mA. The thermal contact potentials, V_a and V_b, are typically 1 mV. With these values, the measured resistance would be $(V_a + Vr + V_b) / I_S$ = (1 mV + 0.01 mV + 1 mV)/100 mA = 20.1 mΩ!

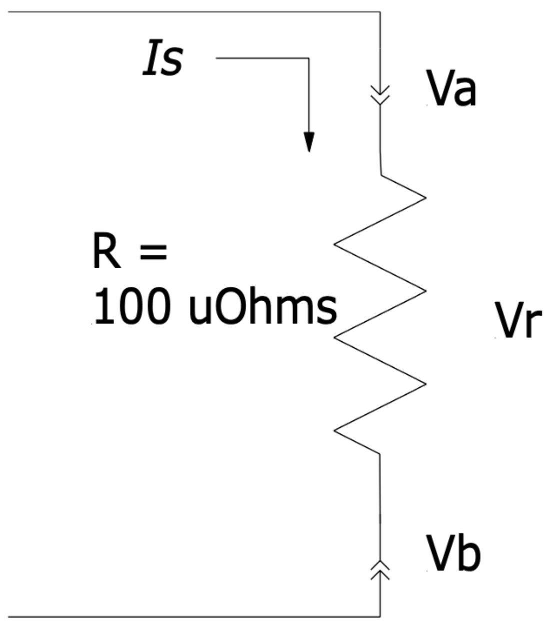

Figure 2: Thermal contact potentials can totally throw off a low-resistance measurement.

The solution is to apply the test current first in one direction and then the other and make two measurements. Assuming the test current is the same in both directions, the thermal contact potentials will be equal and opposite. The final value will be the average of the two measured values. This is shown in Figure 3. The first measurement will be the same as in the previous example, or 20.1 mΩ. The second measurement will be $(-V_a + Vr + -V_b) / I_S$ = (-1 mV + 0.01 mV + -1 mV)/100 mA = -19.9 mΩ, and the average value 20.1 mΩ – 19.9 mΩ /2 = 100 μΩ.

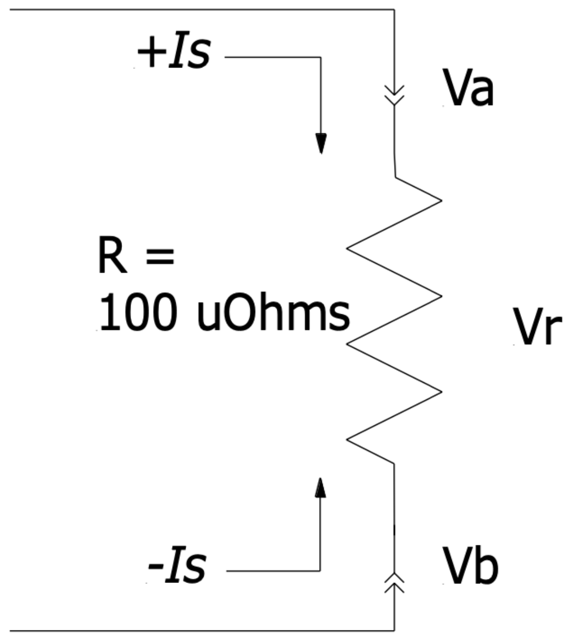

Figure 3: Making two measurements and averaging the results completely eliminates the effects of thermal contact voltage on low-resistance measurements.

Bond Meter Probe Selection

To make a good connection to the structure, the right probe must be used. TEGAM offers several different types of four-wire Kelvin probes that allow making a proper connection. A Kelvin probe is one that makes two connections to the bond under test, one for the test current and one for sensing the voltage. Example of this type of probe are the BKP probe (shown in figure 2) and the MKP probe (shown in Figure 3). **BKP probes are designed for making four-wire surface resistance measurements on films and other metallic surfaces, while the MKP probes were designed for making low-level resistance measurements in tight spaces.** Both types of probes feature replaceable pins should the pins wear out or get damaged while in use.

Some bond testing applications require a probe connection to a screw. For such applications, use the KC Kelvin Clip Leads (shown in figure 4). The alligator clips in this set contain two contacts—one for the test current lead and one for the voltage sense lead—and make a very secure connection to screws and other hardware.

The final consideration is whether the bond will move at all. When performing resistance measurements on bonds that either are designed for movement during aircraft operation or that use bonding straps, gently vibrating the bonded parts to ensure their tightness is recommended.

Troubleshooting and Inspecting Bonds

Should a bond's resistance not meet spec, or while performing a preventive maintenance inspection, check for the following:

- Evidence of electrical arcing. If there is any evidence of arcing, check for intermittent electrical contact between conducting surfaces that may be part of a ground plane or a current path.
- Insecure or corroded bonds. The bonds should be free from any corrosion or dirt.
- Bonds that interfere with movable parts. Bonding jumpers should be installed in such a manner as not to interfere in any way with the operation of movable components of the aircraft.
- Frayed or kinked bonds.
- Self-tapping screws. Self-tapping screws should not be used for bonding purposes. Only standard threaded screws or bolts of appropriate size should be used.
- Bonds that do not connect directly to the aircraft structure. Bonds should not be attached through other bonded parts.
- Washers of dissimilar metals. Use appropriate washers when bonding aluminum or copper to dissimilar metallic structures so that any corrosion that may occur will be on the washer.

A Safety Thought

Bond testing on surfaces of electro-explosive devices or where explosive hazards are present, such as near propellants or volatile compounds, requires test instruments that will not inadvertently ignite these devices or materials. These kinds of instruments are specially certified to be intrinsically safe. If measurements under these conditions are necessary, consider using the TEGAM 720A Intrinsically Safe Bond Meter. Being intrinsically safe means that the 720A will not supply enough energy to cause the ignition of hazardous gases. Refer to its manual for the specific ratings and conditions under which the 720A may be used.

About TEGAM

TEGAM, Inc. is a manufacturer of electronic Test, Measurement and Calibration standards equipment. We have experience in providing test equipment to aircraft MRO applications and to all branches of the U.S. military. Here are a few examples:

- Model 710A is used by Lockheed Martin and its suppliers as a production test instrument for the F-35 Joint Strike Fighter. The 710A is also used on the Textron King Air and Longitude airframes.

- Model R1L-BIR1; NSN 6625-01-625-1970: is commissioned as ground support equipment to support the US Army Kiowa Warrior.

- Model R1L-E2A; NSN 6625-01-527-5543: The TEGAM Model R1L-E2A is a portable, intrinsically safe milli-ohmmeter that is required ground support equipment for the Sikorsky S-70B, S-92, and MH-60R helicopters. The R1L-E2A is currently being purchased by US Navy for support of the USMC and USN versions of these aircraft. The R1L-E2A is also specified group support equipment for the Lockheed F-35 Joint Strike Fighter.

- Model R1L-BI; NSN 6625-01-350-8774: The TEGAM R1L-BI is a bench-top version of the R1L-BIR1 that is currently specified ground support equipment for the Boeing CH-47 Chinook and Sikorsky UH-60 Black Hawk. In both cases the US Army is taking steps to replace the R1L-BI with the more rugged and complete R1L-BIR1.

- Model 252/SP2596; NSN 6625-01-474-6981: The 252/SP2596 LCR Meter is specified for testing the Kidde/Fenwal fire detection sensors used in many military and commercial aircraft jet engine assemblies. The 252 is required ground support equipment for the Lockheed C-130 and Bombardier Global Express.

We believe that TEGAM's wide range of milli-ohmmeters / bond meters offer a practical, user-friendly package that is also a durable, cost-effective solution to the day-to-day support demands of our Naval Aviation teams. Please contact us at **440-466-6100 (or, sales@tegam.com)** with any questions regarding your bond testing needs. DEMO tests are available for our bond meters & milli-ohmmeters.

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