Low Outgassing Accelerometers and Cables

For Thermal Vacuum and Vibration Test Environments

Written By

Bob Metz, Director, Aerospace & Defense, PCB Piezotronics, Inc., Depew, NY

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ABSTRACT

Exposure to the high vacuum level of a space environment induces material outgassing in ordinary accelerometers and cables. Any substance subjected to a vacuum has the potential to release trapped gasses. Contaminants from outgassing can condense onto nearby surfaces, such as photo-optic devices, and obscure them, rendering them useless during their intended application.

During random vibration, swept sine or shock testing prior to flight, spacecraft payloads are often fitted with accelerometers in hard to reach mounting locations. As the space structure is built up around them, it can become impossible to remove the accelerometers. Sensors installed for ground vibration testing may therefore remain on the structure—even if they are no longer needed for testing purposes.

In any application involving a thermal vacuum environment, care must be taken to select the proper accelerometers and cables prior to vibration testing. Accelerometer designs with hermetic housings and connectors can have low outgassing qualities. For all non-metallic materials outside of a hermetic package, such as cables with polymer strain relief that do not typically have low outgassing qualities, verification is required to ensure that the materials have less than or equal to 1% TML (total mass loss) and a CVCM (collected volatile condensable mass) less than or equal to 0.1%. This is verified either using NASA documentation or test results from an outside laboratory.

Given these design parameters, a series of accelerometer and cable designs for the thermal vacuum environment will be discussed in this paper. They have been specifically designed or tested for low outgassing properties in accordance with the report NASA RP-1124, "Outgassing Data for Selecting Spacecraft Materials." [1]

KEY WORDS: Low Outgassing, Thermal Vacuum Chamber, Vibration, Shock, Acceleration, Accelerometer, Total Mass Loss, Collected Volatile Condensable Materials

DEFINITIONS OF TEST STANDARDS

After a series of tests and verification of procedures, an American Society for Testing and Materials (ASTM) Standard Test Method was developed to qualify materials for space environments. The method, "Total Mass Loss (TML) and Collected Volatile Condensable Materials (CVCM) from Outgassing in a Vacuum Environment," is identified as ASTM E 595.

The test procedures evaluate changes in the mass of test specimens under vacuum at a temperature of 125°C, and the mass of those products that leave the specimen and condense on a collector at a temperature of 25°C. The simulation of the vacuum of space in this procedure does not require that the pressure be as low as that encountered in space flight, for example, 1x10^{-12} Pa. The pressure is only required to be low enough in proportion to test chamber dimensions. [2]

Collected Volatile Condensable Material (CVCM) is the quantity of outgassed matter from a test specimen that condenses on a collector maintained at a constant temperature for a specified period of time, and is measured before and after the test outside the chamber. CVCM is expressed as a percentage of the initial specimen mass. [3]

Total Mass Loss (TML) is the mass of material outgassed from a test specimen and measured within a test chamber while the chamber pressure and temperature is maintained over a specified period of time. TML is expressed as a percentage of the initial specimen mass. [3]

THE VIBRATION ENVIRONMENT

Random vibration, swept sine or shock testing is performed on aerospace structures and payloads to determine their durability prior to flight. In the real operational world of flight, random vibration excitation comes from a combination of high velocity turbulent airflow over aircraft or spacecraft. Acoustic excitation comes from jet or rocket engines. Shock events occur from various impacts or pyrotechnic events, such as explosive bolts. Onboard equipment can be easily damaged unless it is designed to withstand these vibration levels. An example of a random vibration response channel is shown in Figure 1.

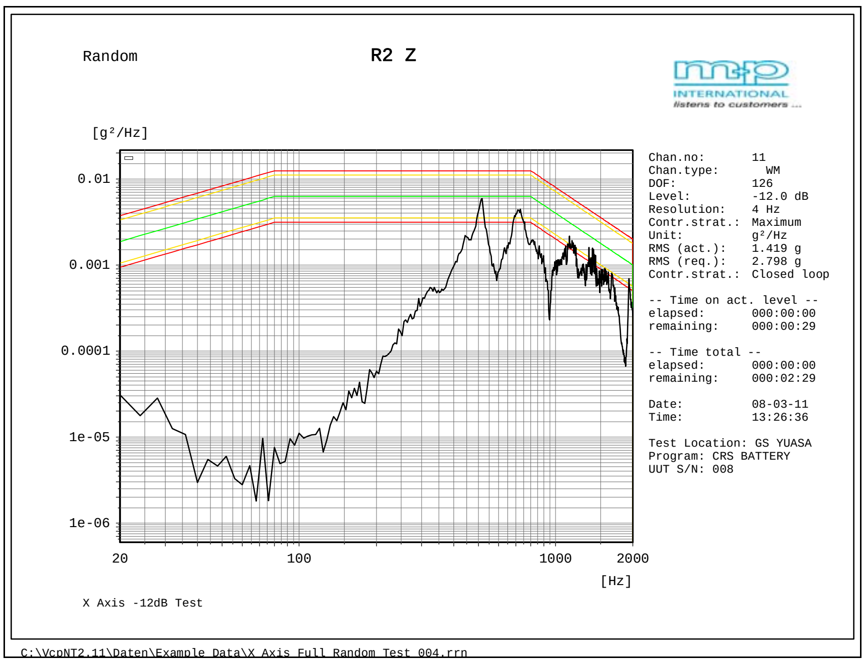


Figure 1
Random Vibration Response Plot
Courtesy of m+p International

Swept sine testing is typically performed to search for test item resonances to determine fatigue life in each mode. A sine sweep may be performed before and after a random vibration, acoustic or shock test. If the before and after vibration records match, the equipment under test most likely has not been damaged. [4] An example of a swept sine response channel is shown in Figure 2.

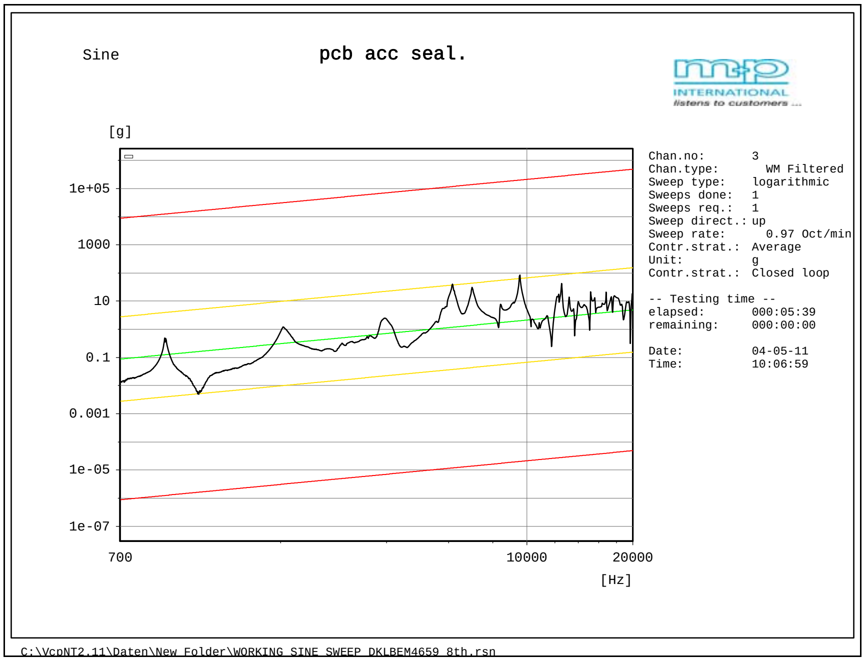


Figure 2
Swept Sine Response Plot
Courtesy of m+p International

ACCELEROMETER DESIGN

The random vibration, swept sine and shock test environment is very harsh, so a robust accelerometer design is required that exceeds the test levels. There are a number of important sensor characteristics that benefit from a shear mode accelerometer design, which clamps the sensing crystals between a center post and seismic mass.

Figure 3 shows a compression ring that applies a preload force required to create a rigid linear structure. Under acceleration, the mass causes a shear stress to be applied to the sensing crystals. The advantage of this design is that by isolating the sensing crystals from the base and housing, the shear accelerometer excels in rejecting thermal transients and signal noise resulting from base bending effects. This is a very important feature when performing operation vibration testing in a thermal vacuum chamber.

The shear geometry also lends itself to small size, which minimizes mass loading effects on the test structure. To assist in weight reduction, most low mass accelerometers are made from titanium. The accelerometer is assembled using a laser welding process (Figure 4) to ensure good weld penetration and resulting hermetic seal.

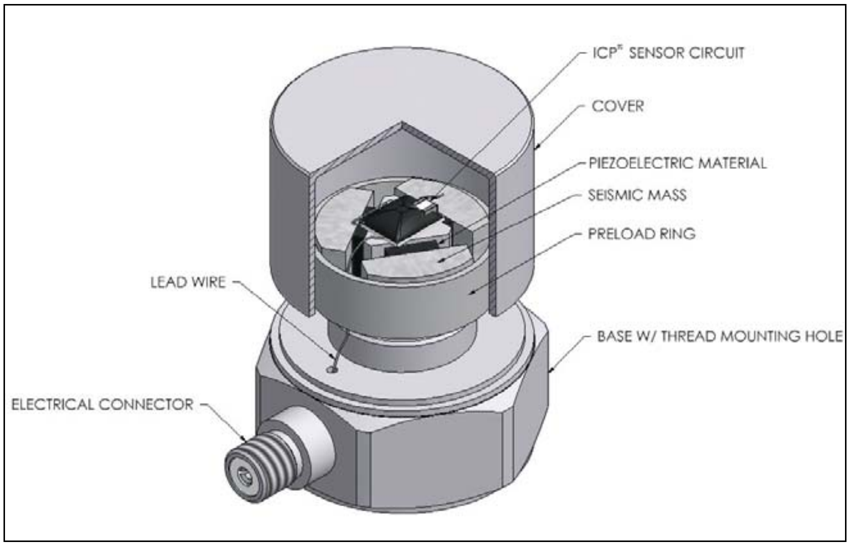


Figure 3
Shear Mode, Welded Hermetic Accelerometer

Figure 4
Inert Gas Laser Welding System

ANATOMY OF A HERMETIC CONNECTOR

Hermetic connectors are designed using compression metal to glass bonds to provide both electrical insulation and a hermetic seal. The design must be robust enough to withstand in-process handling, multiple cable connections, cable strain, thermal cycling, and cycling ambient conditions to a vacuum. The connector depicted in Figure 5 has a simple three piece design that is manufactured holding very tight dimensional tolerances.

A glass pre-form is pressed into the connector shell, followed by insertion of the electrical contact. The furnace, shown in Figure 6, is used to melt the glass that creates the bond between the shell and electrical contact. The melt occurs during a 90 to 120 minute process at approximately 1000 °C (1830 °F).

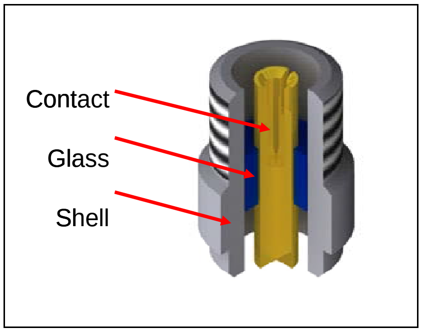


Figure 5
Typical Hermetic Connector

Figure 6
Glass Bonding Furnace

After a cooling period, each connector is leak rate tested for hermeticity. The connector is attached to the accelerometer signal electrode wire and then laser welded to the accelerometer housing to complete the hermetic seal.

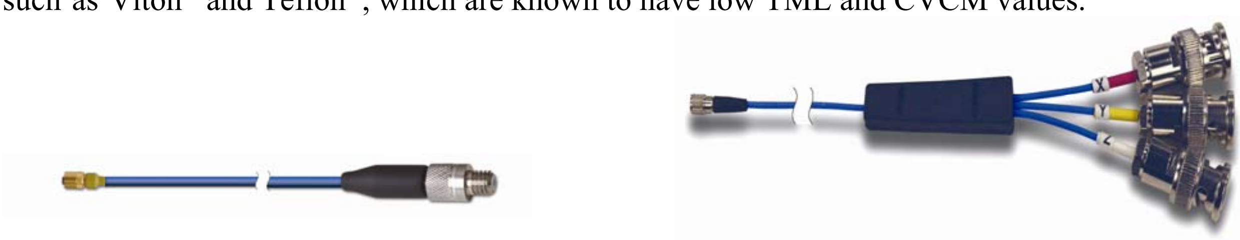
MATERIAL COMPOSITION FOR NON-HERMETIC SENSORS

Due to their small size, some low mass miniature accelerometers do not lend themselves to hermetic construction because they can not be welded or sealed in a hermetic manner. In such cases a manufacturer must adhere to certain low outgassing material restrictions during design of the accelerometer. Items often used and subsequently banned in thermal vacuum chamber environments include brass, epoxies and polymers.

At 0.6 grams, PCB Piezotronics, Inc. Model 357A09 is an example of a low mass accelerometer that is not hermetically sealed. However, the construction uses low outgassing materials which make it suitable for use in thermal vacuum test or space operations. An example of its material composition is listed in Appendix 1.

CABLE DESIGNS

Ordinary output cables used for signal transmission are the greatest source of outgassing contamination, with insulation and strain relief at each connector being the largest contamination contributors. Some examples of cables, shown below in Figure 7, use materials such as Viton® and Teflon®, which are known to have low TML and CVCM values.



Series 030EXPH Mini-coax Cable **Series 034 Triaxial Breakout Cable**

Figure 7
Low Outgassing Cable Examples

In a similar manner to sourcing a non-hermetic accelerometer with known material properties, most cables require an associated material list to be confirmed as multiple types of polymers are used in their construction. An example of the material composition for the PCB Series 030EKPH mini-coaxial cable is listed in Appendix 2.

LEAK TESTING

Leak testing on hermetic sensors can be performed on accelerometers at various test levels dependent on the required level of hermeticity documentation. The two most common testing methods are a gross bubble test and a helium leak test. A bubble test is typically provided for all hermetic accelerometers. For finer test work, the helium leak test is performed.

The gross bubble test verifies a leak rate with less than $1x10^{-3}$ cc/sec flow. This relatively fast bubble test is a variation of MIL-STD-883E, Seal Test Method 1014.10, Section 3.3.1. [5] In this test, accelerometers are submerged into a tank of heated fluroinert liquid. The fluorinert is maintained at an operating temperature of approximately 100 °C (212 °F). [7] The heated fluroinert causes any trapped gasses inside the accelerometer to expand and to bubble out of the sensor. The bubbles become visible during the test in the fluroinert liquid (refer to Figure 8).

Figure 8
Gross Leak Test Apparatus
TrioTech International G-203A Bubble Chamber

For a more thorough investigation of hermeticity, accelerometers are subjected to a fine helium leak test. The fine leak test uses a mass spectrometer, where the accelerometers or their connectors are pressurized in helium. A mass spectrometer vacuum leak detector then verifies a leak flow rate of less than $2x10^{-8}$ cc/sec. Figure 9A shows an example of a Veeco MS-50 system.

Figure 9A
Mass Spectrometer Leak Detection System
Photo Courtesy of Vacuum Instrument Corporation

There are three types of helium testing done with the mass spectrometer equipment. The first test is performed on all electrical connectors intended for use with hermetic accelerometers. This test involves forcing helium past the connector glass to metal bond (Figure 9B). The connector passes this test when the leak rate is less than $2x10^{-8}$ cc/sec.

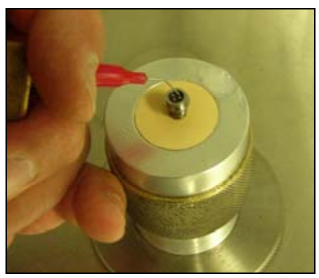


Figure 9B
Leak Detection Test on Glass Bond

The second test is for a finished accelerometer. The accelerometer is pressurized to 300 psi with helium and then placed in the mass spectrometer chamber. The accelerometer passes this test when the leak rate is less than $2x10^{-8}$ cc/sec. If it does not pass, the third test is performed, which is a sniffing test to pinpoint the source of leakage. In the sniffing test, a hose is connected to the mass spectrometer test chamber. The sniff hose uses a probing needle (Figure 9C) to sniff around all welds, chamber seams, the sensor connector shell, and center electrical contact to pinpoint the leak.

Figure 9C
Leak Detection 'Sniff' Test on Weld Joint of a Hermetic Connector

ACCELEROMETER CONFIGURATIONS AND APPLICATIONS

Four fundamental accelerometer designs typically require low outgassing properties; triaxial, miniature, shock, and high-temperature. Some examples are shown in Figure 10, yet there are many possibilities for other design configurations.

Triaxial 356M208 | Miniature 352M212 | High-temp 357A07 | Shock 350M72

Figure 10

Spacecraft structures are often made of thin, lightweight materials. Low mass accelerometers are desirable to prevent mass loading the unit under test. Spacecraft random vibration responses are three-dimensional, so the combination of a triaxial, low mass accelerometer with low outgassing properties is recommended. Figure 11 shows a triaxial accelerometer installed on a cantilever bracket assembly during test.

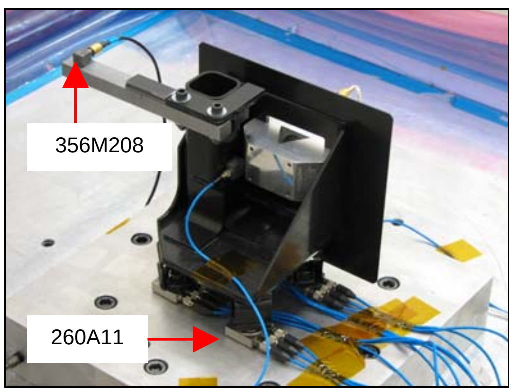


Figure 11
PCB Model 356M208 (arrow used during vibration testing of a bracket assembly at Utah State Space Dynamics Lab

Also highlighted in the photo are four piezoelectric three-component force sensors mounted under the bracket that serve a Force Limited Vibration Testing function. Just like accelerometers, force sensors can be made hermetic for low outgassing environments.

Separation of booster stages or pyrotechnic bolt cutters and squibs cause shock events that may be transmitted to the spacecraft payload. An example of a low outgassing shock accelerometer may be found in Figure 10 (PCB Model 350M72), and it may be launched with the payload to monitor shock levels, or used in a thermal vacuum chamber to simulate launch conditions.

Environmental stress screening is typically performed in thermal chambers under extreme environments for qualification or life cycle testing. This testing is often at the component level rather than on a full-scale vehicle. Figure 12 shows a high-temperature hermetic accelerometer that weighs 0.9 grams, with a wide operating temperature range from -73 to +260 °C (-100 to +500 °F).

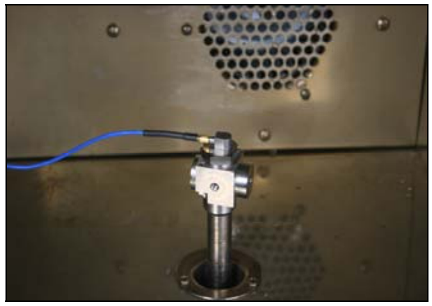


Figure 12
PCB Model 357A07 in Thermal Chamber

CASE STUDY

Ball Aerospace, located in Boulder, CO, required a low outgassing accelerometer and cable assembly for ground vibration testing of the NASA Suomi NPP (NPOES Preparatory Project) Satellite during thermal vacuum testing. The Suomi NPP space segment is comprised of seven elements; the spacecraft, the five instrument/sensor payloads, and the associated ground support equipment and simulators. The spacecraft is a member of the Ball Configurable Platform (BCP) family of spacecraft designed for cost-effective, remote sensing applications.

The accelerometers and cables that were exposed to the vacuum chamber had to meet or exceed an outgassing rate less than $1x10^{-12}$ gm/cm^2-s @ +30 °C. Additionally, the accelerometers and cables internal to the vacuum chamber had to be baked out and certified clean. Prior to bake out, they were cleaned with isopropyl alcohol and then installed on the satellite. Ten PCB Model 356M98 accelerometers, cables and hermetic feed-thru connectors were used for the thermal vacuum test (Figure 13). Nine of the accelerometers were installed on the Suomi NPP Satellite.

Figure 13
PCB Model 356M98
Low Outgassing, 1 V/g accelerometer

Figure 14 shows the mounting locations for four of the accelerometers. The other five accelerometers were located either on the Cross-Track Infrared Sounder (CrIS) instrument or on its base plate. The CrIS instrument is colored green in Figure 14, and the locations of the accelerometers are depicted by red circles.

The accelerometers were installed on the Suomi NPP Satellite to determine if any operational vibration was affecting the CrIS instrument during its thermal vacuum operational checkout. The CrIS, a Fourier transform spectrometer with 1305 spectral channels, will produce high resolution, three dimensional pressure, temperature, and moisture profiles. These profiles will be used to enhance weather forecasting models. They will facilitate both short and long-term weather forecasting. [5]

Figure 15 further shows a photograph of the Model 356M98 accelerometer mounted on the Suomi NPP Satellite, with is low outgassing connecting cable attached. [6]

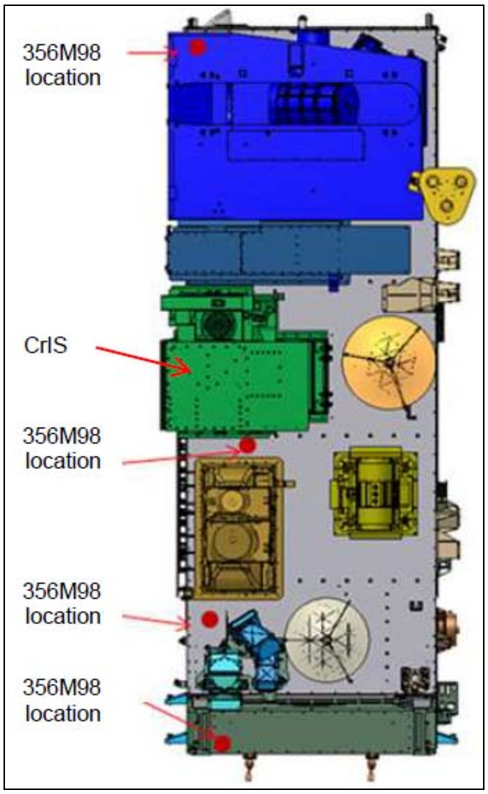


Figure 14
NASA Suomi NPP Satellite
Image Courtesy of Ball Aerospace & Technologies Corporation

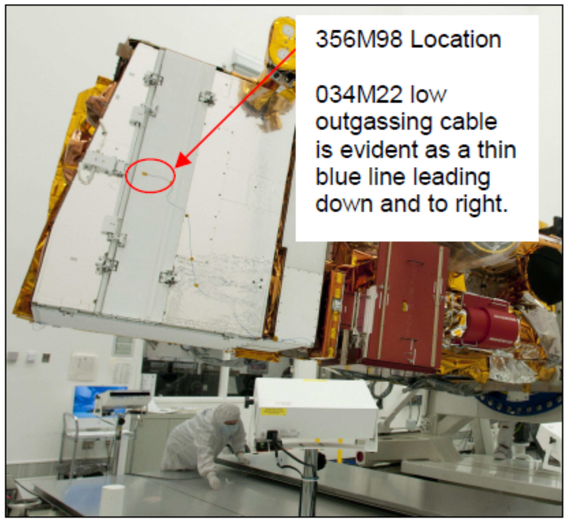


Figure 15
Post Thermal-Vac Testing
NASA Suomi NPP Satellite at the Ball Aerospace Facility
Photo courtesy of Ball Aerospace via NASA

SUMMARY

In any application involving a thermal vacuum environment, it is the responsibility of the test program to ensure that suitable test equipment is selected and properly handled prior to test. Care must be taken to select appropriate accelerometers and cables prior to vibration testing, and this paper serves as a guide to accelerometer and cable selection.

Many welded hermetic accelerometer designs can have low outgassing qualities. All should be approved for vacuum conditions via hermeticity testing in accordance with MIL-STD-883E using a bubble test. Additional leak testing using mass spectrometry allows a more precise verification of an accelerometer's hermetic condition, and should be used in thermal vacuum environments that require strict contamination precautions. For miniature accelerometers that do not lend themselves to hermetic construction, the manufacturer must adhere to certain low outgassing material restrictions during design of the accelerometer.

Cables with polymer strain relief boots or shrink tubing typically do not have low outgassing qualities. It is important that selected cables use polymers and epoxies that have been verified for TML and CVCM for low outgassing properties. Materials are selected upon consulting the NASA guide CRm2001-210909, where they have been tested by NASA to ASTM E 595 standards for suitability in vacuum environments.

As shown in the Suomi NPP Satellite case study, even with accelerometers and cables that are designed for low outgassing environments, additional precautions such as bake out or special cleaning processes may be required.

Appendix 1
Non-hermetic Material List Suitable for Low Outgassing

Accelerometer 357A09, P357A09

Drawing/Item Number	Description	Material	Secondary finish
Element Assembly	Crystal	PZT Ceramic	Gold over Nickel
	Mass	Tungsten	
	Memory Ring	Nickel - Titanium	
Housing Assembly	Housing	TI6AL4V	
	Contact	BeCu	Gold plate over Nickel plate
	Insulator	Torlon	
	Epoxy	104A/B	
Cover		TI6AL4V	
Epoxy		H20E	
Epoxy		104A/B	
Wire		44AWG Copper	
Solder		SN63/37	

Appendix 2
Series 030EKPH Mini-coax Low Outgassing Cable Material List

030EK001PH Materials List

030 Cable	
Jacket	Teflon (PTFE Tape)
Shield	40 AWG Silver Plated Copper Wire
Low Noise Barrier	Graphite
Insulator	Teflon (Extruded PTFE)
Conductor	34 AWT (7x.0.063) Silver Plated Copper
PH	
Connector Shell	SS 304L
Insulator	#9013 Glass
Contact/Socket	SS 430, Nickel Sulfamate Plate per SAE AMS-QQ-N-290 Class 2, Grade G
Backshell	SS 304L
Jerk Ring	Brass, Gold Plate per MIL-G-45204 Type II, Grade C, Class 1 over Nickel Plate per QQ-N-290
Strain Relief	Viton
Pin Retaining Ring	Teflon (PTFE 15% Glass)
Tubing	Teflon
Solder	SN10PB88AG2
EK	
Coupling Nut	6061-T6 Al. with gold plate over nickel plate
Housing	6061 Al. with gold plate over nickel plate
Insulator	Torlon
Socket	BeCu with gold plate over nickel plate
Strain Relief	Torlon
Solder	SN10PB88AG2

REFERENCES

1. NASA Reference Publication 1124 (January 1997).
2. ASTM E595.
3. NASA/CRm2001-210909.
4. Tustin, Wayne, Random Vibration & Shock Testing, Equipment reliability Inst. (2005): 4-5.
5. MIL-STD-883E.
6. npp.gsfc.nasa.gov/spacecraft_inst.html (2012).
7. ISA-RP37.2-1982, rev 1995, section 5.3.1 (Acceleration Transducer Guide) and ISA-S37.10-1982, section 6.1 (Piezoelectric Pressure Transducer Guide).

PCB PIEZOTRONICS
AN AMPHENOL COMPANY

3425 Walden Avenue, Depew, NY 14043 USA

pcb.com | info@pcb.com | 800 828 8840 | +1 716 684 0001

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