HIGH-G SURVIVABILITY OF AN UNPOTTED ON-BOARD RECORDER

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ABSTRACT

On-Board Recorders (OBRs) provide developers with data from sensors and computers by storing the data to memory devices contained within it's on board electronics system. At the expense of recovery, reusable OBRs provide projects with cost savings in terms of upfront non-recurring engineering, unit costs savings, and reduced field support setups. In this paper, the ARRT-158 OBRs used within artillery munitions systems to capture interior and exterior ballistics sensor and mission computer data will be discussed.

INTRODUCTION

On-Board Recorders (OBRs) provide developers with data from sensors and computers which are sampled and stored in on-board memory devices. At the expense of recovery, reusable OBRs provide projects with cost savings in terms of upfront non-recurring engineering, unit costs savings, and reduced field support requirements. In order to achieve a reusable, survivable onboard recorder, potting materials are often utilized to provide structural support to electronics. This paper discusses prior work done on potted OBRs as well as the experimentation of a pottingless OBR used within artillery munitions systems to capture interior and exterior ballistics sensor and mission computer data.

BACKGROUND

The ARRT-158 is a two rigid printed circuit board (PCB) data acquisition electronics design, interconnected by wires and secured to a 7075-T6 aluminum housing using mechanical standoffs, as shown in Figure 1. The entire assembly, within the housing is then potted using a reworkable potting compound to provide structural support, outside the load path of the acceleration forces, to the electronics board stack for high acceleration (high-g) environment survivability.

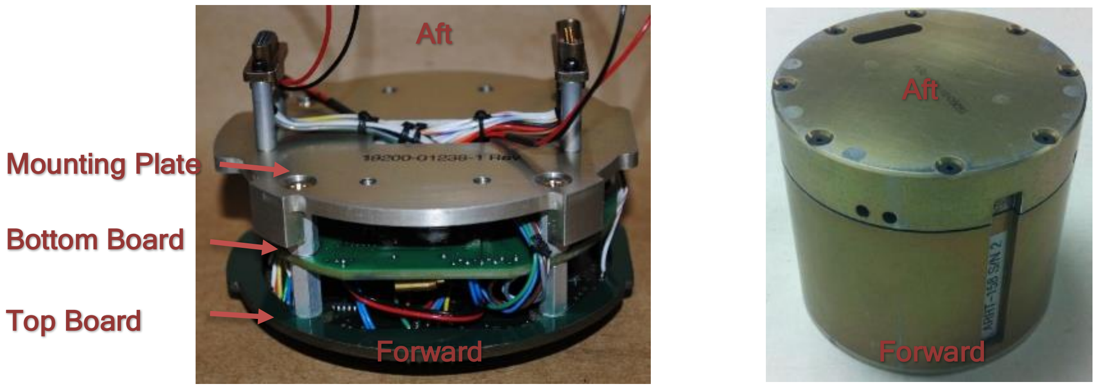

Figure 1 ARRT-158 Electronics Stack (Left); Fully Integrated ARRT-158 OBR (Right)

The ARRT-158's mission is to record interior and exterior ballistics acceleration environments for use in component or subassembly qualification. The operational environment for the ARRT-158 OBR is Picatinny Arsenal's 155mm Soft CATch (SCAT) Gun where test articles are subjected to accelerations up to 17,000G's during setback and balloting accelerations at muzzle exit and transition tube entry. The SCAT Gun is approaching 1,000 testing events with nearly each projectile tested an accompanying OBR is onboard recording the environment. Reusability of OBRs are vital to keeping testing costs low and ensuring operational readiness testing.

To achieve a level of reliability in such an extreme environment, potting materials are frequently used to fully support electronics to achieve survivability. However, potting materials themselves can lead to reliability problems resulting from improper cure and melting time and temperature which can lead to potting fracturing during testing, coefficient of thermal expansion and modulus mismatch during curing and testing, component stressing during potting removal, and dynamic component stresses caused by potting mass movement and fracturing during acceleration. It is important that fully coupled modeling and simulation environments be developed to evaluate the effects of potting materials. [1,2] Two of examples of reliability problems are shown in Figure 2.

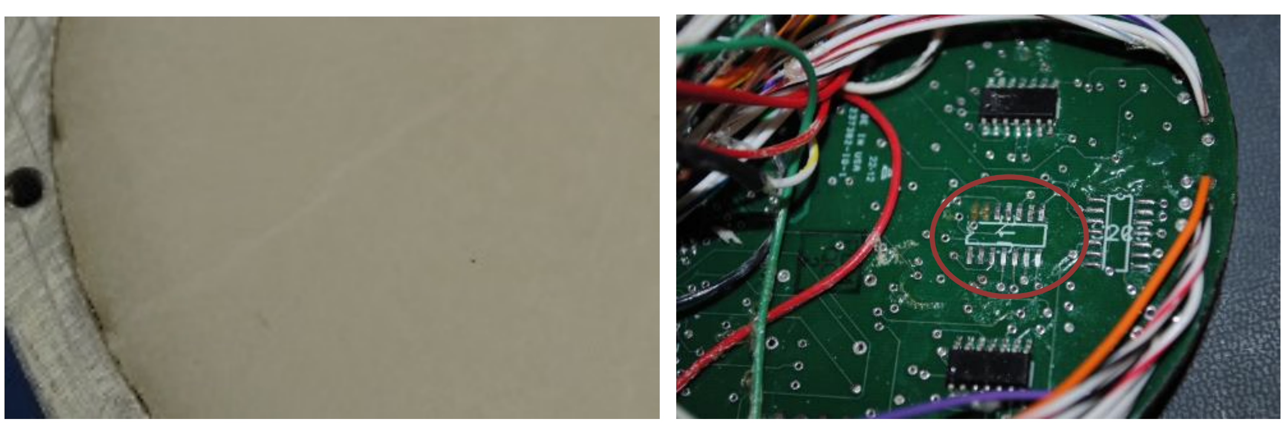

Figure 2 Cracked Potting (Left); Missing SOIC Package After Potting Removal (Right)

Extensive modeling and simulation of the electronics has been conducted in order to determine optimal electronics housing design as well as potting procedures and materials for survivability in high acceleration environments. A static deflection test was also conducted on the ARRT-158 digital board during a failure analysis effort.

Successful potting processes are important to reliability. If the process for the potting material is not strictly followed a repeatable process will be hard to achieve. This process variation can be detrimental to the cured material properties and lead to failures. Although modeling and simulation pointed to an acceptable level of board deflection within the potting structure, an effort was undertaken to eliminate potting materials so that the tensile and compression forces enacting on electronics components during potting preheating and curing processes were also eliminated. A pottingless solution is a valuable mechanical support alternative for any electronics assembly to achieve greater process repeatability and reliability as well as being able to be reworked.

PROOF OF CONCEPT

Before any changes were made to the ARRT-158 OBR to accommodate a pottingless design, two candidate rigid flex PCB designs were evaluated both of which had two 3.5" diameter 0.093" thick rigid PCBs with 22 independent traces run from one rigid board to the other through a flexible circuit, and is shown Figure 3.

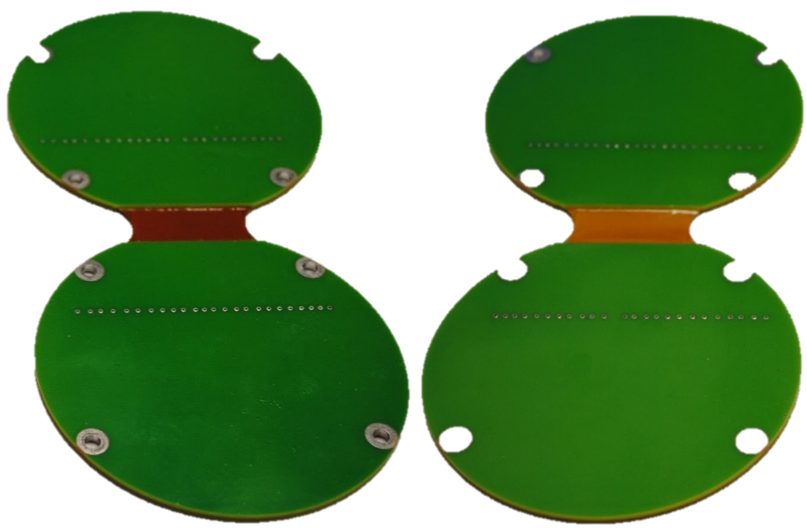

Figure 3 Rigid Flex Test PCBs: Flex Stack Up #2 (Left), Flex Stack Up #1 (Right)

The difference between the two rigid flex PCBs was the thickness of the flexible circuit dielectrics. An additional Dupont Pyralux dielectric was added to both sides of the flexible circuit making a second candidate deign. The flexible circuit material stack is shown in Figure 4 and the final integrated test article, without a lid, is shown in Figure 5.

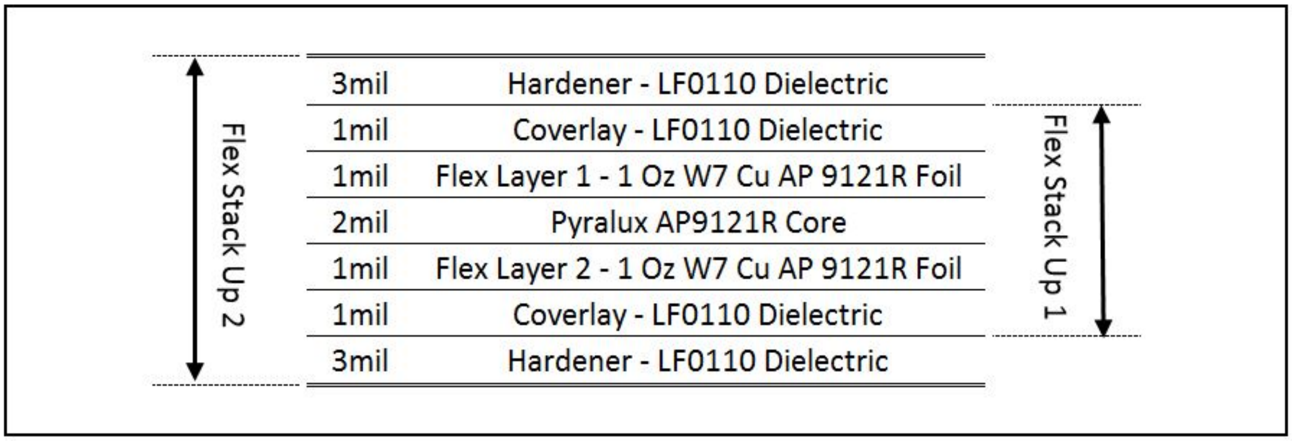

Figure 4 Proof of concept flex cross sections

Structural analysis predicted a maximum board deflection of 0.00535” (Manole, et al., US Army Armament Research, Development and Engineering Center, Picatinny Arsenal, NJ, In Publication) using a similar 155mm SCAT Gun MACS Zone 5 firing setback acceleration load curve as the analysis performed on the ARRT-158 OBR. With a reduction in PCB deflection of 0.0217” the team was confident in proceeding with testing the design.

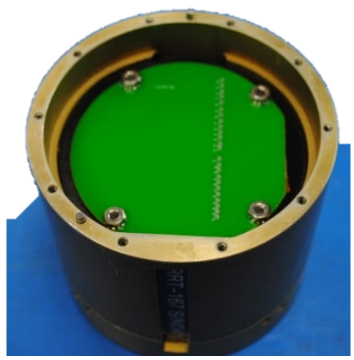

Figure 5 Integrated Proof of Concept Test Article

The PCBs were inspected visually and via X-Ray before and after they were tested to determine if there was any damage to the flexible material or conductive traces when subjected to a high acceleration environment. The boards were tested at Picatinny Arsenals Soft CATch 155mm gun at MACS Zone 5 on March 13, 2014. No damage was observed to either test articles. Consequently the decision was made to choose the stiffer flex material design for added strength and protection.

PROOF OF DEMONSTRATION

With a successful Proof of Concept, the ARRT-158 OBR was redesigned to be a two board rigid flex PCB design taking on the new part number ARRT-167. During design of the new rigid flex OBR design, structural modeling and simulation was concurrently taking place and provided keep out areas on the PCB where structural spacers would reside for electronics survivability without potting. These cross hair style keep out areas are shown in electronics design artwork in Figure 6.

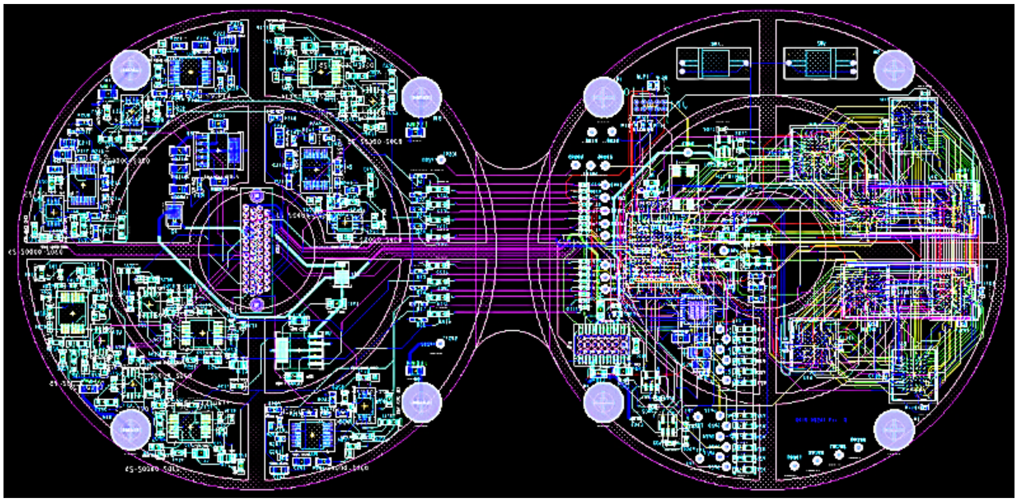

Figure 6 ARRT-167 PCB Layout with Spacer Keep Out Areas

The result was a 0.093" thick rigid PCB with the flexible section having two layers of DuPont Pyralux LF0110 composite coverlay for added flexible circuit support. The fabricated electronics board stack and structural spacers are shown in
Figure 7 and Figure 8.

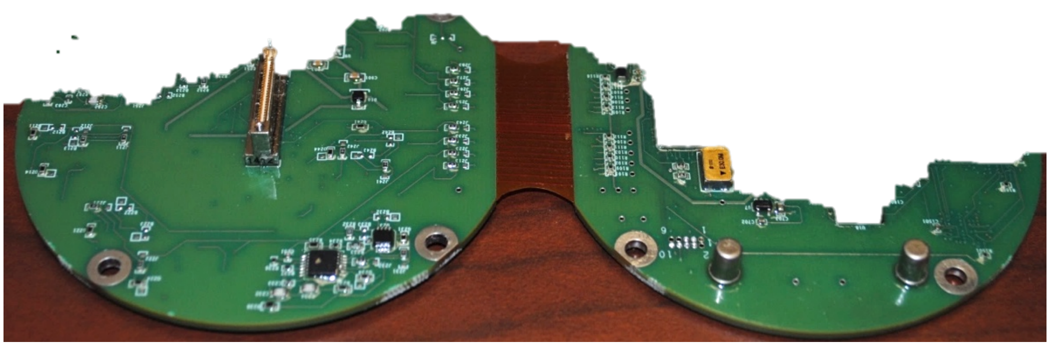

Figure 7 ARRT-167 Rigid Flex PCB

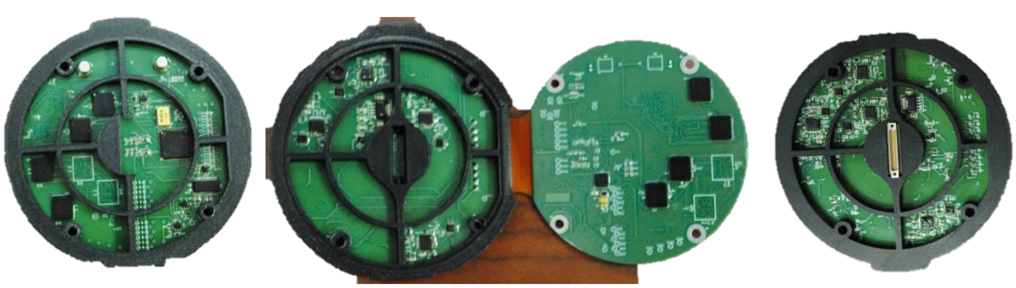

Figure 8 OBR Spacer Fitment: (Left) Top, (Center) Middle, and (Right) Bottom

The flexible material eliminated the need for wired connections between the PCBs unlike what is shown in Figure 1. Unsupported wires during high-g events, under their own mass, can impart enough stress on the solder joints to create intermittent or loss of electrical connection. Even in potted structures, wires that happen to be in a potting void can also impart stress on itself and solder joints. In this design, the rigid boards fit within a recess of the spacer such that the flexible section between the two circuit boards would be supported by a rounded groove in the spacer design as shown in Figure 9.

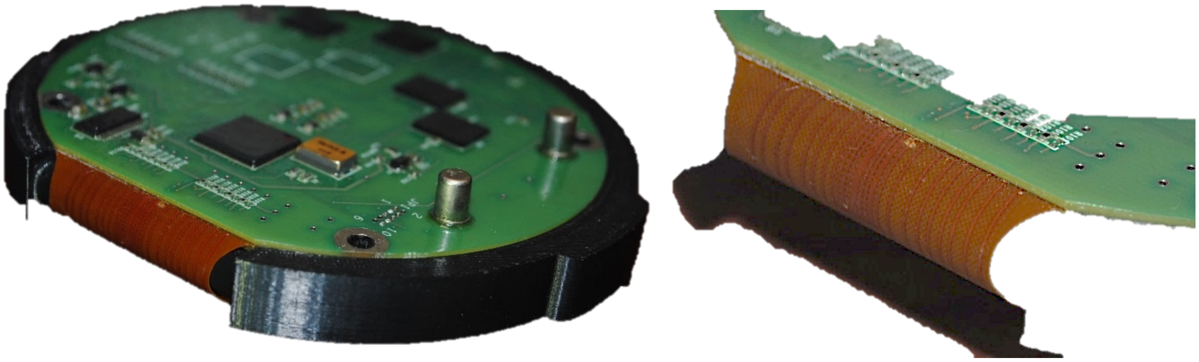

Figure 9 Flexible Circuit Interconnect Spacer Support

Component underfill material was applied to all PCB components to increase component adhesion to the PCB thereby reducing solder joint strain associated with component movement during accelerations. The purpose of this test was to evaluate the ability of the electronics to function during a high acceleration event without potting material, and while solder joints can structurally hold up to such accelerations this variable was removed to demonstrate the spacer performance in minimizing board deflections. A urethane conformal coat was also applied to seal the boards for added protection. Shown in Figure 10 are the complete electronics board stacks with and without spacers outside of its mechanical housing.

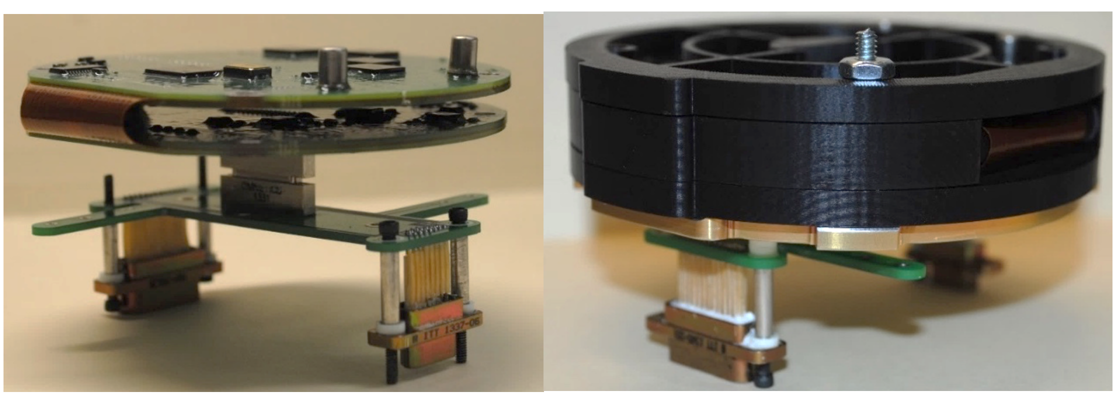

Figure 10 OBR in (Left) Board Form and (Right) with Spacers

While the schematic and the firmware were identical between the ARRT-158 and ARRT-167 OBRs the differences included: different PCB layout, flexible interconnect over thru hole wired connections, and 20,000 g range accelerometer (50 kHz frequency response) that were reused from previous systems over 60,000 g range accelerometer (100 kHz frequency response) that are replaced at the first sign of measurement anomalies.

TEST EVENT #1

ARRT-167 Serial Number 1 was tested alongside an ARRT-158 OBR during SCAT Gun Test #825. SCAT Gun Test #825 was fired at MACS Zone 5, had a projectile weight of 103.4 lbs, and an estimated muzzle velocity of 792.27 m/s. The data of both the Spacer OBR and Potted OBR are found in Figure 11.

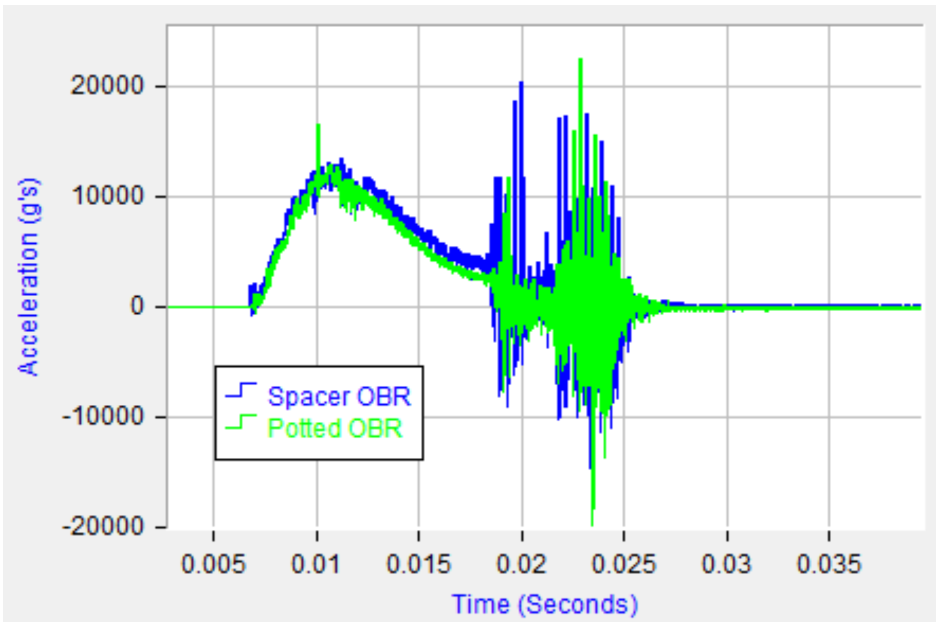

Figure 11 SCAT Gun Test #825, Spacer & Potted OBR Axial Acceleration Data

The data recorded on the Spacer OBR correlated to that of the Potted OBR significantly. Spacer damage was noted in two places. The first location is marked by a broken inner ring on the top spacer, and the second location is noted where one of the innermost supports around the connector separated at its thinnest section (shown in Figure 12). This spacer supported the bottom board to the mechanical housing. The damage was most likely attributed to the set-forward event and insufficient electronics stack preloading within the aluminum housing.

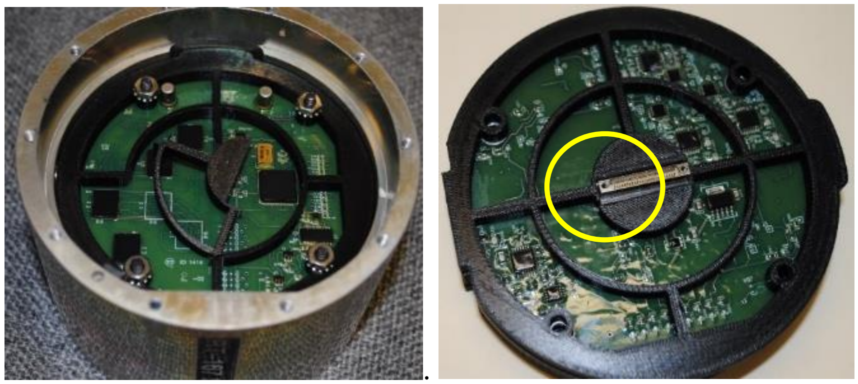

Figure 12 OBR Spacer Damage

The cracks developed in an area with a sharp edge, as highlighted in the images above. The spacers were redesigned (shown in Figure 8) to incorporate fillets and subsequent testing with these fixes have shown increased survivability.

TEST EVENT #2

The updated spacer design was tested in ARRT-167 Serial Number 2, in SCAT Gun #911, #912, and #914. Parameters for these test are shown in Table 1.

Table 1 SCAT Gun Test #'s 912 and 914 Firing Parameters

Shot Number	Charge (MACS)	Total Weight (lbs)	Estimated Muzzle Velocity (m/s)	Breech Pressure & Rise Time	Chamber Pressure
911	4	104.08	683	32.24ksi @ 4.88 ms	31.7ksi
912	4	96.84	701.55	30.4ksi @ 4.85 ms	29.9 ksi
914	4	97.18	698.57	29.99ksi @ 4.88 ms	29.69 ksi

The first shot in this event, SCAT Gun Test #911, involved shooting both the spacer OBR and a potted OBR for continued comparison. The electronics within both OBRs survived SCat Test #911, and captured identical data as shown in Figure 13. The post acceleration event bias shift is a result of common accelerometer die shifts that occur independent of the instrumentation electronics.

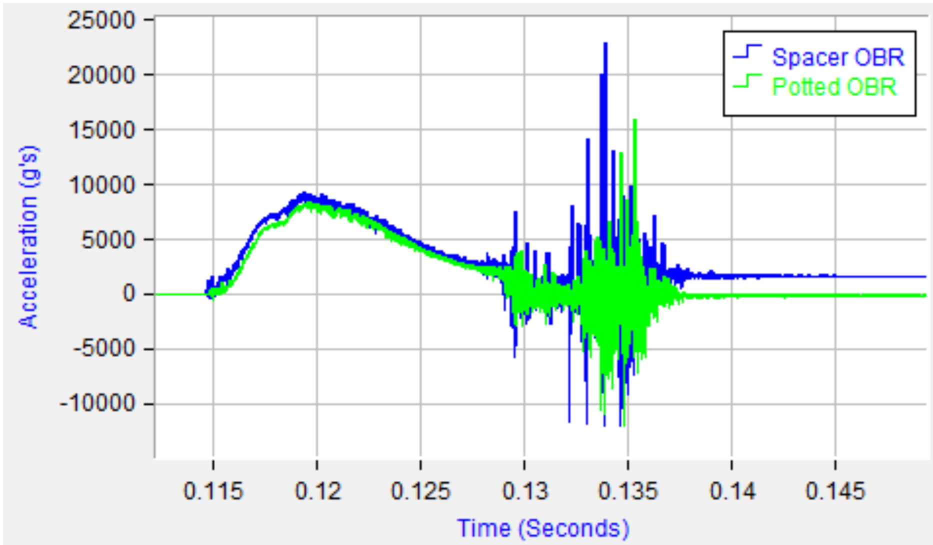

Figure 13 SCAT Gun Test #911, Spacer and Potted OBR Axial Acceleration Data

SCAT Gun Test #912 and #914's accelerations curves were over plotted due to their very similar firing parameters, and are shown in Figure 14.

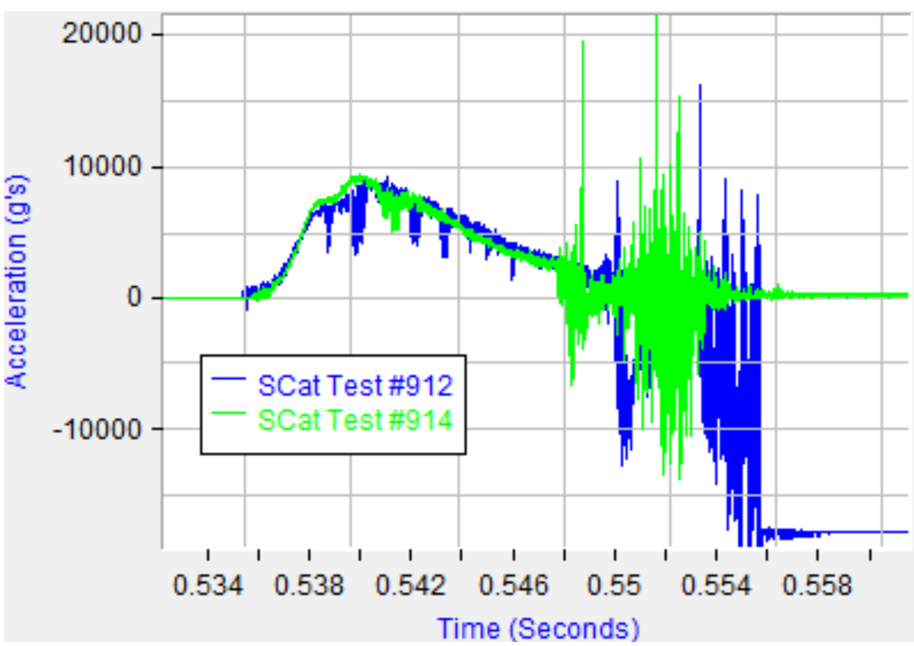

Figure 14 Spacer OBR SCat Test #'s 912 & 914 Axial Acceleration Data

From the data shown in Figure 14, the axial acceleration recorded from Shot #912 was very noisy and had a bias shift occurring after the set forward event. The accelerometer was not replaced before the next testing event and while it measured both set back and set forward acceleration phases in Shot #914, the data captured is questionable due to the fatigue of the gage incurred during Shot #912.

DISCUSSION

The ARRT-167 OBR's successfully demonstrated that the structural spacers supported the electronics board stack without potting materials during setback and set forward phases of a live fire 155mm artillery testing event. Additionally, with a significant reduction in board deflection, both the spacers and the electronics were able to be reused for continued survivability testing and reduced instrumentation cost. It is recommended that any electrical modifications necessary to update the design based on any revisions to the ARRT-158's electronics boards be made to move test articles away from the potted ARRT-158 OBR to the unpotted ARRT-167 design for further reliability and survivability characterization leading to reduced maintenance costs.

REFERENCES

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