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HIGH-G SURVIVABILITY OF AN UNPOTTED ONBOARD RECORDER

Richard F. Granitzki
Douglas Weinhold

October 2017

U.S. ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

Munitions Engineering Technology Center

Picatinny Arsenal, New Jersey

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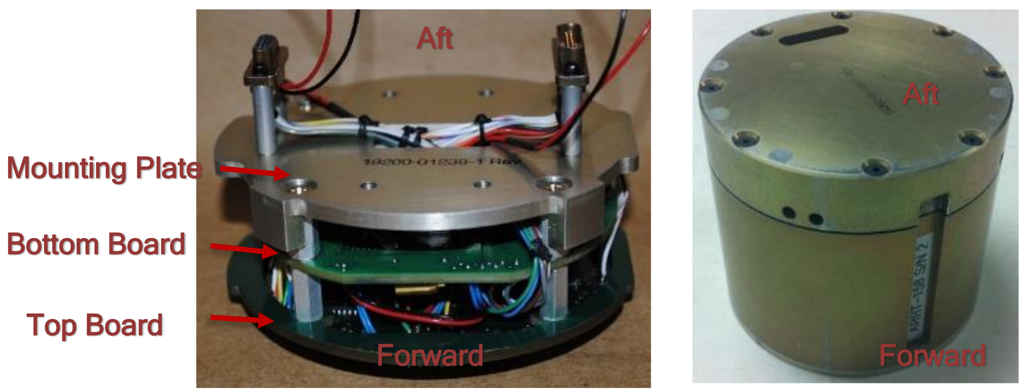
INTRODUCTION

Onboard recorders (OBR) provide developers with data from sensors and computers that are sampled and stored in onboard memory devices. At the expense of recovery, reusable OBRs provide projects with cost savings in terms of upfront nonrecurring engineering, unit costs savings, and reduced field support requirements. In order to achieve a reusable, survivable OBR, potting materials are often used 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 sensors 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 (fig. 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.



(a)
ARRT-158 electronics stack

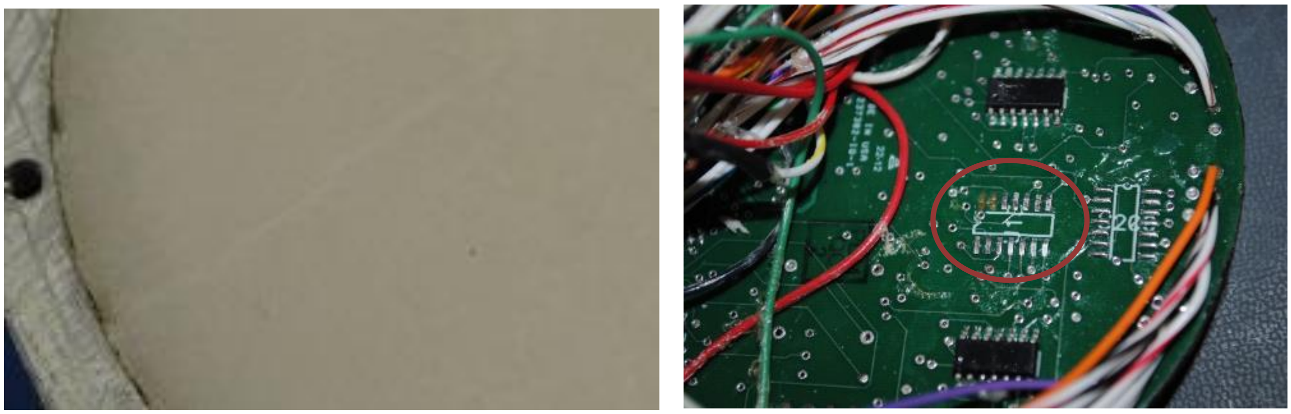
(b)
Fully integrated ARRT-158 OBR

Figure 1
Images of the ARRT-158

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 the U.S. Army Armament Research, Development and Engineering Center (ARDEC), Picatinny Arsenal, NJ, 55-mm Soft CATch (SCAT) Gun where test articles are subjected to accelerations up to 17,000 g's during setback and balloting accelerations at muzzle exit and transition tube entry. The SCAT Gun is approaching 1,000 testing events, and with nearly each projectile tested, an accompanying OBR is 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 (ref. 1). Two of examples of reliability problems are shown in figure 2.



(a)
Cracked potting

(b)
Missing small outline integrated circuit package after potting removal

Figure 2
Two examples of reliability problems

Extensive modeling and simulation of the electronics has been conducted in order to determine an 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-in. diameters and 0.093-in. thick rigid PCBs with 22 independent traces run from one rigid board to the other through a flexible circuit. This is shown in figure 3.

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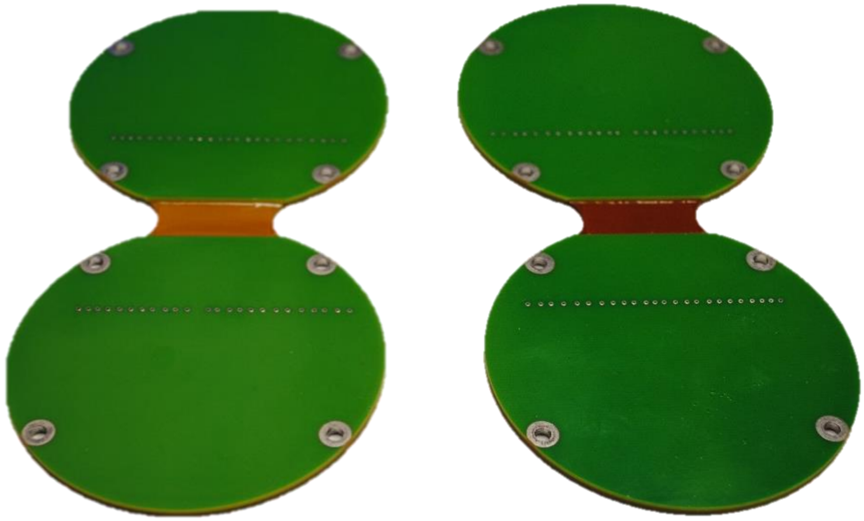


(a) Flex stack up no. 1   (b) Flex stack up no. 2

Figure 3
Rigid flex test PCBs

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.

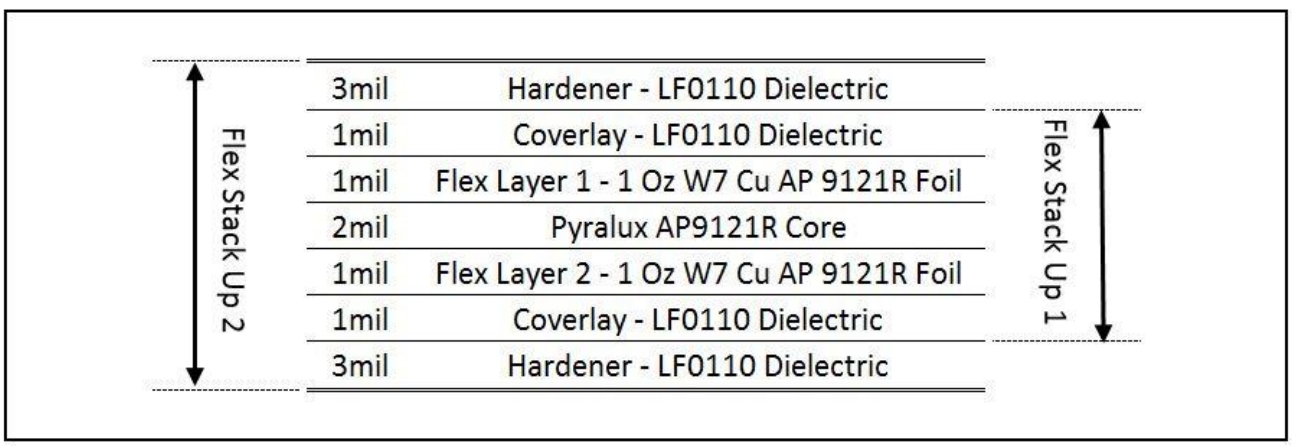


Figure 4
Proof of concept flex cross sections

Figure 5
Integrated proof of concept test article

Structural analysis predicted a maximum board deflection of 0.00535 in. (ref. 2) using a similar 155-mm SCAT Gun Modular Artillery Charge System (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 in., the team was confident in proceeding with testing the design.

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 on ARDEC's SCAT 155-mm 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 the design of the new rigid flex OBR, 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 crosshair style keep out areas are shown in the electronics design artwork in figure 6.

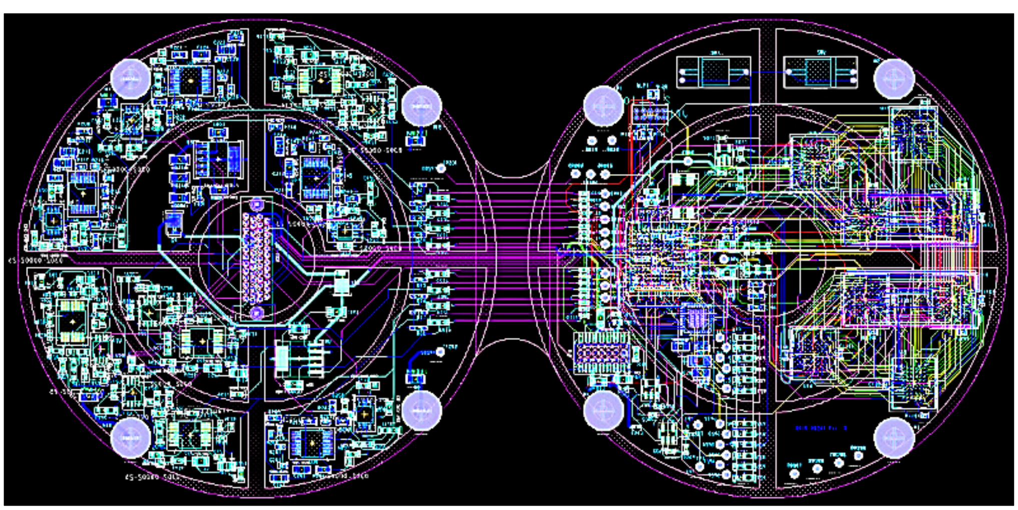


Figure 6
ARRT-167 PCB layout with spacer keep out areas

The result was a 0.093-in. 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 figures 7 and 8.

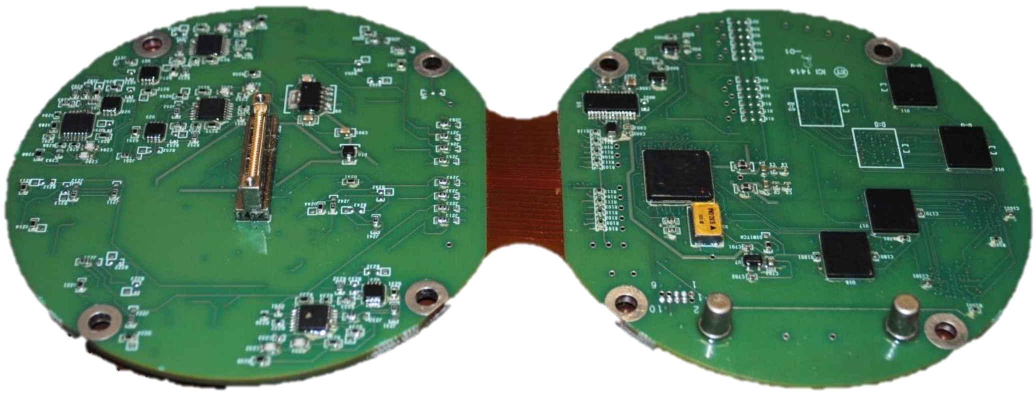
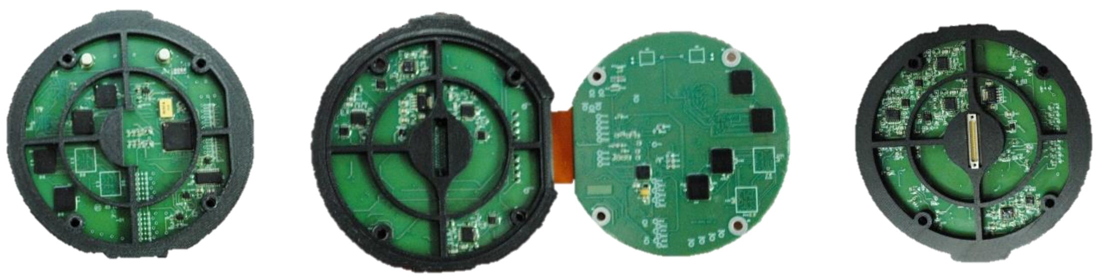


Figure 7
ARRT-167 rigid flex PCB



(a) Top | (b) Middle | (c) Bottom

Figure 8
OBR spacer fitment

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.

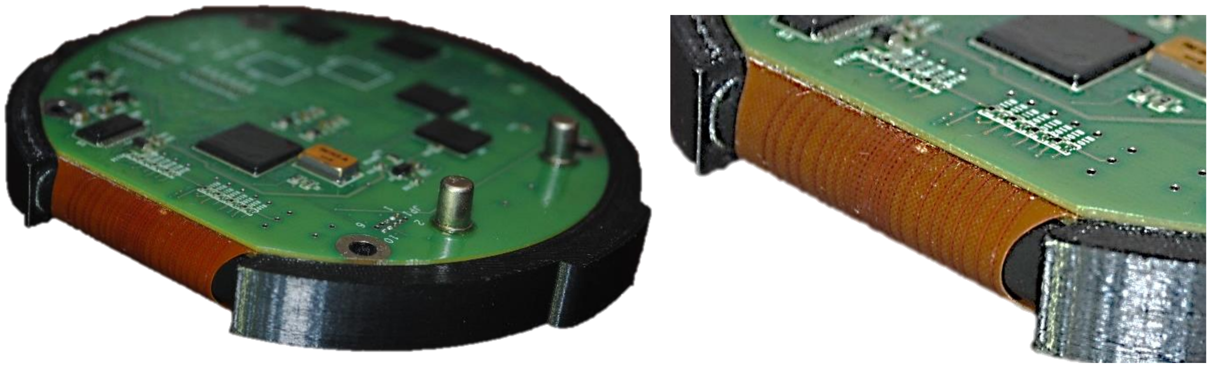
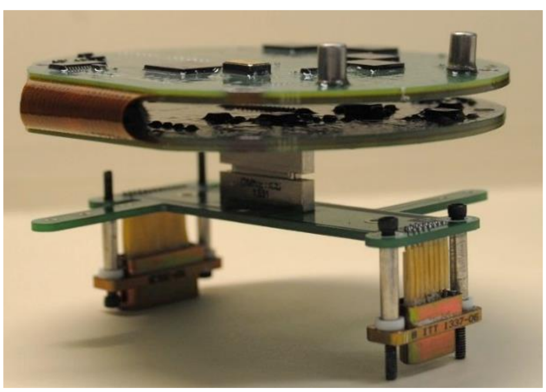
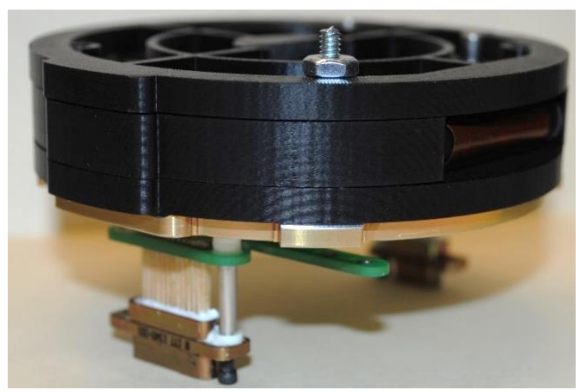


Figure 9
Flexible circuit interconnect spacer support

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. Figure 10 shows the complete electronics board stacks with and without spacers outside of its mechanical housing.



(a)
OBR in board form



(b)
OBR with spacers

Figure 10
Complete electronics board stacks with and without 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 and through hole wired connections, and 20,000-g range accelerometers (50-kHz frequency response) that were reused from previous systems over the 60,000-g range accelerometers (100-kHz frequency response) that are replaced at the first sign of measurement anomalies.

Test Event No. 1

The ARRT-167 serial number 1 was tested alongside an ARRT-158 OBR during SCAT Gun test no. 825. The SCAT Gun test no. 825 was fired at MACS zone 5, had a projectile weight of

103.4 lb, and an estimated muzzle velocity of 792.27 m/s. The data of both the spacer OBR and potted OBR are shown in figure 11.

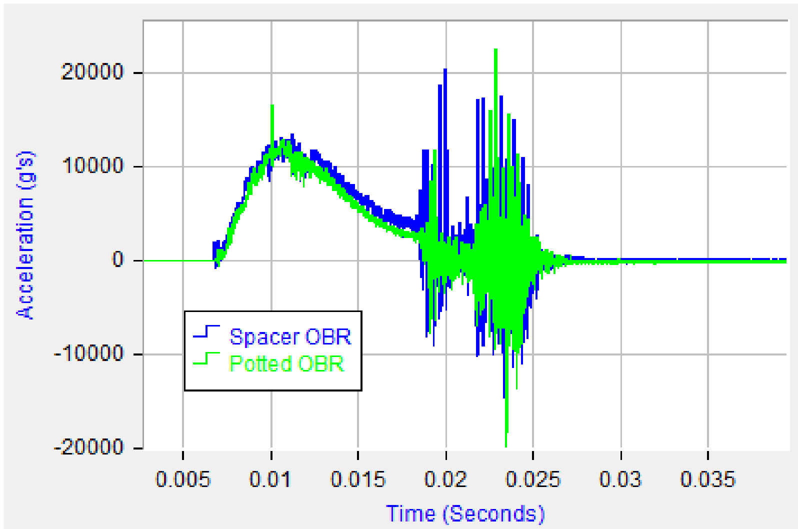


Figure 11
SCAT Gun test no. 825, spacer and potted OBR axial acceleration data

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 (fig. 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.

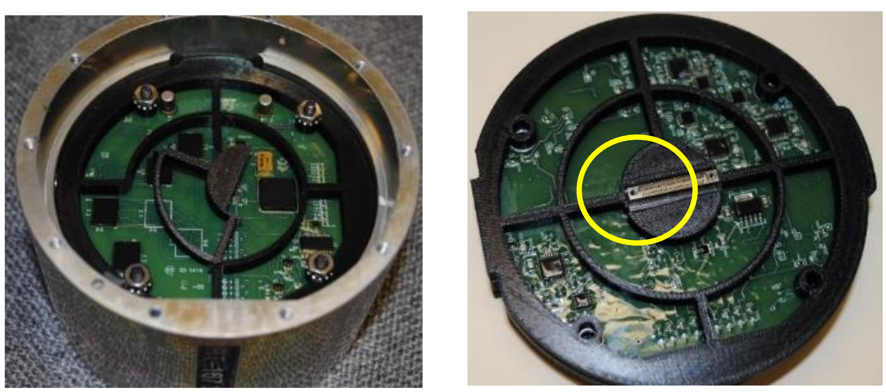


Figure 12
OBR spacer damage

The cracks developed in an area with a sharp edge, as highlighted in figure 12 previously. The spacers were redesigned (shown previously in fig. 8) to incorporate fillets, and subsequent testing with these fixes have shown increased survivability.

Test Event No. 2

The updated spacer design was tested in ARRT-167 serial number 2 in SCAT Gun nos. 911, 912, and 914. Parameters for these test are shown in table 1.

Table 1
SCAT Gun test nos. 911, 912, and 914 firing parameters

Shot no.	Charge (MACS)	Total weight (lb)	Estimated muzzle velocity (m/s)	Breech pressure and rise time	Chamber pressure (ksi)
911	4	104.08	683	32.24 ksi at 4.88 ms	31.7
912	4	96.84	701.55	30.4 ksi at 4.85 ms	29.9
914	4	97.18	698.57	29.99 ksi at 4.88 ms	29.69

The first shot in this event, SCAT Gun test no. 911, involved shooting both the spacer OBR and a potted OBR for continued comparison. The electronics within both OBRs survived SCAT test no. 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.

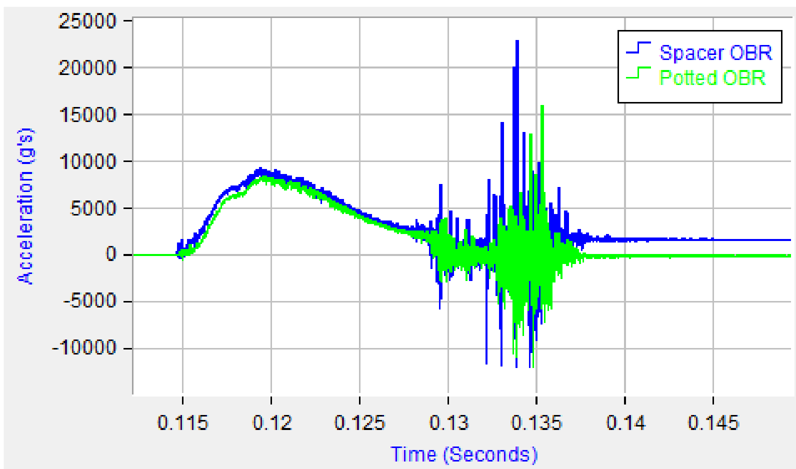


Figure 13
SCAT Gun test no. 911, spacer and potted OBR axial acceleration data

The SCAT Gun test nos. 912 and 914's acceleration curves were over plotted due to their very similar firing parameters and are shown in figure 14.

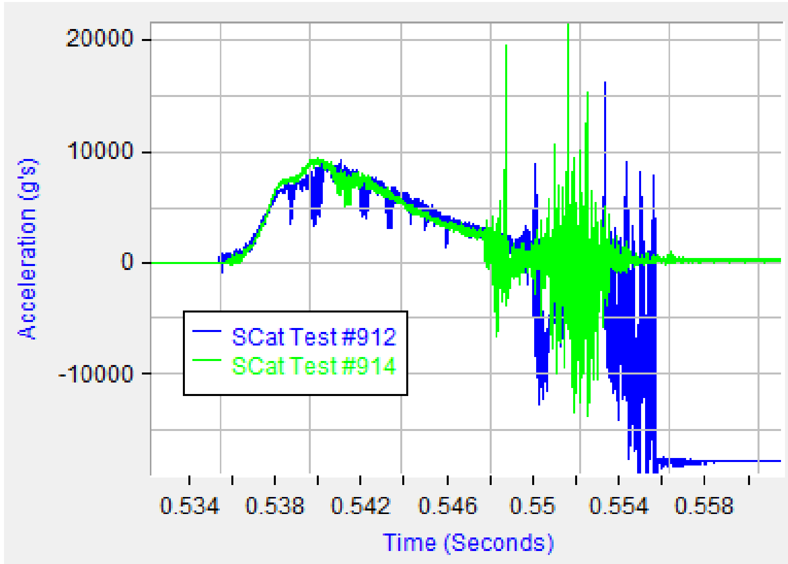


Figure 14
Spacer OBR SCAT test nos. 912 and 914 axial acceleration data

From the data shown in figure 14, the axial acceleration recorded from shot no. 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 setback and set-forward acceleration phases in shot no. 914, the data captured is questionable due to the fatigue of the gage incurred during shot no. 912.

CONCLUSIONS

The ARRT-167 onboard recorders (OBR) successfully demonstrated that the structural spacers supported the electronics board stack without potting materials during setback and set-forward phases of a live-fire 155-mm 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.

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