

# Higher speed demodulation of fiber grating sensors

John Seim<sup>\*a</sup>, Whitten L. Schulz<sup>a</sup>, Eric Udd<sup>a</sup>, and Mike Morrell<sup>a</sup>

<sup>a</sup>Blue Road Research, 2555 NE 205<sup>th</sup> Avenue, Fairview, OR 97024

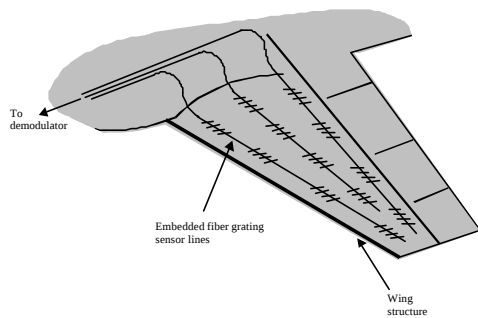
## ABSTRACT

For very high-speed events, such as ballistics testing, strain measurement speed is not limited by the response of the fiber grating sensor, but rather the demodulation system used. This paper focuses on a current 10kHz fiber grating demodulator used to support impact and ballistics testing of a composite panel. It also explores the next generation demodulator, pushing the limits of speed upwards of 3Mhz.

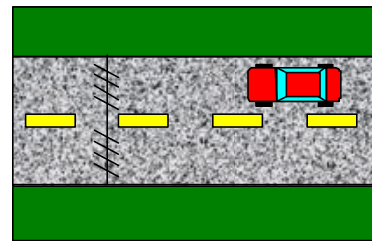
**Keywords:** Fast, strain, ballistics, composite panel, impact

## 1. HIGH-SPEED DEMODULATION

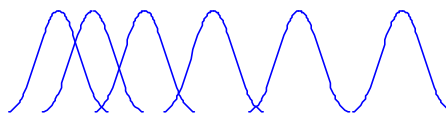
There are many applications where the high-speed demodulation of fiber grating strain sensors is necessary (Figure 1.) In the aerospace industry, in-flight health monitoring; In civil structures, traffic monitoring [1]. Others include vibration, wave propagation and oversampling.



In-flight monitoring



WIM



Vibration & wave propagation

Figure 1. Applications for high-speed demodulation of fiber grating sensors

## 2. CURRENT TECHNOLOGY

In response to these high-speed demodulation needs, Blue Road Research designed and built a prototype fast fiber grating demodulator based on using a chirped fiber grating spectral filter [2-4]. Currently, the demodulation box (Figure 2) has 10kHz capability. Figure 3 shows a frequency roll off ( $f_0$ ) at approximately 13 kHz for the current demodulator.

---

\* Correspondence: Email: johnseim@teleport.com; web: www.BlueRR.com; Telephone: 503 667 7772 x102; Fax: 503 667 7880

| Report Documentation Page                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                    |                                     |                               | Form Approved<br>OMB No. 0704-0188                  |                                    |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|-------------------------------------|-------------------------------|-----------------------------------------------------|------------------------------------|
| Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. |                                    |                                     |                               |                                                     |                                    |
| 1. REPORT DATE<br><b>1999</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                    | 2. REPORT TYPE                      |                               | 3. DATES COVERED<br><b>00-00-1999 to 00-00-1999</b> |                                    |
| 4. TITLE AND SUBTITLE<br><b>Higher speed demodulation of fiber grating sensors</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                    |                                     |                               | 5a. CONTRACT NUMBER                                 |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                               | 5b. GRANT NUMBER                                    |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                               | 5c. PROGRAM ELEMENT NUMBER                          |                                    |
| 6. AUTHOR(S)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |                                     |                               | 5d. PROJECT NUMBER                                  |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                               | 5e. TASK NUMBER                                     |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                               | 5f. WORK UNIT NUMBER                                |                                    |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br><b>Blue Road Research,2555 NE 205th Avenue,Fairview,OR,97024</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                    |                                     |                               | 8. PERFORMING ORGANIZATION<br>REPORT NUMBER         |                                    |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                    |                                     |                               | 10. SPONSOR/MONITOR'S ACRONYM(S)                    |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                               | 11. SPONSOR/MONITOR'S REPORT<br>NUMBER(S)           |                                    |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT<br><b>Approved for public release; distribution unlimited</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                    |                                     |                               |                                                     |                                    |
| 13. SUPPLEMENTARY NOTES<br><b>The original document contains color images.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                    |                                     |                               |                                                     |                                    |
| 14. ABSTRACT<br><b>see report</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                    |                                     |                               |                                                     |                                    |
| 15. SUBJECT TERMS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                    |                                     |                               |                                                     |                                    |
| 16. SECURITY CLASSIFICATION OF:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     | 17. LIMITATION OF<br>ABSTRACT | 18. NUMBER<br>OF PAGES<br><b>9</b>                  | 19a. NAME OF<br>RESPONSIBLE PERSON |
| a. REPORT<br><b>unclassified</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | b. ABSTRACT<br><b>unclassified</b> | c. THIS PAGE<br><b>unclassified</b> |                               |                                                     |                                    |



Figure 2. Blue Road Research fast fiber grating demodulation box, currently with 10 kHz capability.

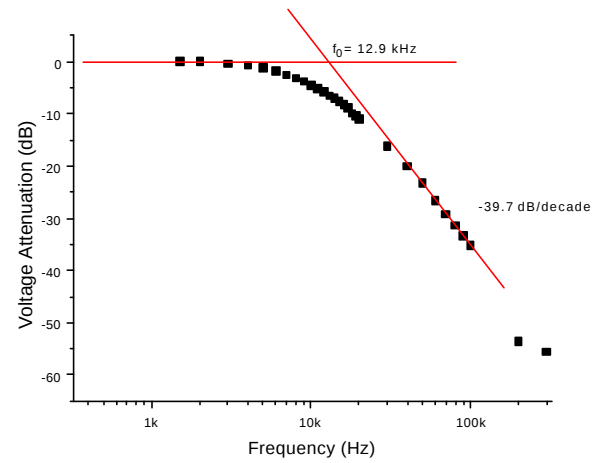


Figure 3. Measured frequency response of the current fast demodulator.

This demodulation box has been used to support several tests including ballistics, impact, and load to failure on concrete [5] and composites. The latest of these tests are impact and ballistics testing of composite panels.

### 3. IMPACT AND BALLISTICS TESTS

As part of an Army Research Lab program to study composite armor smart structures, a panel with embedded fiber grating strain sensors was subjected to impact and ballistics tests.

#### 3.1. Impact Tests

The impact tests consisted of dropping a chisel from varying heights onto a composite armor panel. These second series of tests (details on the first series of tests can be found in [2]) used the Blue Road Research fast demodulation box. Data from the tests can be seen in Figure 5 - Figure 7. Due to limitations on the data acquisition card running multiple channels, the sampling occurred at 2.5kHz.

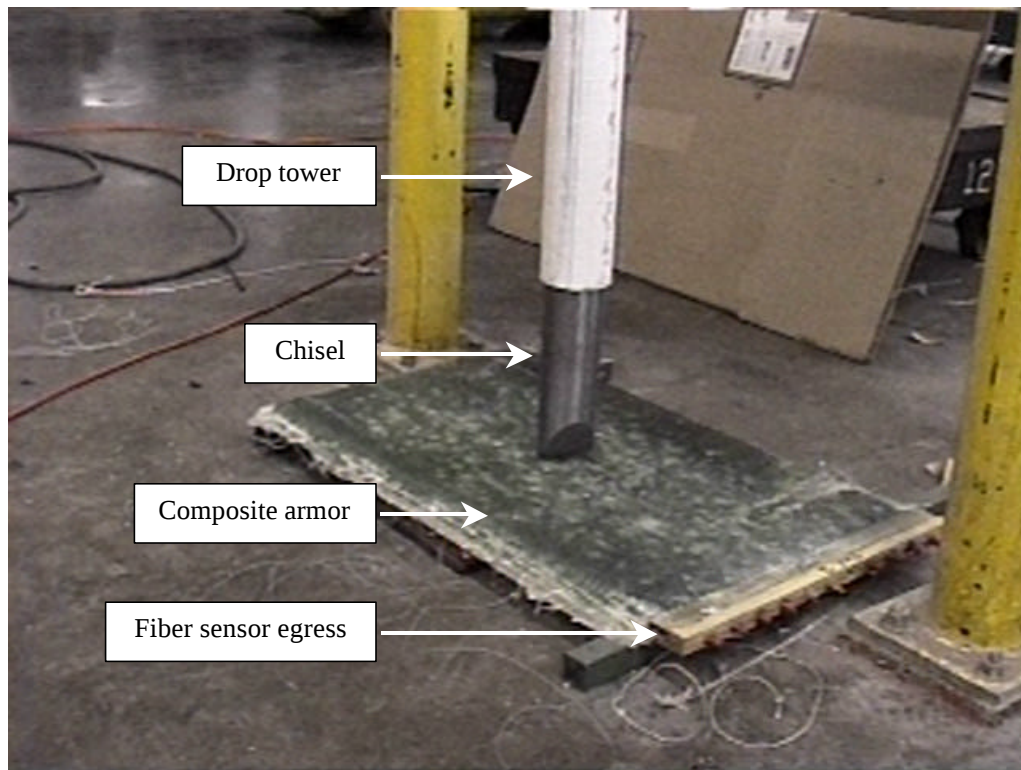


Figure 4. Impact testing of composite smart armor with embedded fiber grating strain sensors.

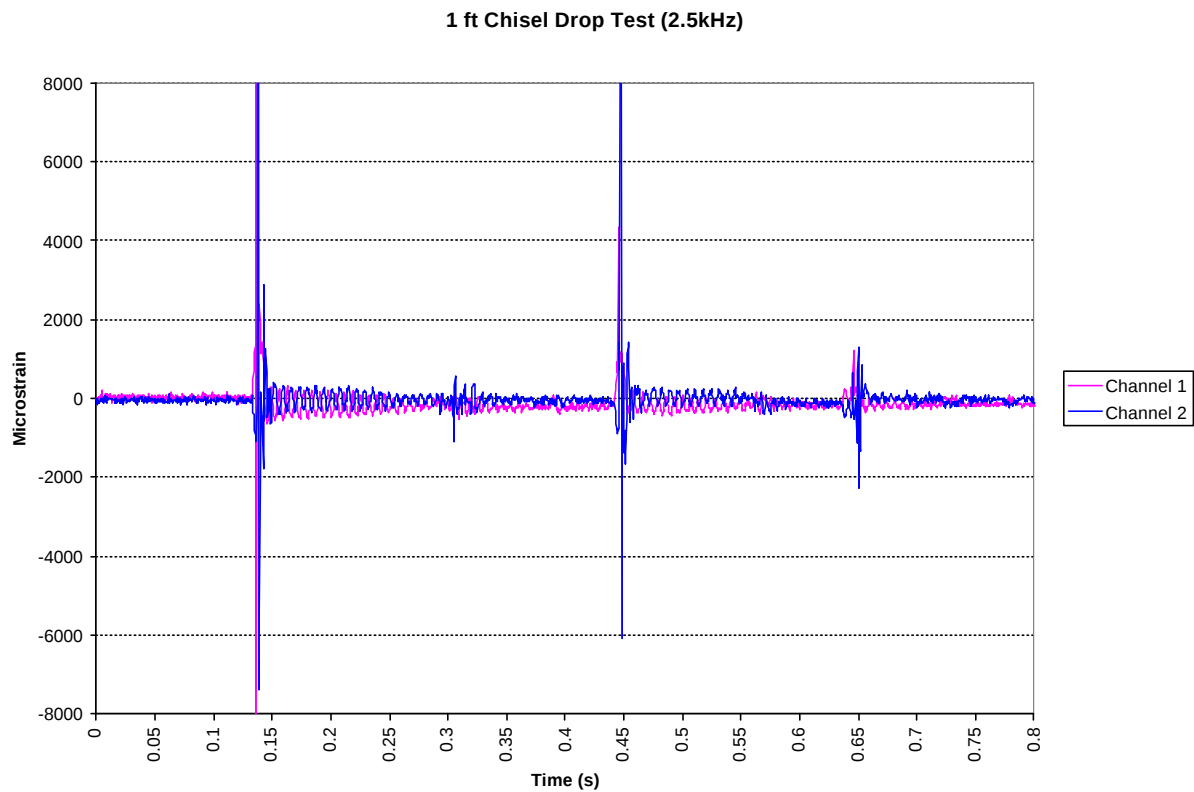


Figure 5. Fast (2.5kHz) demodulation of chisel dropped from 1 foot above composite panel with embedded fiber grating strain sensors.

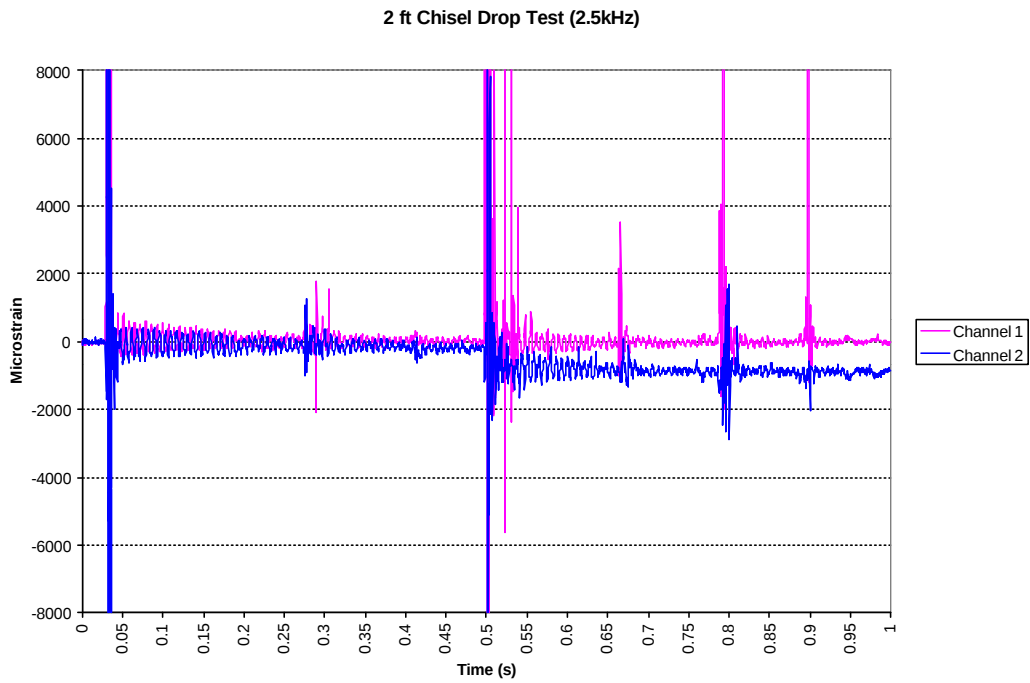


Figure 6. Fast (2.5kHz) demodulation of chisel dropped from 2 feet above composite panel with embedded fiber grating strain sensors.

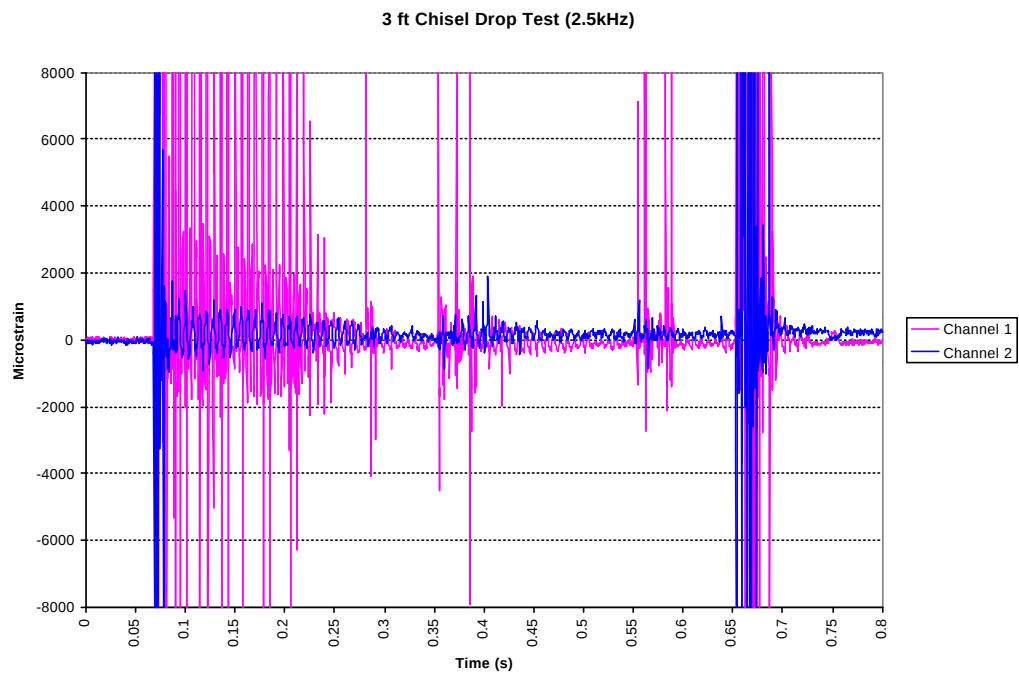


Figure 7. Fast (2.5kHz) demodulation of chisel dropped from 3 feet above composite panel with embedded fiber grating strain sensors.

### 3.2. Ballistics Testing

The composite armor was also subjected to ballistics testing. Figure 8 shows the panel and test area prior to ballistics testing. The composite panels were shot with a 22 and with 9mm shells. Figure 9 shows the panel after two 9mm rounds were fired.

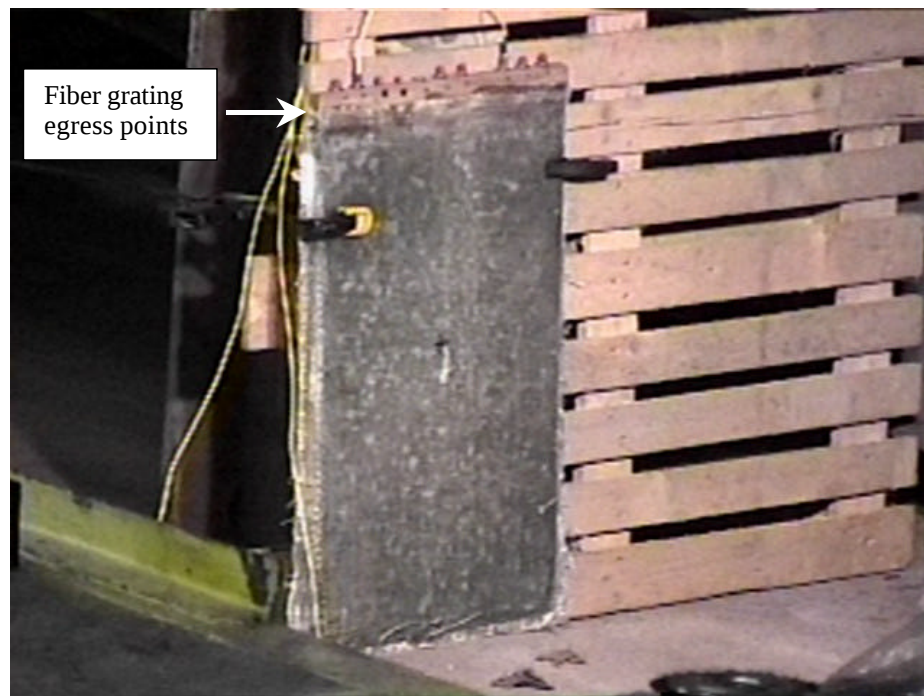


Figure 8. Composite smart armor with embedded fiber grating strain sensors prior to ballistic tests.

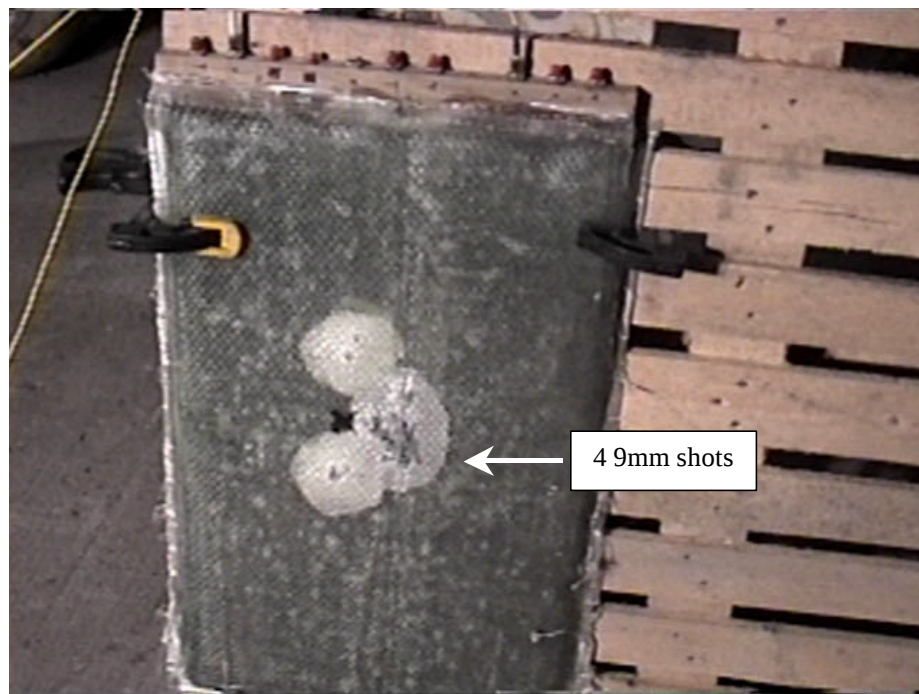


Figure 9. Composite smart armor after 4 9mm shots.

Figure 10 shows the back side of the panel after ballistics testing. Figure 11 and Figure 12 show data from the ballistics tests.

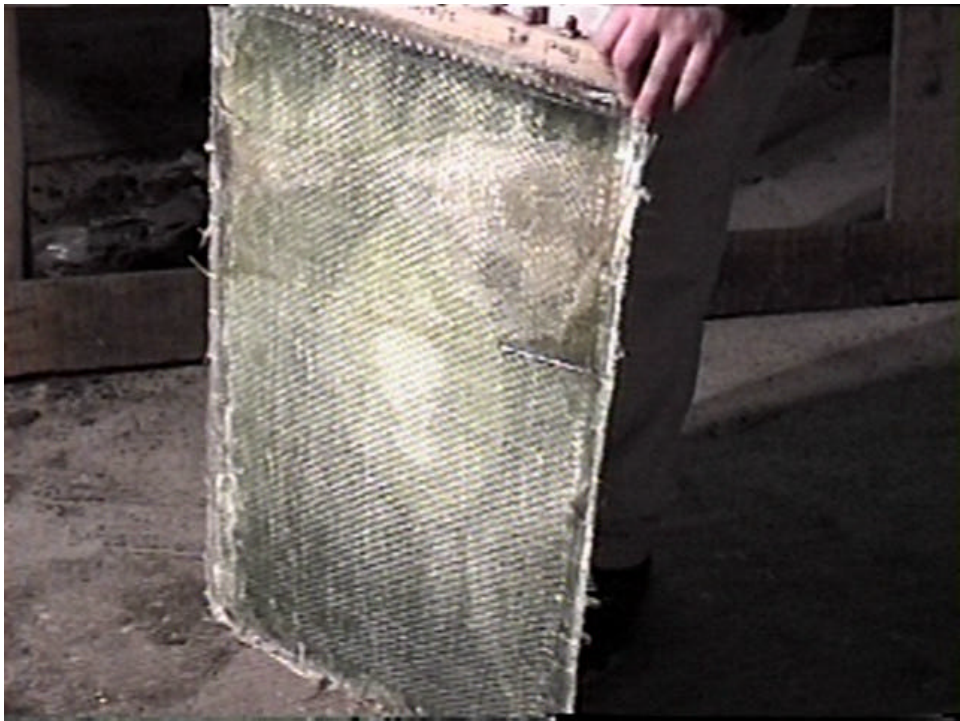


Figure 10. Back side of composite smart armor after ballistics testing

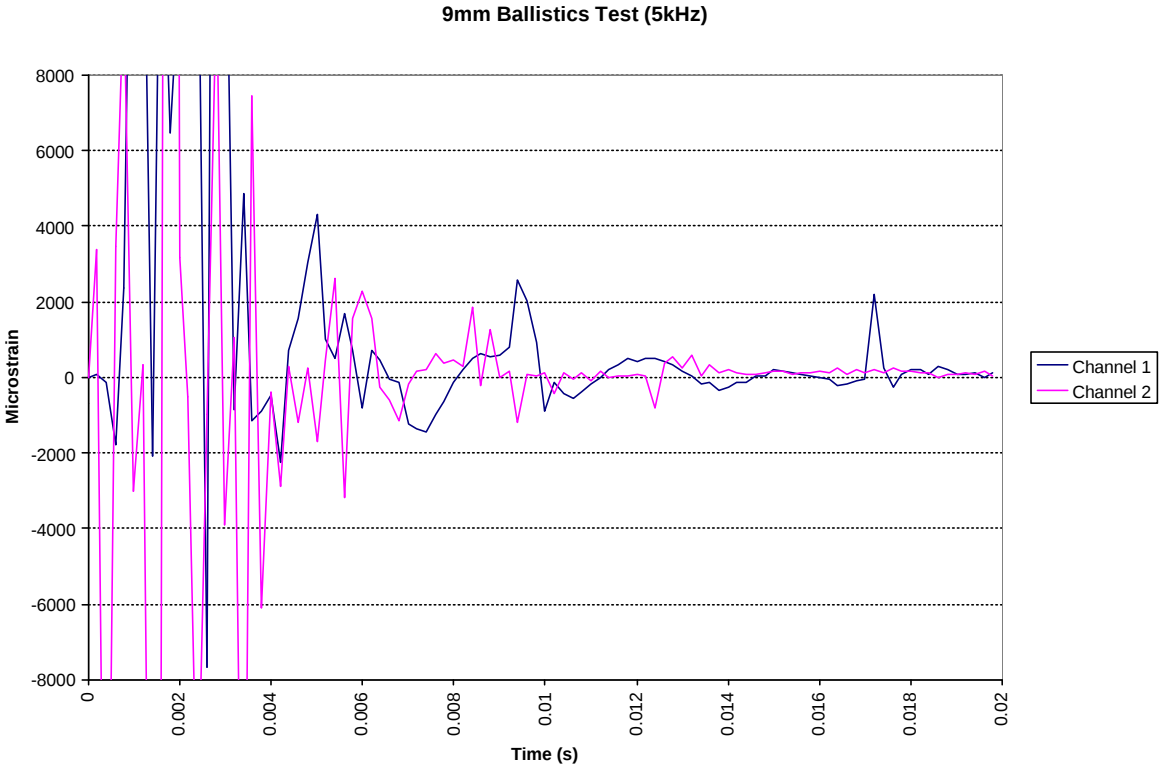


Figure 11. Ballistics test (5kHz) with 9mm shell on composite panel with embedded fiber grating strain sensors.

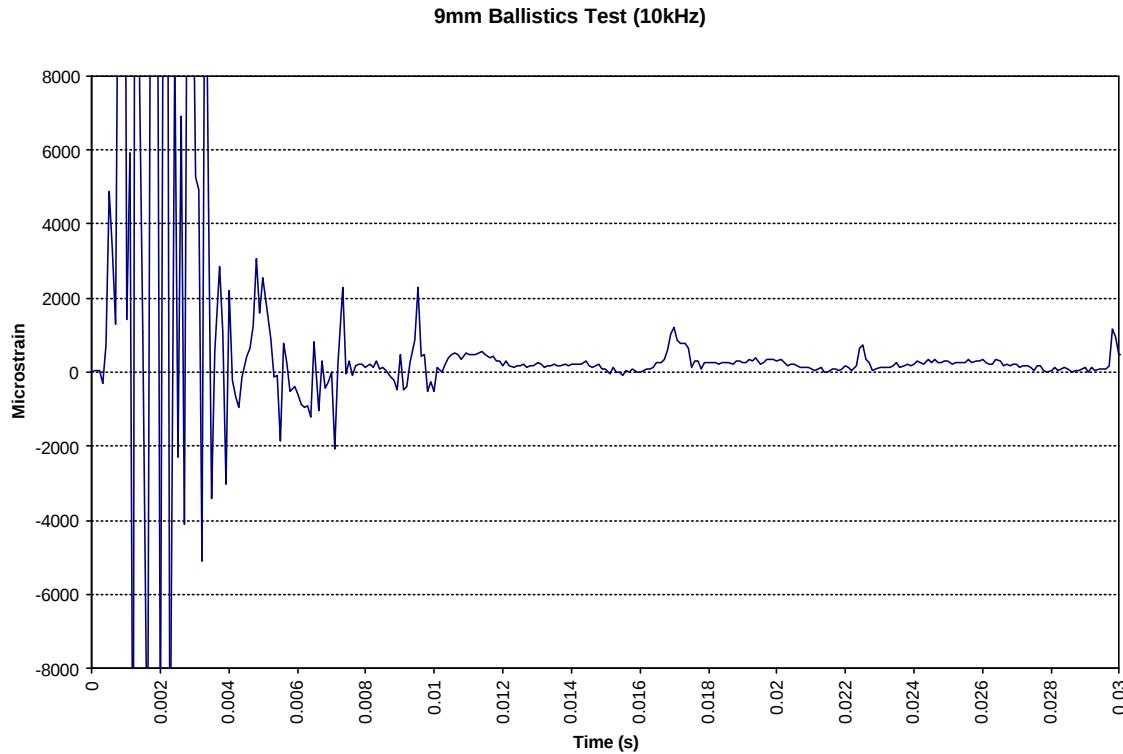


Figure 12. Ballistics test (10kHz) with 9mm shell on composite panel with embedded fiber grating strain sensors.

#### 4. HIGHER SPEEDS

For certain applications such as ballistics testing, speeds higher than the current 10kHz are desired. A reasonable limit for the speed of a fiber grating demodulator of this type is 10MHz. There are several tradeoffs associated with this.

The first and perhaps most limiting tradeoff is sensitivity. The higher the speed, the lower the sensitivity. Another tradeoff with higher speeds is the demodulator's ability to measure steady state events. Cost is another obvious tradeoff.

#### 5. FUTURE WORK

Blue Road Research's next efforts will be to construct a 3 MHz version of its fast fiber grating demodulator to further support ballistics tests. Blue Road will also be working on multiple channel versions operating at both speeds.

#### 6. ACKNOWLEDGEMENTS

The authors would like to thank the Army Research Lab for its support and funding under the "Liquid Molded Composite Armor Smart Structures Using Embedded Sensors" program.

#### 7. REFERENCES

1. W.L. Schulz, J. Seim, E. Udd, M. Morrell, H.M. Laylor, G.E. McGill, R. Edgar, "Traffic Monitoring/Control and Road Condition Monitoring using Fiber Optic Based Systems", SPIE Smart Structures and Materials Symposium, Newport Beach, CA. March, 1999.
2. J.M. Seim, W.L. Schulz, E. Udd, K. Corona-Bittick, J. Dorr, K.T. Slattery, "Low-Cost High-Speed Fiber Optic Grating Demodulation System for Monitoring Composite Structures", SPIE Proceedings, Vol. 3326, p. 390, 1998.

3. E. Udd, K. Corona-Bittick, K. T. Slattery, D. J. Dorr, C. R. Crowe, T. L. Vandiver and R. N. Evans, "Fiber Grating Systems Used to Measure Strain in Cylindrical Structures, Optical Engineering, Vol. 36, p. 1893, 1997.
- E. Udd, K. Corona-Bittick, J. Dorr, K.T. Slattery, "Low-cost fiber grating sensor demodulator using a temperature-compensated fiber grating spectral filter", Proc. SPIE Vol. 3180, p. 63, 1997.
4. J. Seim, E. Udd, W.L. Schulz, M. Morrell, H.M. Laylor, "Health Monitoring of an Oregon Historical Bridge with Fiber Grating Strain Sensors", SPIE Smart Structures and Materials Symposium, Newport Beach, CA. March, 1999.

5.