In-situ Measurement of Liquid Crystal Spatial Light Modulators’ Beam Steering Characteristics During Gamma Irradiation.

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ABSTRACT

Recent interest in liquid crystal spatial light modulators as a potential replacement to traditional optical beam steering methods have engendered experiments to determine the technology’s resistant to gamma radiation such as may be encountered in a space environment. We previously investigated the effects of exposure of liquid crystal devices to ionizing radiation to total dose levels consistent with a 14-year mission at geostationary orbits (GEO). We reported on the parameters of retardation, contrast ratio and primary power current, which were monitored at various dosing intervals for liquid crystal cells and a spatial light modulator. Here we present for the first time measurements of spatial light modulators’ beam steering characteristics taken while they are undergoing gamma irradiation. We examine data on angular deflection, intensity, and beam spread for the liquid crystal spatial light modulators obtained during irradiation. The modulators were in continuous operation during irradiation at approximately 23 Rad (Si)/s, and, again the total ionizing dose reached levels consistent with 14 years at GEO. We observed minimal to no degradation in performance, either from dose rate effects or from total ionizing dose, in these environments.

Keywords: Liquid crystal spatial light modulators, gamma radiation, environmental testing

1. INTRODUCTION

Non-mechanical beam steering eliminates the need for massive optomechanical components to steer the field of view of optical systems. A space platform for optical communications could benefit from nonmechanical beam steering in which no inertia is used to redirect the laser communications link. This benefit can be realized by compact, low-power, light-weight liquid crystal spatial light modulators [1]. Consequently, this technology is being investigated for how well it operates under conditions of ionizing radiation consistent with a space environment.

We previously investigated the effects of exposure of liquid crystal devices to ionizing radiation to total dose levels consistent with a 14-year mission at geostationary orbits (GEO) [2]. Here we present for the first time measurements of spatial light modulators’ beam steering characteristics taken while they are undergoing gamma irradiation. We examine data on angular deflection, intensity, and beam spread for the liquid crystal spatial light modulators obtained during irradiation. The methodologies for testing generally followed the MIL-STD-883, Method 1019.6.
2. TEST PROTOCOL

The objective of this test was irradiation using a gamma radiation source to dose switching spatial light modulators that are optically steering incident laser radiation. Performance was characterized as a function of gamma dose rate and total accumulated dose. The irradiation was up to a total dose commensurate with the environments determined in previous research (> 200 kRad).

2.1 Test Environment and Conditions

The gamma radiation source is a Teletherapy Model 400, Cesium-137 source manufactured by Picker International. Its present activity is approximately 800 Ci. This gamma source is located with the Flash X-ray source in the concrete block test cell depicted in the floor plan in Figure 1. The relatively large floor area of the test cell allows for maximum flexibility in experiment setup geometries. Instrumentation feedthroughs in the test cell wall allow equipment racks to be placed in close proximity to the device under test, eliminating the need for line drivers in the experiment.

The Cs$^{137}$ source is stored in a depleted-uranium container that combines both shielding and exposure mechanism. In use, a remotely-activated pneumatic control system rotates the source and inner ring of the housing, aligning two concentric apertures and thereby exposing the device under test (DUT) to the source. Gamma flux levels are controlled by adjusting the distance between the gamma source and the DUT and/or using lead attenuator sheets. Figure 2 shows the uranium housing and the source rotation mechanism.

![Figure 1. Configuration of the Cs$^{137}$ source with the optical breadboard for the SLM experiment.](image)

The spatial light modulators received a dose rate of 23 Rad (Si) per second (± 10%). This agreement meets MIL-STD-883E 1019.4 paragraph 3.6.3 Condition B requirements. Gamma flux levels at representative distances have been measured using an air ionization chamber calibrated to NIST standards. This calibration is reliable to within ±3% of the measured reading. Thermoluminescent dosimeters (TLD’s) are routinely used for determination of the dose at the test device. These TLD’s are read out on site. The temperature of the test cell and the optical phased arrays and their respective op-amp boards was maintained at a temperature of 25 °C ± 5 °C. This meets MIL-STD-883E 1019.4 paragraph 3.7 requirements.
Figure 3 shows a schematic view of the experimental setup. The optical source was a helium neon laser operating at 633 nm. The laser output beam was expanded to almost fill the active area of the optical phased array spatial light modulator. The specular reflection (0th order) and deflected beams are collected and focused onto a CCD detector using a 5-cm-diameter, 15-cm-focal length lens, producing the far-field diffraction pattern at the sensor. The illustration in figure 3 shows the zeroth order, ±1 and ±2 order deflections collected by the lens and focused onto the detector array. Given the experiment geometry, beams deflected by up to about ±3 degrees were captured by this optical diagnostic. The laser beam is vertically polarized, and the deflections produced by the SLM are in the vertical plane. Given this configuration, the minimum grating period usable for these tests was 40 pixels. Operational effectiveness was characterized by three parameters: (1) intensity degradation, (2) steering angle, and (3) spot size, all of which were determined by examination of the far-field diffraction pattern images.

Figure 4 shows the experiment configuration. The SLM was irradiated from the reverse side, allowing it to be placed very close to the gamma source. The laser source, CCD array detector and SLM control circuitry were placed outside the irradiation footprint of the source (approximately ±45° from the symmetry axis) and
shielded by two inches of lead. The CCD sensor output (standard RS-170 video format) was recorded using a Roadrunner video capture card manufactured by Bitflow, Inc.

![Figure 4. Experimental setup for gamma operability and gamma total dose testing of SLM.](image)

### 3.0 Test Results

The devices were exposed to the gamma radiation, up to total dose of 250 kRad(Si), in the incremental steps shown in Table 1. below. The dose rate was approximately 23 Rad(Si)/s, so that the total irradiation time was about three hours for each DUT. For the first two devices, BS-225 and BS-251, the gamma source was shut off after each irradiation step for approximately 10 minutes while characterization data for the DUT were collected. For the last two devices, BS-281 and BS-262, the gamma exposure was continuous and data were collected on the fly, while dosing. There appeared to be no transient effects associated with data collection during gamma irradiation.

#### 3.1 Diffraction

Measurement of diffraction efficiency turned out to be more difficult than anticipated, due to instability of the output of the relatively inexpensive laser source used in the experiment. The laser output was passed through multiple attenuators and a thin-film polarizer before illuminating the SLM, and the short-term stability of both the power and the polarization of the laser were not adequate to allow sequential measurements. We therefore calculated efficiency by comparing the signal in the first-order diffracted spot to the total signal in all spots, for a single image. Temporal stability issues are thus circumvented, and the results are reproducible to within a few percent, as demonstrated in the data shown below. For the smaller grating periods, in which the higher-order diffracted beams are not captured on the detector array, there is a small error in the absolute efficiency measured, but the relative measurement as a function of total ionizing dose is still accurate to a few percent.
Table 1. Radiation Dosing Protocol.

<table>
<thead>
<tr>
<th>Test Stage</th>
<th>BS225, BS251 Total Dose (kiloRads)</th>
<th>BS281, BS262 Total Dose (kiloRads)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
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<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1.25</td>
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</tr>
<tr>
<td>3</td>
<td>2.5</td>
<td>6.3</td>
</tr>
<tr>
<td>4</td>
<td>6.3</td>
<td>12.5</td>
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<td>5</td>
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</tr>
<tr>
<td>Total</td>
<td>250 kRad</td>
<td>250 kRad</td>
</tr>
</tbody>
</table>

All of the results reported below are based on the single-frame analysis method described above, in which the power in the principal diffracted spot was compared to the power in all other orders in the same video data frame. This approach of course necessitated performing a blur spot analysis for each blur spot in the image. As a check of the fitting routine, efficiency was computed in two ways: (1) using fitted parameters for amplitude and spot size from the blur spot analysis; or (2) simply summing the signal from all pixels in pre-defined area centered on the spot centroid. The two methods turned out to yield comparable, almost indistinguishable, results. The plots in Figures 5-12 show representative data for each of the SLMs for the 128-pixel grating period configurations. The trends with total ionizing dose are typical of the response of the other diffraction configurations.

3.2 Angle
The angle through which each of the test patterns deflects the spot is the most obvious parameter of interest in an SLM. Using the spot centroid parameters computed using TDAT, the deflection angle in the vertical (or elevation) plane for the first-order diffracted spot for each diffraction configuration was calculated. There does not appear to be any measurable deviation in deflection angle with increasing radiation dose, as shown in Figures 13-16 for the respective devices.
Figure 5. Variation with total dose of diffraction efficiency for BS-225, “128-.”

Figure 6. Variation with total dose of diffraction efficiency for BS-225, “128+.”

Figure 7. Variation with total dose of diffraction efficiency for BS-251, “128-.”
Figure 8. Variation with total dose of diffraction efficiency for BS-251, “128+.”

Figure 9. Variation with total dose of diffraction efficiency for BS-281, “128-.”

Figure 10. Variation with total dose of diffraction efficiency for BS-281, “128+.”
Figure 11. Variation with total dose of diffraction efficiency for BS-262, “128-.”

Figure 12. Variation with total dose of diffraction efficiency for BS-262, “128+.”
Figure 13. Sample BS-225, elevation angle vs. dose

Figure 14. Sample BS-251, elevation angle vs. dose
3.3 Spot Size

The effective $1/e^2$ radius of the blur spot can be obtained from the Gaussian fit from:

$$w = \sqrt{w_x \cdot w_y}$$

(1)

where $w_x$ and $w_y$ are the vertical and horizontal widths, respectively, from the blur spot parameter fit. An increase in spot size might be expected if the diffraction efficiency of the SLM were degraded by radiation. There does not appear to be any significant effect, as shown in figures 17-20.

For the CCD sensor used in this experiment, each pixel is 10 μm. Hence the typical spot size dimension was 20 μm to 30 μm. For all four test articles, the spot size for the “64+” and “40+” diffraction configurations was significantly larger than that observed for the other diffraction configurations. This anomaly may have been the result of some experimental artifact, such misalignment at the collecting lens. Nevertheless, spot size is in all cases quite stable with increasing accumulated radiation dose.
Figure 17. Sample BS-225, spot size vs. dose.

Figure 18. Sample BS-251, spot size vs. dose.

Figure 19. Sample BS-281, spot size vs. dose.
5. CONCLUSIONS

The SLM devices evaluated in this test appear immune to total ionizing dose up to 250 kRad(Si) for the parameters that would likely be critical in a beam steering application. Angular deflection, intensity, and beam spread do not appear to be significantly affected by the gamma dose environment to be found in a geosynchronous or mid-earth orbit. These tests demonstrate the capability of the liquid crystal spatial light modulator technology.

6. REFERENCES
