Custom Optics vs Modified COTS for Small Spacecraft: The Build vs Rebuild Decision

or

A Case Study in Applied Hubris

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Summary

• Original commercial lens
• Its shortcomings
• Our first custom lens
• Its advantages
• Its shortcomings
• Our second custom lens
• Conclusion
# Original Commercial Lens

## Lens Datasheet Specifications

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Marshall Electronics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part Number</td>
<td>V-4416.0-1.2-HR</td>
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<tr>
<td>Focal Length</td>
<td>16 mm</td>
</tr>
<tr>
<td>f-number</td>
<td>f/1.2</td>
</tr>
<tr>
<td>Intended Market</td>
<td>Security cameras</td>
</tr>
<tr>
<td></td>
<td>Machine vision</td>
</tr>
<tr>
<td>Prior Space Heritage</td>
<td>“Used on Mars”</td>
</tr>
<tr>
<td></td>
<td>Unable to verify claim</td>
</tr>
</tbody>
</table>
• Black anodized surface
  – Impossible to make electrical ground
• Aluminum expands faster than glass
  – Preload vanishes at high temperature
• Many lenses have zero preload from factory
  – Front glass can be rotated by hand
• Trapped air pockets
  – Venting is not assured
• No model available
  – Cannot perform optical simulations
• Poor match to detector microlenses
  – Significant loss of sensitivity at edges of FoV
Commercial Lens F-number Discrepancy

- Entrance pupil directly imaged

\[ f/# = \frac{9.52 \text{ mm}}{16 \text{ mm}} = f/1.68 \text{ (actual)} \]

- \( f/1.2 \text{ (datasheet)} \)

- Lens vendor unwilling to explain discrepancy

- Caveat emptor!
The 1st Custom Lens: ST-16RT

- 16 mm focal length
- f/1.6
- Conductive mating surfaces
- O-ring ensures preload over temperature
- Venting path for all air pockets
- Achromatic doublet

Bezel
O-ring
1-2 Spacer
Field Stop
Barrel
3-4 Spacer
Vent Hole
Element 1
Element 2
Element 3 (doublet)
Element 4
Photometric Performance

- Custom lens admits more light
- Custom lens has wider FoV without vignetting
Relative Resolution

<table>
<thead>
<tr>
<th>Off-Axis Angle</th>
<th>COTS</th>
<th>Custom</th>
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<tbody>
<tr>
<td>1</td>
<td>5.04</td>
<td>4.32</td>
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<tr>
<td>4</td>
<td>5.03</td>
<td>4.59</td>
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<td>7</td>
<td>5.84</td>
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</tbody>
</table>

(in pixels, 85% Encircled Power)

Custom lens has higher resolving power
Custom lens has far better stability over temperature
Optical cement in achromatic doublet cracks over long-term temperature
The Second Custom Lens: ST-16RT2

- Doublet materials changed to match CTEs.
- Design tuned for:
  - Shorter length
  - Reduced chromatic aberration
  - Better photometric efficiency
  - Wider unvignetted field
- First prototypes assembled mid-August.
Conclusion

• Commercial lenses may have undesirable characteristics

• Validate all datasheet claims before use

• Custom lenses have the potential to boost system performance

• Never run qualification campaign in parallel with flight manufacture

• Design error cost me:
  – $300k in scrap ST-16RT optics
  – 6+ month delay in $3M in deliveries