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Tech Notes

Wide Field-of-View Curved Focal Plane Array

An array of uniquely fabricated curved charge-coupled devices expands the capabilities of deep-space surveillance

MIT Lincoln Laboratory has demonstrated the first digital, wide field-of-view (FOV), curved focal plane array. This unique device corrects for the inherent aberrations of mirrors and lenses in optical systems, and thus enables wide FOV surveillance of space. The curved focal plane was developed for the Defense Advanced Research Projects Agency's (DARPA) Space Surveillance Telescope (SST), a new, very wide FOV, ground-based, space surveillance system (Figure 1).

The SST is a novel, three-mirror, Mersenne-Schmidt f/1 telescope design that retains its inherent field, or Petzval, curvature. This design choice produces a much larger FOV than the FOV of a conventional telescope while providing sufficient sensitivity to detect faint targets. The combination of wide FOV and sensitivity enabled by the curved focal plane array makes SST the nation's premier detector and tracker of objects in deep space. The SST's 3.5 m primary light-collecting aperture provides an order of magnitude improvement in detection sensitivity over current optics

that employ flat charge-coupled devices (CCDs).

DARPA initiated the SST program in 2002 to enhance the capabilities that could be offered to the U.S. Space Surveillance Network (SSN). The SSN is a worldwide network of radars and optical telescopes that provides tracking and custody of resident space objects. Ground-based optical telescope sites are the backbone of U.S. surveillance of so-called deep-space objects, i.e., those located out to altitudes of 36,000 km.

What motivated interest in a more capable system was the advancement of satellite technologies into the microsatellite scale. Such payloads pose a collision danger to critical communication, military, and weather satellites, particularly in deep space. However, the SSN's assets have lacked the necessary sensitivity and FOV to detect and track very small objects in deep space. The existing SSN optical components employ modest 1 m apertures with ~1 square-degree FOV, while the radars are aimed at lower altitude (250–10,000 km) orbit regimes and have "pencil-beam" search capability.

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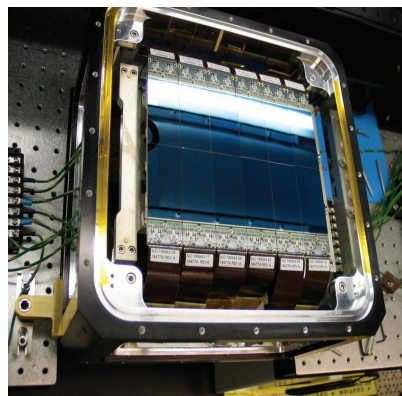


Figure 1. Left, the wide field-of-view CCD in the integration test lab at Lincoln Laboratory. Note the curvature of the image of a fluorescent bulb at the top of the unit. Right, the core of the Space Surveillance Telescope comprising a two-axis mount, large horizontally rotated yoke, and Mersenne-Schmidt optics in the center. The wide field-of-view CCD is located at the base of the central column.

Concept

Like conventional CCD cameras, the SST's wide FOV camera is cryogenically cooled, senses photons by the photoelectric effect, and, through a series of electronic control boards, provides a digital readout necessary for computer manipulation. However, the flatness of the CCDs in traditional cameras forces optical system designers to introduce complex lens and mirror arrangements to compensate for the curvature of the FOV. Because this introduction of additional components enhances optical aberrations inherent in the main light-gathering mirrors, the designers must make a choice between smaller FOVs (that ensure uniform focus) or larger FOVs (that result in large-scale spatial nonuniformity). Degraded focus in the latter choice will lead to sensitivity loss across such a nonuniform FOV (Figure 2).

A solution to the problem of achieving a wide FOV while retaining uniform high sensitivity would be an imager that corrected for those optical aberrations—an imager with a curved focal surface (Figure 3). The wide FOV camera developed for the SST is a mosaic of 12 curved CCD imagers that matches the telescope's inherent Petzval curvature. To curve the silicon wafers of each CCD and precisely align them, Lincoln Laboratory innovated new manufacturing and metrology techniques. Three components

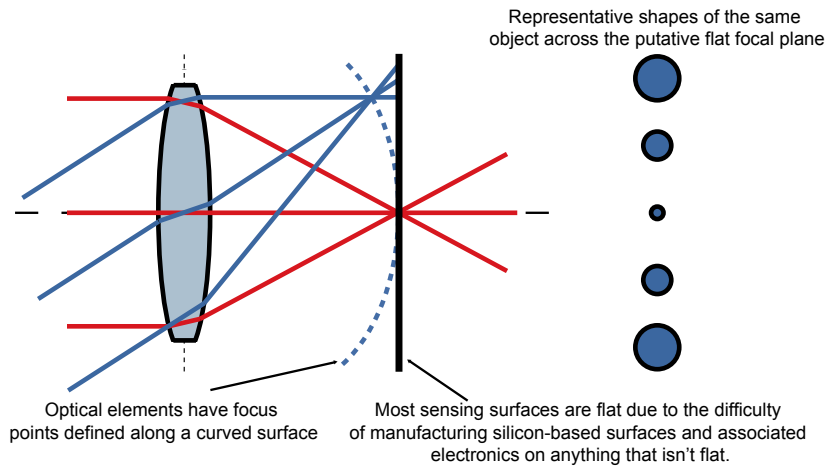


Figure 2. Impact of inherent Petzval curvature on focused light on a flat detector. Bigger spots lead to lower signal-to-noise ratio, reducing the sensitivity of the instrument. To compensate, one must choose a smaller field of view for the sensor or adopt a curved focal plane.

of the CCD imager—the sensing layer, its associated etched circuitry, and a carrier silicon wafer—were altered to achieve the desired curvature. To make each individual curved CCD, researchers developed new mechanical processes:

1. Double-flush thinning to make flexible, back-illuminated, imager wafers.
2. Fixture bonding to align the image wafers onto the curved silicon mandrel and eliminate clocking or slippage after application of the epoxy; good alignment is essential to the telescope's performance because it ensures that the sensing surface is orthogonal to the incoming light cone at all times.

3. Vacuum chuck curing to ensure that the epoxy bonding was strong enough to resist large temperature swings.

Advantages of the Wide FOV Camera

Metaphorically, the current method of observing and tracking objects in orbit around the Earth provides a “soda straw” view. The SST, enabled by the wide FOV camera, performs more like a “vacuum cleaner and hose,” covering a wide region of the sky for a time; “drawing in,” i.e., locating, multiple objects in that region; and “shooting out” the data to a processor that determines the orbits of the objects.

The wide FOV camera

- Enables the use of unconventional wide FOV designs such as Mersenne-Schmidt
- Eliminates time-consuming alignment of multiple lenses and mirrors needed to produce the flat fields FOVs of conventional science-grade systems
- Reduces aberrations, including the two common off-axis distortions, astigmatism and coma
- Improves off-axis sharpness, resolution, and brightness

Because many applications use CCD detector technology, adaptations of the camera may find use in disciplines that require wide FOV imaging and surveillance, for example, remote sensing and environmental monitoring, persistent surveillance of wide areas, and medical imaging. ■

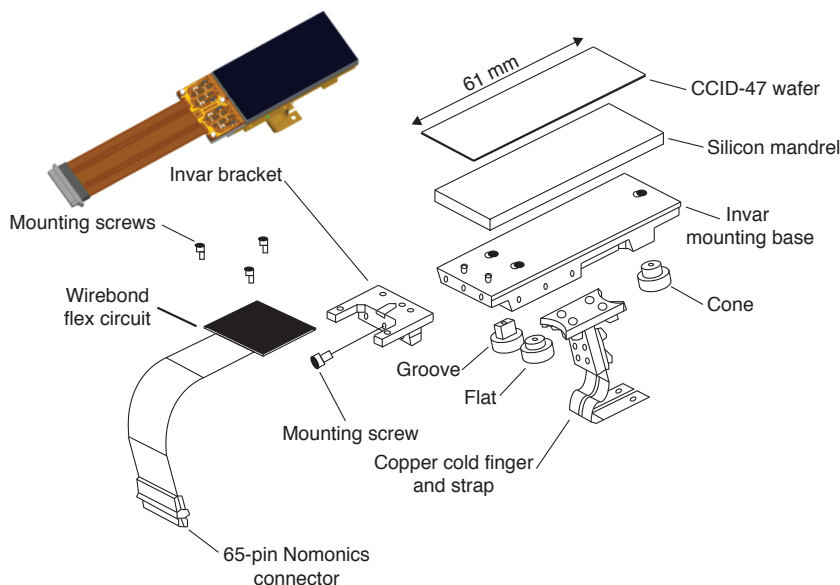


Figure 3. Breakout of an individual curved CCD imager. The light-sensing surface, or wafer, has been thinned by the double-flush method and bonded to a machined silicon mandrel. Thermal variations throughout are minimized by using Invar steel components, which have very low expansion coefficients. A copper cold strap provides heat removal through a special mounting in the dewar interior. The flexprints connect down to the analog electronics that are responsible for “counting” the photons.

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