Electrostatic deflection in conformable mirrors

Steve Taranovich - October 11, 2017

Recently, Apex Microtechnology introduced a power amplifier IC with a high voltage operation of 220V and a continuous output current capability of 1A. The PA164 device has a monolithic MOS technology for the amplifier core and a separate output power stage.

One key thought came to mind for neat applications for such a component: conformable mirrors for such systems as NASA’s CubeSat/small satellite program, telescopes, confocal microscopes, and other adaptive optics conformable membrane mirrors. I will touch upon all of these applications in this article and then discuss adaptive optics using feedforward control of the deformable membrane mirror.

Deflecting a deformable/conformable mirror

Apex has a nice circuit for electrostatic deflection for their power amp (Figure 1).

![Figure 1](Image courtesy of Apex Microsystems)

The CubeSat deformable mirror

A coronagraphic space telescope needs wavefront control systems to get high-contrast imaging for such applications as direct imaging of exoplanets. These kinds of adaptive optics are necessary for future mission plans in space observation and communication, as the mirrors improve distortions and reduce bit error rates for low-power space-based laser communications. High actuator count,
microelectromechanical systems (MEMS) deformable mirrors (DM) will be the crucial components in such an adaptive system.

The CubeSat deformable mirror (DeMi) demonstration is to characterize the performance of a small deformable mirror over a year in low-Earth orbit. The satellite testbed platform is a 3U CubeSat bus, 150×95×25 mm allocated for the mirror driver electronics and 150×95×70 mm for the optical system (Figure 2).

![Figure 2: MIT's 3U DeMi CubeSat frame and optical payload architecture](Image courtesy of Reference 1)

The system architecture accommodates two sources of light: an internal fiber-coupled laser and an external source (bright star or extended object). A beamsplitter will transmit 92% of the incident light to the focal plane sensor and then reflect 8% back to be sent on to the Shack-Hartmann sensor.

**Boston Micromachines Mini-DM deformable mirror**

The Boston Micromachines Mini-DM deformable mirror surface is controlled by up to 32 electrostatic actuators, individually commanded, to give a desired shape (Figure 3).
The Shack-Hartmann sensor

The Shack-Hartmann sensor architecture is composed of a lenslet array and a camera. Wavefronts enter the lenslet array, and a spotfield is created on the camera; each spot is analyzed for intensity and location. Using this method, these sensors dynamically measure the wavefronts of laser sources or characterize the wavefront distortion caused by optical components (Figure 4).

The APEX PA164 greatly reduces weight, size, and cost for the control system power driver portion of this architecture.
A flexible radio telescope

Radio telescopes are high-precision telescopes which are essentially flexible structures whose shape is affected by gravity, temperature, and wind. These seemingly small deformations can lead to focus, pointing, and path-length errors with a gain loss that will provide an incorrect image, light years away. Deformable mirrors come to the rescue again.

The functionality of a radio telescope is based upon a finite-element analysis (FEA) which investigates the structural deformations and associated focus, pointing, path length, and gain errors under the influence of gravity, temperature, and wind.

The FEA of a telescope under gravity load provides the analytic relations for focus and pointing control and look-up-tables (LUTs) of gravity-induced main reflector surface deformations. The elevation-dependent reflector surface deformations can be corrected using a deformable mirror.

A deformable mirror in the optics portion of this architecture can correct for reflector surface deformations in the 70-m Deep Space Network antennas. The mirror can be placed close to the receiver while still providing for good phase correction.

On the Effelsberg 100-m telescope, correction of deflector deformations is made from a deformable flat mirror in the optics path.

A confocal microscope

A deformable membrane mirror can be used for fast, flexible focus control in a commercial confocal microscope. These kinds of microscopes are typically used for real-time imaging of human tissue, which is a process that can replace the need for a more invasive biopsy, to detect dysplastic (abnormal) or cancerous cells.
When 200V is applied to the MEMS conformable mirror, it has a focal length of 120 mm causing a change in focus of 55 μm within the specimen.

**Using feedforward control for deformable mirrors**

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Now let’s look at a deformable mirror (DM) consisting of a flexible membrane and voice coil actuators and how its performance can be enhanced for optics. With this type of mirror design, feedback control of the distributed actuators cannot be implemented in these mirrors due to a lack of high speed internal position measurements of the membrane’s deformation.
Figure 6 The layout of an adaptive optics control loop with a DM, a wavefront sensor, and a wavefront reconstructor (Image courtesy of Reference 4)

Here is how Figure 6 works: To correct for optical anomalies, the wavefront sensor will measure the optical phase deviations of the incoming wavefront. Next, the wavefront reconstructor will compute the best DM deformations so that the optical aberrations are compensated when the light is being reflected from the deformed DM.

Next, Figure 7 shows that the modal dynamics of the DM can be approximated by second-order ordinary differential equations with modal inputs (Reference 3). Using an eigenvector-based multivariate analysis of the static actuator influence functions, the theoretical modal inputs are deduced experimentally. After performing a modal parameter identification based on the determined modal inputs, it is shown that modal feedforward control can be used to improve the performance of membrane DMs effectively.

So, the computed modal input commands are transformed into physical actuator commands with an inverse modal transformation based on a principle component analysis of measured actuator influence functions.

Reference 3 shows that in order “to obtain suitable input commands for the excitation of specific eigenmodes, the modal contributions are derived via static actuator influence function measurements and analysis. The measurements are performed with a standard phase-shifting interferometer. The interferometer is constructed in Twyman-Green geometry, and a relay system is employed to image the DM surface,” as shown in Figure 7. Thereby, the mirror deflection is sampled over the domain at specific measurement points. During the measurements, each actuator is triggered with a voltage of 0.25 V to obtain the deformation and a five-step phase shifting method is then used to get the corresponding height map.
By the implementation of feedforward control, the dominant dynamics of the DM can be controlled, leading to faster settling times and reduced membrane vibrations after set-point changes. Experimental results show that for an ALPAO DM with 88 distributed actuators (The ALPAO DM88) on a circular membrane, the settling time can be reduced from 10 to 2ms. I am sure more innovations are forthcoming for this technology.

Please share any experiences you may have with our audience in the comments below.

Steve Taranovich is a senior technical editor at EDN with 45 years of experience in the electronics industry.

References

3. MEMS mirror for flexible z-axis control in a commercial confocal microscope, Sarah J. Lukes, David L. Dickensheets, IEEE
4. Feedforward Control of Deformable Membrane Mirrors for Adaptive Optics, Thomas Ruppel, Shihao Dong, Frédéric Rooms, Wolfgang Osten, and Oliver Sawodny, IEEE TRANSACTIONS ON CONTROL SYSTEMS TECHNOLOGY, VOL. 21, NO. 3, MAY 2013

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