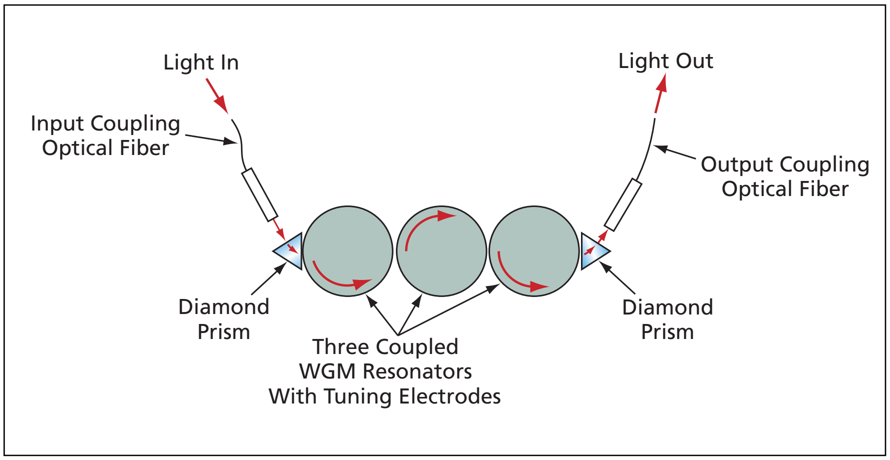

Figure 1. **Three Coupled, Tunable WGM Resonators** constitute a third-order tunable band-pass optical filter.

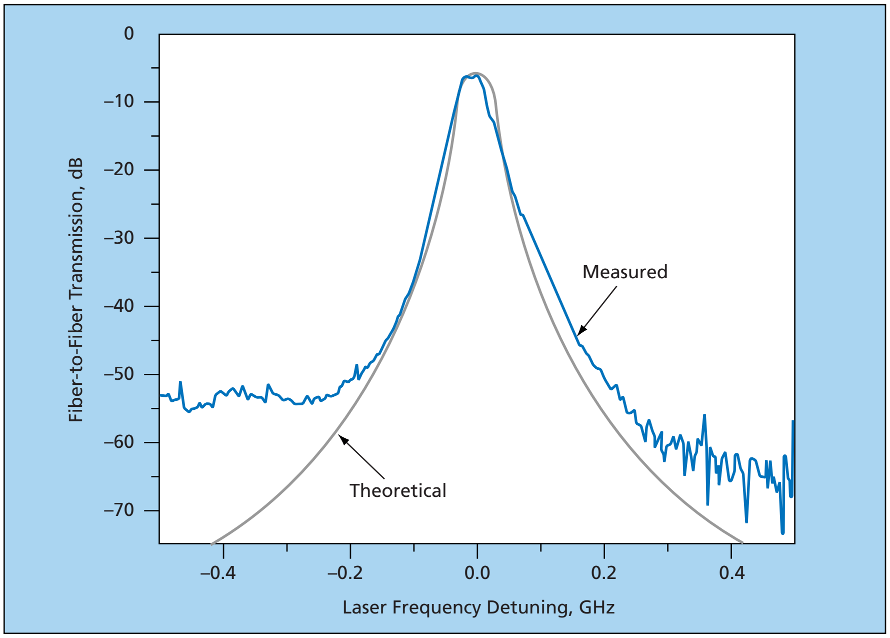

Figure 2. The **Measured Transmission Spectrum** of the filter was fitted with a Butterworth profile function $\gamma^6/[(\nu)^6+\gamma^6]$, where γ = 29 MHz and ν is the laser frequency detuning (the difference between the laser frequency and the peak-transmission frequency).

Figure 1 depicts the optical layout of the present filter comprising an assembly of three coupled, tunable WGM resonators. Each WGM resonator is made from a disk of Z-cut $LiNbO_3$ of 3.3-mm diameter and 50-µm thickness. The perimeter of the disk is polished and rounded to a radius of curvature of 40 µm. The free spectral range of each WGM resonator is about 13.3 GHz. Gold coats on the flat faces of the disk serve as electrodes for exploiting the electro-optical effect in $LiNbO_3$ for tuning. There is no metal coat on the rounded perimeter region, where the whispering-gallery modes propagate. Light is coupled from an input optical fiber into the whispering-gallery modes of the first WGM resonator by means of a diamond prism. Another diamond prism is used to couple light from the whispering-gallery modes of the third WGM resonator to an output optical fiber.

The filter operates at a nominal wavelength of 1,550 nm and can be tuned over a frequency range of ±12 GHz by applying a potential in the range of ±150 V to the electrodes. The insertion loss (the loss between the input and output coupling optical fibers) was found to be repeatable at 6 dB. The resonance quality factor (Q) of the main sequence of resonator modes was found to be 5×10^6, which corresponds to a bandwidth of 30 MHz. The filter can be shifted from one operating frequency to another within a tuning time ≤30 µs. The transmission curve of the filter at frequencies near the middle of the passband closely approximates a theoretical third-order Butterworth filter profile, as shown in Figure 2.

This work was done by Anatoliy Savchenkov, Vladimir Iltchenko, Lute Maleki, and Andrey Matsko of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Dynamic Pupil Masking for Phasing Telescope Mirror Segments

Piston and tilt adjustments could be performed more efficiently.

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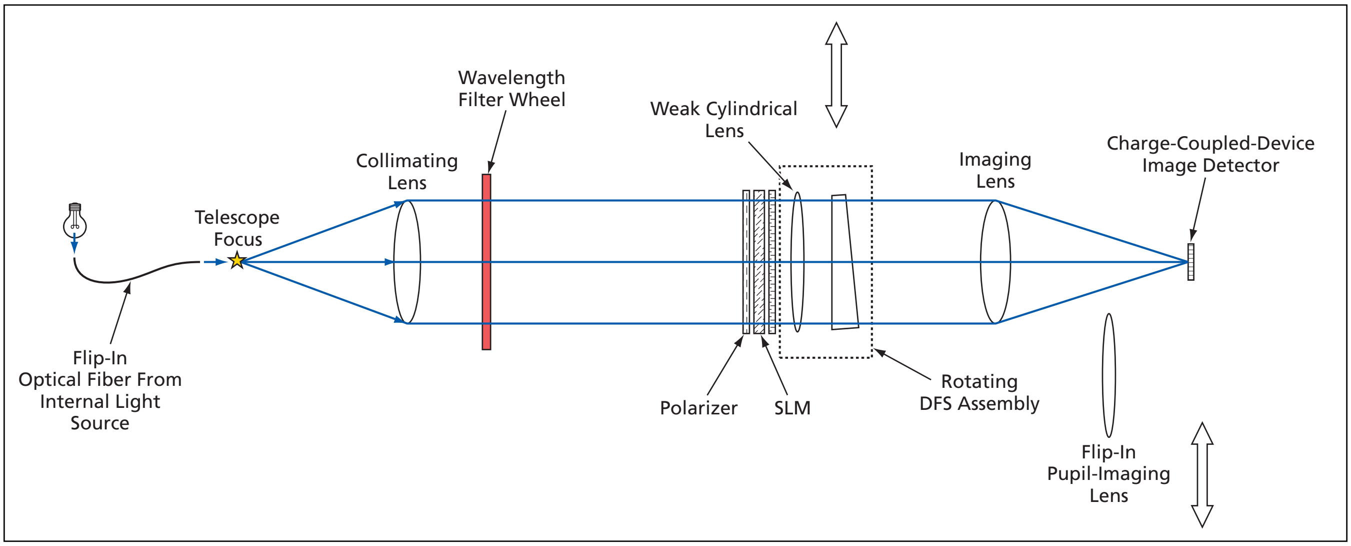
A method that would notably include dynamic pupil masking has been proposed as an enhanced version of a prior method of phasing the segments of a primary telescope mirror. The method would apply, more specifically, to a primary telescope mirror that comprises multiple segments mounted on actuators that can be used to tilt the segments and translate them along the nominal optical axis to affect wavefront control in increments as fine as a fraction of a wavelength of light. An apparatus (see figure) for implementing the proposed method would be denoted a dispersed-



A **DPCS** would combine several telescope-alignment instruments into one that would function more efficiently.

fringe-sensor phasing camera system (DPCS).

The prior method involves the use of a dispersed-fringe sensor (DFS). The prior method was reported as part of a more comprehensive method in "Coarse Alignment of a Segmented Telescope Mirror" (NPO-20770), *NASA Tech Briefs*, Vol. 25, No. 4 (April 2001), page 15a. The pertinent parts of the prior method are the following:

- The telescope would be aimed at a bright distant point source of light (e.g., a star) and form a broadband image on an imaging detector array placed at the telescope focal plane.
- The construction and use of a dispersed-fringe sensor would begin with insertion of a grism (a right-angle prism with a transmission grating on the hypotenuse face) into the optical path. With other segments tilted away from the investigating region of the detector, a dispersed-fringe image would be formed by use of a designated reference segment and a selected mirror segment. The modulation period and orientation of the fringe would be analyzed to determine the magnitude and sign of the piston error (displacement along the nominal optical axis) between the two segments. The error would be used to perform a coarse-phase piston adjustment of the affected mirror segment. This determination and removing of piston error is what is meant by "phasing" as used above. The procedure as described thus far would be repeated until all segments had been phased.

A major drawback of the prior method is the time-consuming nature of the repeated tilting of mirror segments, necessitated by the fact that the DFS as described above could not be used to phase more than two mirror segments at a time. To be able to phase more than two segments simultaneously, it would be necessary to augment the DFS with an array of prisms and a pupil mask and to implement a complicated pupil-registration process.

In the proposed method, the need for repeated tilting would be eliminated by using a programmable spatial light modulator (SLM) as a dynamic segment edge mask in conjunction with a weak cylindrical lens: At a given instant of time, the SLM would be made transparent only in areas containing the edges of the mirror segments to be phased. Elsewhere, the SLM would be opaque to block light from all other mirror segments. The SLM would also enable accurate *in situ* pupil registration and could readily be adapted to different segment geometries. Also as part of the proposed method, the weak cylindrical lens would be used to separate DFS fringes across the wavelength dispersion of the grism, thereby making it possible to phase multiple pairs of mirror segments in one image exposure. Hence, the combination of the SLM and the weak cylindrical lens would greatly increase the efficiency of the segment-phasing process.

Other elements of the proposed method are the following:

- The DPCS could be designed to enable simultaneous measurements on two edge orientations of the hexagonal segments by use of both polarization channels. Alternatively, as shown in the figure, the DFS assembly in the DPCS could be designed to rotate about the optical axis, enabling measurements on all segment edges.
- The combination of a flip-in pupil imaging lens and the SLM would enable accurate pupil registration.
- The DFS assembly could be removed and a weak spherical lens used in combination with the SLM to form a Shack-Hartmann sensor for measuring tilts of mirror segments. In this case, the SLM would be used to create subapertures within each segment.
- The weak spherical lens could also serve as part of a prescription-retrieval sensor, the use of which would enable further reduction of piston errors. In this case, the SLM would be used to form subapertures on the segment edges.

This work was done by Fang Shi, David Redding, Catherine Ohara, and Mitchell Troy of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1). NPO-41996*