bate doped with erbium (Er:$LiNbO_3$). The oblateness of the spheroid or disk would be essential for suppressing undesired electromagnetic modes of the resonator. Continuous-wave (CW) pump laser light at a wavelength of 1.48 μm would be coupled into the WGM optical resonator via a diamond prism. Light would be coupled out of the optical resonator via another diamond prism. As a result of the interaction between the pump light and the dopant erbium ions, modes at wavelengths in the vicinity of 1.54 μm would be amplified. In the absence of the design features described below, the device as described thus far would emit CW light in the 1.54-μm wavelength band.

The optical resonator would be placed between two plates of a microwave resonator. By adjusting the shape of the microwave resonator, one could adjust the frequency of resonance of the microwave field to fit the difference between the frequencies of successive modes of the optical resonator. Under this condition, the nonlinearity of dielectric response of $LiNbO_3$ would serve to couple the modes of the microwave and optical resonators.

Because of the optical/microwave coupling, the device would function as a mode-locked laser in the presence of both CW pump light and CW microwave radiation. The net result of the interaction would be the generation of pulses of light in the WGM optical resonator. Because the optical amplification would not be sensitive to phase, pulses are expected to travel circumferentially around the resonator in both directions. Hence, for example, it should be possible to extract an optical pulse train propagating in the circumferential direction opposite of that of the pump light, as shown in the figure.

The performance of the device has been estimated theoretically on the basis of the underlying physical principles and the performances of prior WGM electro-optical modulators and erbium-doped glass lasers: Pulse durations as short as several picoseconds and pulse-repetition rates of tens of gigahertz should be readily achievable, and it may be possible to reach repetition rates as high as 100 GHz. The required microwave power is expected to be no more than a few milliwatts. The pump power is expected to range from a threshold value as low as several microwatts to a maximum value high enough to yield the CW equivalent of several milliwatts of output. With respect to pulse-repetition rates and power efficiency, the proposed device would perform better than any prior device designed to satisfy the same requirements.

This work was done by Andrey Matsko, Vladimir Iltchenko, Anatoly Savchenkov, and Lute Maleki 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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Spatial Light Modulators as Optical Crossbar Switches

Optimization computations would take account of realistic characteristics of all optical components.

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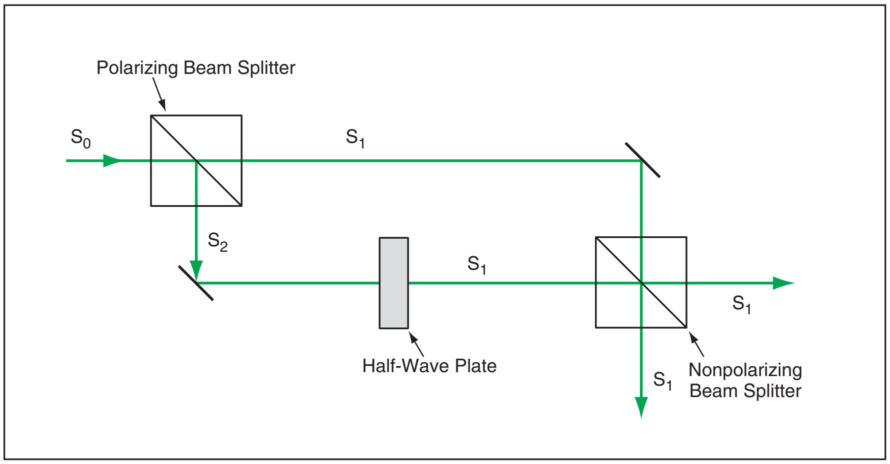
A proposed method of implementing cross connections in an optical communication network is based on the use of a spatial light modulator (SLM) to form controlled diffraction patterns that connect inputs (light sources) and outputs (light sinks). Sources would typically include optical fibers and/or light-emitting diodes; sinks would typically include optical fibers and/or photodetectors. The sources and/or sinks could be distributed in two dimensions; that is, on planes. Alternatively or in addition, sources and/or sinks could be distributed in three dimensions — for example, on curved surfaces or in more complex (including random) three-dimensional patterns.

The proposed method offers the following advantages over prior methods:

- Invariance to polarization of incoming light;
- Minimization of crosstalk;
- A full connectivity matrix (that is, the possibility of connecting or disconnecting between any input and any output terminal) in a given optical crossbar switch;
- Retention of switched information in light-borne form (in contradistinction to absorption of light, intermediate processing in electronic form, and reemission of light);
- Accommodation of the undesired but unavoidable coupling of phase and amplitude modulation in a realistic spatial light modulator;
- Automated dynamic alignment of the components of a newly assembled optical crossbar switch;
- Switching in a single stage rather than multiple “butterfly” stages;
- Computational tradeoff among desired but at least partly mutually exclusive switch characteristics (for example, among diffraction efficiency, uniformity of connection strengths, and crosstalk);
- Design for operation in the Fresnel (near-field) diffraction regime rather than in the Fourier (far-field approximation) regime;
- Ability to utilize inexpensive lenses and other less-than-ideal fixed optical elements; and
- Direct (in contradistinction to indirect) optimization of switch properties.

The method incorporates a combination of synergistic techniques and concepts developed to solve problems encountered in prior research on crossbar optical switches. The combination of techniques and concepts is so extremely complex that only a highly abbreviated summary of a few salient features, addressing some of the aforementioned advantages, can be given below.

The issue of polarization arises because the performances of many SLMs affect the polarization of output light and are affected by the polarization of input light. Because it is impractical to guarantee the polarization of input light from disparate sources, it would be better to render a crossbar switch insensitive to input polarization. In a crossbar switch according to



This **Optical Assembly** would convert input light of any polarization (S_0) to two mutually independent polarizations (S_1 and S_2). S_2 would then be further converted to S_1. The output beam would be pure S_1, attenuated from S_0 by a factor of 2.

the proposal, all of the input light would be converted to a single input polarization desired for the SLM by use of an optical assembly like that shown in the figure. The light would be attenuated by a factor of 2 by passage through this assembly, but in a typical case, the disadvantage of this attenuation would be offset by the advantage of obtaining the polarization needed to optimize the performance of the SLM.

The method provides for the choice of input and output locations in a computational optimization process to minimize crosstalk, while making it possible to connect from any desired input terminal(s) to any desired output terminal(s). In this process, the far-field approximation would be irrelevant and unnecessary because one would utilize realistic near-field measured and/or computed diffraction patterns generated by the SLM. The inherently comprehensive nature of the optimization calculations is such that realistic modulation characteristics of the SLM, realistic optical characteristics of all components, alignment or misalignment of components, diffraction efficiency, uniformity or nonuniformity of signal strengths, and crosstalk would all be automatically taken into account.

This work was done by Richard Juday of **Johnson Space Center**. *Further information is contained in a TSP (see page 1).*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center, (281) 483-0837. Refer to MSC-23320.