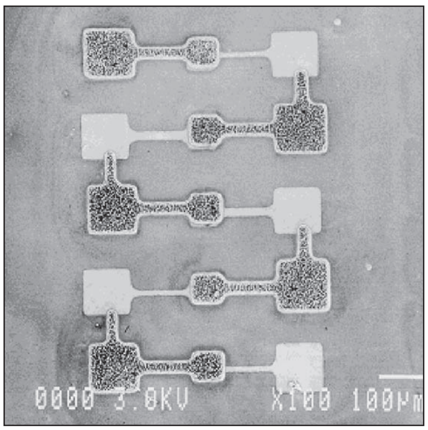
Microbattery arrays (see figure) are fabricated on substrates by use of conventional integrated-circuit manufacturing techniques, including sputtering, photolithography, and plasma etching. The microbatteries incorporate the same cathode materials of interest for conventional lithium-ion batteries such as $LiCoO_2$ and $LiCo_xNi_{1-x}O_2$. If multiple deposition sources are used in the fabrication of a given array, then the chemical compositions of battery components of interest can be varied across the substrate, making it possible to examine what amounts to almost a continuum of compositions. For example, assuming that a 4-in. (10-cm) substrate is used, the test-device pitch is 50 µm, and the concentration gradient is 80 percent across the substrate, then the compositions of adjacent test cells can be expected to differ by only about 0.04 percent. Because thousands of test cells can be fabricated in a single batch, it becomes practical to test thousands of combinations of battery materials by use of microbattery arrays, as contrasted with only about 10 to 20 combinations by use of macroscopic cells.



This is a **Scanning Electron Micrograph** of a microbattery array. The lightly shaded contact pads are cathode current collectors. The darker contact pads are anode current collectors. The cathodes and solid electrolyte of each cell are sandwiched between the anode and cathode contact pads and are not visible in this view.

The following is an example of a procedure for fabricating an array of [$LiCo_xNi_{1-x}O_2$ cathode/lithium phosphorus oxynitride solid electrolyte/nickel anode] cells like those shown in the figure, with a gradient in the cathode composition.

1. A Ti film is deposited on a 4-in. (≈10-cm) oxidized Si substrate. A Mo film is subsequently deposited on the Ti film.
2. The Mo-Ti bilayer is patterned by use of photolithography and wet etching to define the cathode current collectors.
3. The substrate is patterned with thick negative photoresist, with vias in the photoresist opened over selected areas of the current collectors.
4. A film of $LiCo_xNi_{1-x}O_2$ cathode material is deposited on the substrate with the desired gradient in x and selectively removed by use of a lift-off process, such that $LiCo_xNi_{1-x}O_2$ is present only on the cathode current collectors.
5. A film of the solid electrolyte lithium phosphorous oxynitride is deposited.
6. A film of Ni is deposited.
7. The Ni film is patterned to define the anode current collectors.
8. The Ni film is selectively removed by ion milling.
9. A protective coat (for example, vapor-deposited Parylene) is applied.

All depositions described above are performed by magnetron sputtering. The procedure can be readily modified to yield gradients in the cathode with other cations of interest: for example, $LiCo_xNi_{1-x}O_2$ could be replaced with $LiCo_xNi_yMn_{1-x-y}O_2$ with the desired gradients in x and y.

The cells can be tested by use of a commercial semiconductor-parameter analyzer connected to the test cells via tungsten probe needles. By applying a current of the order of 5 nA to a cell from the cathode to the anode, the cell can be charged by oxidizing the cathode and reducing the Li at the anode. The charged cell can be discharged by reversing the polarity of the current. The cells can be tested in the same manner as that used to test conventional lithium-ion cells to obtain information on such characteristics as cycle life and charge/discharge capacities, all as a function of compositions of the cathode.

This work was done by William West, Jay Whitacre, and Ratnakumar Bugga of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-21216

Correcting for Beam Aberrations in a Beam-Waveguide Antenna

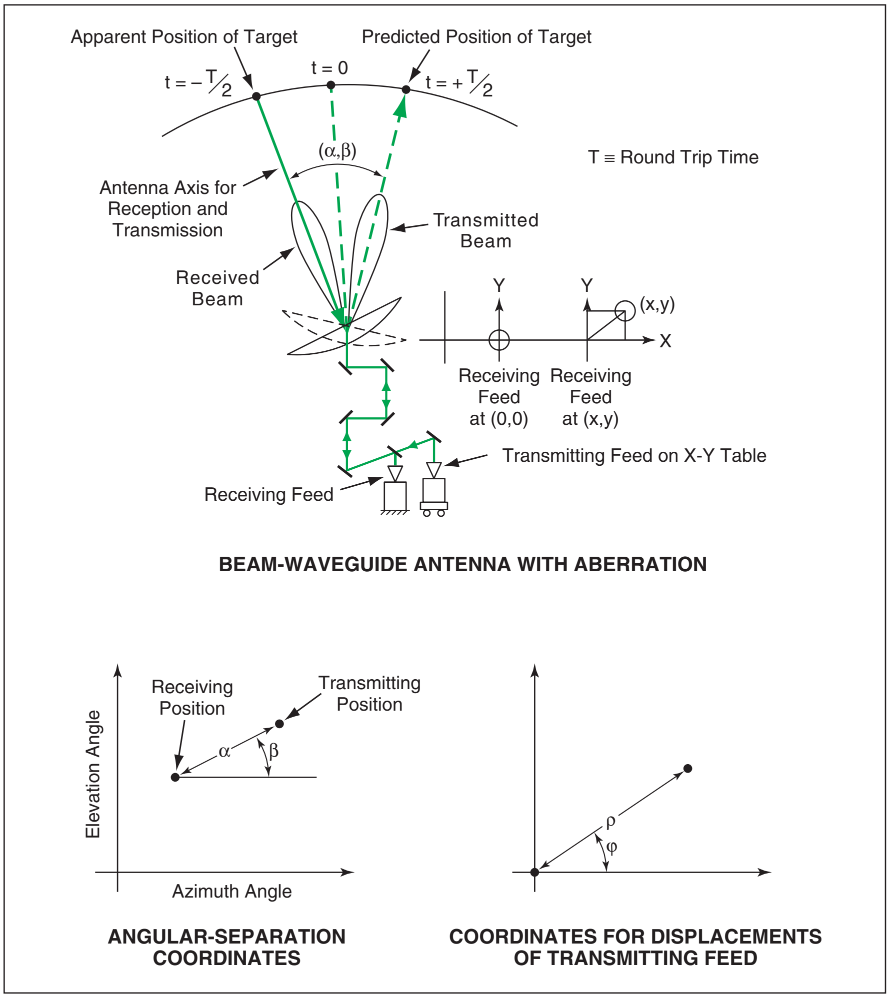
The transmitting feed is moved to compensate for movement of the target.

NASA's Jet Propulsion Laboratory, Pasadena, California

A method for correcting the aim of a beam-waveguide microwave antenna compensates for the beam aberration that occurs during radio tracking of a target that has a component of velocity transverse to the line of sight from the tracking station. The method was devised primarily for use in tracking of distant target spacecraft by large terrestrial beam-waveguide antennas of NASA's Deep Space Network (DSN). The method should also be adaptable to tracking, by other beam-waveguide antennas, of targets that move with large transverse velocities at large distances from the antennas.

The aberration effect arises whenever a spacecraft is not moving along the line of sight as seen from an antenna on Earth. In such a case, the spacecraft has a cross-velocity component, which is normal to the line-of-sight direction. In order to obtain optimum two-way communication, the uplink and downlink beams must be pointed differently for simultaneous uplink and downlink communications. At any instant of time, the downlink (or receive, R_x) beam must be pointed at a position where the spacecraft was 1/2-round-trip light time (RTLT) ago, and the uplink (or transmit, T_x) beam must be pointed where the spacecraft will be in 1/2 RTLT (see figure). In the case of a high-gain, narrow-beam antenna such as is used in the DSN, aiming the antenna in other than the correct transmitting or receiving direction, or aiming at a compromise direction between the correct transmitting and receiving directions, can give rise to several dB of pointing loss.

In the present method, the antenna is aimed directly at the apparent position of the target, so that no directional correction is necessary for reception of the signal from the target. Hence, the effort at correction is concentrated entirely on the transmitted beam. In physical terms, the correction is implemented by moving the transmitting feed along a small



The **Transmitting Feed Is Displaced in X and Y** by amounts needed to point the transmitting beam away from the receiving beam (which coincides with the antenna axis) by angular-separation amounts α and β.

displacement vector chosen so that the direction of the transmitted beam is altered by the small amount needed to make the beam point to the anticipated position of the target at the anticipated time of arrival of the transmitted signal at the target.

The angular and linear coordinates mentioned in the following sentences are defined in the figure. The angular separation between the transmitting and receiving beams is described in terms of the separation angle α and the clock angle β. The transmitting feed is mounted on an X-Y translation table. The problem is to compute the polar coordinates ρ and ϕ of the amount by which the transmitting feed must be displaced in the X-Y plane to move the direction transmitting beam, away from the direction of the receiving beam, by the amounts of the required angular separation. The problem becomes one of computing the ρ and ϕ needed to obtain the required α and β. (Then the required X and Y are calculated from ρ and ϕ by simple trigonometry.)

The algorithm used to control the X-Y table implements a closed-form representation of the coordinates ρ and ϕ as functions of the coordinates α and β. This representation can be obtained by experimentation and/or physical-optics-based, computational-simulation studies of electromagnetic scattering by the pertinent antenna optics configuration for various combinations of ρ and ϕ. The representation is of the general form

$$\rho = c_1\alpha + c_2\alpha^2 \text{ and}$$

$$\phi = \phi_F - \beta + \theta_{EL} - \theta_{AZ} - n\pi/2 \text{ radians,}$$

where c_1 and c_2 are coefficients determined by the computational study; f_F is related to the feed position on the floor; θ_{EL} and θ_{AZ} are the elevation and azimuth angles, respectively; and n is one of the integers between –1 and +2, determined through measurements of beam offsets obtained at known feed offsets.

This work was done by Manuel Franco, Stephen Slobin, and Watt Veruttipong of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-30534

Advanced Rainbow Solar Photovoltaic Arrays

Concentrated sunlight is spectrally dispersed onto adjacent cells with different bandgaps.

NASA's Jet Propulsion Laboratory, Pasadena, California

Photovoltaic arrays of the rainbow type, equipped with light-concentrator and spectral-beam-splitter optics, have been investigated in a continuing effort to develop lightweight, high-efficiency solar electric power sources. This investigation has contributed to a revival of the concept of the rainbow photovoltaic array, which originated in the 1950s but proved unrealistic at that time because the selection of solar photovoltaic cells was too limited. Advances in the art of photovoltaic cells since that time have rendered the concept more realistic, thereby prompting the present development effort.

A rainbow photovoltaic array comprises side-by-side strings of series-connected photovoltaic cells. The cells in each string have the same bandgap, which differs from the bandgaps of the other strings. Hence, each string operates most efficiently in a unique wavelength band determined by its bandgap. To obtain maximum energy-conversion efficiency and to minimize the size and weight of the array for a given sunlight-input aperture, the sunlight incident on the aperture is concentrated, then spectrally dispersed onto the photovoltaic-array plane, whereon each string of cells is positioned to intercept the light in its wavelength band of most efficient operation. The number of cells in each string is chosen so that the output potentials of all the strings are the same; this makes it possible to connect the