



Coronagraphic Notch Filter for Raman Spectroscopy

Design could be optimized for attenuating pump light and transmitting Raman-scattered light.

NASA's Jet Propulsion Laboratory, Pasadena, California

A modified coronagraph has been proposed as a prototype of improved notch filters in Raman spectrometers. Coronagraphic notch filters could offer alternatives to both (1) the large and expensive double or triple monochromators in older Raman spectrometers and (2) holographic notch filters, which are less expensive but are subject to environmental degradation as well as to limitations of geometry and spectral range.

Measurement of a Raman spectrum is an exercise in measuring and resolving faint spectral lines close to a bright peak: In Raman spectroscopy, a monochromatic beam of light (the pump beam) excites a sample of material that one seeks to analyze. The pump beam generates a small flux of scattered light at wavelengths slightly greater than that of the pump beam. The shift in wavelength of the scattered light from the pump wavelength is known in the art as the Stokes shift. Typically, the flux of scattered light is of the order of $10^{-7} \times$ that of the pump beam and the Stokes shift lies in the wave-number range of 100 to 3,000 cm^{-1} . A notch filter can be used to suppress the pump-beam spectral peak while passing the nearby faint Raman spectral lines.

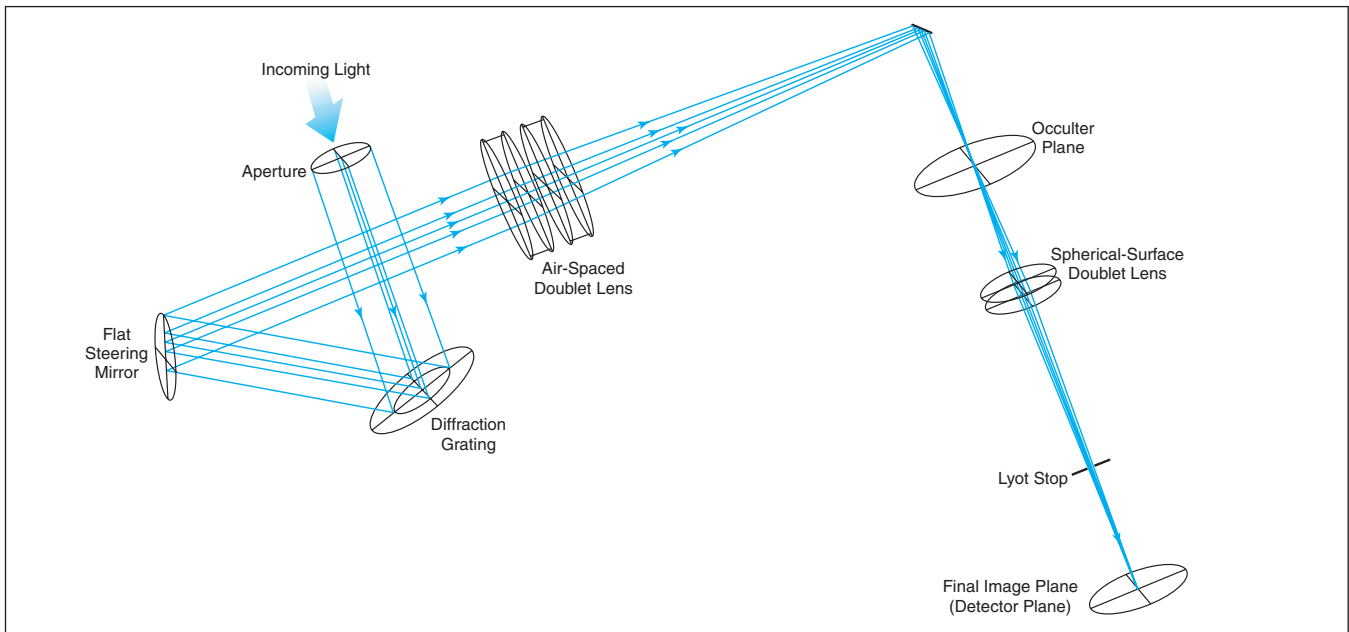
The basic principles of design and operation of a coronagraph offer an opportunity for engineering the spectral transmittance of the optics in a Raman spectrometer. A classical coronagraph may be understood as two imaging systems placed end to end, such that the first system forms an intermediate real image of a nominally infinitely distant object and the second system forms a final real image of the intermediate real image. If the light incident on the first telescope is collimated, then the intermediate image is a point-spread function (PSF). If an appropriately tailored occulting spot (e.g., a Gaussian-apodized spot with maximum absorption on axis) is placed on the intermediate image plane, then the instrument inhibits transmission of light from an on-axis source. However, the PSFs of off-axis light sources are formed off axis — that is, away from the occulting spot — so that they become refocused onto the final image plane.

A properly designed coronagraph utilizes the diffraction from the intermediate occulting spot. In the exit-pupil plane, this diffraction forms a well-defined ring image in the vicinity of the geometric

image of the exit pupil. By placing an aperture stop sized to block the passage of the diffracted light (such an aperture is known in the art as a Lyot stop) in the exit-pupil plane, it is possible, in principle, to obtain an extremely high rejection ratio.

While coronagraphs are not new, recent developments make it possible to enhance performance. One such development is that of the ability to write arbitrary absorption patterns on occulting spots at submicron resolution by use of electron-beam lithography. Another such development is that of superpolished optics.

One characteristic of a classical coronagraph essential to the proposed notch filter is that within the narrow typical Raman spectral range associated with a given pump laser line, the size of the PSF changes little with wavelength. However, the position of the PSF (in particular, its displacement from the occulting spot) can be made to vary considerably with wavelength by introducing a diffraction grating or other dispersive element into the optical train. Hence, one could obtain an extraordinarily sharp notch in the spectral transmittance of a coronagraphic filter by designing the dispersive element



A Coronagraphic Filter would include a modified coronagraph equipped with a diffraction grating and other components. The modification would be such as to optimize the functioning of the resulting instrument as a narrowband rejection (notch) filter.

and the other coronagraphic optics so that at the pump wavelength, the PSF is centered on the occulting spot.

The figure shows the optical layout according to one possible design of the proposed coronagraphic filter for a pump wavelength of 550 nm. The dispersive element would be a 500-line-per-millimeter diffraction grating, of which the first-order diffraction would be utilized. After passing through an aperture, the incoming light would strike the grating, followed by a flat steering mirror. An air-

spaced doublet lens incorporating an aspherical element would generate a PSF at the occulter (intermediate-image) plane. A spherical-surface doublet lens would reimage the light onto a detector plane. On its way to the detector plane, the light would pass through a Lyot stop. In principle, a linear array of photodetectors could be placed in the final image plane to measure the Raman spectrum. The depth of the notch at the pump wavelength, as well as other parameters of the performance of the coronagraphic filter,

could be tailored through the choice of the parameters of the optical components, including especially the dispersion of the grating; the aperture diameter, focal length, and aberrations of the first doublet lens; the length of the occulting spot along the axis of dispersion; and the diameter of the Lyot stop.

This work was done by David Cohen and Robert Stürl of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-30504

On-the-Fly Mapping for Calibrating Directional Antennas

Source-size corrections are not necessary in this method.

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An improved method of calibrating a large directional radio antenna of the type used in deep-space communication and radio astronomy has been developed. This method involves a raster-scanning-and-measurement technique denoted on-the-fly (OTF) mapping, applied in consideration of the results of a systematic analysis of the entire measurement procedure. Phenomena to which particular attention was paid in the analysis include (1) the noise characteristics of a total-power radiometer (TPR) that is used in the measurements and (2) troposphericly in-

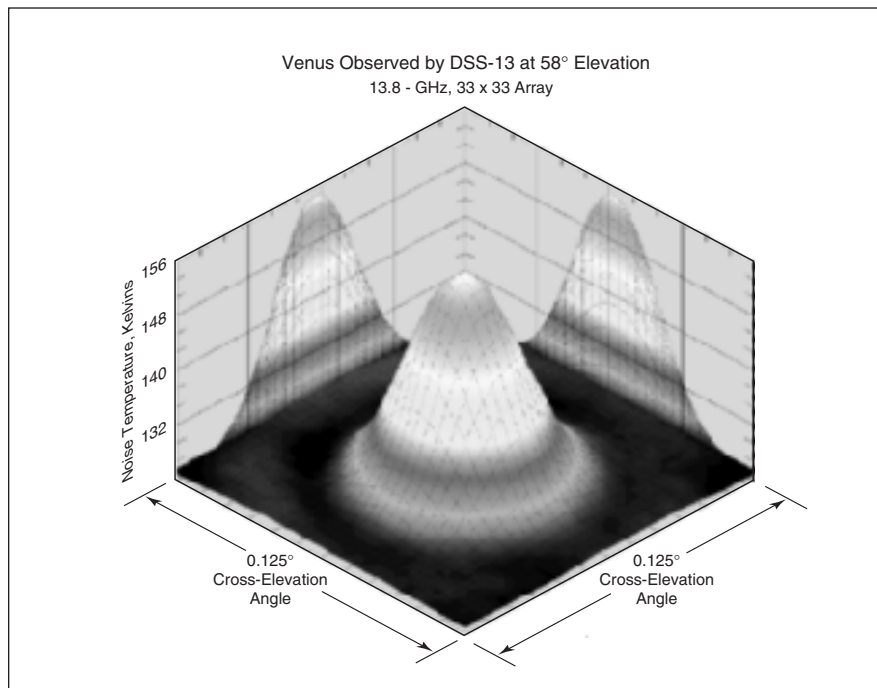
duced radiometer fluctuations. The method also involves the use of recently developed techniques for acquisition and reduction of data. In comparison with prior methods used to calibrate such antennas, this method yields an order-of-magnitude improvement in the precision of determinations of antenna aperture efficiency, and improvement by a factor of five or more in the precision of determination of pointing error and beam width.

Prerequisite to a meaningful description of the present method is some background information concerning three aspects of

the problem of calibrating an antenna of the type in question:

- In OTF mapping measurements in which a TPR is used, the desired data are the peak temperature corresponding to a radio source, the pointing offset when the antenna is commanded to point toward the source, and the shape of the main lobe of the antenna beam, all as functions of the antenna beam elevation and azimuth angles. These data enable one to calculate the (1) antenna aperture efficiency by comparing the measured peak temperature with that expected for a 100-percent-efficient antenna, (2) the mechanical pointing error resulting from small misalignments of various parts of the antenna structure, and (3) misalignments of the antenna subreflector and other mirrors.
- For practical reasons having to do with obtaining adequate angular resolution and all-sky coverage, it is necessary to perform azimuth and elevation scans fairly rapidly.
- Many natural radio sources used in calibrating antennas are only approximately pointlike: some sources subtend angles greater than the beam width of a given antenna. In such a case, the antenna partially resolves the source structure and does not collect all of the radiation emitted by the source. This makes it necessary to estimate how much of the total known radiation from the source would actually be collected by the antenna if it were 100-percent efficient. The resulting estimate, leading to a source-size correction factor, introduces another degree of uncertainty to the measurements. OTF mapping can remove this uncertainty.

The key to using OTF mapping to solve all three aspects of the calibration problem



The TPR Readout Data plotted here were acquired in a test raster scan of a portion of the sky, near an elevation angle of 58°, that contained the planet Venus when it was relatively close to Earth. The horizontal axes on this plot correspond to elevation and cross-elevation angles. The vertical axis represents noise temperature in Kelvins.