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INSTRUMENTATION ADVANCES ENHANCE SPECTRORADIOMETERS

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Instrumentation advances enhance spectroradiometers

High-performance spectrometers, sources, detectors, and accessories increase sophistication of available spectroradiometry systems.

Richard Young and William E. Schneider

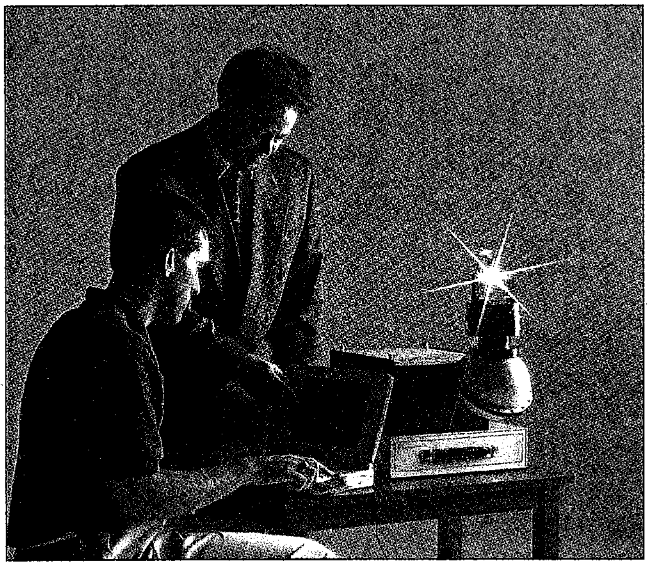
Radiometry is the quantization of electromagnetic radiation and its interaction with matter. Expressed more simply, it embraces the theory, measurement, and conventions of light generation, transmission, reflection, absorption, and detection. Spectroradiometry, in which individual wavelength components are measured, forms the basis of most calibrations and accurate measurement techniques. Because light is an integral part of life on earth, applications of spectroradiometry are numerous and vary from astrophysics, ocean ecology, and military sensing to detection of eyesight defects and measurement of "holes" in the ozone layer.

Institutions and industry are demanding increased speed, accuracy, and ease of use in radiometry. Academic and commercial groups have responded by producing several useful innovations. But developments in computer and related technologies have dominated the direction and rate of improvements in most areas of spectroradiometry.

Ten years ago, automation in spectroradiometry meant relief from tedious tasks such as positioning monochromators and recording readings. The benefits were immediate and tangible. Now, state-of-the-art automation has replaced virtually all human tasks, and benefits of one system over another are complex.

Spectrometers are far more sophisticated. Gone are the errors associated with wavelength counters, manual grating and detector changes, and rudimentary filter wheels. Instead, we have accurate self-calibrating wavelength readings, polynomial-fit algorithms to give much greater wavelength accuracy, continuous scans over extended wavelength ranges, and extremely reliable data. Even the old cosine-bar mechanism has been replaced by direct drive and computer calculations in many spectrometers.

Several separate advances—automated grating turrets and slits, improved filter wheels and detectors, and versatile detector-selection mechanisms—have made continuous scans possible over the 200-nm to 30-µm range (see Fig. 1). Grating turrets are not new, of course; what is new is the reliable automation of positioning gratings, often combining wavelength control in the same direct-drive mechanism to reduce moving parts. Computer-controlled grating-turret mechanisms also provide indirect benefits to the user over manual turrets. There are no holes (and, hence, possible light leaks) in the lid, and access to the gratings is not required (hence, fingerprint damage to them is eliminated).



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Richard Young (standing) and P. Austin calibrate compact spectroradiometer that has been optimized to make UV solar irradiance measurements.

Automated slit mechanisms have been developed, though continuously variable slits still lack the reproducibility and reliability of their selectable fixed-slit counterparts. Filter wheels are more advanced, incorporating more filters for extended scans, shutters for auto-zeroing, and open positions for deep-UV scanning. Filter wheels can now be completely computer-controlled, easily accommodating any combination of filters and allowing for automatic grating changes.

Many detectors have been improved—including photomultiplier tubes (PMTs) and germanium, indium gallium arsenide, lead sulfide, lead selenide, indium antimonide, and mercury cadmium telluride detectors—giving extended wavelength response, enhanced sensitivities, and better uniformities in larger areas. A large-area silicon photodiode, for example, can be configured to have a fourteen-decade response.[1] A limited selection of dual-material sandwich detectors is also available, giving extended wavelength ranges. When selecting a detector, the user should be aware

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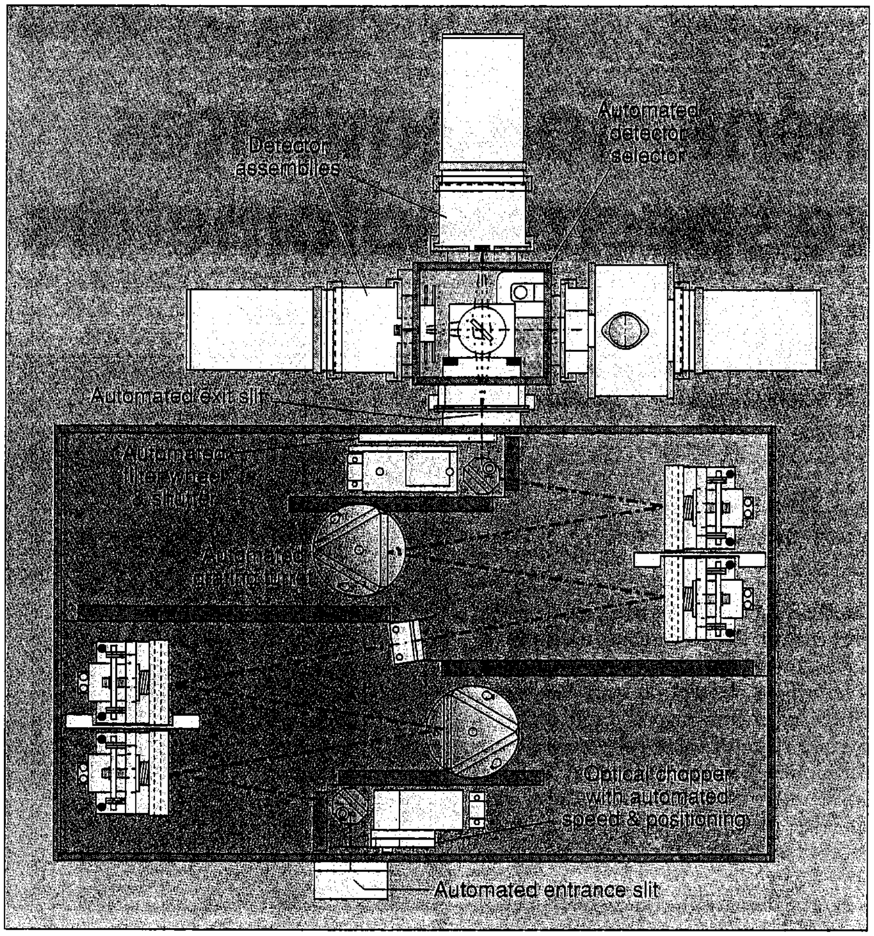

FIGURE 1. Modern spectroradiometer features automated detector, filter-wheel selection and control, grating-turret changing, chopper positioning, and slit adjustment.

that, because these advances have been so rapid, the same type of detector from different manufacturers can have very different characteristics.

Detector selection devices, having either dual or single detectors, provide the ideal solution to extended-wavelength scans. These devices can be fitted with optics to match the requirements of individual detectors, giving the best sensitivities under all conditions.

Advances in amplification and digitization techniques have made significant improvement in signal accuracies possible. Also, a mixture of ac, dc, and photon-counting techniques can be put under computer control to provide the necessary links for automated detector selection. The combination of such techniques depends on controlling the position of an optical chopper as well as its frequency, but modern systems integrate such features seamlessly. Today, signals are often limited only by detector noise so that, for instance, silicon detectors are much closer to PMT sensitivities. In fact, photon-counting photodiodes are now available, although they are still too small to be practical for general radiometry.

Digital-signal-processing technology is currently emerging in the radiometry market, giving far better performance than the conventional ac lock-in and dc amplification and sampling techniques.

Lamp improvements

Standard lamps still provide the basis of instrument calibrations and hence the ultimate limit to accuracy for radiance and irradiance measurements. Over the last decade, improvements have been made on specific lamp types, but unfortunately the range of lamps, and in some cases the quality, available from lamp manufacturers has diminished.

One of the most encouraging developments for lamp standards has been the use of digital-feedback systems in lamp power supplies, which significantly increases the stability, accuracy, versatility, and ease of use relative to their analog counterparts. The availability of more-accurate power supplies means that uncertainties in incandescent standard lamp emission are reduced, especially in the UV, and the extra versatility results in better protection and longer life.

With the introduction of more accurate standards in the near future, such as those described in the 1995 report "Pressing problems and projected national needs in optical radiation measurements" from the Council for Optical Radiation Measurements, absolute current errors of less than 0.01% will be required, and many of the older power supplies will be inadequate. Additionally, the much improved stability of lamp supplies will increase the reliability of single-beam transmission, reflection, and detector-characterization measurements.

Accessories automated

With the full automation of spectroradiometers, many accessories involving movement also have been automated. Gonioreflectance and detector uniformity measurements are now routine rather than arduous and time-consuming, source or detector calibrations are simplified, and single-beam systems can achieve the stability of double-beam systems. However, even those accessories without moving parts have generally improved.

Polytetrafluoroethylene (PTFE), with its superior reflection properties, has all but replaced barium sulfate as a diffuse reflector in standards and integrating spheres. Washable PTFE- based varieties are currently available—two examples include Optolon from Optronic Laboratories Inc. (Orlando, FL) and Spectralon from Labsphere (North Sutton, NH). Integrating-sphere design has also improved, giving nearly ideal cosine response in some cases (see Fig. 2). Indeed, some new designs for integrating devices are not spherical at all.

Significant improvement to imaging input accessories, specifically reflective and refractive optics, and the inclusion of direct-viewing optics have made alignment and measurement easier, more accurate, and generally more useful. "Through-the-slit" viewing accessories are now becoming available, allowing direct imaging of light actually entering the spectrometer and hence improving alignment and accuracy still further.

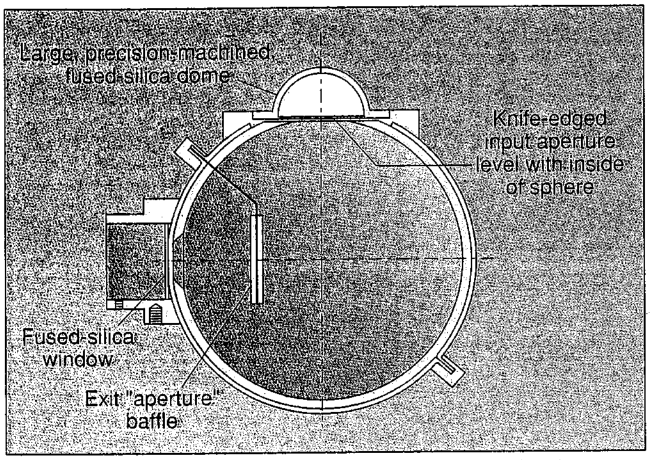

FIGURE 2. Having knife-edge input aperture level with inside sphere gives nearly ideal cosine response (Young & Schneider design).

Many applications of radiometry in difficult situations or hostile environments can benefit by the use of fiberoptic components. These have improved in UV and IR transmission, stability, and price so as to be practical for many applications as links to accessories. Moreover, certain applications, such as measurement of specular and diffuse reflectivities of glass windshields *in situ*, would be impractical without the use of optical fiber (see Fig. 3).

Further use of fiberoptic technology can be expected in the future as wavelength ranges are extended and transmissions improve. In some cases, optical fiber has been used without input or exit optics. Such applications can improve the ease of measurement greatly, but care should be taken that angular dependencies of the fiber and source/detector do not introduce errors.

Modern spectroradiometers manage to combine two previously incompatible properties: versatility and simplicity. Often, the same spectroradiometer can perform source, detector, and material property measurements using interchangeable, prealigned accessories and powerful all-purpose software. Because all control is automatic and common elements of the measurements are housed within the monochromator, a minimum of knowledge or effort is required by the user.

Sometimes certain attributes outweigh others for specific applications, giving rise to specialized spectroradiometers. One example of this is the determination of solar UV radiation, where the stringent demands of measurement must be coupled to the user's requirements of compactness and stand-alone field operation (see photo on p. 1). Because stringent requirements of one application often enhance performance in other areas, this instrument is also well suited to underwater, reflectivity, and other types of measurement with appropriate accessories.

Caution advised

With such advances, caution is again advisable. The creation of a completely automated system, often providing fully integrated measurement, calculation, and report generation, may also decrease the user's awareness of the processes and procedures involved in spectroradiometry. This implies a certain trust or even a transfer of responsibility for proper protocols to the supplier, but, as regulation of manufacturers has not been implemented, caution should be exercised when selecting equipment.

To ensure good results, it is essential that the user have an instrument-control facility, where all operations of the instrument can be tested and optimized. Sophisticated software is attractive and even expected in modern systems, but it should not be confused with good instrument performance. In addition, several new techniques are being introduced into spectroradiometry, notably CCD technology and Fourier transform, that have not been fully evaluated. Because these techniques introduce new types of error and may require different calibration methods, they are not, as yet, generally recommended.

Spectroradiometry has come a long way in the last 10 years, providing new levels of accuracy, automation, and ease of use. Systems offering virtually complete "hands-off" operation are now readily available. In the next 10 years, we expect currently emerging technologies, such as digital signal processing and "intelligent" computers, to make further improvements in spectroradiometric systems. ☐

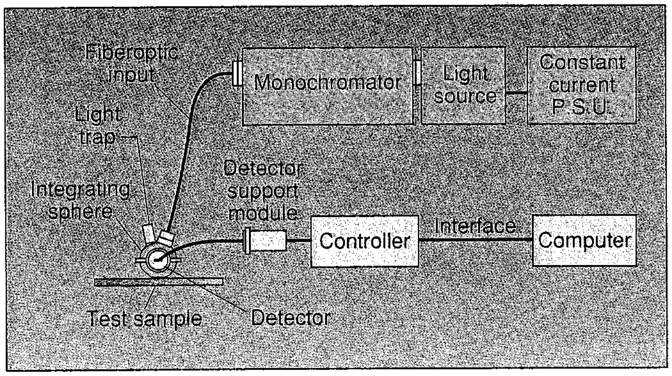

FIGURE 3. Flexible spectroradiometry system components make possible measurement of radiometric properties of glass windshields *in situ*.

REFERENCE

1. G. Eppeldauer and J. E. Hardis, *Appl. Opt.* *30*(22), (August 1991).