FieldSpec® Pro

User's Guide

ASD Part # 600000
Rev. C

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Warranty

ASD 1 YEAR LIMITED WARRANTY

Analytical Spectral Devices, Inc. (ASD) warrants the hardware of this product to be free from defects in materials and workmanship for a period of one year from the date of delivery. The accompanying computer and its accessories and software are products of their manufacturer and are warranted by that manufacturer*. ASD warrants the portable storage media containing ASD programs, including memory cards and accompanying documentation against physical defects for a period of one year from the date of purchase.

Limitation of remedies: ASD's entire liability and your exclusive remedy for defective hardware, media, and documentation shall be the repair or replacement of any product not meeting ASD's "limited warranty". ASD will pay for all expenses directly related to repair, maintenance, or replacement under warranty including all labor and material. In no event will ASD be liable for any damages, including any lost profits, lost savings, lost data, or other incidental or consequential damages arising from the use or inability to use such product even if ASD has been advised of the possibility of such damages.

EXCLUSIONS FROM COVERAGE: Products excluded from this limited warranty coverage are products that have been abused, misused, altered, neglected, or subjected to unauthorized repair or installation, as determined by ASD. Misuse includes, without limitation, use of an incorrect power source for the instrument or its accompanying computer. If the instrument housing is opened anywhere but at the ASD factory, the warranty is voided. Software programs supplied by ASD are provided "as is". ASD makes no warranty or representation, whether express or implied, including but not limited to, the implied warranties of merchantability and fitness for a particular purpose. With respect to any non-ASD software, its quality, performance, merchantability, or fitness for a particular purpose, the customer bears the entire risk as to quality and performance. This limited warranty is exclusive and may only be modified in writing by ASD. This warranty is customer specific, is not transferable, and is not redeemable for cash. This warranty gives you specific legal rights. You may also have other rights, which vary by state and country. Any claim procedure under this limited warranty must be submitted to ASD at the address listed below. The product should be insured, freight prepaid, and securely packaged. After your first year warranty expires, ASD offers additional extended service contracts, which can be purchased by contacting ASD.

ONE YEAR EXTENDED SERVICE CONTRACTS: A one year extended service contract represents an extension of, but is not limited to ASD's original limited factory warranty. All warranty exclusions and exceptions also apply to extended service contracts. These extended service contracts are customer specific and are not transferable, may not be used in exchange for other items, are not refundable, and are not redeemable for cash. The extended service contract begins immediately at the end of ASD's 1-year original limited factory warranty. Contact ASD for cost quotation.

DEFINITION OF INSTRUMENT SPECIFICATIONS: Specifications for the specific model, as published in the most current flyers, catalogs, price lists, or manuals for a specific model and model year, especially those listed for noise characteristics and spectral resolution. This definition is subject to any exclusions from coverage or exceptions detailed herein.

INSPECTION: If your current warranty or extended service contract has expired, an ASD inspection of the spectrometer and related accessories may be required at additional cost (contact ASD for quotation) to determine product eligibility for service contract. Requirement of such an inspection is solely at the discretion of ASD factory personnel and shall be based on model year, prior maintenance history and estimated condition of the products.

CONDITIONS (ORIGINAL ASD FACTORY WARRANTY & EXTENDED SERVICE CONTRACTS):
In addition to any other exclusions referenced herein, the ASD limited warranty and extended service contracts shall be void without refund if the customer fails to meet any of the following conditions: (C1) Customer contacts ASD Technical Support and pre-arranges the scheduling and RMA numbers for routine re-calibrations and check-up at least 60 Days in advance of shipping the items to ASD.
(C2) Customer contacts ASD Technical Support and pre-arranges the scheduling and RMA numbers for non-routine warranty and extended service contract repairs before shipping the items to ASD. This same scheduling policy applies to any work not covered under warranty or extended service contract. (C3) Customer reads the ASD Manuals and operates ASD products correctly. (C4) Customer does not tamper with the internal components or assembly of the products covered. (C5) Customer does not operate ASD products with power supplies, computers, software, or other optical systems or instrumentation that are not approved by ASD.

COVERAGE DETAILS (ORIGINAL ASD FACTORY WARRANTY & EXTENDED SERVICE CONTRACTS):
SOFTWARE: For the period of the extended service contract, coverage shall include software maintenance necessary for compatibility between the customer's current spectrometer and computer. Coverage for LabSpec Pro models is limited to computers that meet ASD specifications. This coverage assumes normal use and no abuse of the spectrometer. The following ASD software categories

and associated installations are covered: User interface: Spectrum calculation and display, data storage. Upgrades: Bug fixes, speed and data access enhancements, and user interface upgrades within the limits specified above. Media: floppy disks
EXCLUSIONS FROM COVERAGE: Excluded from coverage are new software or interface-hardware advances that are incompatible with the customer's current spectrometer and computer. Also excluded from coverage are Non-ASD software*, data and/or wages lost due to software malfunction.
HARDWARE: The warranty and extended service contracts shall cover replacement costs of any spectrometer components that cause the instrument to fall out of specifications. For the period of the extended service contract, coverage shall include interface-hardware maintenance necessary for compatibility between the customer's current spectrometer and computer. Interface-hardware coverage for LabSpec Pro models is limited to computers that meet ASD specifications. The following spectrometer components and associated
assemblies are covered: Optics: Gratings, lenses, and internal fiberoptics Detectors: Photo diode array, InGaAs photo diodes, or CCD's, & associated cooling modules Electrical: Electronic components, circuit boards, wiring, connectors, switches, power supplies, charging systems, scanner motor, scanner encoder Mechanical: Grating/detector housing, spindle, bearings, shutter, top plate, case, internal connection of fiber optic cable. ASD External fiberoptic cables: Manufacturing defects only.
This coverage assumes normal wear and tear of the instrument. Damage caused by abuse or carelessness will be charged normal repair rates for parts and labor.

EXCLUSIONS FROM COVERAGE: Computer and its accessories and non-ASD software*, data and/or wages lost due to malfunction, tripods, and reference standard panels*, damages to external fiberoptic cables.

WARNING: Fiberoptic cables must be stowed properly!!!!!!!!

CALIBRATIONS: The warranty and extended service contracts shall cover replacement of any ASD laboratory calibration that causes the instrument to be out of specification. Or, one set of ASD laboratory calibrations may be requested at the customer's discretion during the warranty or extended service contract period. This coverage assumes normal use and no abuse of the instrument. The following ASD laboratory calibration installations are covered: Wavelength: (+/- 1 nm, at specified wavelengths) Radiometric: Radiometric calibrations (previously purchased separately)
EXCLUSIONS FROM COVERAGE: Radiometric calibrations are not included as a standard part of the spectrometer or accessories and must be purchased separately. Therefore, if the calibrations have not been previously purchased, they shall not be covered by the warranty or extended service contract. Note: Reflectance and transmittance measurements are self-calibrated using the appropriate reference standard. If the user does not maintain that standard's properties, then data will vary accordingly.
ACCESSORIES: The original warranty shall cover replacement or repair of any ASD manufactured accessory that proves to be defective. These coverages assume normal wear & tear of the instrument and accessories.
EXCLUSIONS FROM COVERAGE: The warranty or extended service contract shall not cover instrument radiometric and noise performance to specifications where field-of-view limiters and non-standard fiberoptic cables are used. Radiometric calibrations are not included as standard with accessories. Therefore, if the calibrations have not been previously purchased, they shall not be covered by accessory warranty or extended service contract.
SHIPPING: The warranty and extended service contracts shall cover one-way 'UPS 3-day' or equivalent return shipping only (from ASD to the customer), for coverage's 1

through 4 above. Customer shall pay for shipping to: Analytical Spectral Devices, Inc. main factory.

EXCLUSIONS FROM COVERAGE: Customs, import duties, taxes, Insurance, next-day freight, or special courier are not covered.

CHANGES: Coverages and Prices are subject to change without notice. To secure the terms as specified herein, please contact ASD for a firm quotation.

*These items are warranted separately by their manufacturer. The customer is solely responsible for sending in the appropriate registration cards, and for dealing directly with these manufacturers regarding non-ASD warranty issues.

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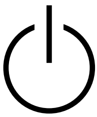
Important Symbols



Power Button

Caution symbol.

Refer to the manual for warnings or cautions to avoid hazards, or damage to yourself or the product.

Cleaning

Keep dirt and grime from the vents at the top of FieldSpec® Pro. After FieldSpec® Pro is completely powered down and cool, and disconnected from all power, clean lightly with a damp cloth and mild soap. Be sure all soap residue is removed and all surfaces are dry before use.

Declaration of Conformity

according to IEC guide 22 and EN45014

Manufacturer's Name: Analytical Spectral Devices, Incorporated.
Manufacturer's Address: 5335 Sterling Drive, Suite A
Boulder, CO 80301

declares that the product

Product Name: FieldSpec®Pro.
Product Number: A110000, A110010, A110030, A110048, A110050
A110057, A110060, A110070, A110073, A110080, A110081

Product Options: none

Conforms to the following EU Directives:

Safety: Low Voltage Directive, 73/23/EEC, as amended by 93/68/EEC

EMC: Electromagnetic Compatibility Directive, 89/336/EEC, as amended by 93/68/EEC

Supplementary Information:

The product complies with the requirements of the following Harmonized Product Standards and carries the CE-marking accordingly:

EN 61010-1:1993, plus Amendment A2: 1995

Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use

EN 61326-1: 1997, plus Amendment 1: 1998
Class A, Electrical Equipment for Measurement, Control, and Laboratory Use –EMC Requirements

Signature: Date 11/19/01

Title: Director of Engineering

For compliance Information ONLY, contact:

European Contact: Your local Analytical Spectral Devices Representative.

USA Contact: Product Regulations Manager, Analytical Spectral Devices, Inc.,
5335 Sterling Drive, Suite A, Boulder, Colorado 80301
Phone: (303) 444 6522

INTRODUCTION

As Analytical Spectral Devices (ASD) grows, so does our knowledge of field spectrometry instrumentation and applications. ASD field-portable FieldSpec® Pro Spectroradiometers, all function on the same basic principles. Thus, all of our instruments have evolved with similar structures, functions and operating procedures. This guide is intended for use with these FieldSpec® Pro models:

- VNIR (350 - 1050 nm) Spectroradiometer (including the HandHeld) ~ An excellent portable vis/nir unit. Often used for colorimetric analysis and vegetation applications.
- Dual VNIR (350 - 1050 nm) Spectroradiometer ~ Collects pairs of spectra from two separate inputs. Helpful for those who need to alternate between reference and target frequently.
- NIR (1000 - 2500 nm) Spectroradiometer ~ For those who strictly limit their analyses to the near infrared regions; excellent in Chemical applications.
- FR (350 - 2500 nm) Spectroradiometer ~ Our Full Range instrument, this unit is used in the widest variety of applications, including remote sensing, mineral analysis, vegetation analysis and more.

The spectral ranges for each of these instruments may vary. Individual detector characteristics and customer needs may affect the range of your FieldSpec® Pro.

A Special Note Regarding the FieldSpec® HandHeld (FSHH):

All discussion about ASD's UV/VNIR instrument pertains to the HandHeld, so this User's Guide is a useful tool for this system also. While the instrument's controlling software is run the same way, its performance and hardware configuration is slightly different. The HandHeld is slightly less sensitive, and communicates via a standard RS-232 serial port interface. This interface is considerably slower than the bi-directional parallel port described throughout this User's Guide, but allows the user to choose from among many more controlling computers. At this revision level, only the serial port interface is available for the HandHeld.

While the principles are the same, the operational characteristic of each model is sometimes different. In this case this manual will present special instrument details or instructions at the end of each section in this format:

VNIR

Everything written below this header would apply, to the FieldSpec® Pro VNIR instrument. If necessary, an "instrument-specific-mode OFF" type header will appear to alert you to information that applies to *all* instruments, like this:

IN GENERAL

Any time the manual begins a new topic or section (~Δ), the reversion to global application is implied.

Please read through this User's Guide. Contact ASD Technical Support with any questions. Contact information can be found on the cover of this manual.

INSTRUMENT CONCEPTS

~Δ Theory of Operation

The FieldSpec® Pro is a highly portable, general-purpose spectroradiometer useful in many applications requiring either the absolute or relative measurement of light energy. While its most highly regarded feature, besides its performance, is its field-portability, this unit performs competitively in the laboratory as well -- occupying less space in the process. The Pro model has been newly-configured for 21st century users who need the portability and ease-of-use a backpack design can provide.

Adding to the unit's versatility is the use of a fiber optic bundle for light collection. Inside the instrument, light is projected from the fiber optics onto a holographic diffraction grating where the wavelength components are separated and reflected for independent measurement by the detector(s). Each detector converts incident photons into electrons that are stored, or integrated, until the detector is "read out". At readout time, the photoelectric current for each detector is converted to a voltage and is digitized by a 16-bit analog to digital (A/D) converter. The digital data is then transferred directly to the computer's main memory using the Enhanced Parallel Port (EPP) on the controlling computer. The spectral data is then available for processing by the controlling software.

The Visible/Near Infrared (VNIR) portion of the spectrum, the 350 - 1050 nanometer wavelength domain, is most commonly measured by a 512-channel silicon photodiode array overlaid with an order separation filter. Each channel, an individual detector itself, is geometrically positioned to receive light within a narrow (1.4 nm) bandwidth. The VNIR spectrometer has a spectral resolution (FWHM of a single emission line) of approximately 3 nm at around 700 nm.

The Short-Wave Infrared (SWIR), also called the Near Infrared (NIR), portion of the spectrum is acquired with two scanning spectrometers. These differ from the array used in the VNIR in that they measure wavelengths sequentially, rather than simultaneously. Each spectrometer consists of a concave holographic grating and a single thermoelectrically cooled indium gallium arsenide (InGaAs) detector. The gratings are mounted about a common shaft which oscillates with a period of about 200 milliseconds (100 ms/scan). Unlike the VNIR, each SWIR spectrometer has only one detector, which is exposed to different wavelengths of light as the grating oscillates. The first spectrometer (SWIR1) measures light between about 900 - 1850 nm; the second (SWIR2) covers the region between about 1700 - 2500 nm. The controlling software automatically accounts for the overlap in wavelength intervals by using a preset wavelength within the common subset at which to place a "splice". The sampling interval for each SWIR region is about 2 nm, and the spectral resolution varies between 10 nm and 12 nm, depending on the scan angle at that wavelength.

~Δ Light Collection

Light energy is collected through a bundle of specially formulated optical fibers which are precisely cut, polished and sealed for the most efficient energy collection we could provide. The fibers themselves are a "water-free" composition providing the lowest NIR light attenuation available. The fiber optic cable has a conical view subtending a full angle of about 25 degrees.

Light may be collected with a bare fiber optic, or with the use of a fore-optic device, designed for individual applications. A variety of fore-optics are available from ASD which serve a number of functions, including: 8 or 1degree Field-of-View (FOV) reduction tubes, Remote Cosine Receptors (RCR) and a number of angle-limiting lens fore-optics, designed to reduce the FOV without cutting out too much energy input. Instrument response can change drastically with the use of certain types of fore-optics.

You, the user, must tell the software when foreoptics are changed so that it can interpret how to catagorize the data.

FR and NIR

Since these two instruments are made of more than one spectrometer, the fiber optic bundles are separated into two (NIR) or three (FR) separate bundles inside the instrument. Each of these bundles then delivers the collected light to the entrance slit of *one* of the spectrometers.

You may have noticed that there are different fore-optics used for the FR and NIR instruments than for the VNIR. There is good reason for this: The larger fiber bundle used for the FR and NIR causes the input end of the fibers to view an area greater than the fibers of a VNIR bundle, making optimum optical geometries and lenses for the two instruments different from those of the VNIR.

Dual VNIR

The configuration of this unit makes it possible to measure a target and reference simultaneously. This unit also consists of more than one spectrometer, but the spectra are not spliced together. Rather they are actually separate, identical instruments using the same space and interface. Therefore, given the need and the uses for such an instrument, the fiber optic cables are separate from each other. It is also common, with this unit, to have an additional jumper cable, i.e., a removable fiber optic extension cable (as long as 10 meters) attached to one or more of the inputs.

~Δ Optimization

For ASD instruments, optimization is much the same as the process of pupil dilation in your own eyes. It is your unit's means of adjusting sensitivity to varying conditions of illumination. The FieldSpec® Pro can do this in two ways: The VNIR region (the array) has a software-adjustable integration time, which determines how long the array will collect energy in the 350 -1050 nm region. The SWIR scanners (1000 - 2500 nm) use automatically adjusted gains to amplify signal.

VNIR

The integration time in your VNIR instrument is manually adjustable through the controlling software; either from the pull-down menu on the toolbar, or from the **Control|Configuration** menu. The choices are 2^n times 17 ms (milliseconds), from 17 ms up to several minutes. The response of the detector will be directly proportional to the integration time, so when a spectrum fills the screen, one more increase in integration time will most likely saturate the data set(report measured values "off-scale high).

Whenever lighting conditions change, even a small amount, it is always a good idea to look at RAW data to see that the integration time is set properly. Practice with the unit in varying conditions of illumination will help demonstrate what to expect with different integration times, light sources, angles and distances.

Dual VNIR

The integration times of both spectrometers behave as noted above, except that control over each spectrometer is independent of the other. Also, while integration times can be manually adjusted, the software will optimize each instrument for you, if desired.

FR and NIR

In the FR and NIR instruments, optimization is fully automated... Almost. You, the user, need to tell the instrument *when* to optimize. For the FR, the VNIR region has its integration time adjusted automatically to give the maximum allowable signal without saturation. The SWIR scanners, having a set scan time, do not have the luxury of an adjustable integration time. Therefore, NIR signals (1000 - 2500 nm) have their amplitudes adjusted by electronic gain. You will discover, during postprocessing of data, that a lower "gain" value, as listed in a data file's header, represents a higher actual gain. The controlling software sees gain as a denominator in its calculations, called Gain Factor. **When using the instrument in even slightly varying light conditions, it is *imperative* that optimization be performed frequently. When in reflectance mode, it is at least important to toggle back to raw DN mode occasionally, to see that there is no signal saturation at the top of the screen.**

FieldSpec® Pro data acquisition software now allows the user to see current integration time and gain settings during FR and NIR data collection, through the Pan/Zoom/Coord/OptPar toggle key. Choose Opt Par to view these settings, by clicking on Pan button or F5. These settings are also always viewable and may be incorporated in postprocessing, when applicable.

~Δ Dark Current and DCC

A certain amount of electrical current is generated by thermal electrons (called dark current), and is added to that generated by incoming photons. It is a property of the detector and the associated electronics (not the light source) and varies with temperature and, in the VNIR region, integration time. If accurate data is to be obtained, the dark current (DC) at each channel must be subtracted from the total signal at that channel. This DC measurement can be updated at any time, but should be updated more frequently in the beginning of a given session, as the instrument warms up. You can perform your own tests on DC variation with temperature and time (VNIR region only) by masking the end of the fiber optic probe and viewing/saving raw spectra periodically. Instrument's with ASD's new DriftLock feature enabled should demonstrate very little DC variation over time.

Note that there is a distinct difference between Dark Current and Noise. Dark current is an offset, often in the thousands, in raw Digital Numbers (DNs) (counts), that may be assumed to be relatively constant. The more stable, and therefore more predictable, it is, the easier it may be calculated out of your spectra. Noise, by definition, is unpredictable. It is the uncertainty in a given measurement, *one channel at a time*, that may be quantified by a standard deviation. Entire spectra of noise values may by calculated with the standard deviation from the mean of 25 or more spectra collected of a source *known* to be stable. Note that darkness itself is a stable source by nature – a measurement series of dark currents, if taken, would have noise values nearly identical to one taken of a bright and stable light source.

Now, more about dark current: Since the VNIR region is covered by an array of many detectors, with varying sensitivities and properties, dark current must be subtracted on a channel-by-channel basis. Whenever dark current is taken, a mechanical shutter is used to block off the entrance slit of the spectrometer so that the signal can be measured. This signal is subtracted from each subsequent spectrum, until another DC is taken.

The dark current shutter is an electro-mechanical device, so there is another level of dark current created by the simple electronics that hold it closed. ASD measures this offset and stores it in the DCC (Dark Current Correction) entry in the instrument's initialization file, ASD.INI. The controlling software automatically corrects all spectra taken with the shutter closed to account for this minor complication.

Caution: *Do not make any changes to ASD.INI unless instructed to by ASD or as a specific step in this User's Guide. This file is user-configurable and editing it will alter instrument performance (often a bad thing). Call or email ASD technical support for more details about this file.*

VNIR

A dark current measurement will be taken whenever the user instructs the software to do so. This is usually done either: 1. With the DC button on the toolbar, or 2. When taking a White Reference for reflectance measurements, or 3. With the dark current hotkey, F3.

Dual VNIR

A dark current measurement will be taken whenever the user instructs the software to do so, *or* automatically, at the beginning of each spectrum collection, if so desired. Manual DC correction can be done either: 1. With the DC1 (spectrometer 1) button on the toolbar (or DC2), or 2. With the dark current hotkey, F3 (spectrometer 1) or Shift+F3 (spectrometer 2). Automatic dark currents may be collected and subtracted from each spectrum by flagging the option in the Auto Menu.

FR and NIR

Because the SWIR detectors consist of one detector per scanner, a single dark current measurement is taken with each scan. At the long wavelength end of each scan, a mechanical arm effectively blocks the entrance slit of each detector, providing a number of dark current reference channels. The data collected from these channels is averaged and automatically subtracted from the entire spectrum covered by that detector in real-time.

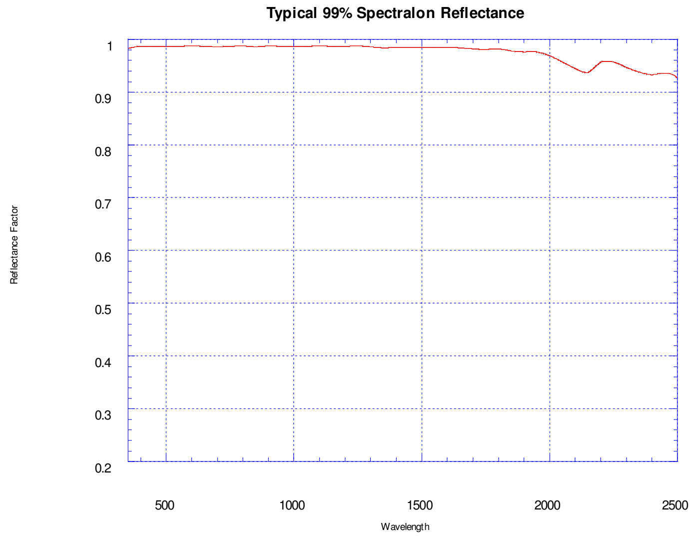
A dark current measurement for the VNIR region (FR) will be taken whenever the user instructs the software to do so. This is usually done either: 1. With the DC button on the toolbar, 2. When taking a White Reference for reflectance measurements, 3. During Optimization, or 4. With the dark current hotkey, F3.

~Δ Spectra

The raw data (**raw DN**, for "digital numbers") returned by the FieldSpec® Pro are, 16-bit numbers corresponding to the output of each element in the VNIR detector array and each 2 nm sample of the SWIR spectra. All other data types: reflectance, transmittance, radiance and irradiance, are calculated by the software from these raw digital numbers. Raw data is a function both of the characteristics of the light field being measured and of the instrument itself. Parameters such as the foreoptic transmission, fiberoptic transmission, grating efficiency, and detector sensitivity all vary with wavelength. This results in a raw spectrum whose shape can be very different from that of the radiance spectrum of the light field being measured. Because these parameters do not vary with time, though, a linear relationship does exist between the raw spectra and the intensity of the light field being measured.

Reflectance is the actual fraction of incident light that is reflected from a surface, while **transmittance** is the fraction of incident light that passes through a given material. Both are inherent properties of that material and are independent of the light source used on the sample. **Because the instrument only measures the intensity of a light field through a given point in space, reflectance and transmittance are computed with measurements from both the unknown material and a reference material with known reflectance or transmittance properties.** This reference material is referred to as either the "reference panel" or the "reference standard". A material with approximately 100% reflectance across the entire spectrum is called a white reference panel or white reference standard. These ratio spectra are calculated in real time with most FieldSpec® Pro models. For the characteristics of the illumination source to be removed in the division, the illumination geometry must be the same for both the unknown and the white reference spectra, and the light source must be stable while both spectra are measured. Any variations can result in unusable data.

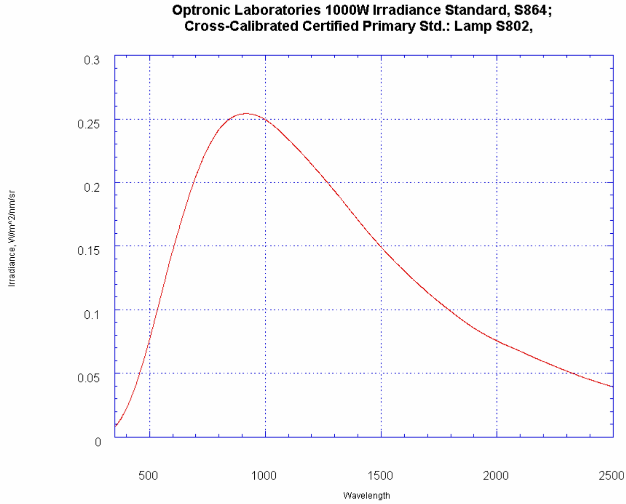
Relative reflectance (the reflectance *factor*), which is the quantity that the FieldSpec® Pro actually measures, can be converted to absolute reflectance in postprocessing by multiplying the reflectance factor spectrum by the actual calibrated reflectance spectrum of the reference standard. Viewing geometries must still be taken into account, because even the best reflectance standard is not a perfectly lambertian reflector, i.e., perfectly reflective, and uniformly radiative in all directions. If you have a *calibrated* reflectance standard, consult its accompanying documentation for further details. For most purposes, an *uncalibrated* reference standard, such as uncalibrated 99% Spectralon® (Labsphere, Inc.), has the near-perfect properties needed for sufficient reflectance data collection.



In order for your instrument to be used to take *radiometric* spectra, it must first be radiometrically calibrated separately with each foreoptic. Radiance ($W/m^2/sr/nm$) can be measured with the bare fiber optic (NFOV) or with directional foreoptics, such as FOV limiters. Irradiance ($W/m^2/nm$) is measured using the remote cosine receptor, which integrates the light flux from all directions that would be intercepted by a planar surface. Again, since the raw spectra returned by the instrument are functions of both the light field and instrument characteristics, a ratio technique is used to remove the effects of the instrument on the spectra. When the unit is calibrated, a raw, dark current corrected spectrum is measured for each fore-optic while viewing a radiance or irradiance source of known intensity. These spectra are known as instrument response functions, and are unique with each foreoptic used. The formula for radiance, for example, at a given channel for a given foreoptic is:

*rad = (known * input) / response*

where *rad* is the calculated radiance, *known* is the known radiance of a calibrated white reference panel illuminated by a calibrated light source, *input* is the dark current corrected input (unknown, in raw DN) spectrum, and *response* is the value of the calibration spectrum (collected at calibration) for that fore optic, also in raw DN. Irradiance is calculated in the same way, except that it uses the known irradiance of the calibration lamp itself, at a given distance, rather than the radiance of the illuminated panel. Of course, this equation is oversimplified, since integration time or gain must be included in the calculation, as well. It must also be noted that calibrations are performed on a fully warmed up instrument, since detector characteristics can change with temperature, particularly in the longer wavelength end of the VNIR detector. Further details will be presented later in this manual (Appendix C).



~Δ Real-time Radiometric Data

While radiometric data can be calculated and saved through the use of the ASD postprocessing utilities, ViewSpec® Pro and RCALC.EXE for MS DOS, it can also be performed with the new

"Rad" button in the FieldSpec® Pro Software, RS^2. The parabolic correction routine described in Appendix C may also be performed in Real-time, using the "PC" button. These functions can also be done with your own routines or through some of the more advanced spreadsheet data analysis programs. This is an extremely tedious process, though, so you may wish to consult with ASD technical support for further details.

~Δ Spectrum Averaging and Noise

The bane of all electrical data analysis is noise. Noise, in all of its forms, manifests itself in detection equipment of any kind as an uncertainty of measurement.

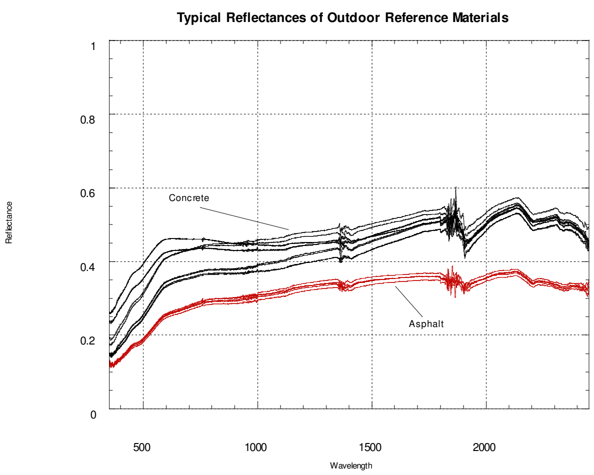
Fortunately though, the majority of noise, by its very nature, is random. This means that it can usually be reduced in the desired spectral signal by a technique called spectrum averaging. If the noise is truly random, then it will be reduced by an amount proportional to the square root of the number of spectra averaged together. Thus, 16 spectra averaged will have one-quarter the noise of a single spectrum, and an average of 64 spectra will have half the noise of 16, and so forth. FieldSpec® Pro software is all set up to do this averaging for you. The cost, of course, is the time it takes to collect the spectra for a single display or file. A 100-sample spectrum will take roughly ten times the time needed to acquire 10 samples. With the FieldSpec® Pro units, you can collect spectra based on an average of any number from one to around 32,000 samples, although in theory, it would take almost an hour to collect a 32,000 sample average! In order to be effective in an attack against noise though, you must *also* collect an equivalent average of dark current spectra (VNIR region only) and, for a reflectance spectrum, an equivalent average of the white reference spectra as well; noise affects all of these equally, so they must be taken into consideration in spectrum averaging.

Most researchers find that a sample average of around 10 to 25 is sufficient. Some need an even better Signal-to-Noise (S/N) ratio than this can provide, but prefer to average some of their own spectra in post-processing, to help eliminate any possible spectral anomalies due to an unusual sample or poor geometry. For example, if a field researcher needs one spectrum to represent the ground foliage on 10,000 square meters of land (and there are no aircraft available for the purpose), he or she might stand on top of a ladder or scaffold in several locations on the land, or merely walk the land, and take a total of 10, or even 100, spectra of 25 to 100 samples each, depending on lighting conditions and humidity. No single one of these spectra is likely to be perfectly representative of this plot, but an average of all of them, calculated through post-processing, will certainly be close!

Also, averaging shorter measurements in post-processing allows you to deal with pesky *low*-frequency noise associated with partial cloud cover, wind and motion through shadowed areas like under forest canopy. Sometimes, if too many files are averaged in real-time, by the time even a white reference is performed you may find the lighting conditions are changed – before you've even had the chance start collecting data you can use.

Most of us reduce noise through averaging spectra both in real-time and in post-processing. Spectrum averaging should be performed in post-processing with care, though; particularly when signal is very low. FieldSpec® Pro instruments use signed arithmetic (positive & negative values) in calculating spectrum averages, but do not write these negative values to file when finished. Therefore, negative values are written to final data as zero values, which should NOT be incorporated into an average in postprocessing, because of their false nature. In addition, an equal number of upper outliers should be discarded to compensate for the loss of these negative values. The simplest solution is to use Median values in postprocessing, rather than averages. You should find that when the number of spectra is greater than 25 or so, the difference in S/N improvement is negligible, and the low values in your spectra, such as those in water bands and other saturated absorption bands will be more accurate when using the median than the mean

You may be curious, now that it has been mentioned, about what effect humidity can have on noise and S/N. It typically only has an effect in outdoor (solar illumination) lighting conditions. And in reality, it has no actual effect on noise itself. What it does affect, however, is Signal (the numerator in S/N). When viewing raw data, one thing that may be found striking is how clear the signal appears, this can be deceiving. The range of the response is a number between zero and about 65,000 DN; so it can be difficult to see small changes of a few tens of DN in the response. In reflectance mode, where two spectra are divided on into the other, these changes become very apparent indeed when signal strength is low. In particular, signal tends to be quite low outdoors at around 1.4 and 1.9 microns, due to the absorption of those wavelengths by water in the atmosphere. ASD continues to make strides in finding ways to reduce inherent electronic noise in the instrumentation, so that it poses less and less of a problem in low signal conditions and keeps S/N as high as it can be.



Typical outdoor reflectance under very dry, clear, mid-day conditions.

~Δ Data Storage

The FieldSpec® Pro software uses the controlling computer's mass storage devices (floppy and hard disk drives, for example) to save spectra as the user chooses. The user *must* set up his or her file-saving preferences from the **Spectrum Save** setup window prior to a save session.
Before spectra are saved, a pathname (C:\FR, C:\VNIR, etc. are the defaults) and a base name for the files should be chosen (SPECTRUM is the default). You may also wish to specify how many files to save with one stroke of the save key, what the starting file number will be, and any additional descriptive comments that would fit the situation. Further details about how to set up a save session will be described later.

Spectra are saved in binary format on disk in order to save space. Spectrum translation utilities such as **PortSpec**, **STable** and **SView** (VNIR units only) may be used to convert the header and data to Human-readable text values and view individual spectra from binary data, respectively. A utility, ViewSpec® Pro, is also available to view and postprocess ASD binary data files.

~Δ Calibration and the .INI file

The raw data returned to the controlling computer consists of a set of data points, the domain of which is the channel numbers (0, 1, 2, 3, ...). Each channel represents a particular wavelength centered on a change of wavelength value (about 1.4 nm for the VNIR region, for example). Because it is generally more useful to know a particular data point's wavelength value rather than its channel number, each instrument is calibrated for these values before it leaves the factory at ASD. The information for this wavelength calibration, among other things, is contained in a file called ASD.INI. This file should never be edited, tampered with or switched between instruments, since it contains vital and *unique* information for the specific instrument. If, for some reason, your ASD.INI file has been lost or damaged, please contact Technical Support at ASD. We retain backup files for each instrument. The calibration of each instrument is unique, with both an instrument number and a calibration number. For example, instrument #201 begins life as 201/1. If it is shipped back to ASD for a recalibration, it will continue as 201/2, and so forth.

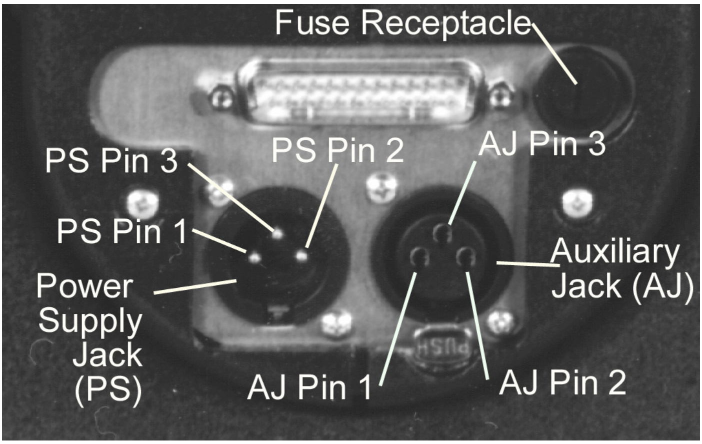
IMPORTANT Safety Precautions & Technical Information

For your safety and to prevent damage to the FieldSpec® Pro, please review the following safety precautions. Please also review the previous section entitled **Important Symbols**. All operators of FieldSpec® Pro should be familiar with this information.

Power Supply

An External Power Supply powers FieldSpec® Pro from a wall receptacle and recharges the FieldSpec® Pro batteries. On one end of the Power Supply is a three-pronged plug (Standard United States 110V) that goes to a wall receptacle. On the other end of the box is a Switchcraft Plug that has been custom-wired by ASD for FieldSpec® Pro.

NOTE: Do not attempt to use non-ASD power supplies or connectors to power FieldSpec® Pro!



Please refer to the 'Set-up Section' of this manual for instructions on the proper installation of the Power Supply. The Switchcraft Connector Power Supply Jack, Auxiliary Jack and Power Fuse are located on the lower backside of FieldSpec® Pro, details above.

See the Specifications section of this manual for power requirements of the FieldSpec® Pro.

The Power Supply Jack (PS) Switchcraft type.

PS PIN 1: 18Vdc PS PIN 2: No Connection PS PIN 3: Ground

Fuses

The FieldSpec® Pro Power System is protected by an external fuse. Do not use fuses other than those specified and do not attempt to override the fuse! The location of the fuse receptacle is shown in the picture at the beginning of this section. Check the fuse label for the correct replacement fuse for your model of FieldSpec® Pro. Replace the fuse by using a small flat blade screwdriver, push in on the fuse cap and rotate it counterclockwise. Remove the fuse cap and fuse.

CAUTION: Fuses contain glass, which can break and cause injury.

Dispose of spent fuse properly.

Auxiliary Jack (AJ)

A 3-PIN Switchcraft Connector Auxiliary Power Jack is provided on Pro for optional ASD approved accessories, which are sold separately. Please contact ASD for information about these accessories. For your safety and the protection of FieldSpec®Pro, never attempt to use unauthorized accessories on the Auxiliary Jack. Please refer to the picture at the beginning of this section. The specifications of the Auxiliary Jack are as follows:

AJ PIN 1 The Pin provides 18Vdc @ 2A (36 Watts) when the FieldSpec® Pro External Power Supply is attached.
The Pin is inactive when the FieldSpec® Pro External Power Supply is not attached.
AJ PIN 2 The Pin provides 12Vdc @ 2A (24 Watts) when the FieldSpec® Pro External Power Supply is not attached.

The Pin is inactive when the FieldSpec® Pro External Power Supply is attached.

AJ PIN 3 Ground

The 'PUSH' button at the bottom of the jack is to assist in

removing the accessory 'male'-version Switchcraft Plug.

Electrical Ground

When using the External Power Supply connected to a wall receptacle, FieldSpec® Pro is electrically grounded through the ground lead of the power cord - power supply box - Switchcraft system. The wall receptacle must be correctly grounded to an earth ground. A receptacle that is not properly grounded could lead to safety hazards and instrument damages.

Batteries

FieldSpec® Pro is shipped with the battery installed and partially discharged. Follow the instructions in the 'Unpacking and Setting Up 'FieldSpec® Pro' section of this manual for replacing and charging the battery. See page 29, "Battery Check & Replacement."

The specifications of the FieldSpec® Pro Batteries are as follows:

Type: NIMH
Built-in Overcurrent and Thermal Protection
Nominal Full Charge Time: 3.6 Hours
Output Rating: 9.0 AmpHours
FieldSpec Pro Continuous Operating Discharge Time (Lamp on) at standard room temperature: 2 Hours
ASD Part Number: Contact ASD for the appropriate part number for your Model Year Series.

Do not use batteries other than those supplied by ASD. Do not use ASD batteries in a manner unauthorized by ASD.   Using improper batteries or improper use of ASD batteries could result in damages to FieldSpec® Pro and safety hazards.

Safe Disposal of Batteries

You can recharge the batteries many times, so they should last for years. You must discard a battery if it becomes damaged or will no longer recharge.

CAUTION: Putting spent batteries in the trash might be illegal. Dispose of batteries as required by local ordinances or regulations. Check with you local government for information on where to properly recycle or dispose of batteries.

Battery Internal Charger

The Battery Status Indicator Light should also function according to the following color codes:

Off:	No Battery Connected or running on battery power only.
Solid Yellow:	Charging
Green:	Fully Charged
Yellow Flashing:	Standby or Battery out of temperature range
Red:	Error (exceed time limit, shorted terminals, etc.)

Note: Older model years may have different status indicator patterns than that listed here.

Auxiliary Battery Charger

Optional External Auxiliary Battery Charges are available at additional cost. Contact ASD for information and safety sheets on the appropriate Charger for your Model Year Series.

Unpacking & Setting Up FieldSpec® Pro

Inspect the shipping container and take careful notes regarding any damages that might have occurred during shipping. Save all packing materials and paperwork for possible future use.

Prepare a clear space on a sturdy bench or counter for FieldSpec® Pro. 2 feet wide x 2 feet deep x 2 feet high is just about right, not including space for your computer. Ideally, try a space near a wall-current receptacle as well as your computer.

Carefully open the shipping container following all instructions and orientation labels on the container.

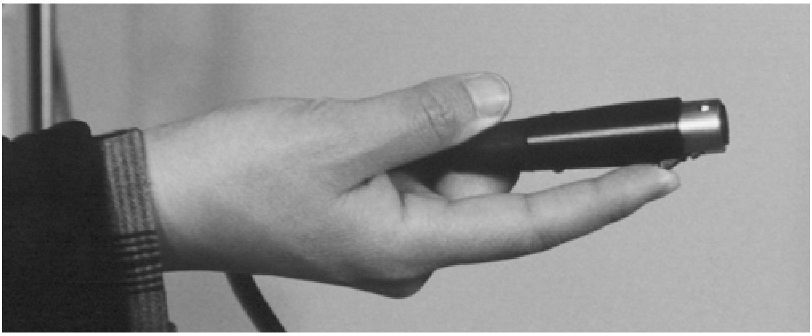
The first item to find is the trough-shaped FieldSpec® Pro Stand. Once you have found the Stand, place it on a counter in the center of the space for FieldSpec® Pro as shown in the picture above.

The next item to find is FieldSpec® Pro. **Note: The fiberoptic cable extending from the front of the FieldSpec® Pro. Use caution to ensure that this fiberoptic cable is not damaged. See " Instrument Care & Handling.** When removing FieldSpec®

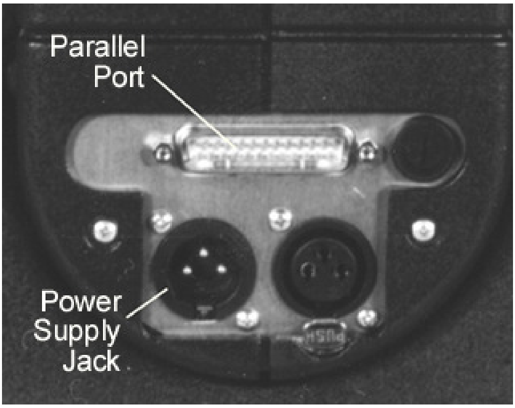
Pro from its carrying case, gently pull the fiberoptic cable from the compartment in the bottom before pulling upward on the instrument. (Photo p. 39 showing fiberoptic cable). Lift FieldSpec® Pro by the handle at its top and insert it into the stand making sure that the two mounting posts in the trough of the stand insert into the holes in the bottom of FieldSpec® Pro. The weight of FieldSpec® Pro should push it down into the trough so the fit is snug and the posts hold the stand onto FieldSpec® Pro. For clarity, we show the backside of FieldSpec® Pro with the computer port and power jacks as shown in the picture on the right above.

FieldSpec® Pro Cables, Plugs, and Power

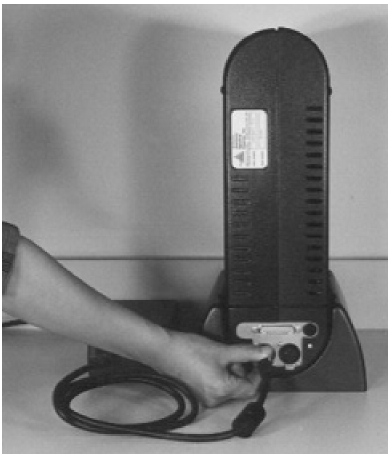
Next, find the FieldSpec® Pro Power Supply box with its Switchcraft plug, and its pronged Power Cord. If you have not done so already, review the IMPORTANT Safety Precautions & Technical Information section of this Manual now. The Switchcraft plug is shown in the picture below. The metal protrusion at the tip of the finger is the release clip, which is to be pressed-in only when detaching the plug from FieldSpec® Pro.



The holes in the Switchcraft Plug shown above are to align with the PS Pins in the left Power Supply Jack shown in the picture below.



Making sure that the Switchcraft Plug holes align with the Jack pins and that the release clip is pointing downward, push the



Switchcraft Plug into the left Jack as shown in the picture on the below. You should hear a click and then the Switchcraft Plug should be firmly connected.

Plug the non-pronged end of the Power Cord into the Power Supply Box Receptacle. The entire power set-up should look like the picture below.

Power-Sequence

Depending on the computer and the communications between your computer and FieldSpec® Pro a 'Power-Sequence' is typically required. Omitting the proper Power-Sequence can possibly result in damages to your computer and/or FieldSpec® Pro. Since it is not possible for ASD to test all computers to find the ones that require the Power-Sequence, we advise you to adhere to the following Power-Sequence rules regardless of your computer, even if you purchased the computer from ASD.

Power-Sequence Rule 1: When your computer is connected to FieldSpec® Pro, power up FieldSpec® Pro first, then power up your computer.

Power-Sequence Rule 2: When powering down, power down your computer first, then power down FieldSpec® Pro.

Power-Sequence Rule 3: If you must operate your computer when FieldSpec® Pro is powered down and turned off, do so with FieldSpec® Pro fully disconnected from your computer.

Power-Sequence Rule 4: As long as you have followed the Power-Sequence, you may leave your computer turned-on and connected to FieldSpec® Pro while the FieldSpec® Pro is also powered up and turned on.

ASD shall not accept liability or responsibility for FieldSpec® Pro or computer damages, lost data, or lost wages that result from violation of any of these Power-Sequence rules.

Parallel Port connection

The FieldSpec® Pro Parallel Port connection to the computer is shown in the picture below.

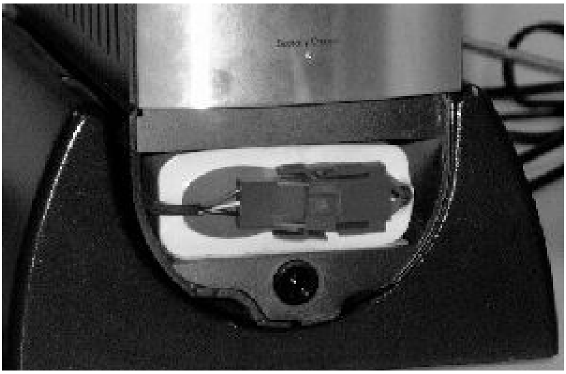
FieldSpec® Pro Battery Check and Replacement

The FieldSpec® Pro is shipped with its Battery installed and partially discharged. To verify that the Battery and the internal FieldSpec® Pro Charging System are functioning correctly, you should check that the Battery is correctly installed now. While you are running FieldSpec® Pro on wall power using the AC/DC Adapter, the Battery will be charging by its internal charger.

IMPORTANT: Review the Power Sequence section above. Make sure that FieldSpec® Pro and your computer are completely powered down and turned off.

Pull/pop out the bottom of the front bezel plate as shown in the picture above, note the FieldSpec® Pro's plate is plastic.

The battery should be connected to the FieldSpec® Pro Battery Cable as shown below.



To remove the battery, press on the Cable Connector clips and gentle pull the two halves from one another as shown below.

Connect the battery to the instrument as shown in the picture above.

NOTE: The Battery Connectors on your model year FieldSpec Pro may differ from the one shown here.

Gently remove the Battery. If the battery is spent, dispose of it properly.

Safe Disposal of Batteries

You can recharge the batteries many times, so they should last for years. You must discard a battery if it becomes damaged or will no longer recharge.

CAUTION: If not properly replaced, used, handled or disposed, the battery might explode. Putting spent batteries in the trash might be illegal. Dispose of batteries as required by local ordinances or regulations. Check with you local government for information on where to properly recycle or dispose of batteries.

To re-install the battery reverse the procedure above. Once the battery cable has been connected, be sure to check that the Connect clips are fully locked into place and the Connection does not pull apart.

As shown below, notice the black Mounting Post at the bottom of the bezel section, which will pop into the Mounting Hole just below the Battery Receptacle.

Making sure that the wires of the Battery Cable are not pinched or protruding out of the Battery Receptacle, replace the bottom bezel plate section by inserting the straight top edge of the bezel into the lip of the upper bezel as shown above.

Push the bottom of the bezel plate in so that the Mounting Post pops into the Mounting Hole.

The Battery Status Indicator Light should function according to the following color codes:

Off:	No Battery Connected or running on battery power.
Solid Yellow:	Charging
Green:	Fully Charged
Yellow Flashing:	Standby or Battery out of temperature range
Red:	Error (exceed time limit, shorted terminals, etc.)

(Older model years may have different status indicator patterns than that listed here.)

FieldSpec® Pro OPERATION

~Δ Instrument Care and Handling

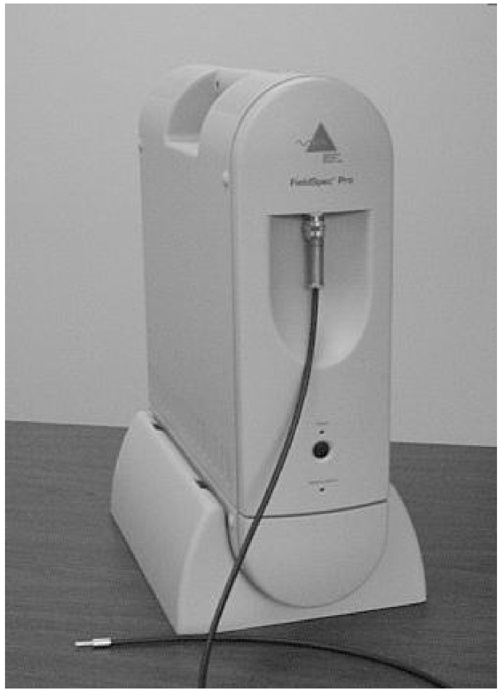
Be prepared for some fun, *now*, because your FieldSpec® Pro was shipped fully prepared and accessorized for indoor use. You *may* have to charge the FieldSpec® Pro battery pack(s) and/or the controlling computer battery for outdoor use.

ASD instruments are designed to be durable, but they should be treated like any other piece of valuable hardware. Avoid dropping the unit; the impact can cause misalignment of the sensitive optics or disconnection of any number of electrical connectors inside.

The ventilated case for the FieldSpec® Pro is weather resistant but not weather proof. When the system is carried in its FS Pro carrying case with one of ASD's custom rain bonnets, light rain is acceptable, total submersion is not. The unit is never air or watertight, due to the FS Pro's ventilation plenum. The original FieldSpec® system can still be manufactured as a custom unit for greater weather resistance, but the benefits of air cooling and the backpack design would be lost.

The fiber optic cable is waterproof, but if water beads on the cable and runs down into the instrument (possible if the system is laid down), it *can* penetrate the unit. Be careful to wipe any excess water from the fiber cable when it is noticed. When not in use the fiber optic cable should be coiled loosely and stored in the compartment provided in the bottom of the carrier. The pistol grip accessory may be left attached to the cable, though any sharp or heavy objects stored with the cable can damage the delicate fibers during transport. If the pistol grip and/or foreoptics are stored in the fiber compartment, they should be packed carefully in soft cloth or bubble wrap to fill the compartment and keep them from moving around. The tightening clamps at the entry point for the optical cable into any cable accessory should not be tightened more than is necessary for holding the cable firmly in place. Tightening with a tool can damage the optical fibers. The Remote Cosine Receptor needs a little extra tightening to make sure the cable is seated firmly, so it is advised that the cable not be left in this accessory for extended periods of time, between data collection sessions, as this tight clamp can weaken the cable jacket over the months and years.

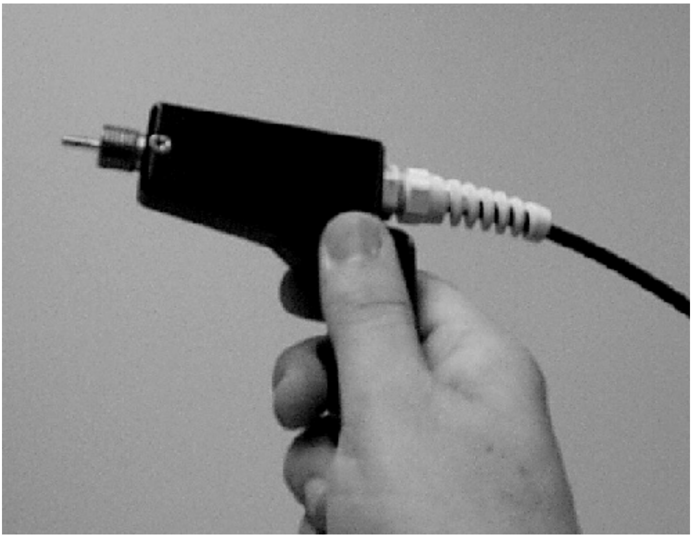
In addition to the fiber optic cable, the most *fragile* part of the whole system is the notebook computer that controls it. The setup, operation and maintenance procedures for the PC can be found in its own accompanying documentation. For your convenience, the PC is configured before shipping it with your instrument.



The FieldSpec® Pro

~Δ Indoor Operation

As a matter of convenience, it usually helps to remove the instrument from the ASD carrying case and stand it securely onto the supplied base unit. When carrying the FieldSpec® Pro from one place to another indoors, it is advised that you support this base unit with one hand to keep it from dropping unexpectedly. Plug the AC adapter that came with the instrument into an AC outlet and connect the cable from the power supply into the three-pin plug on the back plate of the FieldSpec® Pro. If needed, plug the controlling computer's AC adapter into an AC outlet and connect it to the appropriate jack on the computer. It's always a good idea to use the PC from wall power when possible as this will help keep its battery charged and ready for field use.



Positioning of the Fiber Cable in the Pistol Grip

Uncoil the fiber cable and mount foreoptic accessories as necessary. The pistol grip, remote cosine receptor and mirrored foreoptic with pistol grip have a two-piece cable clamp on the back or side of the device. Unscrew the female portion and slide it onto the fiber optic cable. The end of the cable should be inserted into the rear of the accessory you intend to use and wiggled gently until you are sure it is fully seated. Now slide the cable clamp into position and tighten securely only until the cable is held firmly. DO NOT over tighten the clamp, or use any tools for tightening, as this could damage the fiber optic jacket, weakening the protection around the fibers themselves.

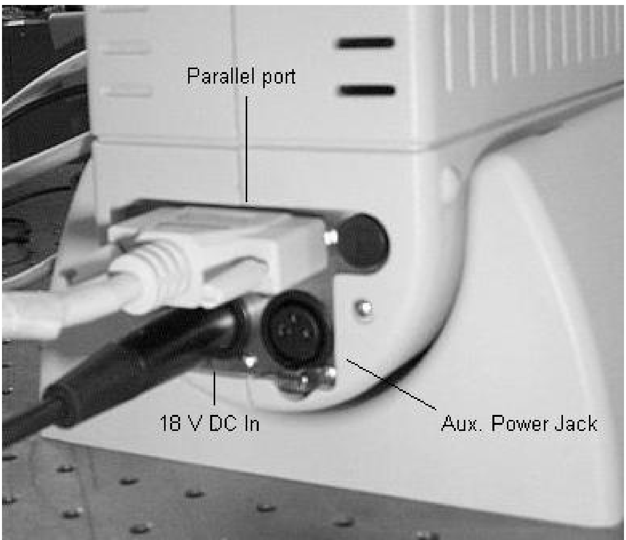
FieldSpec® Pro Power and Port Cable Basic Setup (indoor)

IMPORTANT: Turn on the instrument FIRST, then turn on the controlling computer. The parallel port communications between the instrument and the computer are bi-directional, and the electronics inside the instrument are considerably more sensitive (and expensive) than those in the computer. When the computer is on, in any mode, without the instrument being on, small currents are generated in the communication lines, which **may** cause damage to the instrument electronics over extended periods.

Start the instrument controlling software according to instructions following, under Software Interface.

~Δ Outdoor Operation

Before operating your instrument outdoors, ensure the battery packs for both the controlling computer and the FieldSpec® Pro are charged. Follow the computer's documentation for specific charging instructions. In general, whenever operating the system indoors, keep the instrument and the computer powered with AC power, this will help keep the batteries charged. Some computers have adapter cables available that can be modified by ASD for operation through the Auxiliary Power jack. Consult ASD Technical Support for details, if you are unsure about this function.



~Δ Auto-Adapter Instructions

This auto adapter (DC/DC adapter) allows the user to power the computer from the FieldSpec battery, through an Auxiliary Power Jack.

To use:

1. Verify that PC battery is fully charged and PC is running with wall power (AC adapter).
2. Verify that FieldSpec Pro 12V battery is fully charged and running with wall power (18V power adapter).
3. Plug auto-adapter into Auxiliary Power Jack on back of FieldSpec.
4. LED on auto-adapter will not light. (Power indicator)
5. Unplug 18V FieldSpec power adapter from back of FieldSpec.
6. LED on auto-adapter should now light. Contact ASD Tech Support if LED does not light.
7. Unplug AC power adapter (wall power) from computer.
8. Plug auto-adapter into computer. Computer should "think" it is running of AC power.

With a fully charged PC battery and a fully charged FS 12V battery, you should get approximately two hours of operation.

The FieldSpec® Pro battery pack must be charged with the AC adapter that came with the instrument, either with the instrument running or without. Plug the adapter into your AC source, and the three-hole female plug into the input socket on the back plate of the system. The internal Pro battery pack must be connected in the lower compartment of the instrument in order for it to charge. Charging of a totally discharged pack should be complete within 4.5 hours for each battery, so give yourself plenty of time, especially if you have more than one battery pack to charge. The Battery Status Indicator Light should function according to the following color codes:

Off: No Battery Connected or running on battery power.
Solid Yellow: Charging
Green: Fully Charged
Yellow Flashing: Standby or Battery out of temperature range
Red: Error (exceed time limit, shorted terminals, etc.)

(Older model years may have different status indicator patterns than that listed here.)

Always be careful with the Fiber Optics

The instrument may be slid gently into the FieldSpec® Pro carrying case for assembly with the Pro Backpack Frame. When sliding the system into the case, always lead with the fiber cable to avoid catching it on the edge of the case. When removing the unit from the case, gently pull the cable from the compartment in the bottom before pulling upward on the unit.

The carrier fits securely onto the Pro backpack frame, using the J-tab and slot at the bottom of the carrier, *in addition to* the hook-and-loop straps for securing the carrier handle-bars to the carrier frame.

Follow the simple guidelines in the **Indoor Operation** section (previous) for arranging the fiber optic cable into the appropriate accessory.

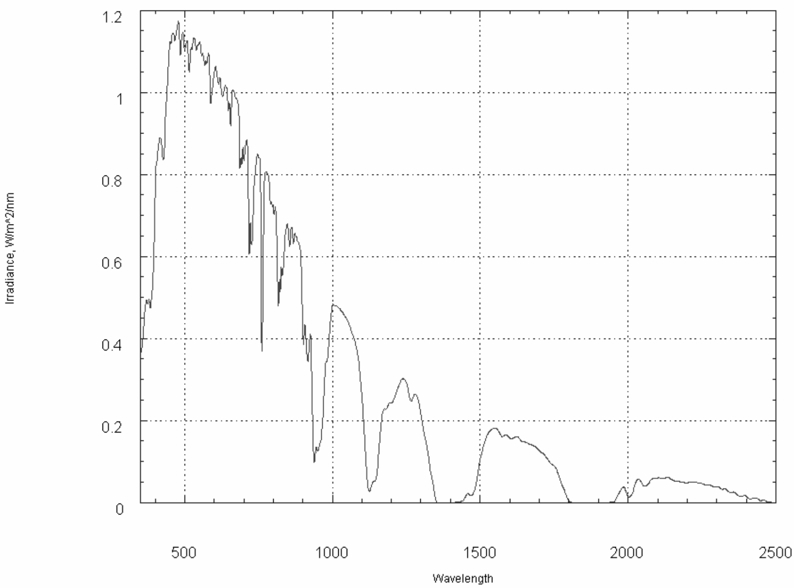
~Δ Illumination

When choosing a light source indoors, it is important that a stable DC power supply is used. AC lamps are likely to produce unwanted fluctuations in spectra that sometimes appear similar to some material spectral features**. Fluorescent lights do not work**; there is no broadband energy available for making comparative spectral measurements.

Different bulbs, even of the same wattage, can produce different results, as well. Bulb temperature will determine the wavelength region of greatest intensity. Users of different instruments may wish to explore which bulb best suits their most common applications. Cooler temperature bulbs will produce typically stronger signals in the NIR wavelength region, while relatively hotter bulbs will give a stronger signal in the visible and even UV regions. Consult a Physics, Astronomy or Optics text to see an explanation of Wien's Law, the mathematical relationship between blackbody temperature and wavelength of maximum signal.

DC lamps available through ASD, are excellent light sources for indoor use. One caveat, though, has to do with the lamp's reflector. If focused to a bright spot on a white reference panel, placing the lamp too close to the panel can result in a constructive and destructive interference pattern that varies as much as three to five percent with wavelength. This is only visible in reflectance or (ir)radiance mode, and is caused by one or more sets of interference "fringes". Again, this *is* a result of what the instrument "sees", so the only way to solve the problem is to adjust conditions, sometimes by increasing the distance between the source and the viewing area. But it also helps to randomize the focus of the lamp beam by covering the face of the rear reflector in the lamp assembly with Aluminum foil, or by using more than one lamp set at a greater distance from the target(s). Another more obvious side effect of placing a hot light source too close (less than 25 cm or so) to the equipment and samples is heat damage.

Outdoor illumination (solar) presents none of the dangers mentioned for indoor lamps. Most of the problems presented by sunlight under clear skies have to do with atmospheric absorption. While solar signal is strong in the VNIR region, there are several broadband absorption features from water in the atmosphere that can be annoying, even on apparently clear days. Some researchers even prefer to use portable DC light sources (such as ASD's High Intensity Reflectance Probe) outdoors, guaranteeing themselves useable data even in cloudy or humid conditions -- unless of course, water content is of particular interest.



Solar Irradiance – Note the deep absorption bands

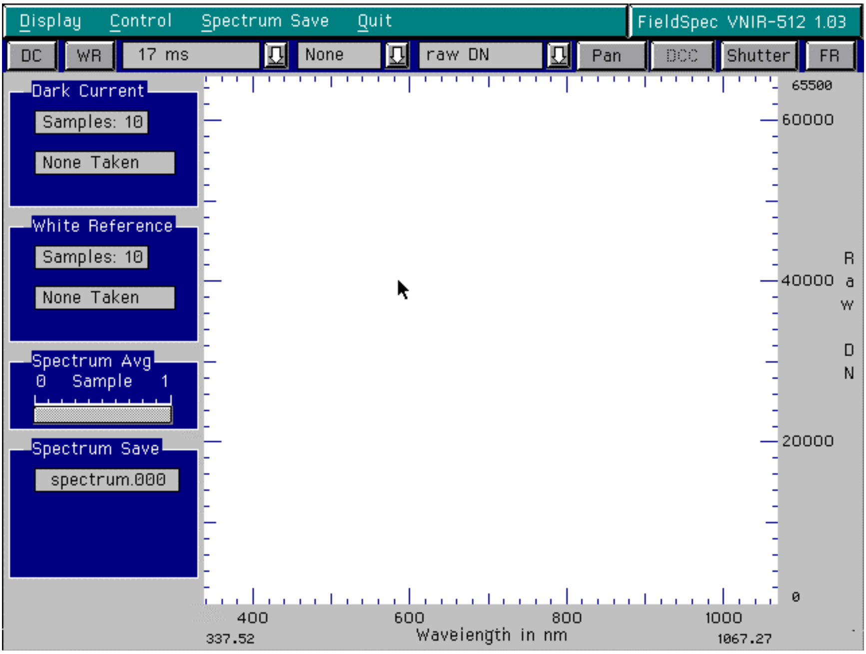
~Δ Software Interface

The FieldSpec® RS^2 software is designed with a Graphical User Interface (GUI) that provides simplicity, redundancy and "ghosting" of illegal operations. It is pre-installed on the computer accompanying your instrument and a single FieldSpec® Pro installation disk is also provided. If your PC came with Windows 95 or 98, the program may be run from a shortcut with an ASD icon. Windows® NT will not give DOS programs control of the instrument, so it is not compatible with this version of software. Consult a Windows manual for instructions on creating your own shortcuts in Windows 95 and 98. If software is lost and it becomes necessary, you may execute the "install" file from your floppy drive. For simple DOS software use, when the instrument and controlling computer are running, from the root (C:\) directory type:

cd fr (return)
fr(space)(instrument #)(space)(calibration #)(return)
If you own a UV/VNIR or a different FieldSpec® Pro instrument, type **vnir**, **nir**, etc., instead of **fr**. For example, you may need to type: **vnir 709 1**. For your convenience, the instrument and current calibration numbers are displayed for you on a label placed near the screen of the controlling PC.

Most of the time, all that is necessary is to double-click the appropriate icon on the Windows® desktop.

Within a few seconds, you will see an interface on the screen similar to that pictured.

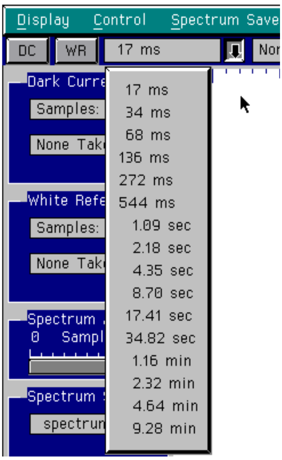


The GUI (VNIR)

~∆ Monochromatic Mode

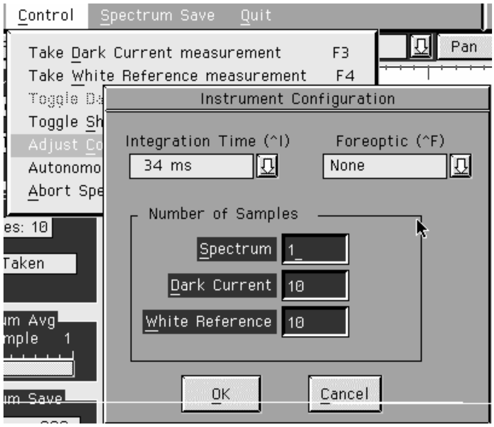
Instruments (except Dual VNIR units) running with Color LCD displays can be run in black and white for better visibility outdoors in bright sunlight. In the executable command line, simply append a "<space>bw" to enable the feature. The file GUI_BW.PAL must be in the instrument directory. A separate shortcut can be created to use this feature in Windows□95 as well. Both point to the same program, but use different color palette files.

The first adjustment you will likely need to make is to the integration time. Your software begins with an integration time of 17 milliseconds. This is as fast as the array will operate, and will be sufficient for lighting conditions roughly twice as intense as solar illumination at sea level. While exposing the fiber optic probe to the brightest conditions it will see this session (typically, the white reference panel under current lighting), click on the integration time that places the peak of your spectrum at the highest point in the screen without saturating. Saturation will appear as a truncated or flattened region of the spectrum near the top. In bright solar conditions, 34 milliseconds are relatively common.



VNIR integration time menu

Next, you may wish to adjust the default spectrum averaging to something more appropriate for the conditions, to help reduce noise. Click on "**Control**" then "**Adjust Configuration**" on the pull-down menu shown. A configuration menu will appear.



Configuration Menu

Note that the Dark Current and White Reference averaging, as well as integration time can be changed from here, also. Simply typing the number 10 will overwrite the current Spectrum averaging of one. It should be noted that 10 is considered by most users to be the ABSOLUTE MINIMUM for all three averaging components, so you will want to adjust this according to conditions. You may also wish to use this menu to tell the software which foreoptic you are using. This can be done from the toolbar as well.

Click the DC button on the toolbar, or hit F3. Dark current will now be collected, making your unit fully ready for data collection. The system prompts you to let it know when you are ready to collect dark current to allow you, if necessary, to cover the probe tip in the event of a shutter malfunction.

Dual VNIR

When the Dual software is launched, it does not automatically go into data collection mode. These instruments collect spectra on demand, so the first thing needed will probably be an adjustment to the Automatic Menu settings. Click on Auto and enable automatic DC collection and integration time adjustment (unless you have already chosen a specific integration time). Disable the save on collection feature, also in the Auto menu. Then select the foreoptic attachments you have fitted to your spectrometer cables, through the toolbar. By convention, spectrometer 1 is the "target" spectrometer, and spectrometer 2 is the "reference".

Position your probes as desired and press the Spacebar. In a very short time, both spectra will appear, giving you an idea of the quality of your data. The target spectrum (1) is blue, and the reference (2) is brown. This is a good convention to adopt, since you will not always be able to tell which is which, due to the independent adjustability of the integration times.

Foreoptic options are available and editable in the FO0.INI and FO1.INI files. These will be created for you at the factory, but if you need help editing or understanding them, you may contact ASD for support.

FR and NIR

Once you have the program running, the first thing needed is optimization. Set up the fiber optic probe, with or without accessories, to view the brightest conditions observed this session (typically, the white reference panel under current lighting). The probes view should be still, since the software optimizes quickly and depends on accurate input for good results.

The FR Menu/Toolbar

Use the mouse to click on the Opt button on the toolbar (or hit the Control-O keys). The mouse pointer will turn into an hourglass shape while the software adjusts the integration time of the VNIR array (FR only) and the gains of the SWIR detectors. At some point, you will be prompted to hit a key or click "OK" while dark current is gathered (FR only). The reason for this is to allow the user to cover the fiber optic probe during dark current collection in the event of a shutter malfunction.

VNIR units and FR

Every few minutes, in the beginning, you will want to collect another dark current spectrum by clicking on the "DC" button or hitting F3 on your keyboard. But only your instrument will see it as a "spectrum". What you will notice, perhaps, is a slight decrease in the VNIR spectral region data, whether in raw DN mode, reflectance mode or radiance mode. This gradual change in dark current, or DC Drift, has been greatly reduced with the aid of DriftLock□, a new feature in the FieldSpec□ VNIR and FR units. For dual units, it is convenient to enable automatic DC collection, particularly in the beginning, while the instrument is warming up.

~Δ User-Editable Features in ASD.INI

Custom Foreoptic Selection: Instrument foreoptics (FOV devices) are now customizable. You can use foreoptics with and without jumper cables, Underwater RCR's, etc… **Operation:** At the end of the ASD.INI file, after the wavelength calibration coefficients, should be a section:

```
[Foreoptics]
FO0 = "Bare Tip", 0, R
FO1 = "8 Degree", 8, R
FO2 = "RCR", 180, I
FO3 = "UW RCR", 181, I
```

FO0 will be the foreoptic to which the software defaults on startup. The (up to) 12-character string in quotes is what will be in the toolbar menu in the GUI, the number following is the foreoptic ID, and the letter at the end signifies that there is a radiometric calibration file for this foreoptic. There can be up to twelve different foreoptics listed.

Parabolic Correction on-the-fly: While in Radiometric data mode, parabolic correction can be applied to the modifier if necessary. **Operation:** Press Ctrl-P or the "PC" button on the toolbar – Correction will be applied to the next spectrum collected and all spectra thereafter while in Radiometric mode. To uncorrect, or refresh the correction, it is recommended that you simply press F9 again to re-initialize the radiometric modifier. Two lines should be in the .ini file, after the Splice entries:

Vertex1 = 675
Vertex2 = 1975

Though these are the defaults if the entries are absent, they can be changed if the instrument is found to have different vertices (see Appendix C).

Cooled VNIR Flag: Some FR's with TE Cooled VNIR arrays have channels that are read in reverse. This must be accounted for before data is assembled into full spectra. **Operation:** In the .ini file, after the "NewFlush = True", "NewShutter = True" or "Swir2DarkSize = ##" line, whichever comes last, should be a line, "CooledVNIR = False (or True)". This sets the Silicon array to be read forward or backward (for some cooled arrays). This line is not necessary, however, with most cooled VNIR systems.

Configurable Default Averaging: Spectrum, DC and WR averaging can be changed from the default of 10, 10 and 10. **Operation:** The .ini file should contain lines like these, at the end of the first section (before the SWIR coefficients):

SpecSampleCount = 25
DarkCurrentSampleCount = 10
WhiteRefSampleCount = 10

Dark Current Drift Correction: DriftLock -- Uses a selected block of darkened channels to correct for Dark Current drift, in real-time. **Operation:** When the masked channels are available, there will be two lines, between the "CooledVNIR" line and the "SampleCount" lines, in the .ini file that should read:

FirstMaskedPixel = # ;(number between 0 and 511)
MaskedPixelCount = #

The defaults are zero. If the "Count" is zero or blank, the function is disabled. This requires a hardware modification which is now readily available from ASD.

Configurable Port Address and IRQ: The port address for the hardware is no longer limited to 378h, IRQ 7. **Operation:** If there are problems and/or good reason for changing them the entries in the .ini file can be changed from 888 (decimal) to 378h, 278h or 3bch, among others, with the IRQ being set to 7, 5 or 9 in any combination the PC will recognize. Note to HandHeld UV/VNIR system users: The serial port is not controlled with this entry, so it goes unrecognized in the FS HH software.

Hexadecimal File Extensions: Allows user to use base-16 file extensions, for a total of 4096 files of the same basename (instead of 1000). i.e., the 32nd file in a list would have an extension of .01f, instead of .031. **Operation:** Boolean operator in the first section of ASD.INI -- HexFileExt = True (or False).

Serial Pulse at File Save: Option to send a pulse to the PC's serial port upon file save. Pulse can be used to activate something like the Two-Lead Closure Circuit **Operation:** To enable this feature, the following line must be inserted into the ASD.INI file:

SerialPulse = True

The pulse width can be adjusted by creating a batch file that executes immediately before the ASD DOS application. The batch file should contain the following line:

Mode com1 [baudrate]

where baudrate = 110, 300, 600, 1200, 2400, 4800, 9600, etc.

The pulse width time will be equal to 10/baudrate in seconds (Pin 3 on a DB-9 connector, Pin 5 is signal ground).

Contact ASD Technical Support for further explanation of these features. Most of them have been updated because of multiple user requests, so they are fairly self-explanatory and simple to utilize.

NIR

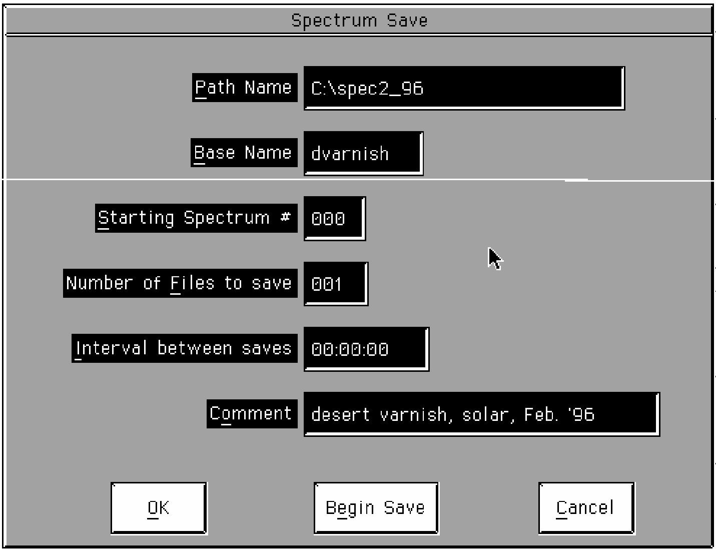
This unit consists only of the two SWIR spectrometers, which collect dark current on each individual scan. There is no need to collect dark current spectra, though the software may prompt you to do so at certain times. Ignore any prompts such as this and carry on as usual.

IN GENERAL

If, at any time, you wish to change spectrum averaging, use the Control|Adjust Configuration menu, as shown earlier, in figure 3.

The FieldSpec® Pro instrument is now ready to collect spectra. Indeed, it is *already* gathering spectra, unless it is a dual unit. Move the probe or place a sample underneath it and watch the spectra change. If you wish to *save* any spectrum, simply hit the Space bar and the *next* spectrum written to screen will be saved. For dual units, you must enable the save feature in the Auto Menu for spectra to be saved with the space bar. The spectrum (or pair) will be saved for postprocessing in the instrument's main subdirectory under the name SPECTRUM.000 (SPECTRA.000 on dual units, with a T or R appended to the two separate file basenames), and the spectrum name in the lower left portion of the GUI will be bumped up to the next number -- This is the *next* spectrum file that will be saved when the Space bar is pressed. This brings us to the **Spectrum Save** form. Click the Spectrum

Save menu once with the mouse pointer, or press Alt-S on the keyboard to bring the Spectrum Save form to front.



The Spectrum Save Form

Path Name: Build the directory path for the spectra you wish to save. This should be something descriptive, that you will recognize when postprocessing. E.g., c:\spec2_96 -- These spectra were gathered in February, 1996. You may also wish to use a location name in the path, if this would be more helpful.

Base Name: The name each saved file will have (without the extension). Again, this should be descriptive. E.g., dvarnish might be Desert Varnish (collected 2/96). Dual unit users will need to use a 7 (instead of 8) character base name; the software will automatically append a "T" (target, spectrometer #1) or an "R" (reference, spectrometer #2) to the basenames at collection time.

Starting Spectrum #: This will be done automatically for you, based on other files of the same name in the Path Name specified. Up to 1000 spectra can be saved in the same path with the same Base Name. If the hexadecimal option is exercised in the ASD.INI file, 4,096 files may be saved with the same basename (a small letter "h" will show next to this field).

Number of Files to save: You may have the software save more than one spectrum each time the Space bar is pressed. Time dependent factors, such as temperature and angle of illumination, may interfere with the validity of too many spectra collected at one time. In the FR and NIR units, if the instrument's optimization falls out of bounds, data collection will stop until you re-optimize the system. Again, if hexadecimal file extensions are being used, you may enter up to 4096 in this field, but enter this number in decimal, not hexadecimal.

Interval between saves: For multi-file save sessions only (as described above), this is for autonomous operation requirements, such as those that might be necessary if the user's shadow will interfere with good data collection. The default is 00:00:00 and multiple files will be saved as quickly as the hardware/software will allow.

Comment: A text description of the spectrum saved, describing things like samples measured, lighting conditions, time of day (local) or year, location, etcetera. This field is optional, but extremely helpful. The default is blank. The field can be viewed, along with other header information, in postprocessing with a FieldSpec® utility like ViewSpec® Pro.

Information which is *automatically* saved with each spectrum, and therefore need not be in the comment field, includes:

- Integration time and gain settings.
- Instrument ID numbers.
- The calibrated starting wavelength and wavelength interval for the instrument.
- The date and time when the spectrum was saved (acquired from the computer's time).
- The number of samples averaged in the spectrum.

- A status field indicating if and when a dark current was collected.
- A status field indicating if and when a white reference was collected, if in reflectance or transmittance mode.
- The type of foreoptic used.

Any other information you feel might be useful in data analysis should be abbreviated in the "Comments" field. For example, if a white reference is used, is the spectrum *reflectance* or *transmittance*? Is angle of incidence or view important? Were filters used? Were any non-standard foreoptics used?

With practice in both data collection and postprocessing, you will learn which methods of file-naming and record-keeping work best for *you*. The methods vary with all applications and software used in postprocessing.

~Δ Raw DN Collection

Collection of raw data is the simplest, but not always the most efficient means of spectral analysis. It is true that if you remain in **Raw DN** mode, you will always recognize conditions of saturation, but you may not necessarily recognize conditions that will develop into noisy data in postprocessing. Among other things, the processing of raw data involves a ratio between two spectra, whether done in real-time or in postprocessing. If signal strength is especially low in any particular region of both spectra in the ratio, the spectra collected will need greater spectrum averaging than usual. Since noise is difficult to see in raw data, it is a good idea to use real-time reflectance data as a guide to see how many spectra should be averaged for useful data collection. If using a Dual VNIR unit, you may need to zoom in on low regions of raw DN data for an idea of S/N.

In all FieldSpec® Pro instruments, you can use raw data values for radiometric measurements, but new software does allow the real-time processing of these spectra if your unit is radiometrically calibrated. All required calibration files must be present in the instrument's software directory and the appropriate entries need to be made in the ASD.INI file for this to function. Also, there must be enough *Lower* DOS memory available to use real-time radiometric readings. ASD has provided a tested CONFIG.SYS file for this purpose on the ASD software distribution disk.

~Δ Reflectance and Transmittance Spectra

FieldSpec® Pro systems, with the exception of dual units, are set up to collect real-time relative reflectance and transmittance spectra. In short, these are calculated with the formula:

R (or T) = Light emitted from Sample / Light emitted from White Reference

For *absolute* reflectance measurements, a calibration "spectrum" of your reference panel must be multiplied with relative reflectance spectra in postprocessing. From here on, we will discuss only relative reflectance measurements, but transmittance can be assumed to be calculated in the same fashion, though collected using different methods. The steps towards collecting lab reflectance spectra, unless using a dual instrument, will typically be as follows:

1. Turn on the FieldSpec® Pro.
2. Turn on the computer.
3. Enter the controlling software as described earlier from the Windows Desktop.
4. Set up your experimental conditions.
5. Optimize, or set integration time to experimental lighting conditions, and inform the software of the foreoptic you are using, if any.
6. Set up spectrum averaging to fit the conditions, and fill out the Spectrum Save form, if you will be saving spectra.

7. Collect a White Reference by clicking the WR button with the mouse (or by pressing F4 on the keyboard).
8. After a straight line spectrum appears on the screen (this is the relative reflectance of the White Reference measured against itself), place the sample in the FOV of the probe in the same orientation and distance from the light source as the White Reference. If the White Reference Spectrum is not a nearly flat line at one, with little noise, go back to step 6, or examine your experimental conditions more closely for potential problems (see below).
9. When the sample is in place, the second spectrum you see ought to be its relative reflectance spectrum. Since the instrument continuously collects spectra, it is important that you not include any intermediate or White Reference spectra in the averaging, so it is best to wait until you see two subsequent spectra on the screen that have similar baselines (overall heights) and features before saving any data.
10. Save the next spectrum displayed at any time by pressing the Space Bar on the keyboard. If you are attempting to capture a short-term event or have variable conditions which make a smooth, continuous spectrum difficult to obtain, you may use the Freeze button (or F6) to freeze the screen with the spectrum you wish to save being displayed. Then press the space bar to save this spectrum, rather than the next. Don't forget to unfreeze the screen following this "cheat".

<u>NOTE</u>: When using the above method for collecting Reflectance Spectra (real-time Reflectance mode), do not forget to toggle back and forth to Raw DN mode periodically to check that your Raw DN data is not saturating. If data is saturated, you must re-optimize (adjust IT) and then take another WR to bring you back to Reflectance mode.

If it is Reflectance data that you desire, but you prefer to collect the data in Raw DN mode, <u>do not</u> forget to save Raw DN spectra of both the white reference panel and your sample. Then you can ratio these pairs of spectra in post processing to calculate relative Reflectance, according to the following formula:

R (Reflectance) = Light emitted from sample/light emitted from white reference (WR)
R = Raw DN spectrum of sample/Raw DN spectrum of WR

Dual VNIR

Dual VNIR users may wish to use this procedure for laboratory reflectance measurements:

1. Turn on the FieldSpec® Pro.
2. Turn on the controlling computer.
3. Enter the controlling software as described earlier.
4. Set up your experimental conditions. Spectrometer 1 views the target, spectrometer 2 views the white reference or downwelling flux with the RCR.
5. Set up and select your foreoptics on the toolbar.
6. Set up the automatic features for dark current and automatic integration time selection. If enabled, disable the automatic save on collection feature.
7. Collect a pair of raw spectra by pressing the Spacebar, to see that the system is functioning well.
8. Use the rubber-band-zoom feature with the mouse to zoom in on narrow portions of the raw spectra. This will help you determine the S/N of your data.
9. Collect further pairs of spectra. When you are confident that everything is set up properly, enable the save feature and save pairs when desired.
10. The saved pairs can be converted to radiometric units, resampled (or interpolated) and ratioed in postprocessing, providing you with accurate reflectance measurements.

Remember that the ratios of *raw spectra* will not give accurate results, because they are taken with separate detector arrays, with unique properties. If it becomes necessary, though, raw response from the two units can be compared for use in postprocessing.

Then the files may be resampled and ratioed with a proper response correction ratio applied.

Special Note: When setting spectrum averaging, you need only set the number of spectra averaged for spectrometer #1 (Target). Because the illumination of the reference spectrum (#2) is typically higher, providing a shorter integration time, spectrometer #2 "slaves" its averaging to #1, allowing as many spectra to be averaged as possible in the time allotted to #1 (IT times number of spectra).

When using the dual instruments in field applications, we *really* begin to understand the usefulness of the spectrometer pair; particularly in airborne and underwater applications. If you have ideas for a particular application, feel free to contact ASD for information regarding methods and necessary accessories.

In General

There are a few things to be aware of:

- Shadows sometimes can play a part in actual sample analysis, but most of the time, they are a nuisance. You must be aware of *all* of the light sources being detected, such as reflections from equipment, windows and vehicles, and light from overhead (incandescent and fluorescent) sources. If you move an object or yourself during data collection, you may have created or removed a shadow or reflection from the collection area. Taking a quick look at the reference panel in the new configuration will show you if any significant changes have been made. For example, if your body blocks a fluorescent light during White Reference collection, then moves aside, you might see emission peaks in the VNIR region that should not be there. This does not mean you must block all other sources of light -- it only means you must be aware of all sources used.
- Backscatter and specular reflections may also be desired aspects of sample analysis, but once again, you need to

beware of them when they are *not* desired. Spectralon® is nearly as close to a lambertian surface as you can buy, but it still has a certain specular reflection characteristic to it that encourages proper positioning when collecting a White Reference spectrum. Try creating a standard for yourself of placing the light source and the fiber optic probe at 90 degrees from each other with respect to the viewing area (viewed from above), and pointing downward into the viewing area at an angle of about 45 degrees from zenith. If the light source is at or near zenith, the probe can be placed anywhere to view the samples from about 45 degrees off nadir. Backscatter is the reflection phenomenon created by very porous surfaces, such as grass or gravel. The brightest viewing position of these surfaces is from the direction of the light source itself. You may find, particularly in outdoor conditions, that you must collect reflectance data from a wide variety of angles and positions, or have the angles of view well documented in the Comment field of your file headers.

- Interference fringes can be extremely annoying in laboratory conditions. You may collect a White Reference and achieve a nice, clean, 100% reference line only to have it distorted by small oscillatory patterns in the VNIR and short-wavelength NIR regions, when the optical geometries are even slightly altered. These patterns can be recognized by a decrease in frequency of the oscillations with an increase in wavelength, and can usually be avoided by placing the light source farther away (more than 30 - 40 cm) from the viewing area, or by using multiple sources of light (preferred).
- The data you collect should be from samples placed in the same configuration as the reference panel. When viewing horizontal surfaces in the lab, the reference panel should be horizontal also, and at the same distance from the light as the samples. When viewing soils or vegetation on a hillside outdoors, use the reference panel at roughly the same slope and configuration with respect to the Sun as the samples for comparison to laboratory results, but always use the reference panel horizontally for comparison to remotely gathered (airborne) results. Differences in configuration will lead to

varying baselines or undesirable detector saturation regions which *can* give you faulty data.

Never forget, particularly when the instrument is still in its warming stages, to check on the quality of the White Reference spectrum frequently (unless using a dual unit). It is convenient to view the spectrum of your White Reference panel in between each sample, to make sure your reference line is still as clean as it was to begin with. If not, it usually only takes a few seconds to replace the reference spectrum with a new one. Since the white reference is updated with each spectrum pair collected with a dual unit, this procedure is not necessary.

~Δ Radiance and Irradiance Spectra

The FieldSpec® Pro, if desired, may be calibrated to collect energy flux spectra for a wide variety of applications. Only you can know if these would be useful calibrations. And as usual, you, the user, have the greatest control over the quality of your data. If your unit is not equipped with, or is not calibrated for a particular foreoptic, it will not be capable of collecting radiance data (or irradiance data in the case of the remote cosine receptor).

The software formula for (ir)radiance spectra is:

*rad = (known * input * cal ITG) / (response * input ITG)*

where *rad* is the calculated (ir)radiance, *known* is the known radiance of a calibrated white reference panel illuminated by a calibrated light source (or, for RCR data, the known irradiance of the calibration lamp at a given distance), *input* is the dark current corrected input spectrum (unknown, in raw DN), *response* is the corrected calibration spectrum (collected at calibration) for that foreoptic, also in raw DN. The software incorporates the inverse ratio of the integration times and/or gain factors, *cal ITG* and *input ITG*, to correct for these values, contained in the file header information.

You may collect (ir)radiance data in real-time the same way you collect Reflectance data, except you use the Rad Button, instead of WR for initialization of the radiometric processor. If steps are present (see below and Appendix C) between spectral regions, the PC Button may be the proper way to correct them. Let experience be your guide in this regard.

Your instrument, if calibrated, is so done at room temperature, after the unit has completely warmed up (typically more than one hour – See Appendix C). Therefore, it is important to consider that certain regions of the spectrum will only be well-calibrated under nearly the same conditions and temperatures. Most affected though, is the red portion (800 to 1050 nm) of the VNIR detector. There is little or no effect of temperature on sensitivity in the other regions; except for that on dark current, and these sensitivity effects can be mathematically characterized and removed using a post-processing utility (PCorrect) or the "PC" button in Real-time radiance or irradiance mode.

Dual VNIR

By necessity, earlier instructions on collecting reflectance (albedo) spectra also covered the collection of radiometric spectra. Further hints may be found, however, under the instructions ahead.

In General

If you choose to use **Raw DN** mode to collect energy spectra, do not forget to specify the type of foreoptic used for data collection. The FieldSpec® Pro postprocessing software will look for this in the header file in comparing the data to the calibration file. If the required calibration file is not in the required directory, the calculation will be aborted.

As usual, watch out for saturation. This is much easier to see in raw mode, but try not to relax in your diligence. The procedure for collecting energy spectra in Raw DN's for the FieldSpec® Pro instruments is as follows:

1. Turn on the FieldSpec® Pro.
2. Turn on the computer.
3. Enter the controlling software as described earlier.
4. Set up your experimental conditions. Position the probe to view the radiant source you are examining. The source **must** fill the field of view of the probe.
5. Optimize the unit for your experimental lighting conditions, and inform the software of the foreoptic you are using, if any.
6. Set up spectrum averaging the fit the conditions. S/N will increase with the square root of the number of spectra averaged. An easy way to get an impression of what your S/N is, is to enter reflectance mode while viewing your radiance source. When S/N is sufficient for your purposes, go back to **raw dn** data collection. This is the form data must be in for postprocessing purposes.
7. Fill out the Spectrum Save form, if you will be saving spectra. When all setup procedures are complete, and the unit is collecting spectra, save anytime by depressing the Spacebar on the keyboard.
8. Periodically collect Dark Current (every 10 - 15 minutes for the first half-hour, then less frequently as time progresses). Reoptimize in varying lighting conditions, or if any data appears "truncated", i.e., if any spectral humps have flat tops.

Raw data can be processed into (ir)radiance data with the postprocessing utility, ViewSpec® Pro. This program absolutely requires that correct setup procedures be followed in order to calculate accurate data. Foreoptic attachment selection, for example, **cannot** be forgotten or misstated, as this program will not work if the unit is not calibrated for the foreoptic selected.

Radiance and Irradiance spectra may be collected in real-time as well simply by using the "Rad" button, or F9.

~Δ Interface Shortcuts

The subnotebook computer supplied with the FieldSpec® Pro comes with its own documentation It is a good idea to familiarize yourself with it so that you can fully utilize the performance features that enhance the use of your instrument. Of particular interest to users are Power Management, battery charging/discharging and screen adjustment, among others.

All computer models have their advantages and their shortcomings. Because of the need for clean, unattenuated fast digital data transfer, we at ASD need to use a PC's EPP performance characteristics in our evaluations and choices for this important part of your system.

One of the disadvantages to virtually all subnotebook computers on the market today is the difficulty of viewing the display in bright sunlight. This is especially aggravating when the FieldSpec® Pro's general purpose is taken into account. While larger details (graphics, mode buttons, etc.) are usually easy enough to distinguish, the mouse cursor can be very difficult to find in outdoor conditions. To allow a user to get by almost entirely without using the mouse, fast keystrokes or keystroke pairs have been incorporated into the interface. Once these shortcuts are well known by the user, they are likely to be used more commonly than the mouse, even when the instrument is used indoors. The following is a table of interface features and how they are accomplished, both with the mouse and with keystrokes alike:

Function	**GUI/Mouse Action**	**Shortcut**
Optimization (FR & NIR)	OPT button	Ctrl O
Change Integration Time (UV/VNIR units only)	Tool Bar button	F1 (Lower) F2 (Higher)
Choose Foreoptic	Tool Bar button	F7 (Smaller) F8 (Larger)
Take Dark Current Measurement	DC Button	F3
Take White Reference Measurement (except dual units)	WR Button	F4
Change between Zoom/Pan/Coord modes (Coord mode shows crosshair location in lower left corner of GUI) Also can shop Optimization Parameters in FR and NIR units.	Pan Button (changes to current mode)	F5
Freeze the Screen (Helpful for examining spectra in the field, also unfreezes the screen)	Freeze Button	F6
Initialize Radiometric Calculation (Single UV/VNIR, FR, NIR units)	Rad Button	F9
Apply Parabolic Correction to Radiometric Spectra	PC Button	Ctrl P
Toggle Shutter (UV/VNIR units)	Shutter Button	F10
Move Cursor left/right one data point (Coord Mode)	None	Left/Right Arrows
Move Cursor to first/last data point (Coord Mode)	None	Home/End
Zoom in/out on X-axis (Zoom Mode)	See rubber band Zoom feature, below	Left/Right Arrows
Zoom in/out on Y-axis		Down/Up Arrows

Zoom in/out full, X-axis		Home/End
Zoom in/out full, Y-axis		PgDn/PgUp
Pan left/right (Pan Mode)	None	Left/Right Arrows
Pan up/down	None	Up/Down Arrows
Pan to left/right edge	None	Home/End
Pan to top/bottom edge	None	PgUp/PgDn
Undo last pan/zoom command	None	Ctrl U
Restore screen to default settings	None	Ctrl R
Open Integration Time Menu (UV/VNIR units only)	Toolbar Button	Ctrl I
Open Foreoptic Menu	Toolbar Button	Ctrl F
Open Spectrum Type Menu	Toolbar Button	Ctrl Y (Up/Dn arrows to change
Abort current task (WR, DC, etc.)	None	Ctrl A

- All top menus may be opened with Alt + the letter underlined on the Menu bar. All second-level menu choices can be opened by pressing the underlined letter in the selection. Alt O exits menu functions, such as Spectrum Save and Control|Adjust Configuration forms.
- Spacebar saves next spectrum collected, when in collection mode. For dual instrument users, the Spacebar activates collection, whether in "save" mode or not.
- In any mode, any portion of the display may be magnified by using the **rubber band zoom**; i.e., left click with the mouse on the upper left corner of the area you wish to view, then left click on the lower right corner.
- Dual instruments, where applicable, use the Shift key to activate features in spectrometer 2. E.g., Shift+F1 will lower the integration time of spectrometer 2, Shift+F7 will change the foreoptic for spectrometer 2, and so forth.
- There is no Coordinate or OptPar mode for Dual instruments.

- If you are unsure if a command will work with your particular unit, try it; it cannot hurt.

SOFTWARE UTILITIES

~Δ ViewSpec® Pro

Each FieldSpec® Pro instrument model comes equipped with its own controlling and data acquisition software. ASD has written several utilities for each of its instruments based on early requests, needs and general marketability of the programs. Specific applications, however, may require postprocessing software to be supplied by the user. More software will certainly be written or adapted from other utilities, but our primary focus must always remain on the most suitable data acquisition software for our units.

All of these utilities, run in DOS, have been incorporated into the new Windows® 95/98 utility, ViewSpec® Pro. ViewSpec® Pro's online help menu is the best resource for help in using it. Install ViewSpec® Pro on any Windows® 95/98 PC using the installation disks provided with your system. If you don't have these disks, contact ASD Technical Support for details on ASD's FTP site, where these things can usually be downloaded at no charge.

If you must use the DOS utilities supplied in the instrument's software folder, instructions for usage may be found in DOS. Each of the supplied utilities come equipped with an onboard usage screen that may be accessed by simply typing the basename of the utility and pressing "enter". Double-clicking on the utility itself in Windows® will accomplish the same thing, but since usage flags must be used in the command line, you'll need to enter DOS for their use anyway.

~Δ File Format

ASD's binary data format is not secret, but it can be difficult to support each and every user's needs for definition in pursuit of the perfect analysis application. If personalized post-processing software is desired, the data file and header formats are described in a few simple description files that may be found in a subdirectory of the controlling software directory (e.g., c:\fr\fileform\). These files are: FS_Data.doc, Gps.h, Time.h and Specio.h. If you can't find these files on the controlling computer or the FieldSpec® Pro Software distribution disk, please contact ASD Technical Support for assistance.

TROUBLESHOOTING

~Δ Spectral Properties

Problem:	**Possible cause/solution:**
~ Oscillations in spectra, not related to spectral properties of the sample	~ The light source (laboratory) could be too close, causing interference fringes. Try moving it further away. If you are using an AC lamp, or a DC lamp without a *stable* DC power supply, you may also be picking up AC fluctuations.
~ "Steps" in reflectance data between spectral regions (multi-region models)	~ FieldSpec® Pro models with more than one spectrometer also have a corresponding number of separate fiber optic bundles, each with slightly different sample views. This is not an uncommon problem when viewing rock or soil samples in the lab; try altering the probe's field of view slightly, or moving the probe further from the sample. Also, if using a bare fiber optic, try attaching a lens foreoptic. The reverse may hold true for other materials.
~ "Steps" in (ir)radiance data between spectral regions	~ Radiometric calibration is performed at the ASD factory, in room-temperature conditions, with a fully warmed-up instrument. There is *some* temperature dependence in some spectral regions on detector sensitivity, so data steps may be a natural occurrence. If further testing shows that the steps do not diminish

	substantially with a temperature increase, the unit may need recalibration. Contact ASD at your convenience (See Appendices). You may also be having troubles as described in Reflectance data.
~ Upward *or* downward spikes in VNIR data	~ Another common laboratory condition, this is usually caused by extrinsic fluorescent lights. You may wish to turn them off for data collection.
~ Noisy data regions in outdoor conditions.	~ The atmosphere absorbs much of the Sun's UV radiation, and water vapor absorbs most of the incoming NIR light around 1400, 1900 and greater than 2400 nm bands. This leads to a normal decrease in Signal to Noise ratios. The simplest solution is to increase spectrum averaging, or to collect more spectra for averaging in postprocessing. **Important note:** When using raw data to later calculate (ir)radiance data, S/N will be impossible to determine. View some reflectance spectra *first* to help determine noise levels and set averaging appropriately.
~ VNIR region drops to zero after dark current collection	~ There is probably a dark current shutter malfunction. Try covering the tip of the probe while collecting dark current. If the spectrum appears normal, use this as a temporary solution and contact ASD at your earliest convenience to schedule a repair.
~ Instrument will not optimize properly (FR & NIR)	~ Try reoptimizing under different (brighter) light conditions. If the unit seems to function normally,

	optimize yet again under intended light conditions.
~ Instrument and controlling computer will not communicate – No spectra appear on the screen.	~ This can be caused by an electrostatic discharge. Quit the program, turn off the computer, and turn off the instrument. After a few seconds, turn the instrument on again, then the computer, and enter the program again.
~ Unusual sudden dips in 100% white reference line	This can happen in gradually increasing lighting conditions or changing SWIR offset. The raw spectra may be saturating, distorting the reflectance ratio. Reoptimize the system.

~Δ Instrument & Accessory Cautions and Hints

- Always turn on the instrument before turning on the computer. Postprocessing is best performed on a separate computer. Copy the c:\fr directory, and its contents, over to the other PC for best results. Use the installation disk for ViewSpec® Pro on another PC as well
- Never overtighten the foreoptic and/or pistol grip clamps over the fiber optic cable. Damage to the fibers may result. **Note:** Destruction of *any* individual fibers in the cable *will* result in lower S/N ratios and the invalidation of radiometric calibration files installed in your PC.
- Always insert the fiberoptic probe *as far as it will go* into whatever accessory you are using. If you are unsure of its actual position, move it around until you are satisfied that it is firmly seated.
- Never use FieldSpec Pro Accessories in a manner other than outlined in this manual, unless specifically instructed to by ASD. See page 21 – 34 for safety precautions and page 38 for out door operation and auto-adapter use.
- The fiber optic cable attenuates light to a greater degree when it is tightly coiled – The tighter the coil is, the lower the transmission will be. Keep the cable as straight as is conveniently possible for data collection, to avoid losing those few percentage points. **Tightly wound cables also fracture easily over short periods of time.**
- A pair (or more) of strong light sources, in laboratory conditions, works much better than one source placed close to the viewing area.
- When using fiber optic jumper cables, move the probe around a bit in the SMA adapter while collecting spectra to be sure of a maximum transmission position.
- Dirty Spectralon® panels may be cleaned with 220 - 240 grit wet/dry sandpaper under clean distilled water. Glue the sandpaper face up on a small plate of glass for best results.
- If the Yellow battery charging light does not illuminate when FS batteries are being charged, check to be sure all connectors are firmly seated. If the yellow status light blinks,

indicating a charge error, disconnect the AC Power adapter and reconnect it after a few seconds' pause. This charge system reset is sometimes all that is needed. If the yellow light still flashes, contact ASD Technical Support to schedule a repair.

- Typical response functions (to zenith angle) for the RCRs are available, if needed, but characterization of an individual RCR is much more reliable. Use a point source and a rotating stage to collect relative measurements, if desired. Contact ASD for more details.

~Δ Accessory Notes:

ASD's Remote Cosine Receptor:

The ASD Remote Cosine Receptor (RCR) is a light-diffusing foreoptic with two main purposes:

1. Full sky Irradiance measurements, when purchased with the required optional radiometric calibration.
2. Full-hemisphere Albedo measurements, i.e., Upwelling Flux ratioed to Downwelling Flux. This can be performed without radiometric calibrations (Raw DN mode).

To attach your RCR perform the following steps:

- Remove the pistol grip from fiberoptic cable coming from the spectrometer.
- Unscrew the fiber clamp from the RCR and thread the FO cable through it. Grasping the FO cable with your thumb and forefinger about 2 inches (5 cm) from the probe tip, insert the probe into the rear of the RCR, making sure it seats itself all the way in – that is, to a point where your fingers are very near to or touching the fiber clamp base. Gently screw the clamp in place, until the cable is firmly held. **Do not** overtighten.
- There is no reason to disconnect the top ring of the RCR that holds the opaque dome into place. Removing this can change the radiometric calibration of the RCR, as well as place parts at risk of damage or loss.

Radiometric Calibration of the RCR:

The calibration file for each RCR is unique. Thus, an RCR that is interchanged with another fiberoptic cable (or unit) will not be radiometrically calibrated. To uniquely identify each RCR, each one is labeled with the number of the instrument with which it was calibrated.

The translucent dome in the RCR is fragile and is susceptible to scratches and cracking. Take care to protect the dome and to keep it clean. If the dome is dirty or scratched, this will introduce error into the RCR's radiometric calibration. It may also help to keep the RCR stored in a small plastic bag when not in use.

Direct Irradiance Attachment:

The ASD Direct Irradiance Attachment couples with the Remote Cosine Receptor (RCR) for the purpose of collecting the direct component of downwelling Solar Irradiance. An ASD RCR and the optional radiometric calibration are both necessary accessories for this function.

Attaching the Direct Irradiance Attachment to the RCR:

To attach your Irradiance Attachment perform the following steps:

- Attach the RCR to the fiberoptic probe (see RCR reference).
- Mount the RCR to a tripod or tracking stage using the photographic-standard ¼-20 thread mount. Then seat the Direct Irradiance Attachment all the way down onto the RCR and use the small hex-head set screw(s) to secure it in place.
- Horizontality is not necessary unless measuring full-sky Irradiance (without the Direct Irradiance Attachment). Secure the desired FOV restrictor to the end of the attachment with its hex-head set screw(s).
- The targeting FOV restrictors for the Direct Irradiance Attachment are for 0.5°, 1.0°, 1.5° and 2.0° fields-of-view. The

Sun's disk subtends about 0.5°, but direct component of Irradiance comes from coronal discharge and forward scattering, as well, which may subtend up to 2°. Experimentation under different conditions will help you determine which is best.

The instrument only needs to be calibrated with the RCR (without the attachment). When collecting data with the full assembly, the shadow from the targeting device should fall neatly upon the target marker at the base of the attachment. Collect desired data in **Raw DN or Irradiance** mode with "**RCR**" selected as the foreoptic. Raw DN Data may then be processed into Irradiance data using **rcalc.exe**, giving you *normal* Irradiance due to direct illumination from the source (usually the Sun). This data should then be normalized to horizontal flux by multiplying each channel by the Cosine of the Solar Zenith Angle at the time of collection, for meaningful analysis and comparison to Full Sky Irradiance. This can be done in a spreadsheet/graphing application such as Excel® or Kaleidagraph® from data files ported into ASCII text format.

<u>Fiber Optic Jumper Cables:</u>

Because of the imperfect connection between jumper cables and permanent cable in the FieldSpec® Pro, radiometric calibration with this accessory is a tricky proposition. If you purchased a fiber optic jumper and one or more radiometric calibrations, you will need to adjust the position of the cable such that the *greatest integrated energy is being received by the instrument.* This is how the unit was calibrated, so to match that calibration, connect the jumper without tightening the set screws. Then measure a white reference and rotate the main cable in the SMA adapter until throughput is at its greatest overall response. If using an FR, look for the greatest overall throughput in SWIR2. Then tighten the set screw. The cable position should be very close to its calibrated position at this point.

<u>Spectralon® -- Care:</u>

The white reference material ASD sells is manufactured by Labsphere. Contact them for further information, but here are their own instructions for care and handling (reprinted from instructions sent by fax from Labsphere, Inc. to ASD on February 26, 1998):

"**General Care**

Spectralon is an optical standard and should be handled in much the same way as other optical standards. Although the material is quite durable, care should be taken to prevent contaminants such as finger oils from contacting the material's surface. Always wear clean gloves when handling the material.

Cleaning instructions

If the material should become soiled, it may be air brushed with a jet of clean dry air or nitrogen. **Do not use Freon**. If this is insufficient, the piece should be sanded under running water* with 220-240 grit waterproof emery cloth until the surface is totally hydrophobic (water beads and runs off immediately). Blow dry with clean air or nitrogen or allow the material to air dry.

If the material is required to have high resistance to deep UV radiation, the piece should be prepared as above and then either of the following two treatments performed.

Flush the Spectralon piece with >18mΩ distilled, deionized water for 24 hours.
Vacuum bake the Spectralon piece at 75° C for a 12 hour period at approximately 1 Torr, then purge the vacuum oven with clean dry air or nitrogen.

*Low reflectance Spectralon (<10% reflectance) should be dry sanded."

Following is a table of Labsphere's published Reflectance data for uncalibrated spectralon (+/- 0.5%):

Wavelength (nm)	SRM-990 "Uncalibrated" Spectralon Reflectance
250	0.950
300	0.985
400	0.990
500	0.991
600	0.992
700	0.992
800	0.991
900	0.991
1000	0.993
1100	0.993
1200	0.992
1300	0.992
1400	0.991
1500	0.991
1600	0.991
1700	0.988
1800	0.989
1900	0.981
2000	0.976
2100	0.953
2200	0.973
2300	0.972
2400	0.955
2500	0.950

~Δ Technical Support & Quality Assurance

Analytical Spectral Devices is proud to provide its customers with the best service and support available. We know the value of service, and we know that we need to take care of the customer first. If any questions arise during the lifetime of your hardware, we're hopeful you'll feel free to contact us for answers. At additional cost, ASD also offers FieldSpec® training and Extended Warranty plans. Contact the Analytical Spectral Devices sales staff for details about these items.

Also, each time your system leaves Analytical Spectral Devices' facility, our Technical Support staff puts the instrument to use in as many ways as possible to verify its conformance to ASD's strict standards of quality.

ASD personnel regularly test system comfort and performance in outdoor environments.

APPENDIX A

FIELD SPECTROMETRY: TECHNIQUES AND INSTRUMENTATION

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ABSTRACT

Applications such as aircraft and satellite sensor calibration, development of remote sensing data exploitation methods, remote sensing feasibility studies, and geologic mapping greatly benefit from the use of field spectrometry. The collection of accurate spectra in the field requires an awareness of the influences of the various sources of illumination, atmospheric characteristics and stability, winds, instrument field of view, target viewing and illumination geometry, instrument scanning time, and the spatial and temporal variability of the target characteristics. The first step in the development of a field experiment is the definition of the overall experimental design. Unfortunately, the formulation of an appropriate experimental design is not always obvious. Issues such as the timing of the data collection, spatial scale of the field measurement, target viewing and illumination geometry, and the collection of ancillary data sets must be considered in light of the objectives of the study. The lack of the appropriate ancillary data sets that often makes previously collected data sets unusable for a new application. Frequently, the experimental design must be

modified to account for the characteristics of the available instrumentation. Instrument characteristics, such as signal to noise ratio, radiometric calibration, spectral resolution, spectrum acquisition time, and angular field of view, all place limitations on the types of spectral measurements that can be made in the field. For example, vegetation canopy spectra collected using a slow scanning instrument will sometimes have small wind-induced "absorption" features in those portions of the spectra when the instrument was viewing more shadow.

1. INTRODUCTION

Field spectrometry is the quantitative measurement of radiance, irradiance, reflectance or transmission in the field. Portable, battery powered spectroradiometers are typically used to make these measurements. In this paper, the discussion will be limited to: 1) visible to near infrared wavelengths, 300 to 2500 nm; 2) examination of geological, man-made, and vegetative materials; and, 3) instrumentation acquiring a continuous spectrum.

There are many reasons why it is desirable to perform spectral measurement in the field, not all related to remote sensing. Field spectra of ground targets that are homogeneous at the scale of the imaging sensor and collected using ambient solar illumination can be used to convert radiance images to reflectance (Conel et al., 1987a & 1987b). Often, field spectra of target materials are collected to allow for more precise image analysis and interpretation (Goetz and Srivastava, 1985). Field spectroscopy is also used as a tool to perform feasibility studies to understand if and how a process or material of interest can be detected using remote sensing. Field spectra of both the material(s) of interest and spectra of other materials present in the environment can be used to address such questions as: 1) What spectral resolution is required for detection?; 2) What spatial resolution is required for detection?; 3) What is the best time of year/day for detection?; and 4) What signal-to-noise ratio is required for detection?. Aside from remote sensing applications, field spectrometers are used to make direct material identifications in the field rather than collecting samples for later laboratory analysis.

2. ILLUMINATION

2.1 ASSUMPTIONS

In order to determine the reflectance or transmittance of a material, two measurements are required: the spectral response of a reference sample and that of the target material. The reflectance or transmittance spectrum is then computed by dividing the spectral response of the target material by that of a reference sample. Using this method, all parameters which are multiplicative in nature and present in both the spectral response of a reference sample and the target material, are ratioed out. These parameters include the spectral irradiance of the illumination source and the optical throughput of the field spectrometer. Thus, when determining the reflectance or transmittance of a material in the field, an inherent assumption is the characteristics of the illumination are the same for the reference and target materials. Variability of the illumination characteristics between the time the reference and target materials are measured will result in errors in the resultant spectra.

2.2 CHARACTERISTICS OF NATURAL ILLUMINATION

Spectral measurements are typically made in the field using ambient solar illumination. In the field, the target material is illuminated by three or more sources (see Fig. 1), each with its own spectral characteristics (Curtiss and Ustin, 1988). Unless the target is in a shadow, the direct solar illumination is the dominant source of illumination. Parameters such as solar elevation angle and atmospheric conditions will effect the overall intensity and spectral characteristics of direct solar illumination. Diffuse skylight illumination can contribute as much as 5-10% of the total illumination reaching a surface. At shorter wavelengths, diffuse skylight can contribute as much as 20-25% of the total. The spectral characteristics of the illumination scattered off of surrounding objects is determined by their reflectance characteristics. In the case of a forest clearing, as much as 20% of the illumination in the 750 - 1200 nm wavelength range can be attributed to sunlight scattered off the surrounding forest canopy (Curtiss and Ustin, 1988). One important source of surroundings scattered light is the person and the instrumentation making the measurement. Objects in the surroundings also effect the overall illumination of the target surface by obscuring a portion of the diffuse skylight and, possibly, shading the target from direct solar illumination. The magnitude of both the diffuse skylight and scattered from surrounding illumination components is determined by the solid angle subtended by these sources when viewed from the reference frame of the target surface. The surface texture of the material being measured also effect the relative proportion of the various sources of illumination. When compared to a smooth surface, a surface with a rough texture will tend to have a higher proportion of illumination from the diffuse and scattered-from - surroundings sources relative to the direct solar illumination (Curtiss and Ustin, 1988).

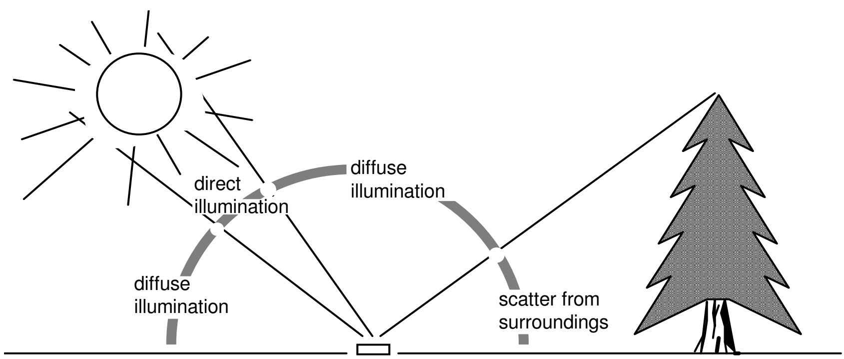

Figure 1. The major sources of illumination. Note that it is possible to have several sources of light scattered off of surrounding objects, each with its own unique spectral distribution.

2.3 CHARACTERISTICS OF ARTIFICIAL ILLUMINATION

While in most cases it is desirable to use ambient solar illumination to maintain equivalence between field spectral measurements and remotely sensed images, there are some cases where the use of artificial illumination is desirable. The use of artificial illumination allows: 1) more control over illumination and viewing geometry; 2) more control over sample geometry; 3) measurements during non-optimal conditions (e.g. cloud cover or at night); and 4) measurement of reflectance and transmittance in the deep atmospheric absorption bands. Several problems with using artificial illumination include: 1) difficulty in maintaining a constant distance between the sample or reference and the light source when measuring samples with irregular geometry; and 2) lights can 'cook' vegetation samples (water loss, chlorophyll degradation). A typical lamp configuration for indoor use is shown in Figure 2. Alternatively, the light source can be either incorporated into the field spectrometer (often precluding the use of solar illumination) or can be provided in the form of an optional accessory that mounts to the light collecting optics of the instrument.

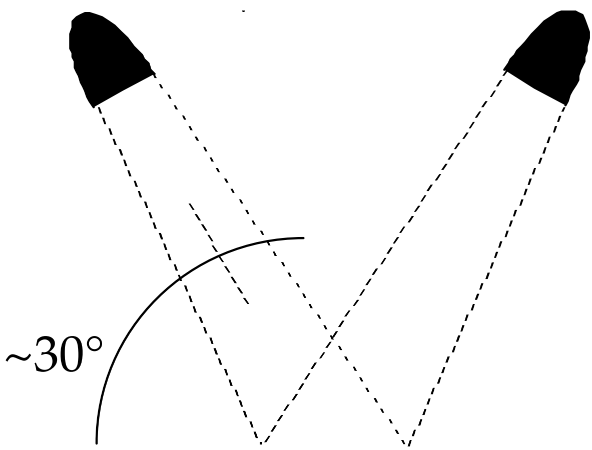

Figure 2. A typical lamp configuration for artificial illumination; the sample is viewed with the collecting optics of the spectrometer nadir to the sample. Use 1 or 2 200 to 500 Watt quartz-halogen cycle tungsten filament lamps (~3400°K color temperature) in housings with aluminum reflectors about 1 meter above the surface being measured.

3. ATMOSPHERIC CHARACTERISTICS

3.1 ATMOSPHERIC TRANSMISSION

Absorbing molecules in the atmosphere strongly modify the incoming solar irradiance (Goetz, 1992). All of absorption features described in this section will increase in intensity as the atmospheric path length of the incoming solar radiation increases (e.g. with changing solar elevation angle). By far, water vapor is the strongest modifier of the incoming solar spectrum (Gao and Goetz, 1990). Water vapor has absorption features spanning the solar reflected region of the spectrum (see Fig. 3), and varies both spatially and temporally. Carbon dioxide has strong features in the 2000-2200 nm range (see Fig. 4), a region of major interest for the identification of layered silicate minerals (Goetz, 1992). Carbon dioxide is a well mixed gas, thus the intensity of the absorption features associated with carbon dioxide are not as variable as those of water vapor, but they do decrease with increasing altitude. Other major atmospheric components that influence the atmospheric transmission spectrum are shown in Figure 5.

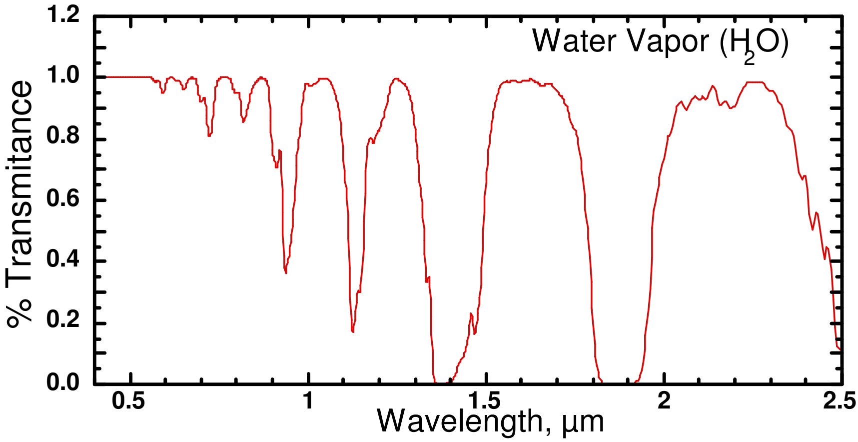

Figure 3. Transmission spectrum of water vapor for typical atmospheric conditions.

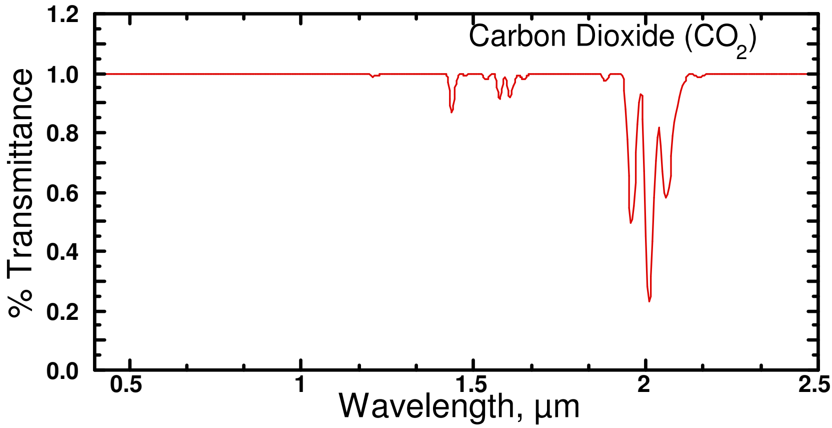

Figure 4. Transmission spectrum of carbon dioxide for typical atmospheric conditions.

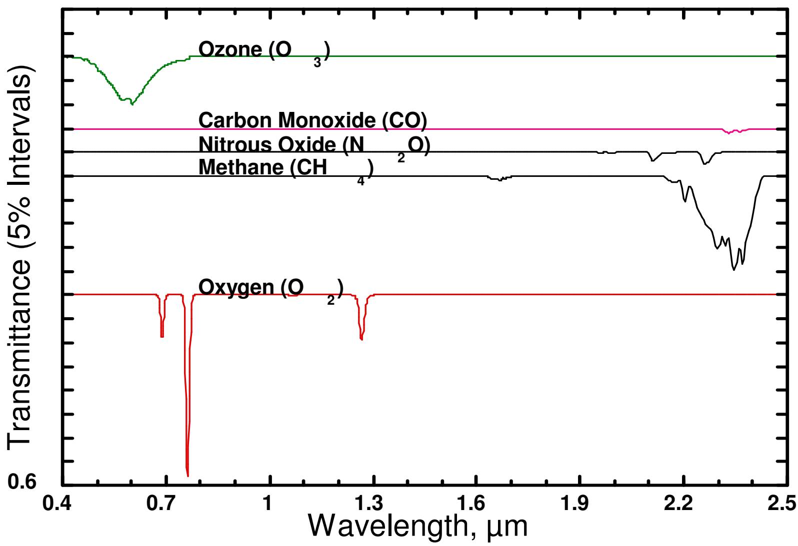

Figure 5. Transmission spectrum of various gases for a typical atmospheric conditions.

3.2 CLOUDS

The presence of partial cloud cover is indicative of highly spatially and temporally variable atmospheric water vapor (Gao and Goetz, 1992). Because of the large influence of water vapor on the atmospheric transmission (see Fig. 3), variability of atmospheric water vapor between the time when the reference and target measurements are made will result in errors in the resultant spectrum. This error can be reduced by minimizing the length of time between the measurement of the reference sample and the target.

While they are difficult to see and often appear inconsequential, the presence of cirrus clouds tends to produce significant variability in atmospheric water vapor (Gao and Goetz, 1992). The field spectrometer itself can be used to measure the magnitude of the effect. Simply standardize the instrument on the reference panel, then continue to view the reference panel with the instrument. If the atmospheric conditions are stable, the computed reflectance of the panel will be a flat spectrum with near 100% reflectance. If atmospheric conditions are unstable, the computed reflectance of the panel will vary over time and will show absorption minima or maxima (depending on whether atmospheric water vapor is increasing or decreasing) at the wavelengths corresponding to the water vapor absorption features. In this way, it can be determined whether spectral data with sufficient accuracy can be acquired.

In addition to the errors produced by time varying atmospheric water vapor, partial cloud cover also greatly increases the intensity of diffuse skylight illumination (Curtiss and Ustin, 1988). This tends to "fill in" shadows and reduce the contrast between surfaces with dissimilar surface textures. If the goal is to collect field spectra for image calibration or interpretation, spectra should be collected under illumination conditions similar to those at the time the image was collected.

3.3 WIND

Wind can be a source of error if the material being measured moves during the time the spectrum is acquired. If a spectrum is slowly scanned, changes in the amount of shadow in the instrument field-of-view will result in erroneous "features" in the spectrum. Vegetation canopies, with their large proportion of shadow, are especially susceptible to wind induced errors. Instruments using an array detector or that scan the spectrum rapidly are not significantly affected by wind.

4. CHARACTERISTICS OF TARGET MATERIALS

4.1 VEGETATION

Because of the complex three dimensional geometry of a plant canopy, light returned from the canopy is a complex mixture of multiply reflected and/or transmitted components (Curtiss, 1990; Curtiss and Maecher, 1991; Curtiss and Ustin, 1989). The canopy level optical signal is dependence upon illumination and viewing geometry, canopy structure, leaf optical properties, and the optical properties of other vegetative and non-vegetative components within and below the canopy. The strong dependent on illumination and viewing geometry can be seen in Figure 6. Both the overall brightness of the canopy and the shape of the spectral signature (e.g. the red to infrared ratio for the canopies in Figure 6) are dependent on the illumination and viewing geometry. Thus, it is only by controlling the viewing and illumination geometry, that changes in canopy reflectance attributable to the canopy itself can be detected.

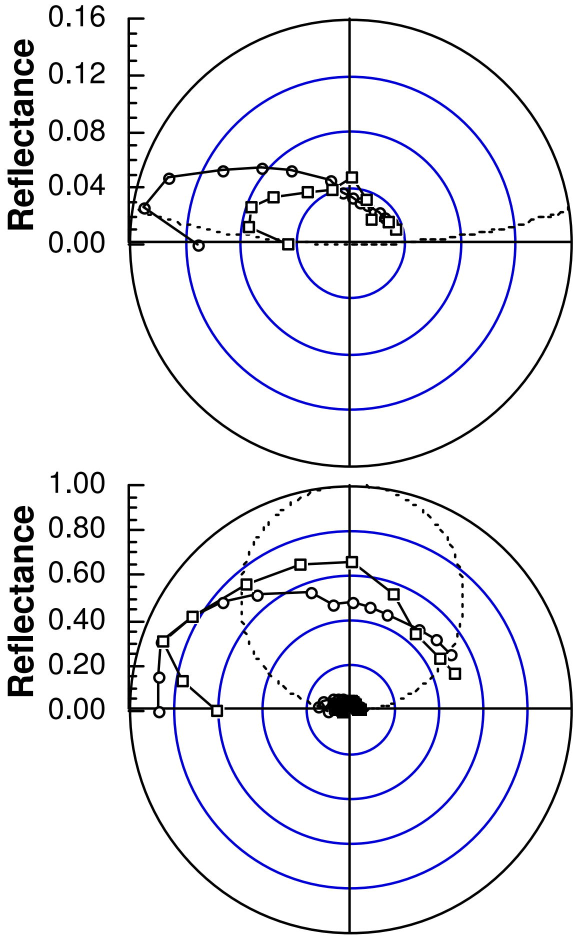

Figure 6. Bi-directional reflectance functions (BRDF) of a conifer, Mugo Pine, (circles) and a broadleaf shrub, Viburnum, (squares). For reference, the BRDF of a lambertian reflector is plotted as a dashed line. The left plot is for a red band (650 nm) and the right plot is for a near infrared band (850 nm). Both canopies were illuminated from the left at an elevation of about 30°.

True differences in canopy reflectance between several canopies may be due to either differences in canopy structure or in leaf/needle optical properties (Curtiss and Maecher, 1991). Using the data presented in Figure 6 as an example, for almost all viewing geometries, a conifer canopy will appear darker in the infrared than the broadleaf canopy even though the reflectance of the individual needles and leaves may be almost identical. Observed differences in canopy level reflectance may be attributable to differences in either leaf level optical properties or other, larger scale, structural properties of the canopy. Important structural properties include leaf/needle size, leaf/needle density at the branch level, number of years of needles retained (conifers), and branching angles. When differences are observed between canopies of the same species, it is almost always due to differences in canopy or branch level structure.

The absorption features seen in vegetation spectra are all related to organic compounds common to the majority of plant species (Peterson et al., 1988; Gao and Goetz, 1992). Thus, the information about a plant canopy is contained in the relative intensity of the various absorption features rather than in the presence or absence of a specific absorption feature. The major spectral absorption features can be attributed to plant pigments (chlorophylls, zanthophyll, and carotenoids) and water. Other, minor, absorption features are attributable to other chemical components; these include cellulose, lignin, proteins, starches, and sugars. Non-photosynthetic components of the canopy have spectra which are dominated by absorption features attributed to lignin and cellulose.

4.2 ROCKS, SOILS, AND MAN-MADE MATERIALS

Unlike vegetation, the shape of the spectral signature of rocks and soil tend to be invariant with varying viewing geometry. Due to changes in the amount of shadow in the field-of-view of the spectrometer, the overall brightness of the observed spectrum does change with illumination and viewing geometry. Absorption features in the spectra of rocks and minerals (See Figure 7) are due to the presence of specific molecular groups and are often diagnostic of the minerals present in the sample (Abrams et al., 1877; Hunt, 1980)

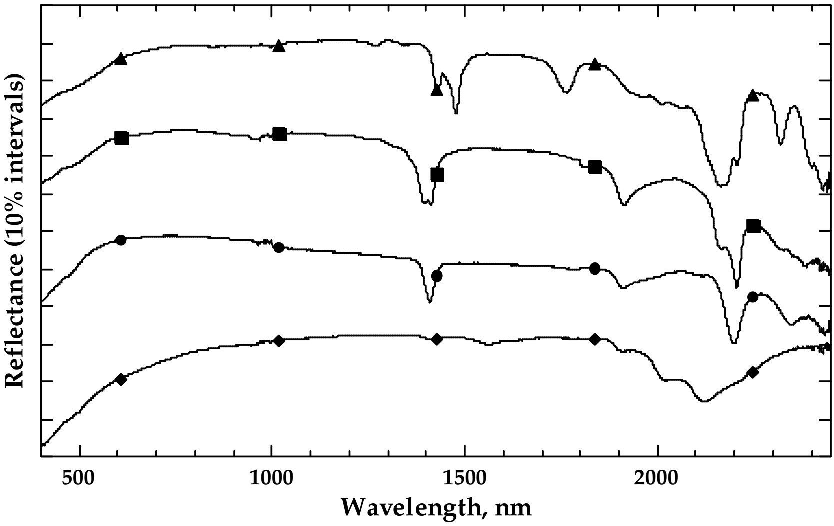

Figure 7. Reflectance spectra of alunite (triangles), kaolinite (squares), illite (circles), and buddingtonite (diamonds) measured with a FieldSpec® FR field portable spectroradiometer.

The dependence of the optical properties of man-made objects on the viewing and illumination geometry will fall somewhere between that for vegetation and rocks/soils. This will depend on the amount of light transmission through elements of the target and on the surface texture of the object. The reflectance spectra of objects with translucent elements and highly textured surfaces have an angular dependence more like vegetation, while those with opaque elements have an angular dependence more like spectra of rocks and soils.

5. INSTRUMENTATION

5.1 SPECTRAL RESOLUTION VS. SPECTRAL SAMPLING INTERVAL

While the terms "spectral resolution" and "spectral sampling interval" are often used interchangeably, they refer to very different characteristics of a spectrometer. Spectral resolution is a measure of the narrowest spectral feature that can be resolved by a spectrometer. It is also defined as the full width at half maximum (FWHM) response to a spectral line source. The spectral sampling interval of a spectrometer is the interval, in wavelength units, between data points in the measured spectrum.
For hyperspectral remote sensing applications, a spectral resolution of about 10 nm and a spectral sampling interval of about 2 to 3 nm is required (Goetz and Calvin, 1987, Goetz, 1992b). The requirement for 10 nm spectral resolution is driven by the spectral resolution of the hyperspectral sensor (about 10 nm). A spectral sampling interval of about 2 to 3 nm provides 3-4 data points in the field spectral data. This oversampling of the spectrum results in less degradation of spectral resolution when resampling the field spectral data to match the wavelengths of the hyperspectral sensor channels. Also, analysis methods utilizing derivative spectra greatly benefit from the oversampling of the spectrum.

5.2 SPECTROMETER DESIGN

Spectrometers used in currently available field spectrometers are either based upon a fixed grating and an array detector, or a single element detector and a scanning grating. One of the drawbacks of an array based spectrometer is the signal-to-noise ratio (SNR) is tied to the sampling interval as well as the spectral resolution (Smith, 1992), while in a scanning spectrometer the SNR is independent of spectral sampling interval. Array detectors in the 350 to 1000 nm region of the spectrum (VNIR) have sufficient sensitivity to allow spectra to be collected with spectral resolutions well above the 10 nm resolution required for hyperspectral remote sensing studies. Thus, in the VNIR, fixed grating, array detector, based spectrometers provide the best performance for most remote sensing applications. Typical VNIR spectrometer designs provide 3 to 5 nm spectral resolution with a spectral sampling interval of better than 2 nm.

Due to the rapid fall-off in energy of the solar spectrum in the 1000 to 2500 nm region of the spectrum (SWIR), spectrometer design is strongly driven by the need to maintain an acceptable SNR. In general, a loss of SNR is not acceptable in exchange for decreased spectral sampling interval. Thus, the use of an array detector in the SWIR spectral region generally precludes the oversampling of the spectrum. While scanning spectrometers do not have this limitation, they have the drawback of not measuring all wavelengths simultaneously. This can result in errors due to changes in the target during the measurement of the spectrum (see Section 3.3). This limitation is overcome by rapidly scanning the spectrum.

Traditionally, scanning SWIR spectrometers have used lead sulfide (PbS) detectors. Due to the lack of sufficient frequency response, the use of PbS detectors precludes rapid scanning. Indium gallium arsenide (InGaAs) detectors have the high frequency response required for rapid scanning (less than 100 milliseconds to scan from 1000 to 2500 nm). InGaAs detectors have the added advantage of having a higher sensitivity than PbS and, also, do not require an optical chopper as does PbS. These increases in performance over PbS allow the design of a rapid scanning spectrometer with equivalent or better SNR performance than a PbS array detector based spectrometer. A scanning design has the added advantage of being having a spectral sampling interval that is less than one fifth the spectral resolution without a reduction in SNR.

While it is possible to include the illumination source within the spectrometer, this limits the applications that can be addressed and the types of targets that can be measured. Because of the need to hold illumination and viewing geometry constant between the field and image spectral data, field spectra collected for either hyperspectral sensor calibration or for direct comparison with hyperspectral image data are best collected using ambient solar illumination. The use of a built-in light source also precludes the measurement of radiance or irradiance. Additionally, targets such as vegetation with a complex three dimensional structure can only be measured in the field using solar illumination.

5.3 SPECTROMETER FIELD OF VIEW

Existing field spectrometers use one of two basic approaches to collect light energy and deliver it to the spectrometer. In some spectrometer designs, foreoptics are used to form an image of the target upon the entrance slit of the spectrometer. This approach results in a ground field of view (GFOV) that has the same shape as the spectrometer entrance slit (often a rectangle with a height to width ratio of more than 10:1). If more than one spectrometer is used in an instrument (e.g. a VNIR and SWIR spectrometer), it is often difficult to ensure both spectrometers are viewing the same GFOV. The use of optical fibers to deliver the light to the spectrometer results in a circular GFOV. The use of more than one spectrometer is accommodated by splitting the optical fiber bundle within the instrument to deliver light to the various spectrometers. The size of the GFOV is determined by the angular field of view of the instrument and the distance to the target. While optics can be added to modify the angular field of view of a field instrument, this is often practical only for those instruments utilizing optical fibers for light collection.

6. EXPERIMENTAL DESIGN

6.1 TIME OF DAY / YEAR

The timing of the field data collection is important if field spectra are to be used to calibrate or interpret a hyperspectral image. Reflectance spectra used to interpret a hyperspectral image should be collected under illumination conditions similar to those when the image was acquired. Time of day and date are the major controlling factors of direct illumination geometry, while atmospheric conditions relating to scattering and clouds are the major factors controlling the geometry and relative intensity of indirect illumination (Curtiss and Ustin, 1988). If field spectra are to be used to convert a hyperspectral sensor image to reflectance, spectra should be acquired simultaneously with image acquisition. If this is not possible, a water vapor correction should be made to the image prior to its conversion to reflectance (Gao and Goetz, 1990).

6.2 SAMPLING STRATEGY

The selection of a particular sampling strategy should be based upon the objectives of the study. If the objective is to determine the detectability of either a target material or of a process effecting the spectral signature of a target material, the sampling strategy must encompass examples of the target material under all expected conditions as well as all other background materials. Consideration must be given to all the processes modifying target and background spectral signatures; these include illumination, slope and aspect, and target surface architecture. Adequate collection of vegetation is even more problematic due to the wide range of processes that effect their spectral signature. These include soil chemical properties, soil reflectance, water availability, time of day, time of year, cloud cover, temperature, and relative humidity.

If the purpose of a study is to understand how a process effects the spectral signature of a target without consideration of how background materials and other sources of variability effect the spectral signature, variance from sources other than the one of interest should be minimized in the selected targets. This is achieved by carefully controlling viewing and illumination geometry, often in a laboratory. This type of study is often performed as a feasibility study prior to a full study evolving collection of spectra of background material.

6.3 VIEWING GEOMETRY

The selection of an appropriate viewing geometry depends upon whether the spectra are used for image analysis or for a feasibility study. For image analysis, a viewing geometry similar to the airborne sensor is required. For a feasibility study it is possible to eliminate much of the confounding variance typically present in an image data set by fixing the viewing and illumination geometry.

For vegetation, spectra can be acquired at the spatial scale of the leaf/needle, branch, or canopy. Canopy level spectra are most suitable for image analysis and interpretation. Rarely can leaf/needle or branch level spectra be used to directly to interpret an image. Leaf/needle and branch level spectra are useful to understand how the canopy level spectra are influenced by changes in leaf/needle and branch spectral changes as opposed to changes in the canopy structure.

6.4 ANCILLARY DATA SETS

Collection of appropriate ancillary data sets is as important as the collection of field spectra. The measurement of processes and material properties directly influencing, or correlated with, the collected spectra are essential to the understanding of the variance observed in a hyperspectral image data set. It is often necessary to collect a set of spectra with ancillary data in order to validate predictions made using the main field spectra plus image data set.

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APPENDIX B

WAVELENGTH AND RADIOMETRIC

CALIBRATION METHODS

by Dave Beal, Analytical Spectral Devices, Inc.

Introduction:

Reliable field spectrometry data collection depends, to perhaps the greatest extent, upon accurate calibration of the instruments used. The Analytical Spectral Devices FieldSpec® line of spectroradiometers is commonly used in the analysis and cross-referencing of Reflectance, Transmittance, and Absorption characteristics of materials and land/sea surfaces. For this reason, accurate wavelength calibration is a necessity and a standard feature included in the acquisition of any FieldSpec® instrument package. Periodic examination of the absorption features in the spectra of materials with known characteristics is highly recommended for the SWIR (short wave infrared; 1000 - 2500 nm) detectors. A mercury discharge tube or other known discrete emission light source works well for verifying calibration in the VNIR (visible and near infrared; 350 - 1000 nm) portion of the spectrum. After the instruments are calibrated at the ASD factory with a 0.1 nm bandpass monochromator, their responses to several known elements and emission sources are checked, before shipment, as a verification of method and equipment.

Due to the consistency of the detector performance in the FieldSpec® instruments, they are also commonly used, as their name implies, in radiometry applications. This, naturally, requires accurate and reliable radiometric calibrations for the instrument and accessories used in such applications, as well as software for manipulation of calibration and data files. Radiometric calibration is an optional feature in the purchase of any FieldSpec® instrument and, in most cases, must be performed at Analytical Spectral Devices' factory, in Boulder, CO, USA. This paper is intended as a guide for current and potential ASD customers who would like to know more about our methodology in calibration so that they can make a better informed decision about how they would like to proceed with their instruments; and perhaps even in how they would prefer to collect and analyze their data.

Reflectance or Radiance?

Many papers written on the subject refer to the use of *spectroradiometers* in field *reflectance factor* measurements. This is because with some instruments, it is best to use the ratio of the reflected radiance of the observed sample to the reflected radiance of a known reference panel (taken at the same time), in order to determine the reflectance factor of the sample. Of course, when this is done, all units fall out in the result, which is typically a number between zero and one for each channel measured. However, instruments such as the FieldSpec® spectroradiometer, with a well-characterized linear response, can be used for the same purpose without going to the trouble and expense of radiometric calibration. Raw signal inputs from the sample and the reference panel can be ratioed to achieve the same result.

This does not mean that FieldSpec® instruments *must* be used only as spectrometers, or spectrophotometers, as the case may be. On the contrary, at least one-fourth of ASD's customers have a true need for spectroradiometric data. Spectroradiometric needs might include: Ground-truthing of reflected radiance data collected from high altitudes or from different instruments, radiance of molten solids such as lava, steel and glass, solar *ir*radiance at various levels of the Earth's atmosphere and points on the Earth's surface, studies in photosynthesis, flame studies, and synthetic light studies, among many others. But for most of our customers, who use the instruments for remote sensing ground truthing exercises, material absorptance/reflectance characteristics, water/snow/ice studies and mineral identification, an instrument with a good linear response to intensity across the spectral region of interest is all that is needed, in addition to an accurate wavelength calibration, of course.

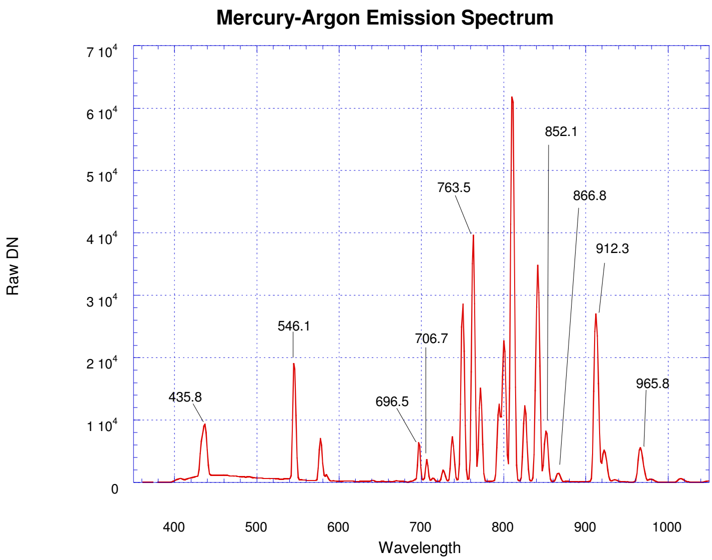
Wavelength Calibration:

Wavelength calibration is a standard feature of all ASD instruments. Typically, one calibration will be accurate to within one nanometer and is guaranteed for one year. ASD will always recalibrate a FieldSpec® instrument's wavelength values once, within that time, at no extra charge.

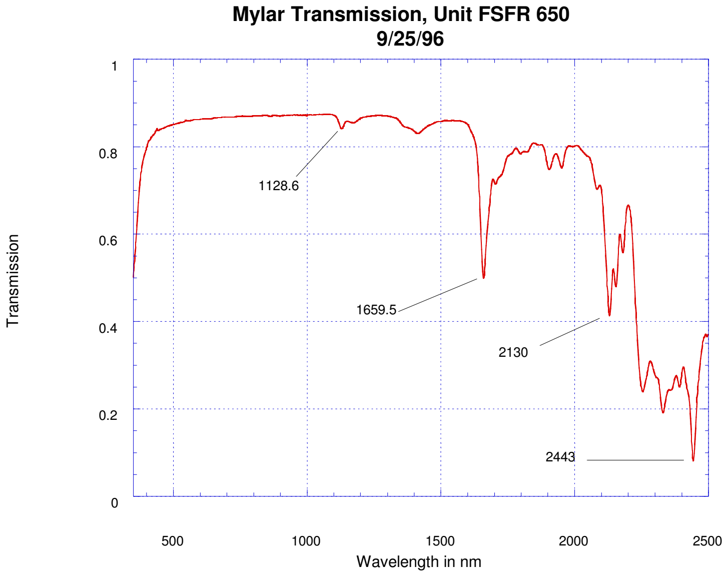
The UV/VNIR detector array and housing combine to provide a simple linear relationship between wavelength and channel number. For this reason, all that is needed for calibration is a few well-characterized emission lines, spread throughout the region from 350 - 1000 nm wavelength, and a finely focused instrument. At ASD, the emission lines come from a separate monochromator, set to emit at 50 nm intervals, which are plotted against the responding channel numbers, and the first channel number's wavelength is extrapolated from a linear regression fit of the data. The final equation is a simple linear formula, in the form:

$$\textit{wavelength} = \text{lamstart} + (\text{lamstep})(\textit{channelnumber})$$

The constants, lamstart and lamstep, are calculated as above, at the ASD factory and installed into the controlling computer's **asd.ini** file for access by the controlling software. The *channelnumber* domain is 0 to 511. Wavelengths of certain emission lines from a Mercury-Argon source lamp are then measured as a cross-calibration of the monochromator values. Some of the HgAr lines may be used for the calibration itself. But the presence of doublets means that not all of the lines should be used. Contact ASD for the purchase price of your own HgAr portable emission source. The monochromator is also frequently cross-calibrated using up to four orders of Helium-Neon laser diffraction.



The SWIR scanning spectrometers, covering the range from 1000 - 2500 nm, use much the same calibration principles, with two major differences: 1. We use a monochromator as our only emission source, and 2. Two *third* order polynomials are calculated for each SWIR detector, to account for both forward and backward scans of the gratings. This amounts to the calculation of eight constants for each detector, listed in the **ini** file, as noted above. We then check the SWIR wavelength calibrations with well-defined absorption features in a material such as Mylar or Polystyrene.



If you would like any further information on wavelength calibration of the FieldSpec® instruments, please contact Sales or Technical Support at ASD.

Radiometric Calibration:

Radiometric readings with the FieldSpec® come in two basic flavors:

1. **Irradiance** (*E*), which is the radiant flux (Φ) per unit of area, or $E = d\Phi/dA$, given in W/m^2. This term is only definable at a given distance from a given radiant energy source, or through a given surface in space, without regard to sources.
2. **Radiance** (*L*) is the radiant flux emitted from a source per unit of solid angle (ω) per unit area. It is useful at this time to define Radiant Intensity as $I = d\Phi/d\omega$, such that $L = dI/dA \cos\theta$, given in $W/sr\text{-}m^2$ (Pedrotti, F. L. & L. S. (1993) Introduction to Optics, 10 - 13).

Thus, the irradiance (*E*) at a given surface may be converted to the radiance (*L*) emitted from that surface by dividing *E* by π. It is important to note, though, that the conversion requires a couple of important properties inherent in the surface, in order to be even a close approximation. First, that the surface be as near to 100% reflective (at all wavelengths) as possible; and second, the surface must be perfectly *lambertian* (or at least nearly so). That is, it must be perfectly reflective, and it must radiate uniformly in all directions. Note that a good quality surface mirror satisfies one, but not both, of these qualities.

As stated earlier, FieldSpec® instruments used for radiometric readings must first be calibrated to do so. Even so, by definition, the quantity actually measured by a spectroradiometer that measures irradiance is *E* per $\Delta\lambda$, while radiance measurements are actually *L* per $\Delta\lambda$ (better known as *spectral* irradiance and radiance), as the data is collected across a given spectrum. The collected curves must be integrated with respect to wavelength to arrive at the definitive terms. All FieldSpec® instruments currently must be set to collect raw data, later to be converted to radiometric data in postprocessing. The following is a rough compilation of the procedures and equipment used in calibrating a unit at the ASD factory.

The first requirement is, of course, a well-focused and wavelength-calibrated instrument. An irradiance source is powered by a *stable* DC current-regulated supply as the calibration standard. We use a lamp and power supply from Optronic Laboratories Inc., which is traceable by NIST (the National Institute of Standards and Technology), in the USA. The 3200 Kelvin lamp irradiance data, at a given distance from the bulb and a given current, is supplied by the manufacturer and guaranteed to be accurate within 1-2% in total irradiance, relative to NIST uncertainty (Optronic Laboratories, Inc. (1994) Condensed Catalog, 7). The system is installed inside a flat black baffled box, to insure that the only energy projected upon the screen is that coming directly from the bulb, itself – Not reflected from equipment, walls, etc. The bulb is calibrated at a healthy 50 cm distance, so uncertainty due to the intersection of the spherical irradiance front with the planar Spectralon® panel can be considered negligible, when viewing a small portion of the surface in the center of normal energy incidence.

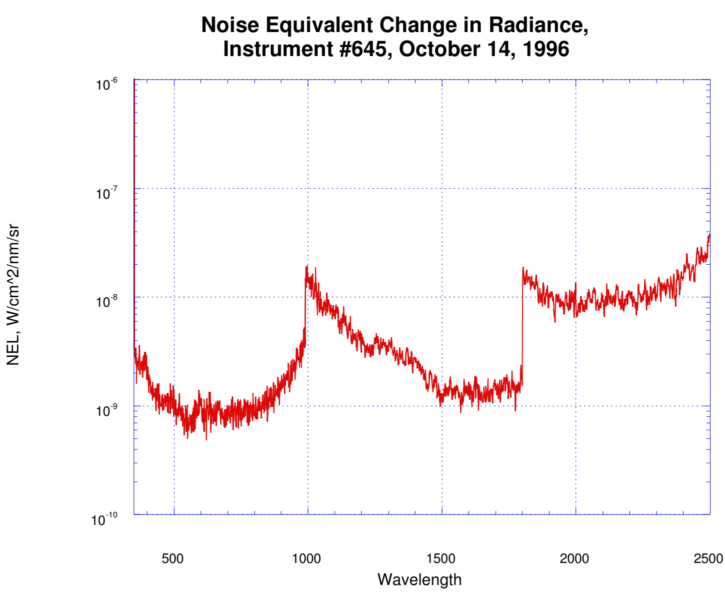
The screen surface is a 12 X 12 inch panel of calibrated Spectralon® made by Labsphere. This panel was calibrated from at least one of a number of NIST-calibrated reference standards, which were in turn calibrated "using the highly accurate NIST reference reflectometer" (Labsphere, (1995) Calibration Certificate, 8° / Hemispherical Spectral Reflectance Factor, Report No.: 14440-D). The random error in the calibration file is estimated to be within 0.5% over the spectral region from 300 - 2200 nm, and within 2% from 2200 - 2500 nm.

An increase in a Full Range instrument's internal ambient temperature leads to an increase in VNIR detector sensitivity from about 700 - 1000 nm, so each unit is allowed to warm up for about 1.5 hours before calibration data is collected. To learn more about this VNIR temperature/sensitivity effect, contact technical support at ASD. ASD monitors the usage of the calibration lamp to maintain the guaranteed irradiance, and periodically checks its performance against at least two backup lamps of the same style and wattage.

Providing a buffer against ground vibrations (caused by construction equipment, trucks, Great American Bison herds, etc.) is a set of six pneumatic high-frequency shock absorbers, placed beneath the optical benchtop upon which the entire apparatus resides. This gives great stability to the actual lamp filament, and increases the lifetime of the bulb as well as its guaranteed accuracy, when compared with our backup.

The power to the bulb is ramped upward over several minutes, to a final current value of 8.0000 Amperes. The calibration room is completely darkened, except for the lamp, and the instrument's fiber optic probe is placed in a stationary position at a 45 degree angle to the illuminated Spectralon® panel. The controlling software is entered, the instrument is optimized, and spectra are saved, as **raw DN** files, with each foreoptic attachment requested, with a spectrum average of 50 scans per spectrum, including 50 dark current scans. If a unit is being calibrated for a Remote Cosine Receptor, the Spectralon® panel is replaced with the fiber optic, fitted with the RCR, in the same irradiance calibration plane.

At this time, it is usually convenient to collect data for the NEΔL (Noise Equivalent change in Radiance) properties of the instrument. We do this with no foreoptic attached, in the configuration for calibration with bare fiber, at 10 spectrum averaging. 30 spectra are saved and the standard deviations from the means at all channels are calculated and converted to radiance data. This data will tell us here at ASD, as well as the customer, what the true performance of their unit is like. And it assures everybody that our units are meeting noise specifications.



The ASD radiometry software, RCALC.EXE (postprocessing) uses the following formula in calculating Radiance:

$$L = \frac{(lampfile)(calpanelfile)(inputfile)(calITG)}{(calibrationfile)(inputITG)(\pi)}$$

where *L* is the radiance to be calculated (on a channel by channel basis)

lampfile is the calibrated irradiance file for the lamp
calpanelfile is the calibrated Spectralon® reflectance file
inputfile is the unknown, dark current corrected input file
calITG is the integration time and/or gain of the calibration file
calibrationfile is the dark current corrected raw data collected at ASD
inputITG is the integration time and/or gain of the input file

The divisor of π is automatically left out in the calculation of an *Irradiance* (*E*) measurement. The software "knows" which formula to use by looking at the foreoptic specified in the header of the data file.

Conclusion:

The expense involved in the calibration process is not limited to calibration equipment and its maintenance, though this is a major portion of it. There is also a considerable outlay of time and research in software development and quantitative analysis of our own results and repeatability. This is not to say that our users would not wish to conduct their own calibrations. Many researchers need the control over and accountability for uncertainties that an outside entity simply cannot provide.

However, when conducting studies concerning the viability of performing their own calibrations (radiometric, in particular) FieldSpec® users should consider the necessity of building postprocessing software from what may amount to a whole new platform, from the ground up. On one hand, this allows great freedom and flexibility in their options; on the other, it also requires great resources and patience.

APPENDIX C

Dynamic, Parabolic Linear Transformations
of "Stepped" Radiometric Data;

Parabolic Correction

Introduction:

ASD FieldSpec® Full Range instruments should be "warmed up" before being used to collect data for radiometric conversion with RCALC.EXE. This is because the units are, as a standard practice, radiometrically calibrated after at least a 75 to 90-minute warm-up period in laboratory conditions – a more stable practice than 70 minutes for one unit, 10 minutes for another, and so forth. The reason for this is the inherent variations in detector sensitivity, at some wavelengths, when used under different ambient temperatures, both internal and external. The variations occur in the VNIR array and the SWIR2 detector, but do not appear to be present in the SWIR1 detector (~1000 to 1800 nm), under normal operating temperatures. A sufficient warm-up period, for the customer, can be difficult, if not impossible, to achieve when the instrument is used in the field – particularly when using battery power alone. So how can we use the stability of the SWIR1 spectrometer to help correct for potential data variations in the other two spectrometers?

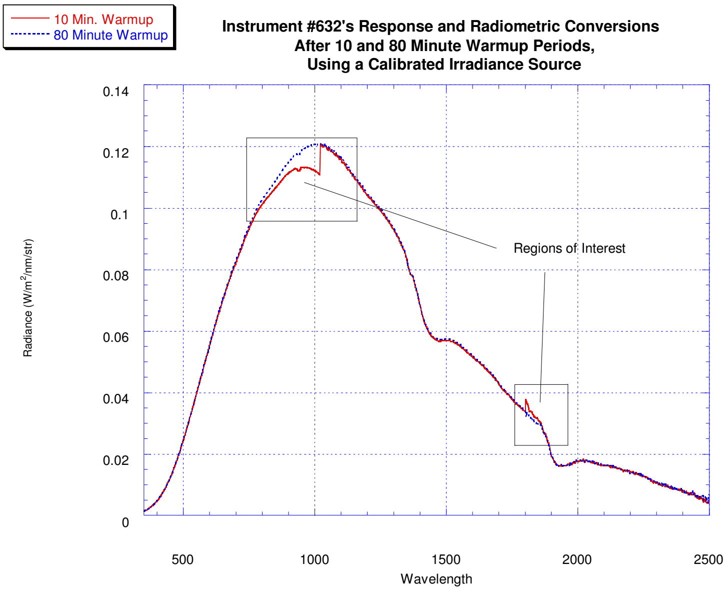


Figure 1

Figure 1 shows the problem, which appears more pronounced at the red end (700 - 1020 nm) of the VNIR spectrum. However, error measured as a percentage of Y-value can actually be greater at the "blue" end (1800 - 2000 nm) of SWIR2 (Figure 2).

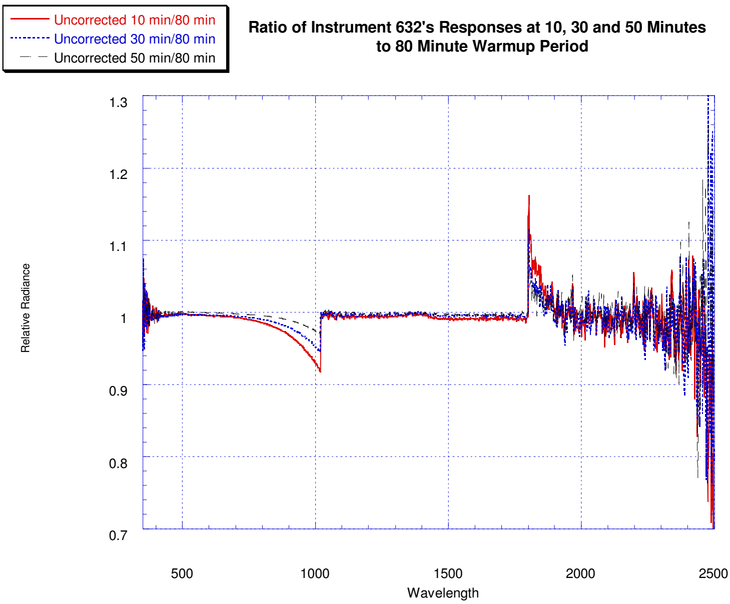


Figure 2

When viewed this way, the problem is quite obvious. But the stability of the SWIR1 detector offers a solution: Using the endpoints of SWIR1 and the shape of the response change curves, it is possible to mathematically characterize and adjust for the temperature-dependent sensitivities of the two variable ranges. While cooling does decrease noise and Dark Current levels, the SWIR2 detector needs a level of fine-tuning that cooling alone may not be able to provide in a cost-effective manner.

A Solution:

Since the varying spectral regions appear somewhat parabolic, it seems that a pair of partial parabolas inserted into what otherwise is an identity matrix can be used to correct the temperature-sensitive channels. These parabolas may be expressed in the form:

$$(x-h)^2 = 4p(y-k)$$

where the vertex is at (*h,k)*; focus is at (*h,k+p)*. In our case, *p* is the distance from the vertex to the focus point and *h* will always be one, so that the parabolas merge with the identity matrix (I) at the vertices. The focus will be the dynamic feature of the parabola, determined directly from the difference between the y-values on either side of the spectral splice of interest. In other words, as a good approximation to correcting the far red endpoint of the VNIR region, we will build a transformation parabola that will set the value of that endpoint equal to the value of the adjacent SWIR1 endpoint; which will determine how "open" the parabola will be, given the same vertex for any correction matrix. A similar situation is true of the SWIR2 correction.

After experimenting with several different vertex choices on several different Full Range instruments, we have found the best general choices for all units were at about the points (700,1) and (1975,1). You may wish to use these as your instrument's "defaults", until a full characterization can be performed. When characterizing your unit's vertices, be sure to view a stable source, and collect a new dark current before each spectrum, so that dark current drift will not be a factor. We used 725 and 1950 as vertices for instrument 632 (Figure 3), with excellent results – a maximum deviation of less than 1% from unity for both trouble regions in the spectrum. The actual ideal vertices for this instrument are at 675 and 1980, so this plot introduces some additional unnecessary error – a worst-case scenario, let's say. The full equation reads:

$$\text{IF } 724 < x < 1021,$$
$$y = (x-725)^2(y_{1021}-y_{1020})/y_{1020}(1020-725)^2 + 1,$$
$$\text{If } 1800 < x < 1951,$$
$$y = (x-1950)^2(y_{1800}-y_{1801})/y_{1801}(1800-1950)^2 + 1,$$
$$\text{ELSE } y = 1$$

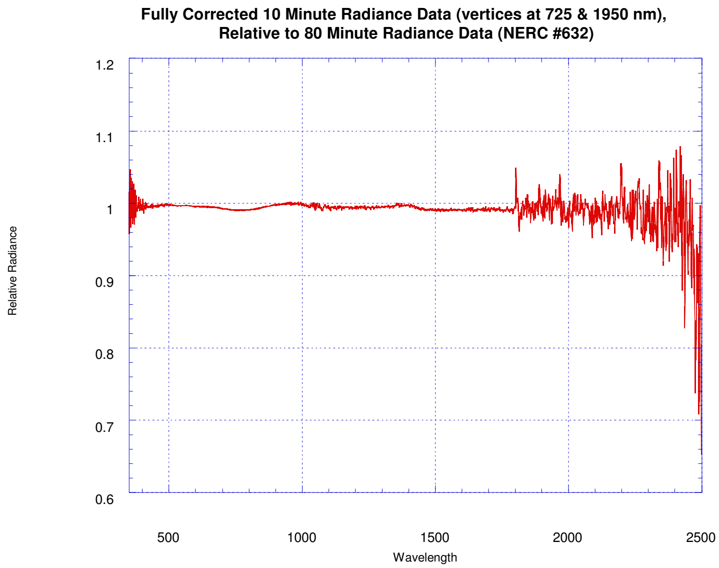


Figure 3

Advantages and Caveats:

If hardware behavior can be characterized mathematically (and consistently), then this is no more unorthodox than the standard procedures for transfer calibrations which must necessarily be used world-wide, from base references such as NIST. Only time and future testing with different pieces of hardware under many different conditions will determine how beneficial this will actually be to ASD FR customers.

The drawback to all of this is, of course, that the procedure absolutely, positively requires the presence of a completely stable SWIR1 package. If SWIR1 fibers have broken, or if the SWIR1 detector has destabilized for any reason, the results of this destabilization will no longer be easily apparent in the instrument's radiometric plots. For periodic inspection of the instrument's calibration and SWIR1 stability, you (the customer) should periodically warm up your unit for one to two hours in laboratory conditions, collect a raw spectrum of a black or gray-body source, and convert the file using RCALC.EXE. Any steps in radiometric data greater than about 4-5 % may indicate a problem, although this is not completely reliable. Your own experience with data collection and analysis can best determine unrealistic results in data and possible problems with your hardware.

Specifications

Dimensions:

Height (with instrument stand) 415 mm (16.3 in.)
Depth (body) 320 mm (12.6 in.)
Width (with instrument stand) 205 mm (8.1 in.)
Width (without instrument stand) 120 mm (4.7 in.)

Indoor Use Powered with AC/DC Adapter/Charger:

Class I Equipment (grounded type)
Mains supply voltage fluctuations are not to exceed ± 10% of the nominal supply voltage.
Installation (over voltage) Category II for transient over voltages
Temperature 0°C to 40°C
Storage Temperature 0°C to 40°C
Altitude up to 2000m
Pollution Degree 2
This equipment is suitable for continuous operation.

Conditions	18 Vdc (AC/DC adapter/Charger) AC input 100-127V (+/-10%)	18 Vdc (AC/DC adapter/charger) AC input 220-240V (+/- 10%)
35°C ambient, 20% Relative Humidity, Altitude: 2000m Light source On, Battery charging, Auxiliary port 2A load	Power: 180 Watts Current: 2Amps (AC)	Power: 180 Watts Current: 0.9Amps (AC)

Indoor/Outdoor Use Powered with Internal Battery: Class III Equipment Temperature 0℃to40℃ Storage Temperature 0℃ to 40℃ Altitude up to 2000m Pollution Degree 2	
Conditions	12 Vdc (Internal Battery)
40℃ ambient, 20% Relative Humidity Altitude: 2000m Auxiliary port 2A load	Power: 50 Watts Current: 4.1 Amps
40℃ ambient, 20% Relative Humidity Altitude: 2000m Auxiliary port: No load	Power: 26 Watts Current: 2.1 Amps

Adapter/Charger Specifications: A.S.D. Part #A146570 Input: 100-120VAC, 200-240VAC (auto range), 3.2A Max. 47-63Hz. Output: 18VDC, 7.2A, 130W Max. INDOORS USE ONLY CSA LR74350, Level 3 UL listed: I.T.E Power supply 6F78, E137895	Battery Specifications: A.S.D. Part #160304 Output: 12VDC Cell type: NiMH Capacity: 9.0 Ah Over current and Over temperature protection.

USER NOTES

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