

Remote Sensing Products

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1. Introduction

CI Systems has been supplying instrumentation for the remote sensing market for over 25 years. Many of these systems were initially developed as customized systems according to customer requests.

CI Systems is a world known manufacturer of specialized E-O equipment and is known for its high quality of engineering and innovative designs.

This catalog presents CI's current line of products for the remote sensing market. Some of these products, such as the SR-5000, have been on the market for many years, and others are newcomers, such as the MCR-8 and the MWIR hyperspectral imager.

CI is committed to continue its development of innovative remote sensing products. Also, we will be happy to provide customized solutions for individual customers.

2. SR-5000 Spectroradiometer



2.1. Some applications of the SR-5000

The SR-5000 Computerized Spectroradiometer can be used for both spectral (intensity versus wavelength) or radiometric (intensity versus time) measurements.

Some specific applications of the SR-5000 include:

- Radiometric temperature measurement and monitoring
- Transfer radiometry
- Radiometric calibration of blackbody sources and electro-optical test systems
- Countermeasures analysis
- Decoy systems development and testing
- Atmospheric transmissometry studies
- Generalized transmittance and reflectance measurements
- Camouflage materials development and testing
- Signatures of military objects
- Signatures of jet plumes and afterburners
- Spectral emittance of sky, ground, horizon, sea and clouds
- Remote sensing of objects
- Emissivity measurements
- Process control and development

2.2. Features

The SR-5000 has many outstanding features, which are described in this catalog. Some of the key features of the system are:

- Extremely high sensitivity to detect faint signals
- Extremely high stability and repeatability for accurate measurements
- Uniform and symmetric field of view performance for distant targets which do not fill the FOV
- All mirror optics (UV to Far-IR) for maximal optical performance
- Advanced state-of-the-art software
- High versatility in measurement setup for a wide range of measurement types
- Display of spectra in irradiance units
- Real-time data analysis and display
- Automatic calibration and reference to an internal floating blackbody source for maximum accuracy
- Modular, rugged and field tested design
- Customized options as required by specific users

2.3. Standard instrument

The SR-5000 combines state-of-the-art sensitivity with a computerized control, data processing and display of spectroradiometric measurements from 0.240 to 14.5 μ in spectral mode, and 0.2 to 30 μ in radiometric mode.

The SR-5000 is the most advanced commercially available spectroradiometer on the market with a vast selection of options to fit user requests.

2.3.1. Field of view

The SR-5000, with its wide range of available fields of view (FOV), is suitable for both small and large objects to cover most applications of radiometry. The system can be configured for narrow fields of view between 0.3 and 6 milliradians. A medium field of view (of up to 5.7 degrees) or a wide field of view (of 15 or 28 degrees) can be ordered, as an option.

In addition, the SR-5000's FOV is exceptionally uniform and symmetric. This very smooth uniformity and symmetry allow for repeatable results when very small, non-uniform or moving targets are measured.

The flatness or uniformity of response is defined by the ratio:

$$f = \frac{S_1 - 4 S_2}{2 S_1}$$

Where S_1 and S_2 are defined in Figure 2-1.

The symmetry of the field of view in the horizontal and vertical directions is defined as:

$$S = \frac{FOV_{Hor} - 4 FOV_{Ver}}{2 \times FOV_{Avg}}$$

Where FOV_{HOR} and FOV_{VER} are the horizontal and vertical fields of view measured at 10% of the maximum signal. FOV_{Avg} is the average value of FOV_{HOR} and FOV_{VER} (see Figure 2-1).

The parameters f and S are specified to be better than $\pm 10\%$ and $\pm 5\%$ (respectively) for the SR-5000 (typically, the values are much better than these values). In competitive systems, these values can be as high as $\pm 25\%$ and $\pm 15\%$, respectively.

Figure 2-1 FOV flatness and symmetry

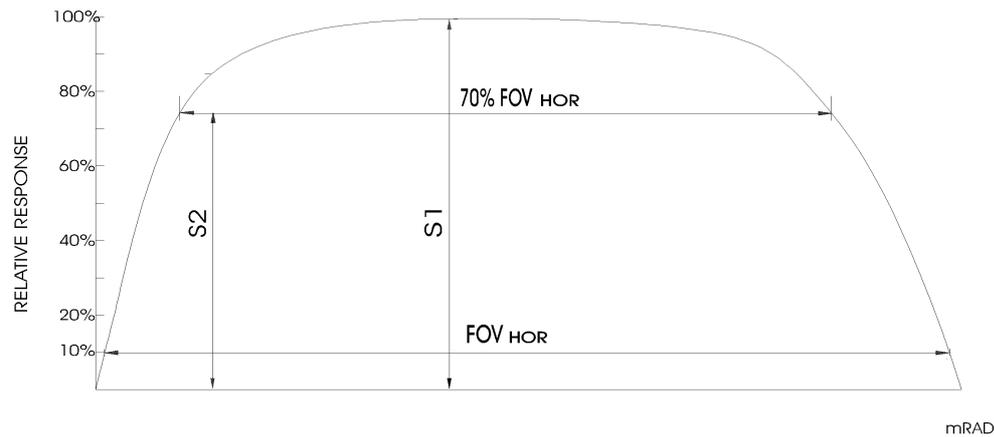


FIGURE 4 : HORIZONTAL SCANNING OF FOV

2.3.2. Internal blackbody

The internal blackbody is at ambient temperature, and it provides a known radiation spectrum, which is used as a reference by the SR-5000. Its temperature is monitored continuously by the computer and is used to adjust the data in case of changes in the ambient temperature drifts after calibration.

An ambient temperature blackbody has distinct advantages over a temperature-controlled blackbody since very small temperature gradients, which occur inside the optical head, do not affect a room temperature source as much as it would affect a temperature controlled source. When errors due to the emissivity of the chopper and internal blackbody are accounted for, a controlled source can cause sensitivity inaccuracies of up to 5% compared to an ambient source with inaccuracies of less than 0.5%.

2.3.3. SR-5000 detectors

CI offers a wide range of detector packages that are suitable for the SR-5000. These packages are complete units that are interchangeable in the field. Complete wavelength regions can be changed in less than five minutes, without realignment. They include:

the detector element

a holder and precision alignment ring

a window and a matched preamplifier for the best performance of each detector

a power supply

a dewar

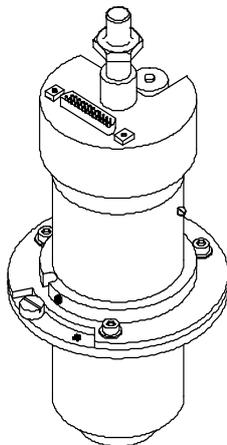
a thermoelectric cooling system

an optically matched cold shield for each detector

the highest transmission window material available, unless otherwise specified.

All liquid nitrogen cooled detectors are supplied with 77K dewars. (Joule - Thompson and Stirling coolers are also available.) The preamplifier is attached directly to the dewar, thereby eliminating an important source of electronic and vibration noise. These dewars have a holding time of above 8 hours, which allows a day's worth of measurements without refilling. They are also rugged and re-pumpable. A one-way, blow-off valve prevents seepage of moisture to the inner vessel. An example of a detector subassembly is pictured in Figure 2-2.

Figure 2-2 LN2 cooled detector subassembly



Detectors requiring operation at 77 K can also be supplied with Joule-Thompson coolers (requiring pressurized high purity gaseous Nitrogen) or closed loop cryogenic coolers (requiring no external cooling whatsoever).

2.3.4. Circular variable filters (CVF's)

A Circular Variable Filter (CVF) is a monochromator, which allows monochromatic light with a specific wavelength bandpass to pass through to the detector. This is a medium resolution component, typically 2% Full Width Half Max (FWHM).

In the SR-5000, the CVF module is an optically encoded, motorized subassembly, which, combined with supplied calibration data, constantly monitors the central waveband the CVF allows to pass through.

A number of CVFs and filter wheel subassemblies are available which, when matched to the correct detector, give spectral data covering the entire CVF wavelength range.

In the past, these filters, were manufactured by OCLI, however the production has been discontinued. CI has developed it own line of CVF's which slightly differ from the ones previously produced by OCLI.

The configuration of the most common OCLI CVF's are listed in Table 1.

Table 2 includes the currently supplied CVF configurations. In addition to CVF's, a discrete six or twelve position filter wheel may also be purchased.

Table 1 OCLI CVF's

CVF No.	SPECTRAL RANGE μm	PROPOSED DETECTOR
CVF 1	0.7 - 2.5	Si/PbS or Si/PbSe Sandwich
CVF 2	0.4 - 1.2	Si
CVF 3	1.3 - 2.5	PbS or PbSe
CVF 4	1.3 - 8.0	InSb, PbS or PbSe
CVF 5	0.4 - 0.7	Si
CVF 6	2.5 - 14.2	InSb/MCT Sandwich
CVF 7	0.4 - 2.5	Si/PbS or Si/PbSe Sandwich
CVF 8	1.3 - 14.2	InSb/MCT Sandwich
CVF 9	0.7 - 4.5	Si/PbSe Sandwich

Table 2 CI CVF's

CVF NUMBER	SPECTRAL RANGE μm	PROPOSED DETECTOR
CVF 4N	1.2 –6.5	InSb
CVF 6N	2.3 - 14.2	InSb/MCT Sandwich
CVF 7N	0.4 - 2.5	Si/PbS or Si/PbSe Sandwich
CVF 10N	0.24 – 1.2	Si UV enhanced

2.4. Basic Software description

2.4.1. Main features

Runs under Microsoft Windows XP thus supporting currently sold PC's, including laptops

User-friendly “wizard style” user interface (UI) with online tips, explanations and help

User-programmable capabilities (macro style operation) in analyzing results

Fully integrated advanced data-base with filters, archiving, backup and export capabilities

A “smart-setup” system for aiding the user in selecting the right parameters for the experiment, thus preventing erroneous setups.

Integration of a CCD, boresighted with LOS, to allow the user to capture snapshots of the object during measurement (synchronously with spectral scans or with radiometric measurement)

Integration of a cross-hairs layer on-top of the CCD image

Import of external files to be used with system acquired data (such as files created by Excel or Modtran).

User-friendly analysis interface.

Advanced measurement and results display

Support for 10 scans/sec as the default and capable of supporting 30 scans/sec

Backwards compatible with older format files (DAS/DAR formats)

2.4.2. Operating system

The new software works under Windows XP to easily connect to peripherals and to allow the user to install additional software on the SR-5000 PC. This also ensures the software will continue to be supported by future Microsoft operating systems. It also allows SR-5000 systems to work with laptops and currently sold PC's.

2.5. Optical and opto-mechanical options and accessories

2.5.1. Fast scanning (30 scans/sec)

As a standard, the SR-5000 runs at a scanning speed of up to 10 scans per second. In many spectral measurements, much faster scanning speeds are desired to monitor rapidly changing events.

CI offers off-the-shelf options for scanning speeds of 30 scans per second.

2.5.2. Motorized field of view

This accessory allows a rapid and accurate change of FOV to give the instrument additional flexibility. The MFOV option consists of an optically encoded motorized wheel with eight FOV positions that can be selected from the computer as follows:

6, 5, 4, 2.4, 1.5, 1, 0.5, and 0.3 mrad for the SR-5000

12, 10, 8, 4, 2, 1 and 0.6 mrad for the SR-5000-W

2.5.3. 5.7-degree angle lens option

The Wide Field of View option increases the flexibility of the SR-5000. It consists of a pre-aligned removable attachment, which is installed between the secondary mirror and the field stop. The unit includes a ZnSe lens coated for the wavelength region between 0.4 and 14.5 μ (UV versions are also available). The lens assembly provides a maximal field of view of 5.7 degrees.

When the Wide Field of View option is used, please take the following into account:

The side-viewing feature cannot be used when this lens is mounted.

The alignment must be performed with the SR-T boresight telescope or the boresight CCD.

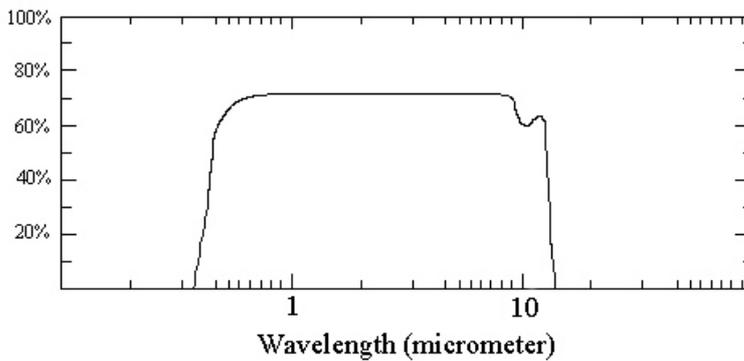
For objects filling the whole 5.7-degree FOV, the sensitivity of the SR-5000 will be approximately a factor of 2-3 less than the full 5" primary system.

The combination of the wide field of view (WFOV) option with the motorized field of view (MFOV) option (see above) allows the user a full field of view range from 0.0285 to 5.7 degrees (0.28, 0.47, 0.95, 1.4, 2.3, 3.8, 4.7, 5.7 degrees).

2.5.4. Front window accessory

A CleartranTM (0.4 to 14.5 μ) transmissive window may be placed in front of the SR-5000 entrance aperture when dust or severe moisture conditions are present during the measurement (UV - IR window is also available).

This accessory, when coupled with the standard dry air purge port, provides a system that can operate under almost any environmental condition.

Figure 2-3 Transmission curve of window

2.5.5. Boresight telescope accessory

This option consists of a telescope mounted on the optical head of the SR-5000. This telescope has a wide field of view. Its crosshair can be aligned with the line of sight of the SR-5000.

It is useful for finding targets when the side viewing of the SR-5000 gives a low intensity image at very long target distances (which occurs with low light levels) or when the WFOV Option is installed.

2.5.6. Ultra Violet (0.24-0.4 μ) operation

The SR-UV option enhances the reflective optical elements of the SR-5000 so that they are optimized for use between 0.2 and 14.5 μ (nominal is 0.4 to 30 μ). The silicon detector provided is also UV enhanced. Coupled with the new CVF 10 users now have the ability to perform spectral measurements in the UV Solar-blind UV range.

2.5.7. Emissivity hardware

The SR-450 heater accessory provides the user with a heating system to make emissivity measurements on samples up to a physical size of 2.0 x 2.3 inches. The SR-450 with a reflective sample and a highly emissive sample is used for comparative emissivity measurements of unknown samples. The SR-450 may also be configured as an extended area blackbody with a temperature range from ambient to 300°C.

2.5.8. CCD camera

One of the additions to the SR-5000 is the option to add a fully-integrated advanced CCD into the system allowing for the acquisition of images synchronized with the spectral/radiometric measurement.

With this new feature, the user records the spectroradiometric data as well as captures an image showing what area of the target was measured and what the target looked like at the time of measurement.

The captured images are compressed into an efficient JPEG format (so as not to take up too much storage capacity) and are saved in the newly developed measurement database.

This new feature has two main advantages:

The live-view image on screen assists in aiming and focusing of the SR-5000 and replaces the current need of a monitor.

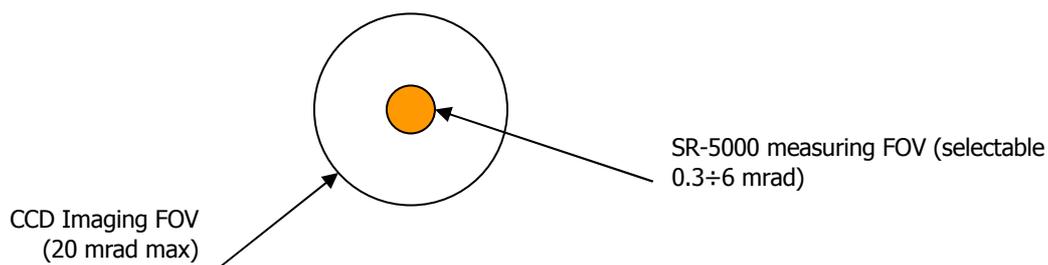
Since the image is created in conjunction with a spectral scan (or a time axis in the case of radiometric measurements), studying dynamic events is more effective.

The CCD has two options for optical connection:

Boresight with instrument line of sight, installed on-top of the SR-5000, including an artificial cross-hairs overlay on the image located at the center of the image.

Connection to the side-view port of the SR-5000, imaging the target and the instrument FOV. The optics of the SR-5000 have been reengineered to increase the imaged FOV to 20 mrad (using the main SR-5000 telescope) with the SR-5000 selectable FOV in its center (see following image).

Figure 2-4: Image seen by side-view CCD:



Imaging System Features

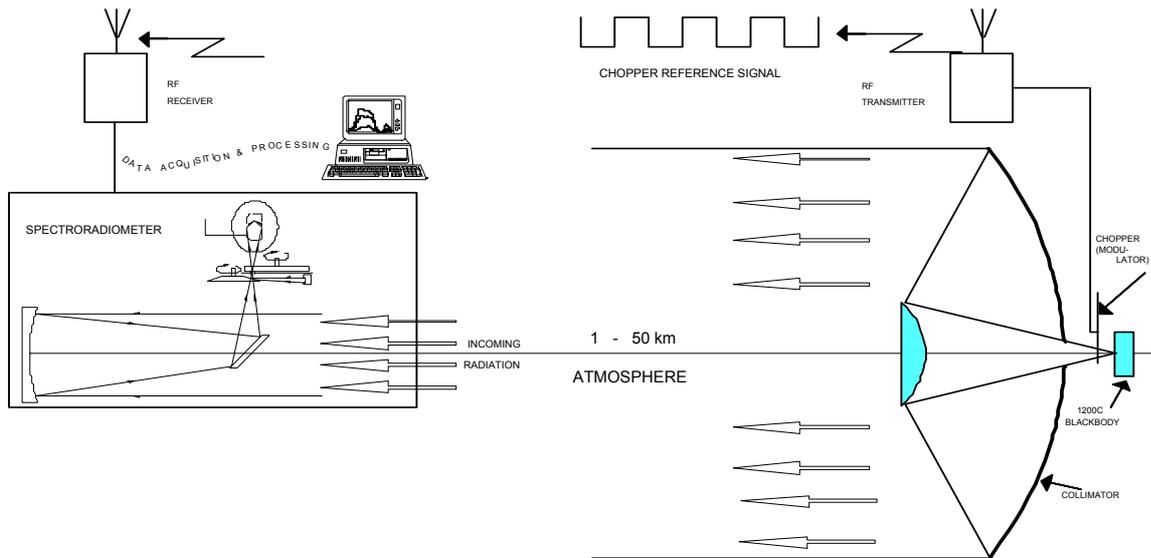
- Fully automated focus and brightness control.
- Live image view for focusing and aiming without the need of an additional monitor.
- One image per scan (spectral mode), and one image per 500 data points (radiometric mode) to easily correlate the spectral data to the target
- Cross-hairs layer displayed with the image (boresight option only)
- Optical multiplier (x 2.5) for longer focal lengths (boresight option only).
- Efficient data management with images stored together with the measurement data.
- Better imaging optical quality with more highly polished aperture material.
- Timing accuracy (within 1/30 of second) with half-size frame-grabber

CCD Specifications:	
Image resolution	640 x 480 pixels
Zoom (optical)	4.1 ÷ 73.3 mm
Brightness control	Fully automated auto-brightness
Focus control	Fully automated auto-focus
Frame rate	30 Hz
Minimum illumination	0.01 Lux

2.5.9. Collimators for transmission measurements

This accessory consists of collimators, with a diameter up to 36", which are used as a transmissometer source at long distances. This collimator, when combined with a high temperature, chopped blackbody source, provides an accurate method for measurement of atmospheric transmittance in a variety of conditions. For this kind of measurement, a chopper reference line must be established for the synchronized detection circuits to operate. Figure 15 gives an optical schematic setup of a transmission measurement.

Figure 2-5 Transmission measurement setup

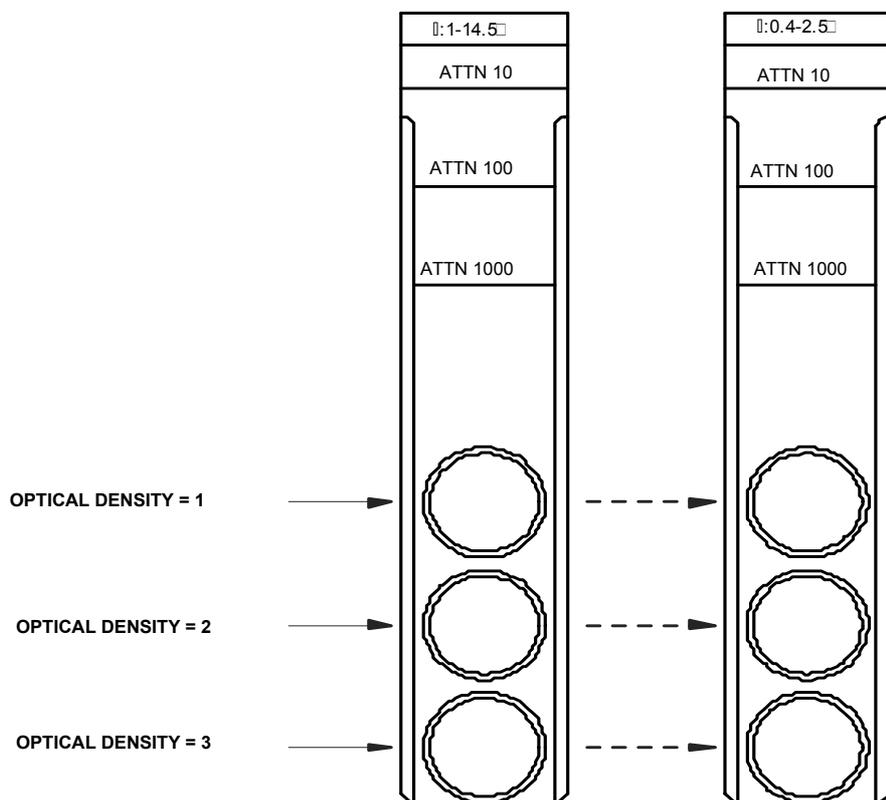


2.5.10. Attenuator set

Attenuators are used when the signal coming into the SR-5000 saturates the detector or has the potential to damage it. Examples of this scenario are laser measurements or measurements of very high temperature sources (such as the sun).

The ATN option provides attenuation levels of 1.0, 2.0 and 3.0, in terms of optical density, over a spectral range of 0.2÷14.5µm (in a set of two assemblies), see Figure 2-6

Figure 2-6 The attenuator set:



2.6. Software, electronics and computer options

2.6.1. Hardware for emissivity measurements

This accessory is used with the SR-5000 to perform emissivity measurements of heated samples as a function of wavelength. By using a special calibration procedure, which involves the measurements of three samples (two for reference and one unknown), this option enables the user to automatically display the spectral emissivity curve of a heated sample calibrated in fractions of unity. The samples should be heated to the same temperature, but there is no need to accurately know this temperature.

Additional options needed for accurate emissivity measurements:

1. Blackbody reference source (for SR-5000 calibration)
2. Diffuse reference plates (material is a function of wavelength range)
3. MCT detector for 5 to 14 μ region
4. InSb detector for 2.5 to 5 μ region
5. Appropriate CVF for required wavelength region

The emissivity program uses a special mathematical algorithm to calculate and display the sample emissivity, $\kappa(\zeta)$, in units normalized to unity. The emissivity as a function of wavelength can then be plotted, printed or saved for later use.

CI can supply a heater for samples, which are metallic, flat (up to 2-3 mm thickness) and of minimum size 90 x 60 mm (maximum size is 160 x 120), including a temperature controller (see page 16) for up to 300°C.

2.6.2. Time tagging with IRIG-B

The IRIG-B option allows the user to time tag data using an external IRIG-B time source. As a standard, the computer's internal time can be monitored. The IRIG-B option requires a computer card inserted in one of the free PC slots. This option allows for data synchronizing of several systems, all taking place in the same experiment.

2.6.3. ModWinPC Software for atmospheric calculations.

ModWinPC, by Ontar, is the most widely used and up-to-date software of its kind in the world for calculating (medium resolution) spectral atmospheric transmittance and radiance. When the operator enters the parameters, such as pressure, relative humidity, target distance and ambient temperature into the computer, the software will automatically predict the attenuation (or radiation) of the atmosphere. For distances of up to several kilometers under most operating conditions, ModWin PC is known for its accuracy.

2.6.4. Remote triggering option

The remote triggering option allows the user to start the data logging from a location remote from the SR-5000. This option is especially useful in ordnance testing where the user cannot be with the SR-5000 during testing because of safety requirements.

2.6.5. SYNC-OUT

The SF-OUT option allows the synchronization of other instruments with the SR-5000. With this feature, a pulse is introduced at a BNC connector in the rear panel of the optical head. This pulse becomes active when the SR-5000 starts an experiment. This feature has been developed to compensate for the delay between issuing the RUN command and the exact time that the data acquisition starts. It can also be used to start any event that one wants to measure, e.g., firing a flare.

2.6.6. Training Seminars

Training seminars are offered at CI Systems or on-site. These seminars are highly recommended in order to properly operate the SR-5000 under different measurement scenarios. The main topics of the basic SR-5000 training course are as follows:

- IR - Basic Theory Review
- SR - 5000 General
- Design Considerations
- Hardware Overview
- Software Overview
- Spectral Measurement
- Radiometric Measurement
- Special Applications
- Maintenance

2.7. Specifications (Basic SR-5000 and SR-5000W)

2.7.1. Optical specifications

	SR-5000	SR-5000W
Optics	5" diameter entrance aperture, all reflective Newtonian telescope, F _# = 4	5" diameter entrance aperture, all reflective Newtonian telescope, F _# = 2
Field Of View		
<i>Standard FOV</i>	6 mrad ± 80%	12 mrad ± 80%
Motorized FOV (option)	0.3 to 6 mrad ± 80% (in 8 steps)	0.6 to 12 mrad ± 80% (in 8 steps)
Wide FOV (option)	5.7° ± 85% (Variable if motorized option is included)	5.7° ± 85% (Variable if motorized option is included)
UV-Wide FOV (option)	4.8° ± 85% (Variable if motorized option is included)	4.8° ± 85% (Variable if motorized option is included)
Very Wide FOV (option)	14 degrees	28 degrees
Focusing Range:	2.5 meters to infinity for std. FOV (measured from front panel)	1.25 meters to infinity for std. FOV (measured from front panel)

Spectral Range: 0.24-14.2 μ (with various CVF's or filter wheels)

Radiometric Range: 0.4-30 μ (UV enhancement option extends region down to 0.2 μ)

Radiometric Mode: For use at every CVF wavelength or with optional bandpass filters (or without a filter)

Spectral Resolution: Typical 2 % of center wavelength at 3 mrad or smaller FOV using a standard CVF (Varies according to wavelength region).

Scan Rates: 0.015 to 10 scans/sec (Optionally up to 30 scans/sec).

Aiming and Focusing: On-line, non-parallax Reflex sight with Focus Lock.

Uniformity of FOV: ±10% in both horizontal and vertical directions across 70% of the standard FOV (±15% for wide FOV option and ±25% for very wide FOV option)

Symmetry of FOV: ±5% when measured at 10% of the maximum response in the horizontal and vertical directions.

- Detector Types:** User interchangeable liquid nitrogen, Joule-Thompson Closed Loop
Cryogenic, thermo-electrically cooled and uncooled detector assemblies.
- Internal Blackbody:** Ambient with minimum drift and gradient. Continuous monitoring and display of temperature with better than 0.1°C accuracy.
- Chopping Frequency:** 100 to 1800 Hz by as small as 50 Hz steps, external chopper input or stop open/closed.

2.7.2. Electronics

Power: 110 VAC, 60 Hz or 220 VAC, 50 Hz. Less than 100 W.

Electronic Bandwidth: Spectral Measurement: Automatically selected by the computer to match data rate (function of CVF scan rate and resolution).

All scan rates - synchronous detection measurement.

- Radiometric Measurement:

50 Hz to 900 Hz sampling rate: synchronous detection measurement

(See detector list for maximum bandwidth)

1500 Hz - 60 000 Hz sampling rate: non - synchronous detection (transient measurement).

Dynamic Range: 1:500,000 and larger depending on detector.

Note: dynamic range can be increased by using variable FOVs or attenuators (options)

A/D: Spectral Measurement: 14 bit

Radiometric Measurement:

1 Hz - 300 Hz Bandwidth: 14 bit

500 Hz - 20 KHz Bandwidth: 8 bit (transient experiment)

Noise Performance: Maximum 5 mdeg Noise Equivalent Temperature (NET) for InSb detector

with CVF at 5 μ , 1 Hz electronic bandwidth, 100°C blackbody and filled 6
mrad
noise
FOV. This is equivalent to an NEI = 8×10^{-13} W/cm². See detectors list for
performance for each.

Saturation Radiation: Dependent upon detector; for InSb without filter, typically 5.4
microwatt on the detector or an equivalent radiance of a 1000°C blackbody
with
0.095" aperture diameter (2.4 mm) at 3 m distance.

2.7.3. Mechanical

Size: Optical head 18.5 x 35.5 x 69 cm
Weight: 25 Kg (reduced weight optical head - optional)
Standard Tripod Mount: 3/8"

3. *Single and multi-channel radiometers*

This line of radiometers offers cost effective radiometers for a wide variety of applications, mainly for use with Infra-Red Counter Measures (IRCM)

3.1. **MPR single channel radiometer**

The MPR (Multi-Purpose Radiometer) is a small portable radiometer designed to measure the radiance of small IR sources within the range of hundreds of meters, especially in field-test configurations. Correspondingly, it uses a TE (thermo-electric) cooled PbSe detector rather than a LN₂ cooled InSb detector. The MPR includes the following main components:

- Green-2 optics composed of an on-axis parabolic collimator.
- A CCD for monitoring the FOV.
- Lock-in Amplifier.
- Data acquisition card with windows based signal-processing software.
- Video monitor.
- Pan and tilt head.



Main technical specifications:

- 6" optical aperture, F#4 (f=600mm).

-
- FOV of 5mrad.
 - Spectral region – customer specified.
 - A TE cooled PbSe detector (with ultra-low noise amplifiers) or any other user-specified detector
 - Sampling rate 300Hz (integration time 3msec or higher).

3.2. Colorad dual-band radiometer

The ColoRad is the ideal system for testing your IR-FM/AM flares and Jammers in two wavebands.

It uses two user-defined channels, in the 1-5 μm spectral range, featuring high flatness, high bandwidth, selection of ND filters and fore-optics, with low NEI.

The ColoRad is lightweight and compact, making it an ideal tool for field measurements.



Main technical specifications:

- Total spectral range (2 user defined channels): 1 – 5 μm
- FOV: 40-50 mrad
- Operating range: 50 to 3000m
- High sensitivity: NEI $\sim 10\text{E}^{-10}$ W/cm².
- DC mode BW: <1000Hz.
- AC mode BW: <30KHz.
- CCD camera boresighted with FOV for field test alignment.

-
- Power supply 220/110/battery operated.

3.3. MCR-8 eight channel radiometer



3.3.1. Introduction

The MCR (Multi-Channel Radiometer) is a custom-made eight-channel radiometer. The MCR was conceived to simultaneously measure, in real time, the radiant intensity of eight discrete spectral channels (in Watt/str). It was designed and built to measure fast transients that have a medium (and high) radiant intensity in the UV-VIS-IR spectral regions. In this way, it satisfies the requirements of flare developers to allow them to compare their signatures to those of the platforms the flares were designed to protect. [The MCR can measure other fast radiometric transients (with duration equal or less than 1msec) according to their sensitivity, dynamic range, and maximal chopping frequency and other specifications.

The MCR has three main components. These are the:

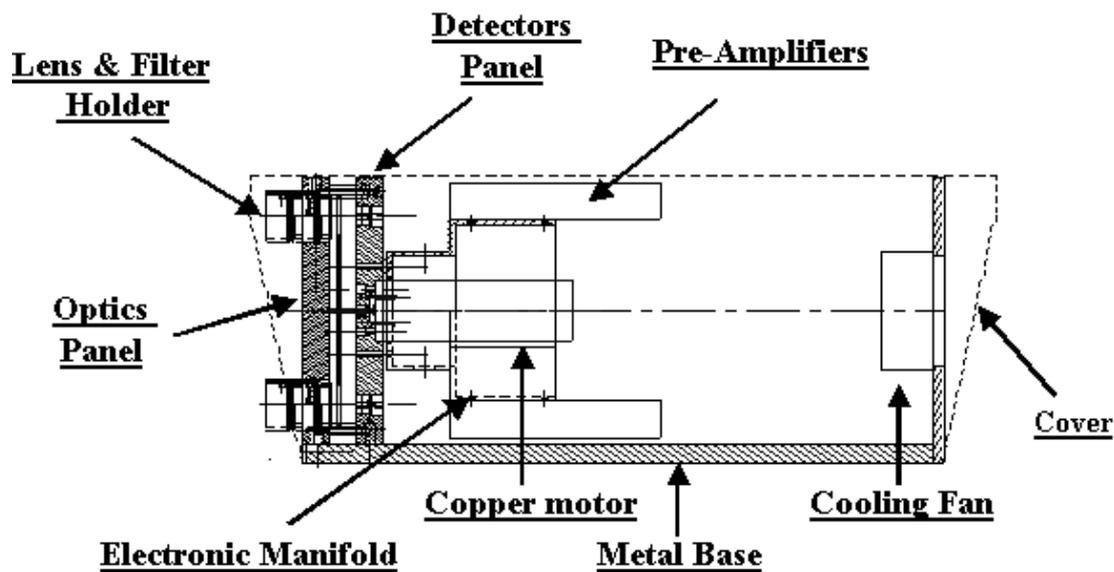
- Optical head
- Controller
- Set of eight lock-in amplifiers

The radiometric output of the MCR is logged into the system computer. User-friendly analysis software processes the data of the measured signals.

All the electronics of the MCR and its subsystems are adapted to an input power of 220VAC. There is no need to change it in any of the MCR subsystems.

3.3.2. The optical head - Optics

Schematic drawing of the optical head is shown in the following figure:



The optical head contains eight optical channels that measure the radiant intensity of the target, which is located in the FOV of the radiometer. Currently there are three options for the FOV of the MCR (other options are available as well):

- I) A 88 mrad FOV (5°) FOV based on the use of $f=51\text{mm}$ lens (F#2.0) for all channels.
- II) A 118 mrad FOV (6.7°) FOV based on the use of $f=38\text{mm}$ lens (F#1.5) for all channels.
- III) A 180 mrad FOV (10°) FOV based on the use of $f=25\text{mm}$ lens (F#1.0) for all channels.

Each optical channel is composed of optics, detector and electronics. The optics, detector and its corresponding electronics are customized according to the customer's needs. The optics and detectors are described in Table 3.

Table 3 MCR 8 channels and detectors

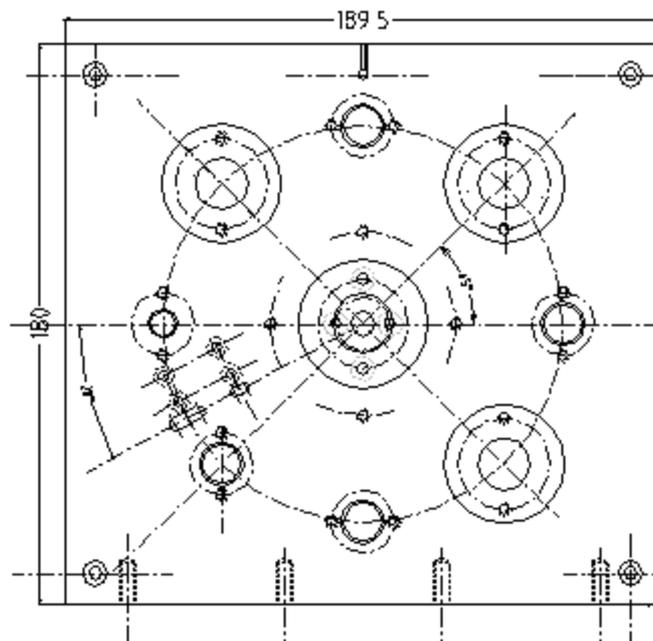
Channel #	Spectral Region (μm) ^(*)	Lens material,	Detector
1	UV	Al ₂ O ₃	Si
2	VIS	Al ₂ O ₃	Si
3	NIR	Al ₂ O ₃	Si
4	NIR	Al ₂ O ₃	Ge
5	MWIR	Ge, ZnSe	PbSe ^(**)
6	MWIR	Ge, ZnSe	PbSe ^(**)
7	MWIR	Ge, ZnSe	PbSe ^(**)
8	LWIR	Ge, ZnSe	Pyroelectric

(**) The user usually defines the spectral regions.

(*) Detectors #5, #6, and #7 are TE cooled

The FOV of the MCR is defined by the field-stop of the optical system. The field-stop is obtained by placing a mask with a diameter of 4.5mm in front of all the detectors and very close to their elements. This adjacency of the mask to the detector element actually makes it a field stop. In this way, for a short operating distance of 30m, the FOV of the MCR covers a circle of 5.0m – a diameter much larger than most of the “fireballs” of common flares.

The optics and the detectors are arranged in a circle with radius of 125mm as shown in the following figure:



The optical axes of all the channel optics are parallel and not bore-sighted to the operating distance. The maximal parallax between the optical axis of two channels at short operating distance of 30m is $\sim 5\text{mrad}$ or 2.5% of the 175mrad FOV. The target location in the FOV is determined by the use of the CCD camera and an additional telescope that is mounted on the base of the MCR. Both the CCD and the telescope are bore-sighted with the center of the 175mrad FOV at a measuring distance of 28m.

The $f=25\text{mm}$ lenses of the optical head were designed to have a blur circle of 0.2mm. This allows the use of an extended blackbody source for focusing the lenses in respect to the field stop. For this purpose, the mask in front of the field stop is rotated so that the 4.5mm aperture located in front of each detector is replaced by a 0.5mm aperture. This aperture defines a “focusing” FOV of 20mrad (for 25mm lens). For focusing, a blackbody with diameter of 22mm is placed in the focal plane of a 1m off-axis collimator. The aperture of this blackbody will subtend an angle of 22mrad in the near-field region of the collimator. The advantage of this method of focusing is that by chopping the blackbody, the focusing process is rather easy. The lenses of all channels of the optical head of the MCR are focused by the manufacturer and locked into their position.

3.3.3. Comparison table of ColoRad and MCR systems:

The following table summarizes the characteristics and potential application of the ColoRad and the MCR

Item	Parameter	MCR	ColoRad	MCR Applications	ColoRad Applications
1	Channels	8	2	R&D of IRCM	Color of IRCM
2	Spectral range	0.3-14µm	1.3-5.5µm	Designed for wide spectral coverage needed for flares R&D purposes. The specific bands are selected by the user	Limited spectral band needed mainly for the spectral ratio between the homing and the discrimination bands of IR flares.
3	FOV	100-200mrad	40-50mrad	Wide FOV for short-range operation usually in test sites. Good for measuring moving targets but only on small part of their trajectories	Medium FOV that is needed for long distance (1-3 km) measurements with real platforms in full dynamic scenarios of flare ejection
4	Channel Boresight	±5mrad	±3mrad		
5	Aperture	25mm	50mm	Small aperture needed for compactness of all channels in one optical head	Large aperture for high sensitivity and the smallest possible NEI
6	F# and FOV Uniformity	1-1.5	2-2.5	Very small F# for fast optics that result in a moderate FOV uniformity	Medium F# that results in a very good FOV uniformity needed for field tests
7	Focal length	25-50mm	100-125mm		
8	Modes	DC and AC	DC and AC	Operates as radiometer mainly for flares	Operates as color radiometer for flares, platforms and also for IR Jammers
9	IR NEI DC mode	3-10 $\times 10^{-9}$ $t_{intg}=10msec$	4 $\times 10^{-10}$ $t_{intg}=10msec$	Ideal for acceptance tests and close test sites. Ideal for measuring flares	Ideal for dynamic studies and test ranges. Ideal for measuring flares with their platforms as well as IR jammers

Item	Parameter	MCR	ColoRad	MCR Applications	ColoRad Applications
10	DC mode BW	<700Hz	<1000Hz	Ideal for radiometry of flares and muzzle flashes	Ideal for radiometry of flares and muzzle flashes
11	AC mode BW	>10KHz (-3db)	>10KHz (-3db)		Excellent frequency response for radiometric measurements of IR Jammers
12	IR NEI AC mode	3-15 μm^2	3-15 μm^2		Excellent for radiometric measurements of IR Jammers from long distances
13	CCD FOV	Ø MCR FOV	Ø ColoRad FOV		
14	Video format	NTSC/PAL	NTSC/PAL		
15	Video boresight	±5mrad	±3mrad		

4. SD 300 visible-near IR spectral imager

4.1. Background on SD-300

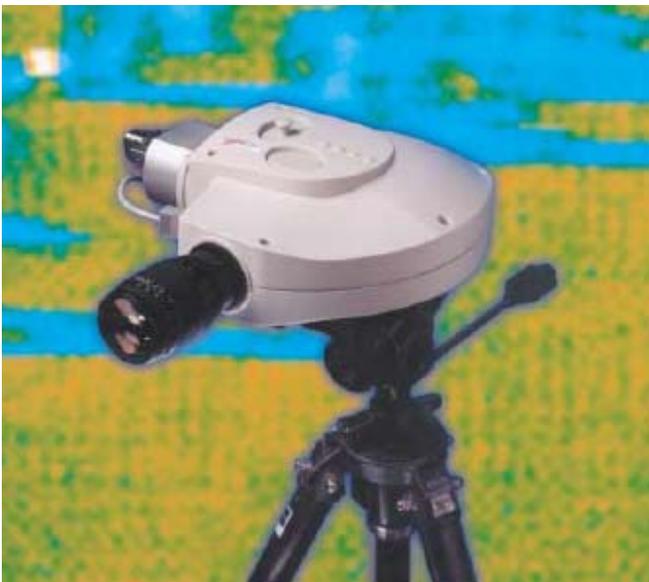
The SD-300 is a third generation in the CI hyper-spectral imagers line. It was preceded by the SD-100 (launched 1993) and SD-200 (launched 1995). The SD-300 was released in 1999 and hundreds of units have been sold since, mainly to the medical market where these units are attached to research fluorescent microscopes for performing a unique diagnosis known as spectral-karyotyping. Units have been sold to remote sensing customers across the world and have been performing well in field measurements.

In the design of the SD-300, many modifications and improvement have been performed in the optical design resulting in a simple and robust instrument.

4.2. Purpose of SD-300

The SD-300 is designed for measuring moderate and low light level spectral images in the VIS-NIR range of stable scenes. Small foot-print and weight, low maintenance requirements and high stability were main design requests.

Figure 4-1 SD-300 optical head

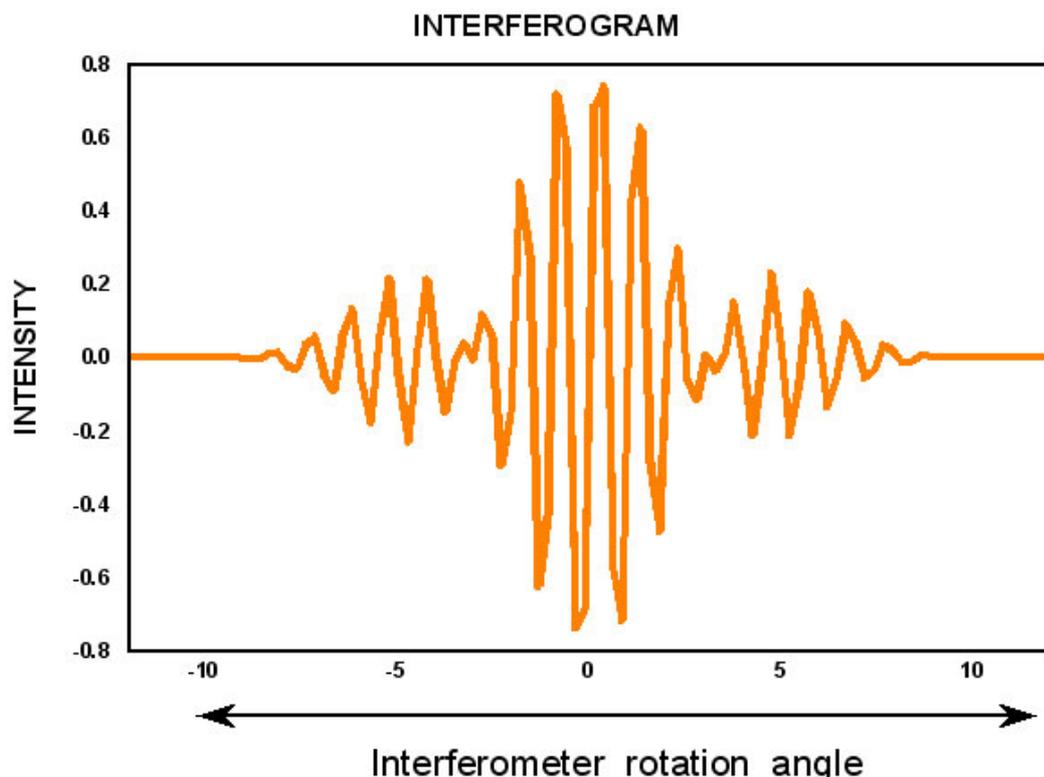


4.3. Theory and design

The SD line of instruments are all based on a Sagnac interferometer. Sagnac interferometers belong to a class of interferometers known as “common-path interferometers”. This means that the transmitted and reflected rays in the interferometer use the same optical elements. As a result, this class of interferometers are inherently stable and less given to drifts.

For measuring spectra with an interferometer, one needs to create an interferogram. An interferogram is a recording of the intensity as a function of optical path difference (OPD)

Figure 4-2 Interferogram (double sided)

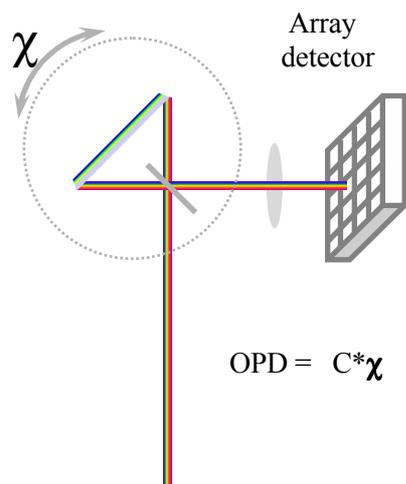


The SD 300 performs a two-sided interferogram, meaning that it scans from $-OPD_{max}$ to $+OPD_{max}$. This is done for reason of improving SNR.

As the interferogram is evenly sampled, FFT can be applied to transform the interferogram to spectrum (intensity as a function of wavelength).

In a hyperspectral imager, one needs to measure the spectral content of each pixel. In a Sagnac based system, this means that first we have produce a complete interferogram for each pixel. In the SD-300, this is achieved by rotating the interferometer at an angle θ . The OPD is $C * \theta$, where C is a constant of the interferometer arising from the angle of the beam-splitter relative to the incoming radiation.

Figure 4-3 Interferometer design of SD-300



In a Sagnac based hyperspectral imager, the image of the object does not move during the interferometer scan. Instead, it is the superimposed interferogram which moves across the array detector/image during the scanning process.

The total scan angle, together with the angle of the beam-splitter (known as the fringe density), define the OPD_{max} that will be created.

The number of sampling points per cycle i.e. the angular “step size” between two sequential image “grabs” defines the SNR of the system. Smaller step size will serve to increase SNR at the cost of increasing acquisition time and increasing file size.

4.4. Additional design issues

The SD-300 has the following design issues implemented:

Software-controlled rotation of the disk, on which the interferometer is assembled, allows for “direct imaging”. This means that the user has the ability to view the scene not obstructed by the interferometer and acquire a high spatial resolution grayscale image of the scene. If needed, the software may acquire the grayscale image immediately prior to the spectral image scan.

The beam-splitter angle can be changed easily in the field in a simple process.

The SD-300 includes a filter holder allowing for the quick insertion of a user-selected filters into the optical path for instances where a part of the spectrum is to be cut off or enhanced.

Semi-automatic spectral calibration is performed in a quick and easy manner by inserting a specially designed filter into the optical path and measuring it.

The SD-300 is an f#4 system and interfaces the fore-optics through a “C-mount”. It also includes a “C to F-mount” converter for an even wider lens selection.

The SD-300 has low-power consumption so that it is powered directly by the PC without the need of an additional power supply.

4.5. Performance

Major performance issues of the SD-300 are reviewed below.

4.5.1. Spectral resolution

The spectral resolution of the SD-300 is user-selectable through both the hardware and software.

By changing the angle of the beam-splitter, relative to the incoming rays, fringe density can be increased or decreased.

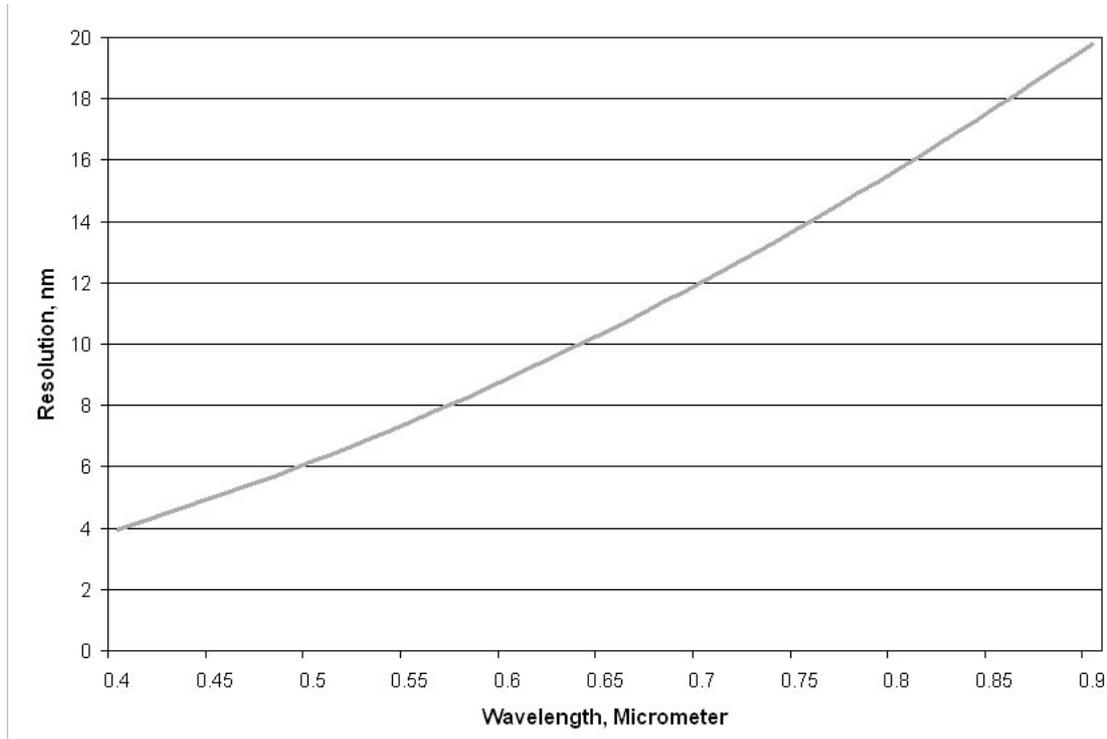
Increasing fringe density means that a higher optical path difference (OPD) is generated per an angle rotation of the interferometer which leads to a greater total OPD thus increasing the resolution ($\text{resolution} = 1/\text{OPD}_{\text{max}}$). The limit to the fringe density is that there must be enough (2 at least) sampling points per cycle for Fourier transform (Nyquist condition).

In the software, the user selects the total scan angle to be performed in the measurement thus defining the total OPD i.e. the resolution.

The type of signal that the instrument measures also influences the spectral resolution. The interferometer measures all wavelengths at once. This is an advantage when sensitivity is considered, but it has the drawback that the shot noise of the system also contributes to the entire signal.

The practical outcome is that, for a set OPD scan, monochromatic or quasi-monochromatic type spectra are measured in highest resolution while broad or absorption line type spectra feature reduced spectral resolution.

Figure 4-4 Maximal Spectral Resolution of SD-300 for a monochrome signal:



4.5.2. Spatial resolution

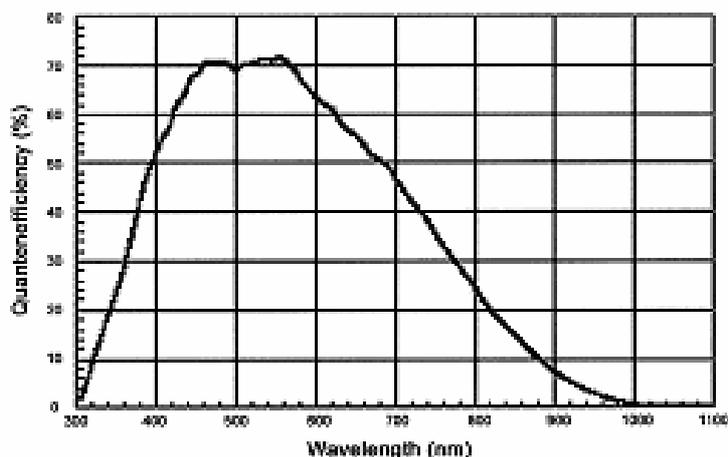
The detector array is a high-quality, low noise, front illuminated, 1280x1024 pixels, 6.7 μm pitch, 2/3" format, 12 bit CCD.

2x2 hardware binning is available, through software control, for improving the signal to noise ratio (SNR) and lowering the file size at the cost of reducing spatial resolution.

4.5.3. Spectral response

The dominant contributors to the systems' response are the detector QE, beam-splitter performance and optical throughput:

Figure 4-5 Detector typical Quantum Efficiency (QE)



The beam-splitter response is relatively flat across most of the 400-1000 nm range, as is the lenses throughput. Therefore, the total spectral response behaves similar to the detector QE.

It is possible to measure the lower response parts of the spectrum by using a cut-on or cut-of filter to enhance the part of the spectrum one needs to measure.

4.5.4. Acquisition time

The acquisition time is a function of the resolution and of the SNR one needs. Typically, a few seconds will be required for a complete acquisition. The scene is required to stay stable during this period. If it is not, the interferogram will be distorted and will produce an inaccurate spectrum.

4.5.5. Radiometric calibration

The SD-300 measures in arbitrary units. There are two valid ways of performing radiometric calibration to the data. The best method is to have a known source included in some part of the acquired image. With this method, the user is sure to eliminate all effects on the measured spectrum by dividing all image pixels by a user-selected pixel (the one that contains the known reference). In this way, the user knows the measurement is calibrated.

The second method is to measure a known source, using the same measurement setup, and then calibrating.

Both of these methods are supported by the SD-300 software.

4.5.6. Noise

As previously stated, the system is dominated by shot noise. It should be noted that in an interferometer system, the same noise is distributed across the entire spectral range. As a result, the SNR distribution is approximately the inverse of the spectral intensity. In other words, the noise is constant at all wavelengths and so the SNR is high where the signal is high and low where the signal is low.

As the detector allows for long exposure times while maintaining low dark noise (approximately 100 counts), we can assume that for most conditions, high detector well-fill is achieved by the measured signal.

4.5.7. Operation software

An intuitive control software is used to operate the SD-300. This software makes it easy for the user to set up the measurement by including an intelligent parameter set-up algorithm.

4.5.8. Additional software

The SD-300 includes, apart from the operation package, two additional software packages:

A database for storing measurements with tools for data filtering, backup and archiving, report generating, security system and more. This database can work in a client-server configuration as well.

Analysis package with advanced tools for creating spectral libraries, classification, linear components analysis, statistical analysis and many more.

5. MWIR spectral imager

5.1. Introduction

The MWIR spectral imager is based on CI Systems experience in the development of hyperspectral imagers and on its 25 years of experience in the IR remote sensing field.

The main purpose of the instrument is to provide hyperspectral, radiometric calibrated measurements of ambient (or close to ambient) stable scenes.

The same system concept (and most of its components) is applicable for airborne applications of hyperspectral imaging in the MWIR.

For measuring intense or rapidly changing targets, CI offers different measurement devices.

5.2. Design

The main design is based on Fourier Spectroscopy technique implemented in the SD-300:

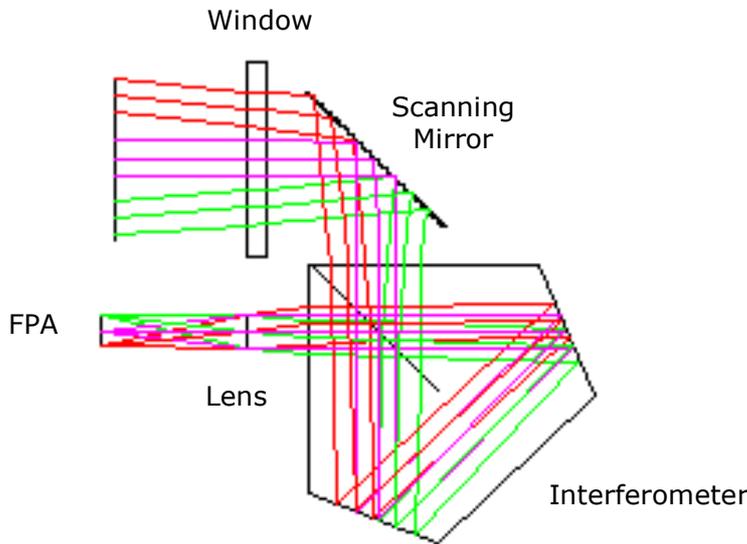
The simplified design of the SD-300 is maintained with the additional implementation of continuous scanning (as opposed to the step scan method used in the SD-300). This results in high-scan accuracy, lowers the requirements on the drive and control systems and allows for faster measurements.

The interferometer is implemented as a solid block interferometer to avoid drift problems that exist in open design interferometers. The selection of a high index of refraction IR material, for the block interferometer, serves to reduce the angles inside the interferometer thus reducing size, and internal reflections.

Cooling of entire optical system reduces the self-emission and therefore allows for low-noise measurements. The cooling system is a close-cycle gas cooling which works with low pressure and so introduces minimal noise and vibration to the optical unit.

A single objective is used in the system. The objective is located between the interferometer and the FPA thus reducing the number of objectives used in the system (the SD-300 uses 3 objectives). This simplification enhances throughput and reduces aberrations in the system.

Figure 5-1 Ray tracing diagram of the block interferometer at zero position



This figure traces radiation entering the system from the window onwards to the scanning mirror, entering the interferometer, passing through the lens and focusing on the FPA.

5.3. Performance

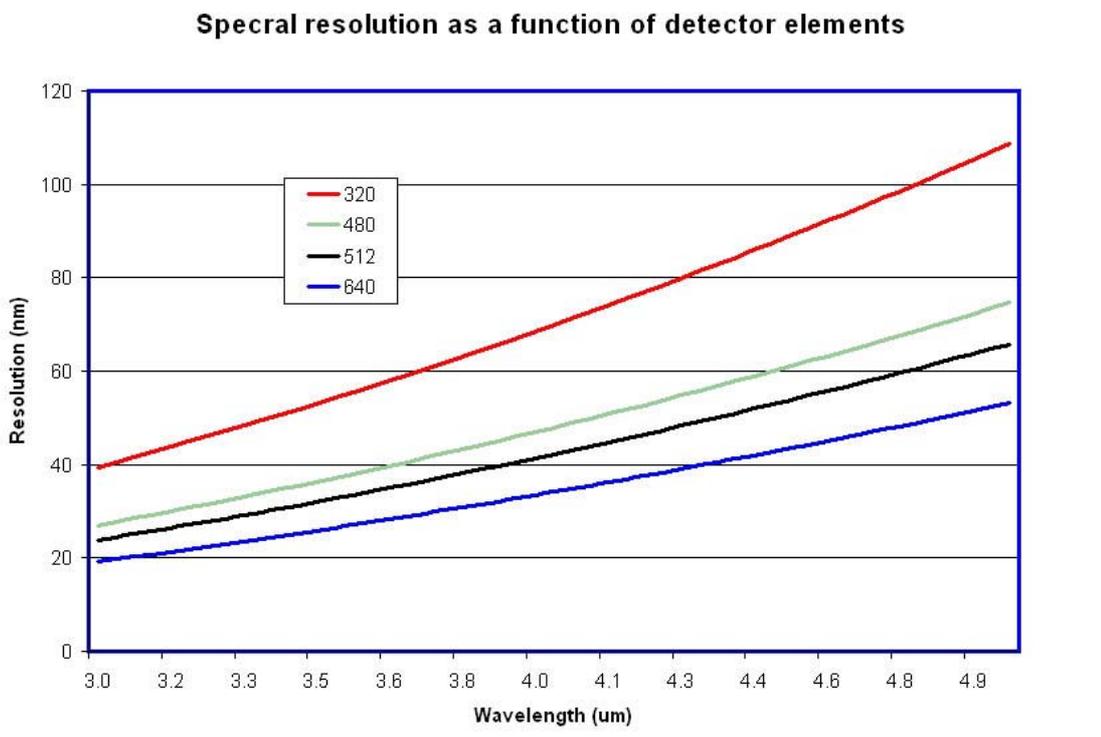
Main performance characteristics of the MWIR spectral imager are presented.

5.3.1. Spectral resolution

The spectral resolution of the system is proportional to the Optical Path Difference (OPD) generated by the interferometer. The OPD is linear with FPA size. The MWIR hyperspectral imager is offered with a selection of 2 FPA's; small and large format (320x256 and 640x512). The spectral resolution for each of these FPA's is presented in Figure 5-2.

The user can define the spectral resolution of the MWIR spectral imager through the software to any value lower than the maximal resolution thus improving total acquisition time.

Figure 5-2 Maximal Spectral Resolution of MWIR spectral imager:



5.3.2. Spatial resolution

The FPA is a Stirling cooled 320x256 pixels (optional 640x512), IFOV is 0.3 mrad. An additional CCD camera boresight with the spectral imager is optional.

5.3.3. Spectral range

The system operates in the 3÷5µm range with good response throughout the range. Means for placing filters (cooled) within the optical path are provided for enhancing the measurement in user-selected spectral sub-regions and for the purpose of calibration.

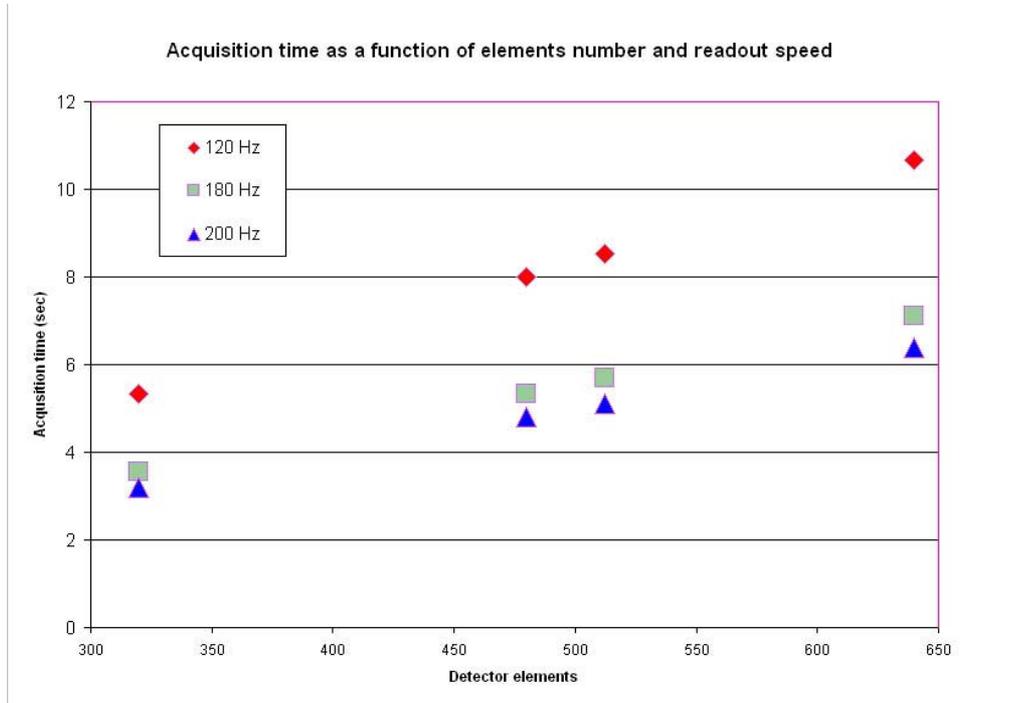
Extending the system to lower wavelength is possible on demand. This will however decrease the spectral resolution of the system.

Implementing the design in the LWIR range is optional.

5.3.4. Total acquisition time

Total acquisition time will vary with signal intensity, SNR requirements, and spectral resolution. Figure 5-3 presents full image acquisition times as a function of readout rate and FPA size.

Figure 5-3 Acquisition time as function of readout rate and FPA size



5.3.5. Radiometric calibration

The MWIR spectral imager is calibrated to radiometric units through a 2-point calibration process using an extended area, high-uniformity, high emissivity blackbody.

5.3.6. NETD and uniformity

The NETD of the system is evaluated when measuring a 300K blackbody. The NETD is a function of the maximal wavelength and can be improved in spectral sub-ranges by using cut-off filters. NETD can be further improved by using longer measurements (denser sampling of the interferograms).

Figure 5-4 NETD in 3-5 micron range of 320 and 640 pixel FPA

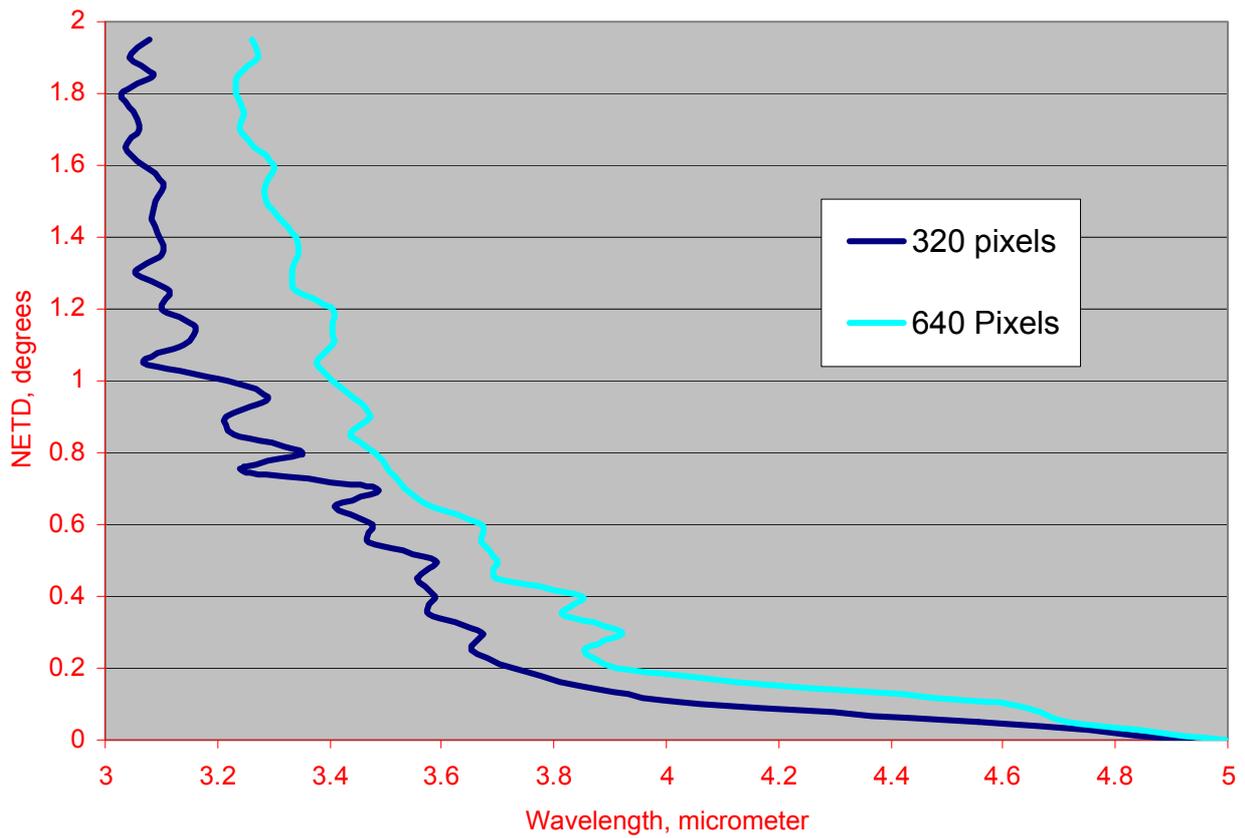
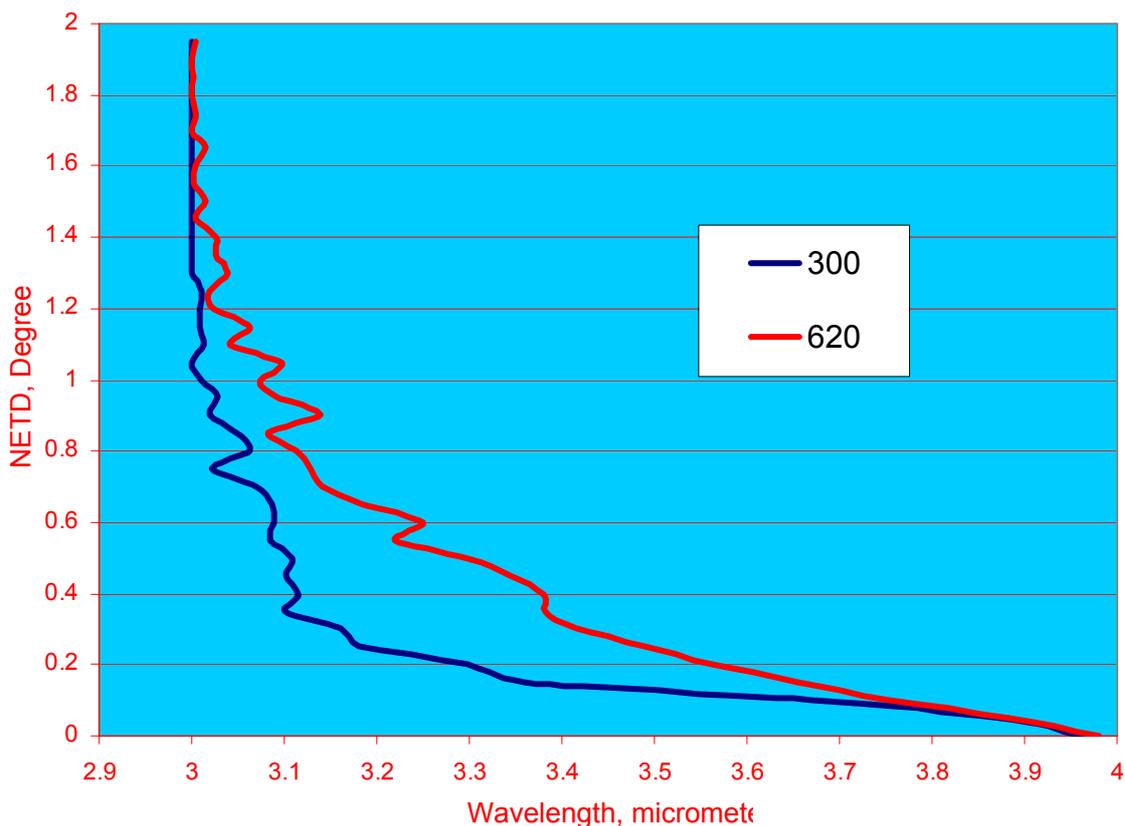


Figure 5-5 NETD with 4 micron cut-off filter of 320 and 640 pixel FPA



The cross pixel NETD (uniformity) will not exceed 100 mk at 4µm with $\Delta\lambda=100\text{nm}$, when measuring a blackbody @ 300 K with a scan time shorter than 10 seconds.

The user can adjust measurement parameters for controlling the measurement SNR. Higher SNR can be achieved through extended total measurement time.

5.4. Operation conditions

The system is designed for field use. Weight of optical head <20 Kg, withstands outdoor environment.

5.5. Wavelength calibration and stability

The MWIR spectral imager maintains a wavelength calibration of 10 nm @ 4 µm through a temperature change rate of 5 degrees per hour in a temperature range of 5÷35 degrees.

Semi-automatic wavelength calibration is built into the instrument and is performed in less than 3 minutes.

5.6. Control and operation

The instrument is controlled by a brand-name desktop PC using Microsoft Windows XP Pro OS.

Complete operation, analysis and database packages are included.

Data size file of full spectral image ~10MB

6. BDR (Background Discrimination Radiometer)

6.1. Introduction

Infrared contrast measurement of a moving target with respect to its background is currently achieved by one of two methods:

- Measuring the background with and without the target in succession and subtracting one measurement from the other. This technique is difficult to perform and relies on a relatively stationary background.
- Measuring with an imaging system equipped with a small number of constantly rotating filters and then using background pixels, within each image, for background characterization. This method has low sensitivity (as a result of the small pixel size) and involves huge amounts of data.

CI's SR 5100 is a unique real-time BDR that eliminates all background and surrounding radiation to provide clear IR contrast of moving targets in Air-to-Air, Ground-to-Air and Air-to-Sea scenarios.

The SR 5100 operates in multiple spectral bands has a wide field of view, ideal for moving target tracking missions, with exceptional flatness of field and sensitivity.

6.2. Specifications

Filter Wheel	Motorized-settable rotation rate between zero and 2 rev/sec. Provision is made for fitting 12 filters.
Sighting	On-line nonparallel boresighting telescope
Focusing	Single focus on infinity
Chopping Rate	25÷300 Hz

6.3. Performance

System Dynamic Range	>10 ⁵ (with InSb detector)
Frequency Response	DC coupled: 1÷100 Hz (synchronous detection mode) AC coupled: up to 20 KHz in transient mode (1 Hz AC coupled)
Minimal detectable Irradiance Difference (MDID)	<2x10 ⁻¹⁰ Watts/Cm ²
FOV (instantaneous)	25 mrad

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