SVC Spectra Vista Corporation

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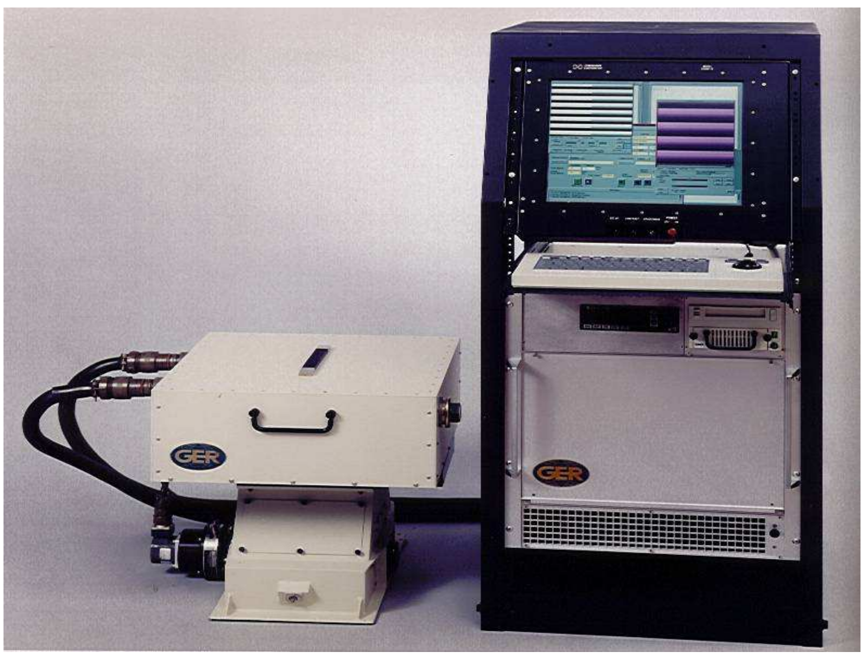
EPS-A-80
Hyperspectral Mapper
Technical Description
Rev. C 11/18/2005



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1.1 Introduction

The EPS-A-80 Hyperspectral imaging system evolved from a long line of previous airborne imaging spectrometers. The EPS-A-80 operates on a 16-bit dynamic range and provides seventy-nine (79) spectral data channels plus one additional housekeeping data channel. The spectrometers are a combination of dedicated Silicon (Si), Indium Gallium Arsenide (InGaAs) and Mercury Cadmium Telluride (MCT) detectors. All detector outputs can be recorded simultaneously and displayed on screen in real time (there is a limit to the number of channels that can be viewed; the channels are operator-selectable). Data are stored in an on-board recorder or memory to achieve optimum data collection rates.

The system is controlled by a VME interface-based controller incorporating an imbedded Sun-compatible workstation. SVC's proprietary **HyperView™** on-board software is used for system control as well as "real-time" data monitoring. GPS navigational information can be displayed and used for real-time image correction and is also recorded on the housekeeping channel with other system parameters. A unique feature of SVC systems is their continuously variable scan speeds. A scan frequency as low as 2 Hz can be employed. The maximum scan speed is limited by the data flow rate of the recording media and by system operating conditions. For the SCSI (DLT) recorder configuration, the maximum scan speed is is 70 scans per second. The continuously variable scan speed allows the system to be set to the optimum scan speed for any altitude and ground speed combinations within the operational envelope. The recorder is connected directly to the SCSI interface of the workstation. Other SCSI recording devices can be connected to the system in the field.

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1.2 Overview

A block diagram of the EPS-A-80 is shown in Figure 1. The Sensor Unit consists of a Scanner Module based on our mid-sized Kennedy Scanner and a custom Spectrometer Module, configured to meet the customer's specific spectral requirements.

The Electronics Rack Unit contains the Workstation Module, the Data Acquisition Module, the Controller Module and the Power Distribution Module. The Operator Interface consists of a Display, a Keyboard/Pointing Device, and the Recorder Module. The workstation Software includes both **HyperView™** real time control software and post-mission Preprocessing Software for data preprocessing.

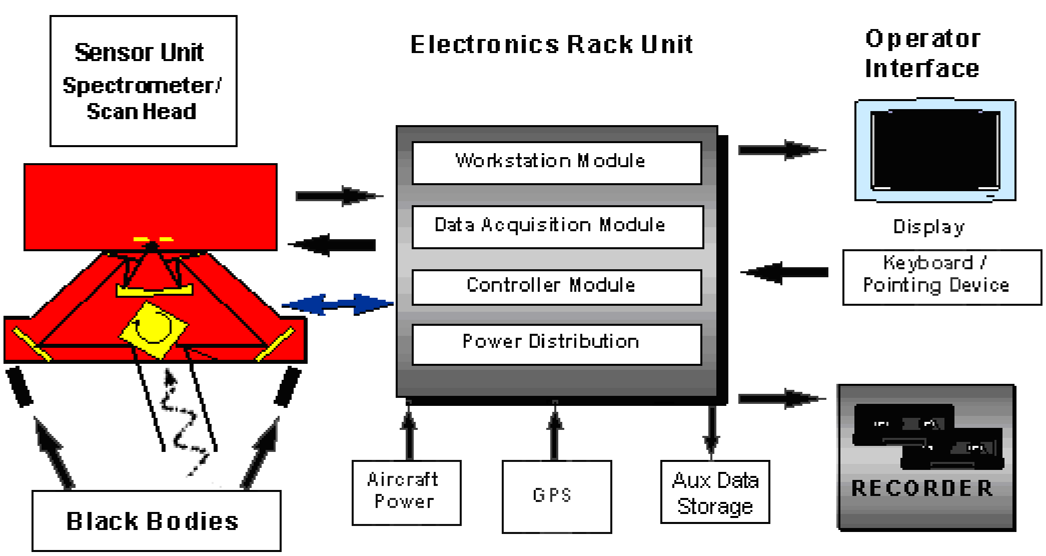

Figure 1 EPS-A Block Diagram

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Sensor Unit

The Sensor Unit contains the Scanner and the Spectrometer. The Scanner defines the spatial characteristics of the acquired image, while the Spectrometer divides the energy of each pixel from the ground into its spectral components and transforms that energy into electronic signals.

Scanner Module

The Scanner Module is a "whisk broom" strip imager. The optical scanner is based on the proven Kennedy Scanner, which employs a multi-faceted rotating mirror. As the mirror rotates, the field of view changes and data are acquired across the flight track to form a scan line (see Figure 2). The rotating mirror provides four scan cycles per mirror revolution. Scan lines are built up along the flight track and a strip map image is produced. The Kennedy scanner splits the optical field into two (2) paths and focuses them at the entrance to the spectrometer. The two optical paths are aligned for co-registration and focussed at infinity. This configuration offers a large effective collection aperture with high scan efficiency (duty cycle) in a compact configuration. The field of regard is 82 degrees. The scanning polyhedral mirror is driven by a DC servomotor and is controlled using a digital, rotary encoder. Rotational speed and absolute position of the scanning mirror are monitored using a digital controller, providing high accuracy in controlling scan properties. Encoder measurement of position is also used in conjunction with the Inertial Measurement Unit to provide real-time compensation for aircraft roll.

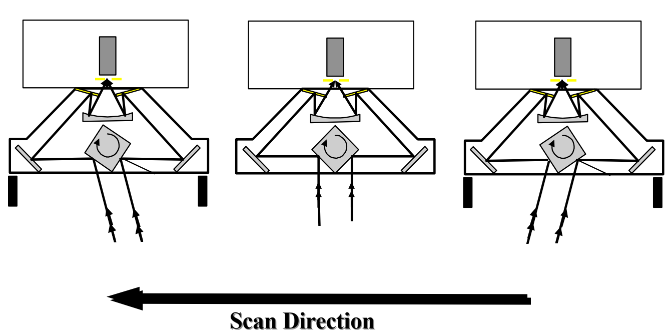

Figure 2 Kennedy Scanner Operation

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Black Bodies

Temperature-controlled black bodies are mounted on either side of the Sensor Unit for real time baseline correction and thermometric calibration. They are scanned at the beginning and end of each scan line.

Remote temperature sensors monitor and control the temperature of each black body. The Graphical User Interface (GUI) provides the operator with the means to set both black body temperatures from the console.

Scan Head Temperature Sensor

The Sensor Unit contains an internal temperature sensor. The temperature is displayed on a **HyperView™** screen on the operator's console and informs the operator in order to help avoid conditions that may lead to subsequent condensation on the optical components.

Spectrometer Module

The spectrometer module contains all the optical components, detector/cooler assemblies and pre-amplifiers required for the parallel measurement of all spectral channels. The imaging spectrometer provides seventy-nine (79) channels of spectral information.

The SVC EPS-A-80 spectrometer electronically co-registers spectral data from each of the channels, assuring accurate measurement of spectra within each individual pixel. The spectroradiometer uses four detector assemblies. The 400 nm – 1050 nm channel (**VIS/NIR**) uses a Si U.V.-enhanced array, the 1550 – 2300 nm (**SWIR 1** and **SWIR 2**) channels both use thermoelectrically cooled InGaAs detectors; and the 80000 nm – 12,500 nm channel (Thermal InfraRed channel (**TIR**)) employs a high sensitivity, Sterling cooled MCT detector.

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The EPS-A-80 Spectrometer is composed of four (4) optical paths and (79) channels of spectral information with the nominal specification shown in Table 1.

Spectrometer Number	Region	Number of Bands	Spectral Region (nm)
1	VIS/NIR	76	350-1070
2	SWIR1	1	1550 – 1750
3	SWIR2	1	2080 – 2350
4	TIR	1	8500-12500

Table 1 EPS-A-80 Spectral Specification

The spectrometer is coupled to the Kennedy scanner via a 3.1 mrad aperture that determines the instantaneous field of view of the system.

Mechanical Description

Electrical connection to the spectrometer head is made through a high-density interface cable, employing aircraft-compatible locking connectors and a power distribution cable of similar design. The spectrometer module is a sealed unit which can be opened for maintenance if required. The spectrometer module can be removed from the scan head module and reinstalled without loss of optical alignment.

Electronics Rack Unit

The Electronics Rack Unit (ERU) performs several functions in the SVC EPS-A-80 series scanners. The ERU uses a 19-inch rack-mountable, industry standard VME enclosure to house the Sun-compatible Workstation Module, Data Acquisition Module, Control Modules (Motor Control Module, Power Amp Module, and Blackbody Control Module), Recorder Module, System Display Module, and any auxiliary electronics. A typical ERU is shown in Figure 3. The ERU provides all required control functions for the operation of the scanner, data acquisition, real-time display, and recording.

The electronics modules are incorporated into VME packages. All required power supplies are integrated into the VME rack system. The functional components of the electronics module are contained in easily replaceable boards and modules that can be serviced in the field. This approach provides flexible configuration and control of system functions as well as easier on-board diagnostics and system maintenance.

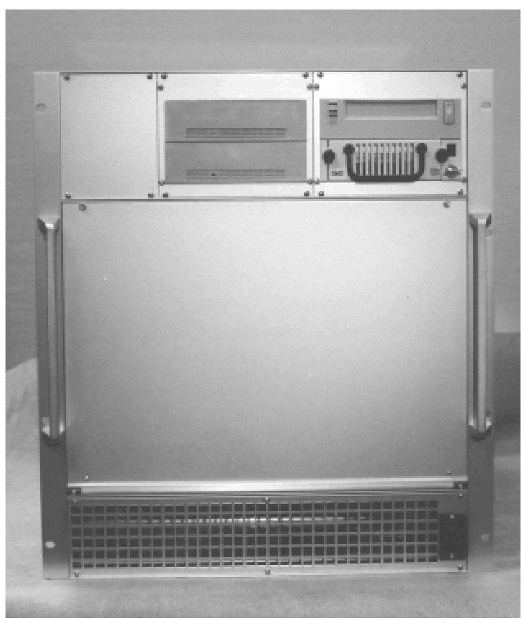

Figure 3 ERU Front View (typical)

Workstation Module

The core of the workstation module is a state of the art CPU running under the Unix operating system. All software required for operation of the scanner resides on the workstation's hard drive. The workstation, using operator input via SVC's **HyperView**™ software, coordinates all scanner control, data acquisition, data recording, and data display functions. The workstation interfaces with the Data Acquisition Module via the standard VME bus, and coordinates the flow of data to the Recorder Module using a standard high speed SCSI bus interface. Data is read from the analog to digital converter (ADC) board and recorded to tape and/or displayed in real time on the scrolling waterfall display. The standard SCSI bus recorder interface allows for future recorder upgrades as performance improves. The workstation also integrates IMU, navigational and other desired information into the recorded data. In addition to the data path function, the Workstation Module also provides simultaneous display of selected scanner channels in a real-time Waterfall or Snapshot Display format.

Data Acquisition Module

The Data Acquisition Module contains SVC's patented, dedicated integrate-and-hold circuitry, 16-bit A/D conversion hardware and dual memory buffers for each channel of spectrometer data. In addition, required bus interface and data formatting functions are included for the coordination and transfer of up to 79 channels of data on each data acquisition card. The data acquisition card receives timing information from the Control Module and a preamplified signal from each spectrometer channel. The Control Module's signals coordinate the sampling, integration, conversion and data manipulation/transfer processes of the data acquisition channels. These processes are synchronized to the scanning mirror. Dual buffer memories are provided to allow simultaneous data transfer and conversion operations to take place providing maximum system capability.

Control Modules

The Control Modules consist of a Motor Control Module, a Power Amp Module, and dual Black Body Control Modules. The Motor Control Module contains the spin mirror motor controller, which uses the spin mirror's encoder feedback to precisely control the motor speed. The Servo Power Amp Module provides current amplification for delivery to the spin mirror motor. The Black Body Control Modules use feedback from the remote black body temperature sensors to provide stable black body temperatures. All controllers are programmed via the user interface of the **HyperView**™ software and provide real-time control of their respective parameters.

The Control Module is contained on a single board and coordinates the data acquisition, data recording and motor control functions. Control signals from the encoder provide scan mirror position and speed information to the Control Module. The module uses this data and data from the GPS to determine position and timing for both the image and blackbody areas to be measured. This control module then provides all timing and control signals required by the data acquisition, workstation and motor control modules. All major parameters are software-selectable and are accessed through the operating and real-time display software.

The Motor Control and Blackbody Control Modules are intelligent controllers that are accessible through the control software and provide real-time control of spin motor and blackbody functions.

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Recorder Module

The recorder module consists of an SCSI recorder and all necessary electronics, software drivers and interfaces. Also included are the required mounting structures for shock isolation of this module. The recorder is then mounted in the Electronics Rack Unit. Raw flight data are stored on this recorder.

Recorder Operation

The recorded data can be reviewed during flight or post-flight at the ground processing facility. Since the recording is done through the high speed SCSI, other compatible recording devices can be connected to the system without any modifications to either the SVC control system hardware or to the SVC software.

2.0 Aircraft Interface

Mechanical Interface

The scanner and spectrometer unit are provided with a shock and vibration isolated mounting frame adapted to meet aircraft mounting requirements and which is secured directly to the airframe.

Electrical Interface

The power required for the system is derived from the aircraft electrical system. A power distribution module within the control electronics connects to the aircraft's 28VDC power source. All system voltages and power needs are supplied by this module.

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3.0 HyperView™

3.1 Overview of HyperView™ Functions

Software for the SVC EPS-A-80 includes the flight software, known as **HyperView™,** that allows the onboard operator to set up the scanner to collect or review data, and ground pre-processing software used after the data collection to correct the data and prepare them for subsequent viewing and analysis.

Running on the Unix workstation, it has a graphical, point-and-click interface. It can be used to set system parameters which control the scanner, view data in real time during collection, or review data collected earlier, from a simple menu-driven user interface.

Running on the embedded workstation, **HyperView™** provides a versatile tool for both data acquisition and monitoring/enforcement applications requiring real-time data display and interpretation.

The three primary functions of **HyperView™** are:

- Acquisition and recording of data from the EPS-A-80
- Real-time waterfall display of acquired imagery
- Display of full-resolution snapshots of selected imagery

These functions are controlled through the point-and-click style, graphical user interface (GUI). The following paragraphs describe each of the primary functions.

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The **HyperView™** software provides interactive control over recording and playback of Hyperspectral scanner data via an X Window System/Motif-based graphical user interface. In addition to the recording and playback functions, the package provides a quick-look capability that supports the simultaneous viewing of:

- Two sub-sampled grayscale data channels displayed separately in real-time
- Three-channel full-resolution red/green/blue composite displayed in real-time
- One full-resolution grayscale data channel displayed in Snapshot
- Three-channel full-resolution red/green/blue composite Snapshot

HyperView™ was designed to operate in an airborne environment to support data collection and analysis tasks, as well as in a ground support environment.

The software records and displays the image data in two modes. The first is full spectrum mode, where continuous strips of imagery are collected with all spectral bands. The second mode is termed "Snapshot," and is for quick display of selected bands in selected geographic areas.

3.2 Operator Interface

The Operator Interface consists of a color display and a keyboard with integrated pointing device.

Console Display

EPS series scanners can accommodate both CRT and flat-screen LCD color displays. DC power for the display is supplied by the Power Distribution Module in the Electronics Rack Unit.

Console Keyboard

The Keyboard employed is a sealed, ruggedized unit with an integrated pointing device/track ball. The user interface to the SVC EPS-A-80 is software based and is easily accessed using this integrated keyboard and trackball.

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3.3 HyperView™ Airborne Graphical User Interface (GUI)

General – Image Display Functions

The graphical user interface (GUI) to the EPS-A-80 is primarily contained in software and consists of an integrated keyboard, computer screen, and trackball. Multiple data display windows are provided with the **HyperView™** operating system. These windows allow real-time data display, tracking of acquisition coverage, and enhanced display and storage of data in-flight.

The convenient window-based menus, controls and displays make the GUI user-friendly even in a harsh aircraft environment. All operating functions of the system are controlled using easily understood menus and pop-up windows.

Recording configuration, display modes, and system functions are software controlled using a simple pop-up menu. Large push button icons activate data record, playback and rewind. Alternate output devices may be selected and activated. Key system parameters may be set and monitored using software control.

Scan speed and black body temperatures are controlled by software. Monitored parameters include black body temperature, scan head temperature, detector cooling status, IMU data, and other user-defined operating parameters. Key system parameters are also recorded during acquisition and stored in a "housekeeping channel" concurrently with spectral data.

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Waterfall Display Mode

The Waterfall Display Window provides to the system operator, in three (3) colors, a dynamic, continuously updated view of up to three (3) channels of the sensor data stream. Menu controls are provided to permit selection and placement of bands and to configure snapshot and display options. In the Waterfall Display Window, the operator can display multiple bands as either multiple grayscale displays or as a single, composite color display. Each band is identified by a label at the top of the display window. The operator can select grayscale, false color, thresholding or inverted display modes. Various real-time data corrections, such as aircraft roll and baseline correction can be applied to the real-time waterfall display.

Snapshot (Static) Display Mode

A Snapshot Window allows the capture and storage of individual frames of data selected from the waterfall display. Snapshots of data may be enhanced for easy interpretation and saved to the system's hard drive.

The operator can select a static display window, where either a single band or a color composite of multiple bands can be viewed at full resolution. There is the capability to perform image enhancement operations in the static image display, as well as scroll and pan, and the ability to save the screen image as a file, for later retrieval.

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3.4 HyperView™ Airborne Control Interface

Operational Modes

The **HyperView™** software can be used in two distinct modes of operation - survey and reconnaissance. In survey mode, full spectral data are collected over a large geographical area. The data are recorded for later analysis and processing on the ground. In this mode, the role of the software is to assist the operator in the operation of the scanner and real-time monitoring of the acquired data. In reconnaissance mode, the emphasis is on near real-time display of data for quick analysis and decisive action typically required during an emergency response. The data may be recorded to tape as full spectral data or recorded to tape or disk as snapshots. In this mode, the recording of snapshots may be continuous, or controlled by the operator.

Post-Mission Pre-processing Software

Pre-processing software is provided with the EPS-A-80 for data pre-processing on the workstation. The Pre-processing software provides a simple graphical user interface for extracting mission tapes to disk and applies baseline, roll, panoramic corrections, and radiometric and thermometric calibration conversions.

Data is output to disk in Band Interleaved by Line (BIL) format for subsequent viewing and processing.

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4.0 System Performance

Image Quality and Spatial Resolution

The optical components that go into SVC scanners are carefully specified to ensure the highest image quality. Likewise, the detectors, amplifiers, and signal conditioning circuitry are precisely balanced. A typical image is shown in Figure 4. This image was taken at an altitude of about 1000 ft. over the Mid-Hudson Bridge with a resolution of about 50 cm. Details such as lane markings, stripes on the flag, bridge cables and their shadows are clearly visible:

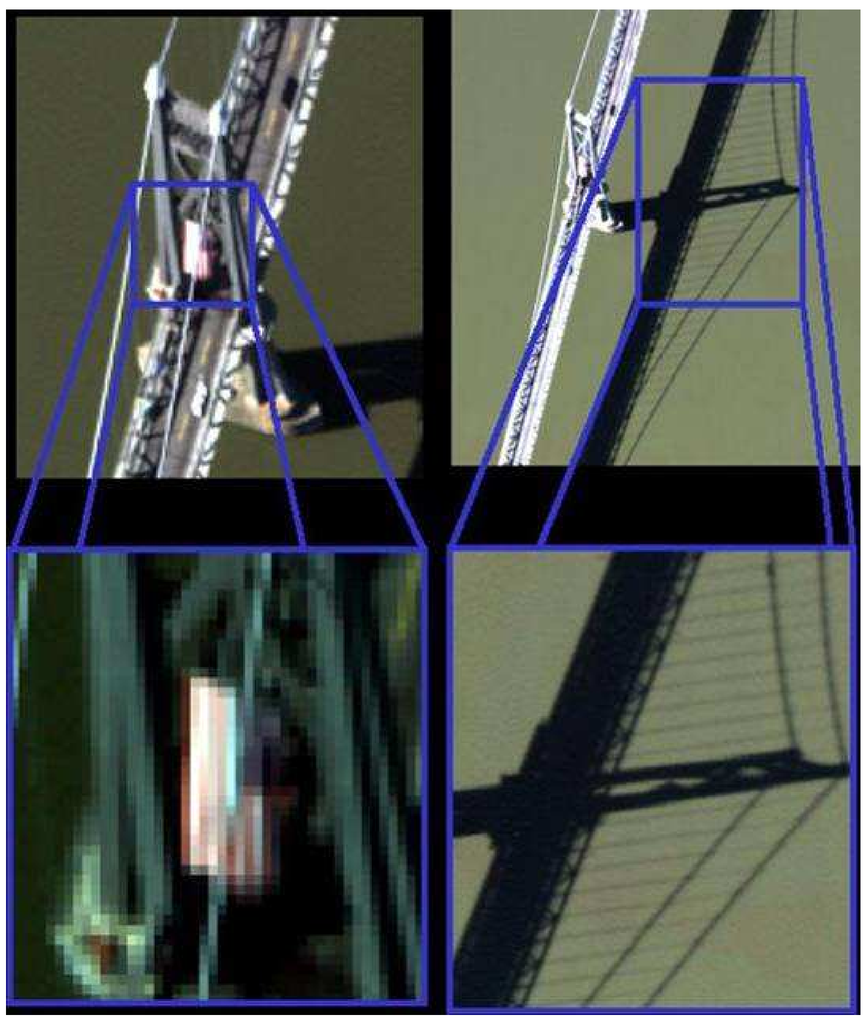

Figure 4
High Resolution Image of the Mid-Hudson Bridge

Thermometric Performance

The EPS-A-80 series scanners have two black bodies that are viewed by the scanner at the beginning and end of every scan line. The black body temperatures are set via HyperView™ so that there is a temperature differential of about 20 – 30 degrees C between them. The black bodies allow the Thermal Infrared (TIR) signal to be converted to apparent brightness temperatures. Temperature sensitivities (expressed as the noise equivalent differential temperature) of better than 0.4 degree C are achieved across the whole scan speed range.

An example from the TIR channel of a EPS-A scanner is shown in Figure 5. This grayscale image reveals the hot water plume discharged by the Indian Point, New York nuclear power station. The lighter area on the right side of the image is the discharge, and the darker area to the left is the unaffected area of the Hudson River.

The discharged plume is about 5 – 10 degrees C warmer than the normal temperature of the river. The image demonstrates that a high spatial resolution is maintained in the thermal region, as shown by the electrical power lines crossing the river, which are visible near the bottom of the image. It also shows the sensitivity of the thermal channel, as evidenced by the structure in the plume, which includes remnants of the wake of a passing boat, seen towards the top of the image.

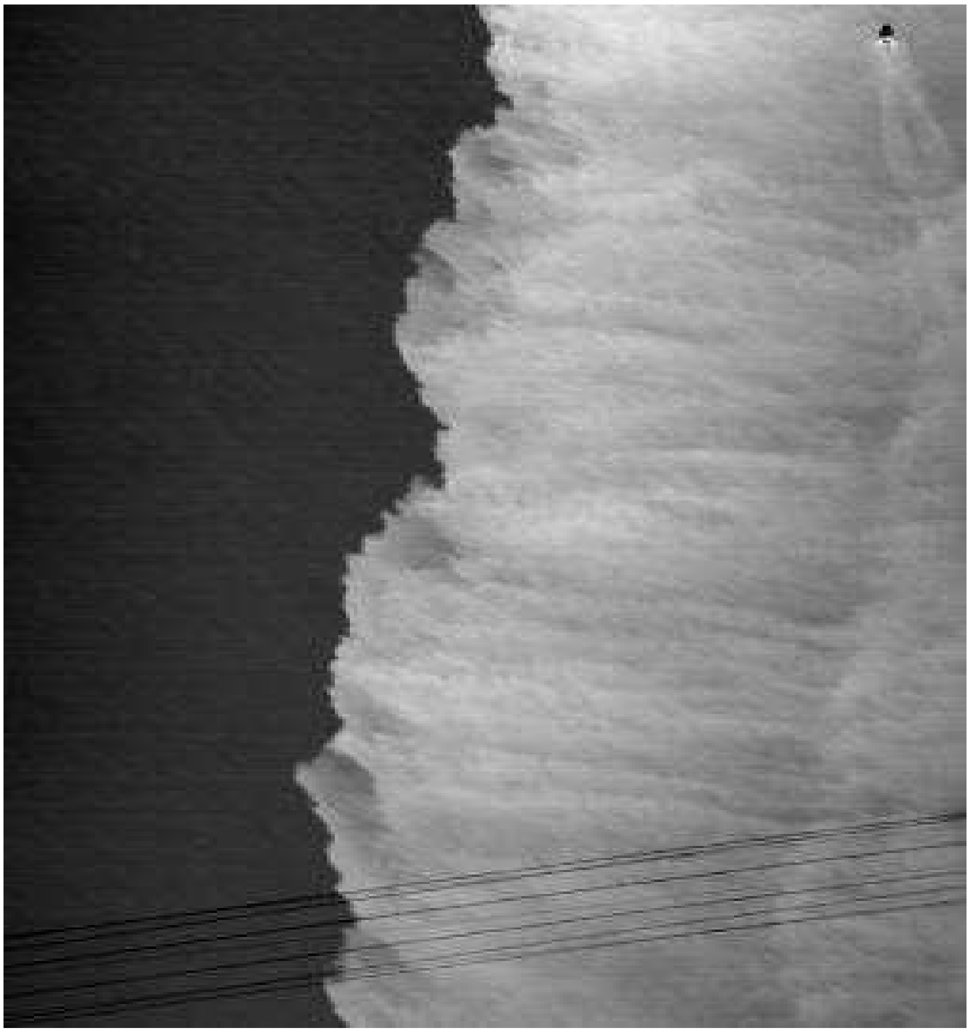

Figure 5 Thermal Image of The Hudson River Near Indian Point Power Plant

(Note high thermal sensitivity discriminating small ∆T of boat wake and high spatial resolution showing power lines crossing over the Hudson River)

5.0 Calibration

5.1 Calibration procedures

Prior to delivery to the customer, each EPS-A-80 scanner is calibrated in SVC's New York facility. The calibration procedure determines the central wavelength and bandwidth of each channel (spectral calibration), radiometric calibration factors (radiometric calibration), and image contrast transfer functions (spatial calibration).

The spectral and radiometric calibration of the thermal infrared channel employs a heat source rather than a standard illumination source.

The complete calibration procedure is automated via purpose built software running on a PC, allowing the calibration to be performed by a single engineer. All calibration procedures use NIST-traceable equipment.

APPENDIX I

SVC EPS-A-80 Specifications

Physical Specification:

Item	Dimensions (H x W x L)	Weight
Sensor Unit	533.4mm L x482.6mm W x609.6mm H 20" L x 18.52" W x 24" H	54.5 kg/ 120 Lbs.
ERU	533.4mm Lx482.6mm Wx 525.8mm H 20" L x 18.52" W x 20.69" H	31.8 kg/ 70 Lbs.

Spectral Specification:

Spectrometer Number	Spectral Region	Number of Bands	Wavelength Range (nm)
1	VIS/NIR	76	350 – 1070
2	SWIR1	1	1550 – 1750
3	SWIR2	1	2080 – 2350
4	TIR	1	8500-12500

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General Instrument Specifications:

Instantaneous Field Of Views (IFOV)	3.10 mrad
Optical Collecting Aperture	137 sq. cm.
Swath Angle (Field of Regard)	± 41.0 degrees
Pixels per Line	544
Dispersion Elements	Diffraction Grating / Beamsplitters
Scan Speed	Up to 70 hz scans per second in 1 scan per second increments (scan speed is limited by data recorder)
Detectors	Silicon (Si): U.V. Enhanced; Two Indium Gallium Arsenide (InGaAs) (thermoelectrically cooled); Mercury Cadmium Telluride (MCT) Sterling cooler.
Thermal References	Two integral, temperature-controlled black body sources
Power	28VDC +/- 3V, 17 Amps peak
Recording Media	High speed SCSI tape drive
System Controller	Current level Unix workstation
Monitor	High resolution color monitor
GPS	Configuration includes an integrated GPS.
Absolute Positioning	Ground processing software for roll and panoramic geo-correction provided
RS422 I/O Ports	Available for IMU information
Cable Sets	One (1) complete cable set to SVC specifications
System Warm Up Time (Typical)	< 5 minutes

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Environmental Specifications:

Sensor Unit (Operating)	Temp: -54° C to +42° C Humidity: 0-95% (non-condensing) Maximum Altitude: 9,750 m / 32,000'
ERU, Display, Keyboard (Operating)	Temp: +15° C to +35° C Humidity: 0-95%(non-condensing) Maximum Cabin Altitude: 3050 m /10,000'
Electomagnetic Interference (EMI) / Electomagnetic Compatability (EMC)	SVC EPS systems are certified to be designed and constructed in accordance with RTCA DO 160 D guidelines.

Radiometric Specifications:

Radiometric Resolution	16 bits
Signal-to-Noise Ratio (SNR) at 50% Albedo & 45° Sun Angle	VIS/NIR 300 SWIR 100
Radiometric Sensitivity	NEDT <0.4° C
Calibration Accuracy (absolute)	5%
Calibration Accuracy (relative)	<2.5% (between bands)
In-Flight Calibration	TIR: Reference blackbodies
Scan Angle Radiance Sensitivity	<2%

Geometric Specifications:

Spatial Resolution	< 0.5 meter
Band-to-Band Registration	<0.1 pixel between all bands
Geometric Positioning	Onboard GPS or optional Inertial Measurement Unit (IMU) Updates each scan line

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EPS – A Series Detector Channel / center wavelength (CWL) assignments (typical calibration):

Channel No.	CWL (nm)	DETECTORTYPE	Channel No.	CWL (nm)	DETECTOR TYPE	Channel No.	CWL (nm)	DETECTOR TYPE
1	352	Silicon	31	610	Silicon	61	907	Silicon
2	359	Silicon	32	620	Silicon	62	918	Silicon
3	364	Silicon	33	629	Silicon	63	929	Silicon
4	371	Silicon	34	638	Silicon	64	940	Silicon
5	377	Silicon	35	647	Silicon	65	951	Silicon
6	383	Silicon	36	657	Silicon	66	962	Silicon
7	389	Silicon	37	667	Silicon	67	973	Silicon
8	395	Silicon	38	676	Silicon	68	984	Silicon
9	406	Silicon	39	686	Silicon	69	995	Silicon
10	414	Silicon	40	695	Silicon	70	1006	Silicon
11	422	Silicon	41	705	Silicon	71	1016	Silicon
12	431	Silicon	42	714	Silicon	72	1026	Silicon
13	441	Silicon	43	724	Silicon	73	1034	Silicon
14	450	Silicon	44	734	Silicon	74	1043	Silicon
15	460	Silicon	45	743	Silicon	75	1053	Silicon
16	469	Silicon	46	753	Silicon	76	1063	Silicon
17	479	Silicon	47	763	Silicon	77	1700	InGaAs
18	488	Silicon	48	773	Silicon	78	2200	InGaAs
19	497	Silicon	49	783	Silicon	79	10000	MCT
20	506	Silicon	50	793	Silicon	80	Housekeeping data	
21	516	Silicon	51	803	Silicon			
22	526	Silicon	52	813	Silicon			
23	535	Silicon	53	823	Silicon			
24	544	Silicon	54	833	Silicon			
25	554	Silicon	55	844	Silicon			
26	563	Silicon	56	855	Silicon			
27	572	Silicon	57	865	Silicon			
28	582	Silicon	58	875	Silicon			
29	591	Silicon	59	886	Silicon			
30	601	Silicon	60	896	Silicon			

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APPENDIX II

Scan Rate vs. Altitude/Groundspeed

Note: The following Scan Rate Tables are provided for aircraft ground speeds up to 240 knots. These tables can be extended for greater aircraft speeds as groundspeeds and altitudes as required.

EPS-A-80 Scan Speed Calculation Chart - 02/01/00

Spatial Frequency	**3.1**	"Scan Speed = ground speed / pixel size"	"Encoder PPR = 9000"
			"SFOV = 4 * P I / (PPR/2) = 2.793 mRadians"
		"pixel size = 2*Altitude*tan(IFOV / 2)"	"FOV = SFOV * NumPixels = 1.43 Radians = 81.92 Degrees"
Max. scan speed	**75**		

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					Groundspeed																
				Kts.	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**	**160**	**170**	**180**	**190**	**200**	**210**	**220**	**230**	**240**
Altitude(AGL)		**Pixel size**		**ft/sec**	**135**	**152**	**169**	**186**	**202**	**219**	**236**	**253**	**270**	**287**	**304**	**321**	**337**	**354**	**371**	**388**	**405**
ft.	**m**	**ft.**	**m**	**m/sec**	**41**	**46**	**51**	**57**	**62**	**67**	**72**	**77**	**82**	**87**	**93**	**98**	**103**	**108**	**113**	**118**	**123**
500	**154**	1.4	0.4																		
750	**229**	2.1	0.6		64	72															
1000	**305**	2.8	0.9		48	54	60	66	72												
1250	**381**	3.5	1.1		39	43	48	53	58	63	68	72									
1500	**457**	4.2	1.3		32	36	40	44	48	52	56	60	64	68	72						
1750	**533**	4.9	1.5		28	31	35	38	41	45	48	52	55	59	62	66	69	72			
2000	**610**	5.6	1.7		24	27	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72
2250	**686**	6.3	1.9		21	24	27	30	32	35	38	40	43	46	48	51	54	56	59	62	64
2500	**762**	7	2.1		19	22	24	27	29	31	34	36	39	41	43	46	48	51	53	56	58
2750	**838**	7.7	2.3		18	20	22	24	26	29	31	33	35	37	40	42	44	46	48	51	53
3000	**914**	8.4	2.6		16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
3250	**991**	9.1	2.8		15	17	19	20	22	24	26	28	30	32	33	35	37	39	41	43	45
3500	**1067**	9.8	3		14	16	17	19	21	22	24	26	28	29	31	33	35	36	38	40	41
3750	**1143**	10.5	3.2		13	14	16	18	19	21	23	24	26	27	29	31	32	34	35	37	39
4000	**1219**	11.2	3.4		12	14	15	17	18	20	21	23	24	26	27	29	30	32	33	35	36
4250	**1295**	11.9	3.6		11	13	14	16	17	18	20	21	23	24	26	27	28	30	31	33	34
4500	**1372**	12.6	3.8		11	12	13	15	16	17	19	20	21	23	24	25	27	28	30	31	32
4750	**1448**	13.3	4		10	11	13	14	15	17	18	19	20	22	23	24	25	27	28	29	31
5000	**1524**	14	4.3		10	11	12	13	14	16	17	18	19	21	22	23	24	25	27	28	29

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					Groundspeed																
				Kts.	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**	**160**	**170**	**180**	**190**	**200**	**210**	**220**	**230**	**240**
Altitude(AGL)		**Pixel size**		ft/sec	**135**	**152**	**169**	**186**	**202**	**219**	**236**	**253**	**270**	**287**	**304**	**321**	**337**	**354**	**371**	**388**	**405**
ft.	**m**	**ft.**	**m**	m/sec	**41**	**46**	**51**	**57**	**62**	**67**	**72**	**77**	**82**	**87**	**93**	**98**	**103**	**108**	**113**	**118**	**123**
5250	**1600**	14.7	4.5		9	10	12	13	14	15	16	17	18	20	21	22	23	24	25	26	28
5500	**1676**	15.4	4.7		9	10	11	12	13	14	15	16	18	19	20	21	22	23	24		26
5750	**1753**	16.1	4.9		8	9	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
6000	**1829**	16.8	5.1		8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
6250	**1905**	17.5	5.3		8	9	10	11	12	13	14	14	15	16	17	18	19	20	21	22	23
6500	**1981**	18.2	5.5		7	8	9	10	11	12	13	14	15	16	17	18	19	20	20	21	22
6750	**2057**	18.9	5.7		7	8	9	10	11	12	13	13	14	15	16	17	18	19	20	21	21
7000	**2134**	19.6	6		7	8	9	9	10	11	12	13	14	15	16	16	17	18	19	20	21
7250	**2210**	20.2	6.2		7	7	8	9	10	11	12	12	13	14	15	16	17	17	18	19	20
7500	**2286**	20.9	6.4		6	7	8	9	10	10	11	12	13	14	14	15	16	17	18	19	19
7750	**2362**	21.6	6.6		6	7	8	9	9	10	11	12	12	13	14	15	16	16	17	18	19
8000	**2438**	22.3	6.8		6	7	8	8	9	10	11	11	12	13	14	14	15	16	17	17	18
8250	**2515**	23	7		6	7	7	8	9	10	10	11	12	12	13	14	15	15	16	17	18
8500	**2591**	23.7	7.2		6	6	7	8	9	9	10	11	11	12	13	13	14	15	16	16	17
8750	**2667**	24.4	7.4		6	6	7	8	8	9	10	10	11	12	12	13	14	14	15	16	17
9000	**2743**	25.1	7.7		5	6	7	7	8	9	9	10	11	11	12	13	13	14	15	15	16
9250	**2819**	25.8	7.9		5	6	7	7	8	8	9	10	10	11	12	12	13	14	14	15	16
9500	**2896**	26.5	8.1		5	6	6	7	8	8	9	10	10	11	11	12	13	13	14	15	15
9750	**2972**	27.2	8.3		5	6	6	7	7	8	9	9	10	11	11	12	12	13	14	14	15
10000	**3048**	27.9	8.5		5	5	6	7	7	8	8	9	10	10	11	11	12	13	13	14	14

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					Groundspeed																
				Kts.	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**	**160**	**170**	**180**	**190**	**200**	**210**	**220**	**230**	**240**
Altitude(AGL)		**Pixel size**		**ft/sec**	**135**	**152**	**169**	**186**	**202**	**219**	**236**	**253**	**270**	**287**	**304**	**321**	**337**	**354**	**371**	**388**	**405**
ft.	**m**	**ft.**	**m**	**m/sec**	**41**	**46**	**51**	**57**	**62**	**67**	**72**	**77**	**82**	**87**	**93**	**98**	**103**	**108**	**113**	**118**	**123**
10250	**3124**	28.6	8.7		5	5	6	6	7	8	8	9	9	10	11	11	12	12	13	14	14
10500	**3200**	29.3	8.9		5	5	6	6	7	7	8	9	9	10	10	11	12	12	13	13	14
10750	**3276**	30	9.2		4	5	6	6	7	7	8	8	9	10	10	11	11	12	12	13	13
11000	**3353**	30.7	9.4		4	5	5	6	7	7	8	8	9	9	10	10	11	12	12	13	13
11250	**3429**	31.4	9.6		4	5	5	6	6	7	8	8	9	9	10	10	11	11	12	12	13
11500	**3505**	32.1	9.8		4	5	5	6	6	7	7	8	8	9	9	10	11	11	12	12	13
11750	**3581**	32.8	10		4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12
12000	**3657**	33.5	10.2		4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12
12250	**3734**	34.2	10.4		4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12
12500	**3810**	34.9	10.6		4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12
12750	**3886**	35.6	10.9		4	4	5	5	6	6	7	7	8	8	9	9	9	10	10	11	11
13000	**3962**	36.3	11.1		4	4	5	5	6	6	7	7	7	8	8	9	9	10	10	11	11
13250	**4038**	37	11.3		4	4	5	5	5	6	6	7	7	8	8	9	9	10	10	10	11
13500	**4115**	37.7	11.5		4	4	4	5	5	6	6	7	7	8	8	8	9	9	10	10	11
13750	**4191**	38.4	11.7		4	4	4	5	5	6	6	7	7	7	8	8	9	9	10	10	11
14000	**4267**	39.1	11.9		3	4	4	5	5	6	6	6	7	7	8	8	9	9	9	10	10
14250	**4343**	39.8	12.1		3	4	4	5	5	6	6	6	7	7	8	8	8	9	9	10	10
14500	**4419**	40.5	12.3		3	4	4	5	5	5	6	6	7	7	7	8	8	9	9	10	10
14750	**4496**	41.2	12.6		3	4	4	5	5	5	6	6	7	7	7	8	8	9	9	9	10
15000	**4572**	41.9	12.8		3	4	4	4	5	5	6	6	6	7	7	8	8	8	9	9	10

AIRBORNE HYPERSPECTRAL REMOTE SENSING APPLICATIONS

I Environmental

1. Environmental Baseline and Change Detection Mapping
2. Wetlands Mapping
3. Ground Water Resource and Inflow Mapping
4. Turbidity Mapping
5. Algal Bloom Detection and Mapping
6. Thermal Plume Detection, Monitoring, and Mapping
7. Oil Spill Detection, Characterization, and Mapping
8. Dredging Operations Monitoring and Mapping
9. Plant Stress Detection and Mapping
10. Disaster Area Assessment:
    Damage Extent Mapping and Remaining Resource Identification
11. Legal: documenting existing conditions (private sector);
    Enforcement: (public sector); Monitoring: (both sectors)

II Forestry

1. Stand Mapping
2. Insect Infestation and Disease Detection
3. Harvest Planning Decision Making

AIRBORNE HYPERSPECTRAL REMOTE SENSING APPLICATIONS

III Agriculture

1. Crop Quality and Yield Assessment
2. Irrigation System Performance Monitoring
3. Crop Stress Detection :

   (Weed Pressure, Pests, Water, and Heat Stress)
4. Fertilizer, Irrigation, Herbicide, and Pesticide Management