CASI-2 SENSOR

1. Overview of Configuration & Specification

The Compact Airborne Spectrographic Imager (casi-2), produced by Itres Research of Canada, is a two-dimensional CCD array based pushbroom imaging spectrograph (Table 1).

Parameter	**Description**
IFOV (Instantaneous Field Of View)	
Across Tack	54.4 ° (custom lens)
Along track	0.1151 °
Aperture	f/2.8 - f/11 (Automated iris control)
Spectral range	405 - 950 nm
Spatial samples	512 spatial pixels
Spectral samples	288 at 1.8nm intervals (2.2nm FWHM @ 650nm)
Dynamic range	12-bits (4096 levels)
Recording	1 removable 9 GByte Hard Disk
Operating Modes	
• Spatial Mode	512 pixels across swath, up to 18 spectral bands (fully programmable).
• Spectral Mode	full spectrum (288 channels) for up to 39 look directions spread across swath (4, 8, 12, or 16 pixel spacing between look directions). Includes a monochromatic image at full spatial resolution (Scene Recovery Channel).
• Enhanced Spectral Mode	full spectrum (288 channels) in a block of 101 adjacent spatial pixels.
• Full Frame	512 pixels across swath x 288 spectral pixels (~1-2 sec. Integration time limits use to laboratory calibration or ground-based field use).
Downwelling Incident Light Sensor (ILS)	
Lumogen coating for enhancement of blue response below 450nm	

Table 1 Specification of the NERC casi sensor.

One dimension of the 578x288 element array is used to obtain an image frame of 512 spatial pixels of the surface that builds up a flightline of data as the aircraft moves forward (Figure 1). On the front of the casi camera head is a custom fore-optic lens with 54.4° FOV which has been designed to provide optimum focussing across the casi wavelength range (achromatic focus). Light levels entering the spectrometer through the lens can be varied by the operator via an automated iris control (Settings 1 to 5) which are approximately equivalent to apertures of f11, f8, f5.6, f4, and f2.8. Setting 0 causes the iris to close completely for use in collecting in-flight dark-current readings, prior to and after a flightline. After passing through a 15mm wide spectrographic slit, a reflection grating disperses the light from each pixel over the 405 to 950nm spectral range and is recorded by the 288 detectors on the orthogonal dimension of the CCD. The row spacing on the CCD equates to a spectral sampling of 1.8nm. However, the effective bandwidth of a single row has an approximate value of 2.2 nm FWHM (Full Width at only Half its Maximum value) at 650nm, resulting from the optical system and convolution of the slit width and detector size.

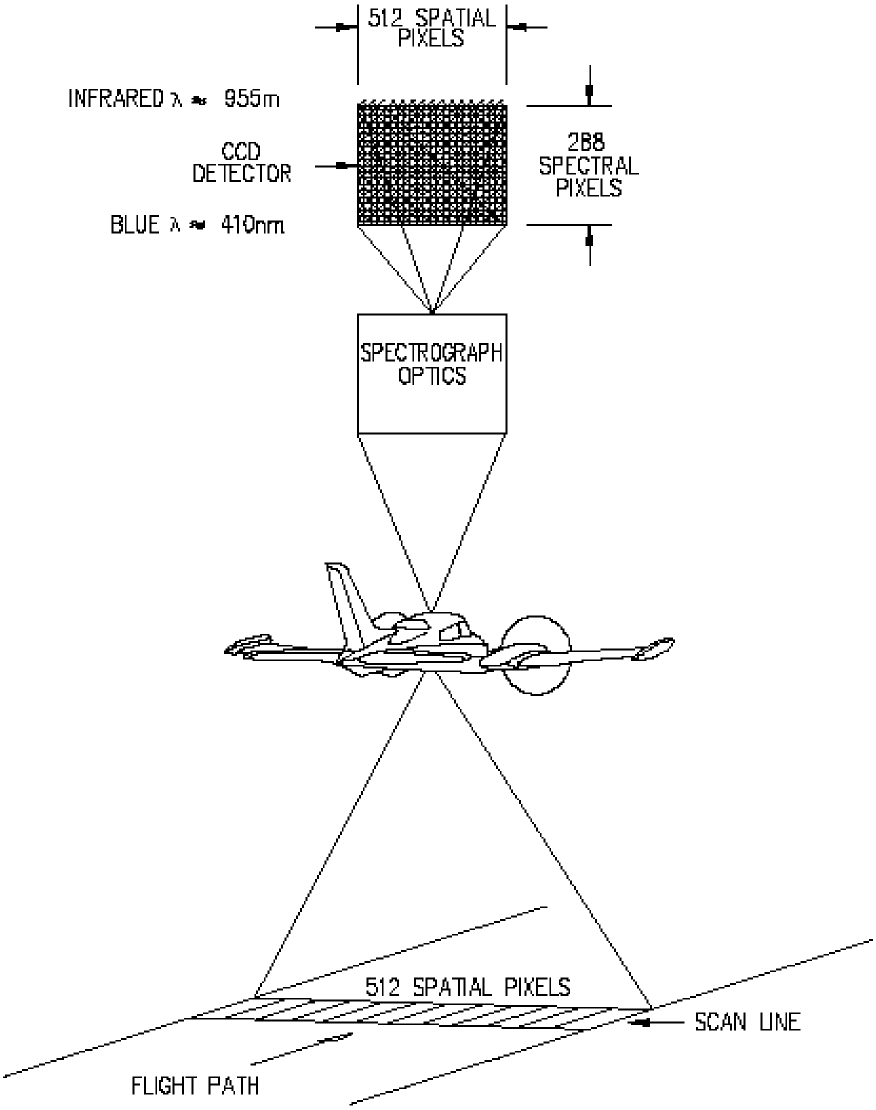

Figure 1 Imaging concept of the casi-2 CCD pushbroom spectrograph (from ITRES)

A section of the array, masked off from imaging scene pixels, is used to record electronic noise, frame shift smear and scattered light contributions for use in post processing calibration. Additionally, a portion of this hidden section is used to image light, transmitted via a fibre optic bundle, from a downwelling Incident Light Sensor (ILS) mounted in the roof of the aircraft. Light from the ILS is dispersed, imaged onto the CCD, and recorded in spectral bands identical to those from the scene viewed by the casi. The analogue signals from the complete CCD array are digitised by a 12-bit A/D converter providing 4096 digital levels and recorded on a removable 9Gbyte hard drive. Signal levels can be adjusted via control of both the auto-iris aperture and the integration time of the CCD, maximising use of the full 12-bit range without saturating the detectors. The sensor operator controls the casi system via a keyboard and a monitor that displays the instrument settings, signal levels, and a scrolling real-time window of the data as it is collected.

2. Data Acquisition Modes

Although it is possible to image all 512 spatial pixels and all 288 spectral channels simultaneously (Full Frame Mode), in practice a compromise is required to avoid excessive smearing of along track pixels caused by the length of time taken to perform the read out for all elements of the array. The compromise takes the form of using two main operating modes - spatial and spectral modes which reduce the data recording requirements.

2.1. Spatial Mode & Default Bandsets

Spatial mode records data from all 512 spatial dimension pixels, but from a limited number of programmable bands (max. 18) by selection and summation of the 1.8nm resolution detector elements (Figure 2). This provides an equivalent, spatially contiguous, multi-band data set to that recorded by the ATM sensor. A spatial bandset can be formed from single detector elements or unique summations of two or more adjacent detector elements located throughout the entire spectral range of the casi (405-950 nm). A single detector element cannot be summed into more than one spatial band, even if the spatial bands are adjacent. The number, locations and bandwidths of the different bands can be set up, according to the user application, to cover either broad spectrally different regions eg. blue, green, red, and near-infrared, or at precisely placed narrow wavelengths to measure specific phenomena e.g. chlorophyll fluorescence, red-edge position, or atmospheric absorptions. Users can provide their own spatial bandsets for programming and use by the sensor operator or can select one of the default bandsets set-up for standard applications.

Default bandsets for terrestrial vegetation and ocean colour applications are included in Appendix A with a general description of the purpose of each band.

The spectral response of green grass is presented in figure 3: note the segmentation of the response due to the limited number of bands (13).

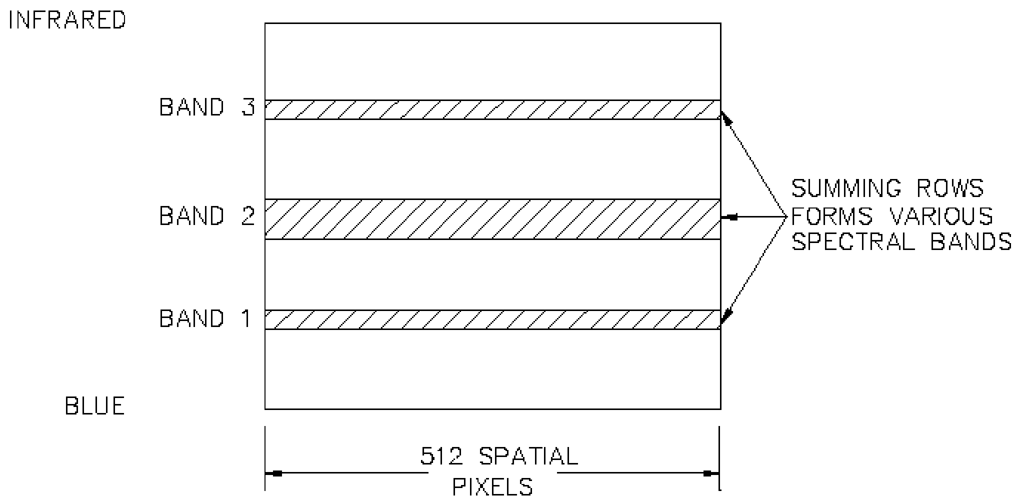

Figure 2 Spatial Mode Operation with 3 spectral band (modified from ITRES)

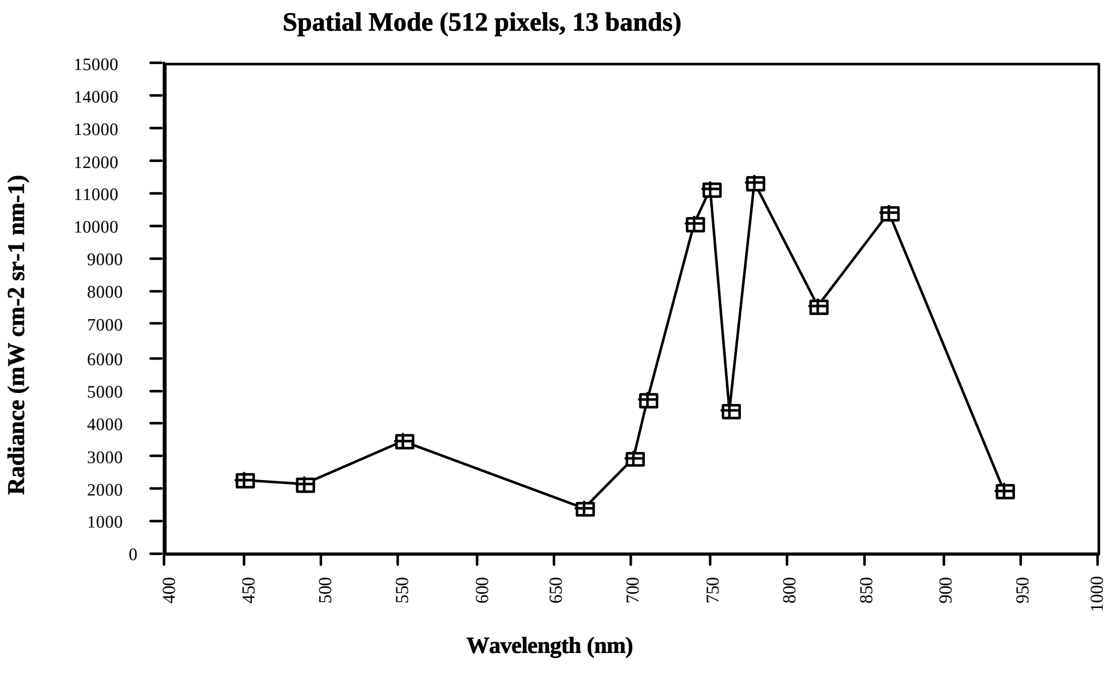

Figure 3 Spectral profile of green grass, spatial mode, 13 bands

2.2. Spectral Mode & Scene Recovery Channel

In spectral mode the full spectral profile of 288 channels can be recorded, but from a limited number of look directions, or pixel positions, spread as a rake across the ground (max. 39) (Figure 4). The 39 'tines' of this 'push-rake spectrometer' mode can be located with either 4, 8, 12 or 16 non-imaged pixels (look spacing) between each recorded spatial pixel, according to the user requirement; concentrating pixels together for high spatial resolution or spreading them out across the entire swath for good spatial coverage. Due to the missing spatial pixels it may sometimes be difficult to precisely locate the rake of spectral pixels within a scene. To offset this problem the Spectral Mode simultaneously produces a single full spatial band, formed from a single detector element, which is inherently co-registered with the separate look-directions. Using this Scene Recovery Channel (SRC) it is possible to locate the pixels positions of the spectral data within the scene. When selecting Spectral Mode for an airborne remote sensing mission the operator needs to program the casi with the spread of the push-rake, either 4, 8, 12 or 16 non-imaged pixels between the 'tines', and the channel wavelength (nm) for the SRC.

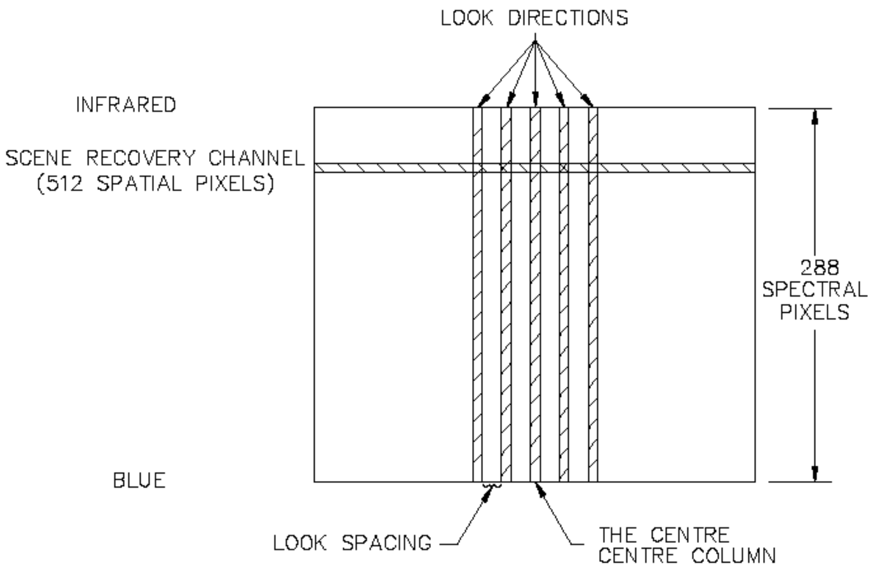

Figure 4 Spectral Mode operation with 5 look directions (modified from ITRES)

2.3. Enhanced Spectral Mode

In Enhanced Spectral Mode the full 3D data cube can be alternatively sliced into a single block of 101 adjacent spatial pixels imaged for all 288 spectral channels. This mode can be further extended into a series with increasing spatial coverage (more spatial pixels) at the expense of decreasing spectral resolution (fewer, wider channels). Each output band being formed by either a single detector element (101 x 288) or summations of adjacent detectors i.e. summations of CCD row 1+2, etc. or 1+2+3, etc. thus maintaining a consistent integration time (Figure 5). Table 2 shows some typical examples of the look directions versus number of spectral channels, indicating the effect on frame rate and pixel resolution.
Figures 6 and 7 shows examples of spectral responses of green grass in two enhanced spectral modes, respectively with 48 or 288 channels.

However, both the Spectral and Enhanced Spectral Modes have a distinct drawback, since integration times are much longer than for Spatial Mode. This precludes the general use of these high data rate modes at low altitudes where fast integration times are required to maintain the squareness of pixels (pixel widths being smaller because of the low altitude). If this is not attainable at the altitude required, an aspect ratio (pixel length to width) of 2:1 or more may have to be selected by the operator.

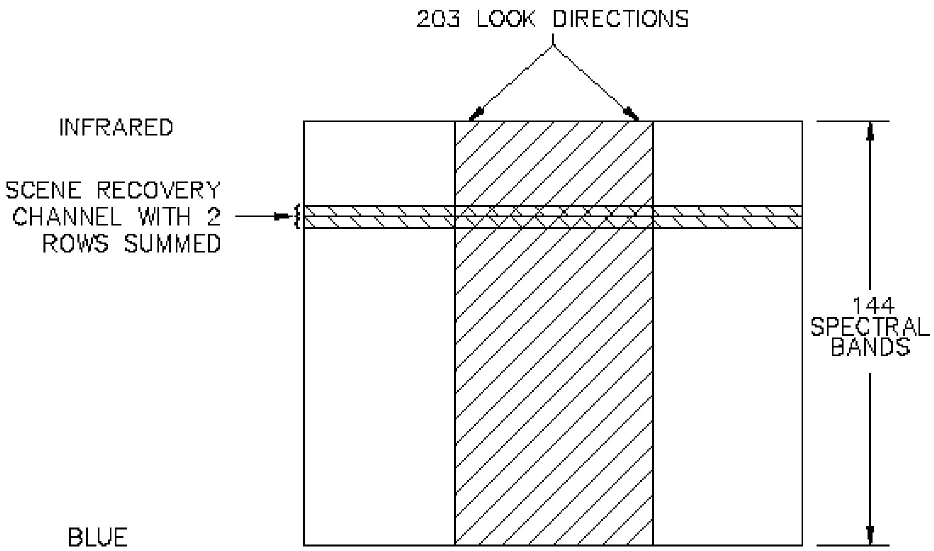

Figure 5 An Enhanced Spectral Mode operation with 2 rows summed (modified from ITRES)

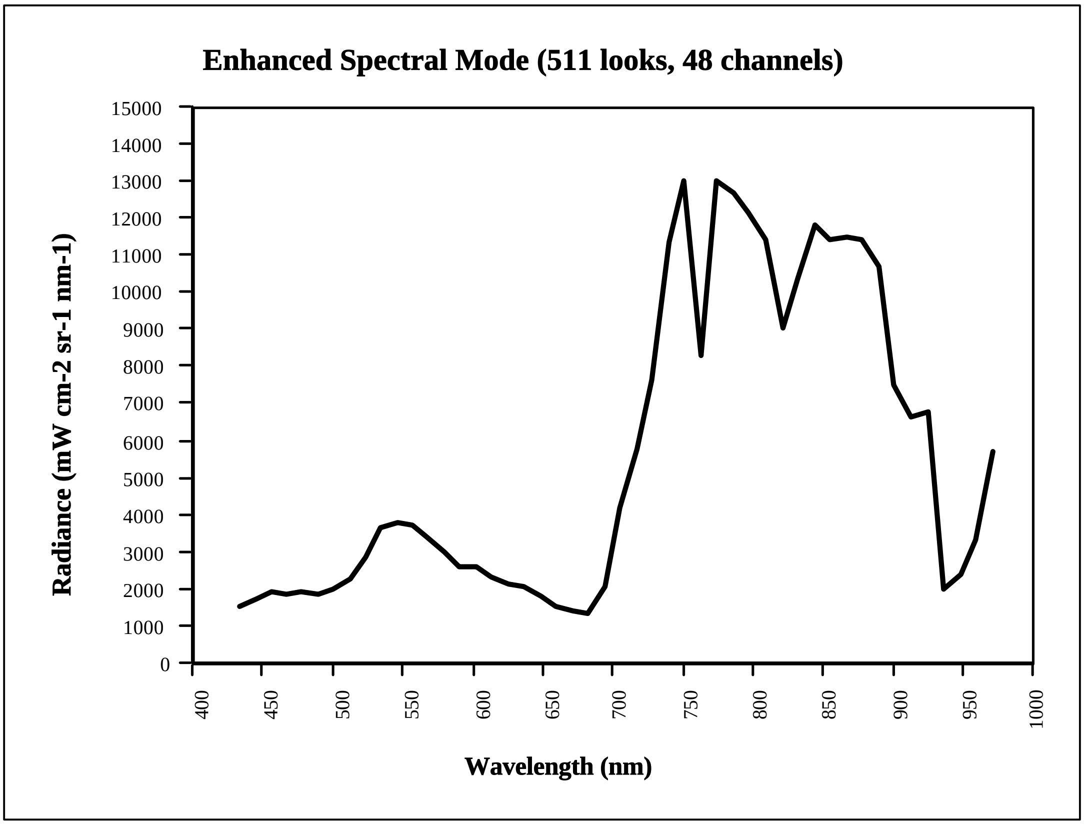

Figure 6 Spectral response of green grass, enhanced spectral 511 looks, 48 rows summed

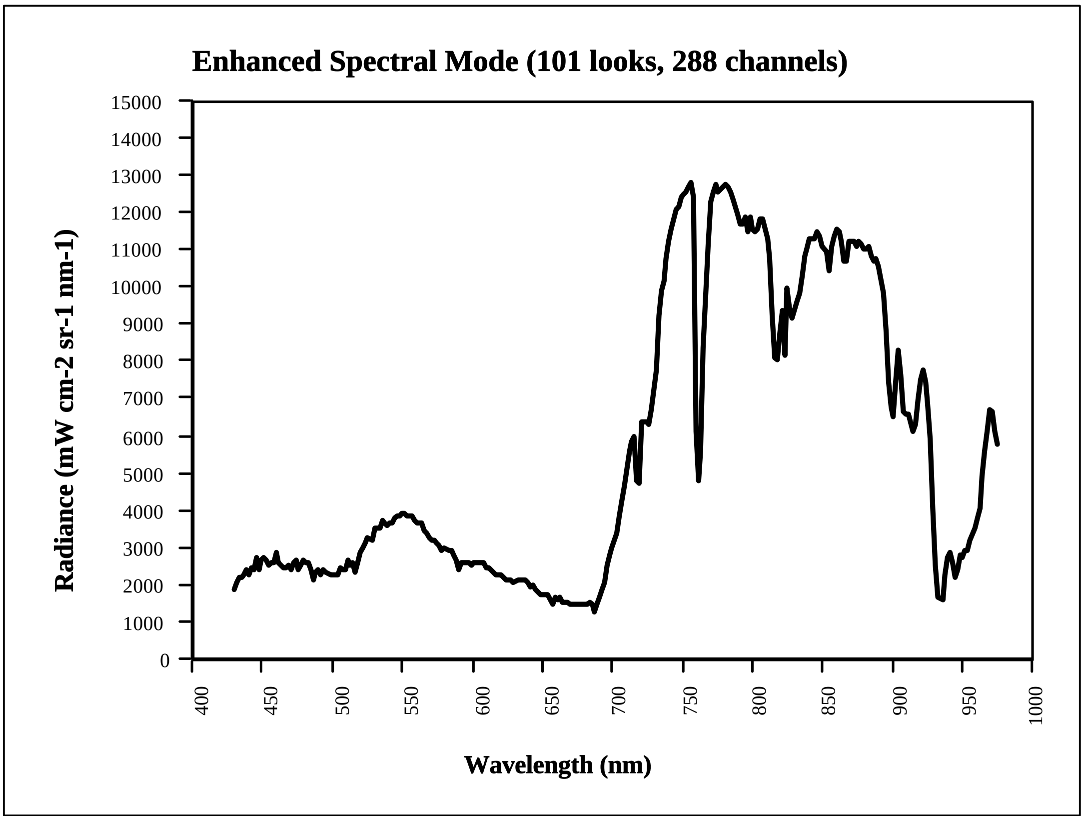

Figure 7 Spectral response of green grass, enhanced spectral mode, 101 looks 288 cannel (full spectral resolution)

Numbers of Rows Summed	Number of Bands	Approximate Bandwidth	Maximum Swath Width (in Pixel Across Track)	Spatial Resolution W x L (m)	Altitude (m a.g.l.)
1	288	2.2	101	3.7 x 7.3	3049
2	144	4.1	203	3.7 x 7.3	3049
3	96	6.0	303	3.7 x 7.3	3049
4	72	7.9	405	3.7 x 7.3	3049
6	48	11.7	511	3.7 x 7.3	3049
8	36	15.4	511	variable	
9	32	17.3	511	variable	
12	24	23.0	511	variable	
16	18	30.6	511	variable	
18	16	34.4	511	variable	
24	15	45.7	511	variable	
32	9	60.9	511	variable	
36	8	68.4	511	variable	
48	6	91.1	511	variable	

Table 2 Typical configurations in Enhanced Spectral Mode

Note: Aircraft speed over ground is assumed to be 100knots (50 m/s) for above calculations (m a.g.l. - metres above ground level).

2.4. Full Frame Mode

Full Frame Mode show in Figure 8 is generally only used during laboratory calibrations since the integration times (1-2 seconds) are too long to be used during airborne flights without tremendous smearing of the image. However, it may be possible to use this mode when the casi is mounted on a ground-based motion tripod to view static objects for use in, for example, colour perception studies.
This mode is normally used for the laboratory casi calibration. Radiometric calibration involves the creation of multiple frames of data. Each frame caries noise as well as signal and part of the calibration process involves minimising the effects of the noise. Averaging signal and noise ratio over long period of time, a few minutes up to a few hours, is one of the means of obtaining these merit figures, The methodology involves summing output values at identical pixel locations over many frames. Full Frame mode has been designed to facilitate this process, by allowing the summation of up to 16 single frames at time (ITRES, User Manual Chapter 3, pp 54).

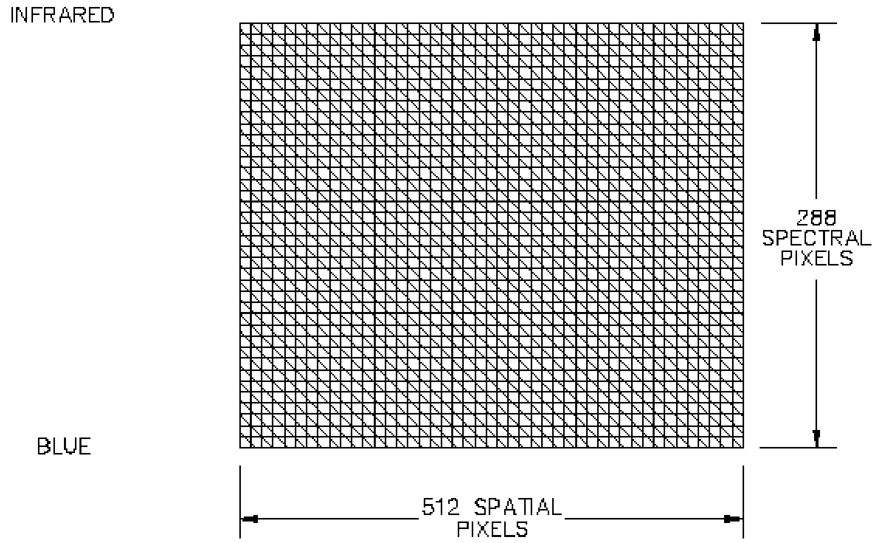

Figure 8 Full Frame Mode operation (modified from ITRES)

Bibliography

ITRES User Manual, Chapter 1 and Chapter 3
NERC ARSF User Guide Hand Book Version 1.0

Appendix A
CASI Default Bandset

VEGETATION

Channel	Centre (nm)	Width (nm)	Start (nm)	End (nm)	Purpose
1	450	20	441.53	459.17	Blue veg response
2	490	20	480.37	499.84	Veg. response
3	552	10	547.74	556.63	Green veg max
4	670	10	665.57	674.74	Veg absorp. max (1)
5	700	10	694.28	703.27	Red-edge (2)
6	710	10	705.07	711.06	Red-edge (3)
7	740	10	735.66	744.67	Red-edge (4)
8	750	7	746.47	753.68	Red-edge (5)
9	762	5	760.90	764.51	Oxigen absorp.
10	780	10	775.34	784.37	Veg reflect. Max
11	820	10	815.13	824.18	Water absorp.
12	865	10	860.46	869.54	NIR plateau

Channels 4, 5, 6, 7, 8 and 10 can be used to fit inverted gaussian for vegetation red-edge.
Channels 4, 6, 7 and 10 for Guyot-Baret red-edge model.
Channels 1, 3, 4, 10 and 12 for various vegetation indices and to simulate main satellite channels.
Channels 10, 11 and 12 for determining water vapour content for atmospheric correction at all wavelengths.
Channels 8, 9 and 10 for determining atmospheric oxygen for path-length correction of above water vapour measurements.

If fewer channels are available due to integration time / altitude conflicts then reduce bandset by deleting ch 2 (490nm), then ch 9 (762) and then ch 7 (740nm) for 11, 10 and 9 channel bandsets, respectively.

SEAWIFS/ OCEAN COLOUR

Channel	Centre (nm)	Width (nm)	Start (nm)	End (nm)	SeaWIFS Channel	Purpose
1	412	20	402.81	422.15	1	Gelb. + Chlor.
2	443	20	432.72	453.87	2	Chlor. + Gelb.
3	490	20	480.37	499.84	3	Gelb. + Chlor. + Acces.
4	510	20	501.61	519.33	4	Acces.
5	555	20	545.97	565.53	5	Acces. + Chlor.
6	620	20	610.1	629.76		MERIS + Acces.
7	670	20	660.19	679.92	6	Chlor+Sed+ChlorF+R-E
8	682.5	5	681.72	685.31		ChlorF.
9	710	10	705.07	715.86		R-E.+ ChlorF.
10	752	15	744.76	759.1	7a	Sed. + Aeros. + R-E.
11	762	5	760.9	764.51		Oxygen Absorp.
12	775	20	766.31	784.37	7b	Sed. + Aeros. + R-E.
13	820	10	815.13	824.18		Water Vapour Absorp.

Gelb. - Gelbstoff
Chlor. - Chlorophyll
Acces. - Accessory Pigment
MERIS - MERIS compatible band
Sed. - Sediments
ChlorF. - Chlorophyll Fluorescence
R-E. - Vegetation Red-Edge
Aeros. - Aerosols

Least important band is Ch 6. at 620nm and then Ch 11. at 762nm (Can be dropped if fewer channels are necessary).
Channels 10 and 12 are both required to simulate the single SeaWiFS channel 7 due to the notch in the satellite sensor response to avoid the oxygen absorption feature.