



Leica Geosystems GIS & Mapping

Introduction to ADS40 components and operation

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ASW 2005, Denver



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- **GSD and Map Scale Range**
- **Principle of pushbroom scanning**
- **Components of the ADS40**
- **Advantages of the Pushbroom Principle**
- **ADS40 Operation**
- **Main parameters influencing image quality**



GSD and Map Scale Range

Large Scale Mapping



**Ground
sample
distance:**
GSD \approx 5 cm
GSD \approx 1/5 ft

**Flying
height:**
480 m
1,580 ft



26 June 2004

Large Scale Mapping



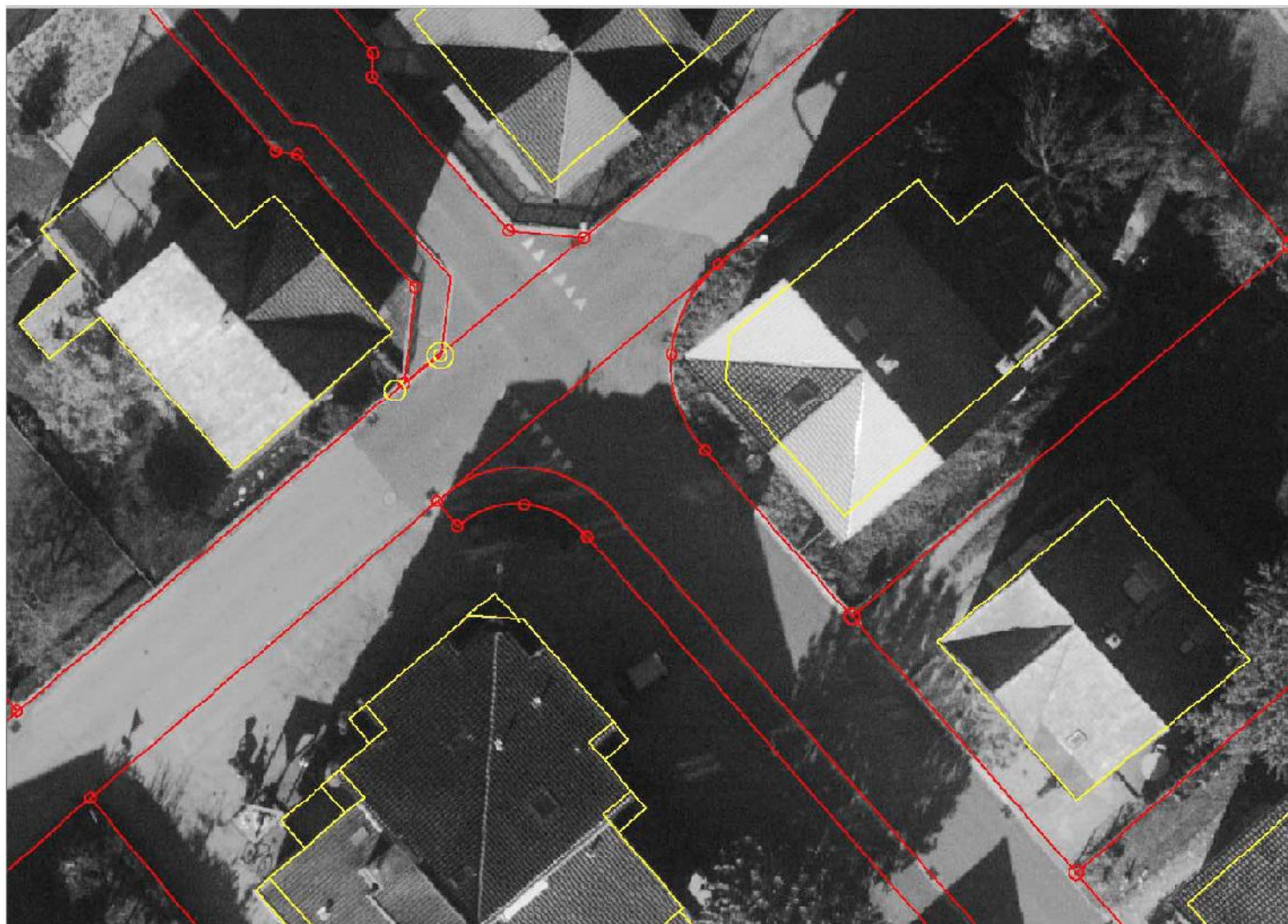
**Ground
sample
distance:**
GSD \approx 5 cm
GSD \approx 1/5 ft

**Flying
height:**
480 m
1,580 ft



26 June 2004

Geo-referenced large scale imagery



**Ground
sample
distance:**
GSD \approx 6 cm
GSD \approx 1/5 ft

**Flying
height:**
580 m
1,900 ft

**November
2003
Sun elevation
23°**

Small Scale Mapping - RGB



Ground sample distance:

GSD \approx 15 cm / 1/2 ft

Flying height:

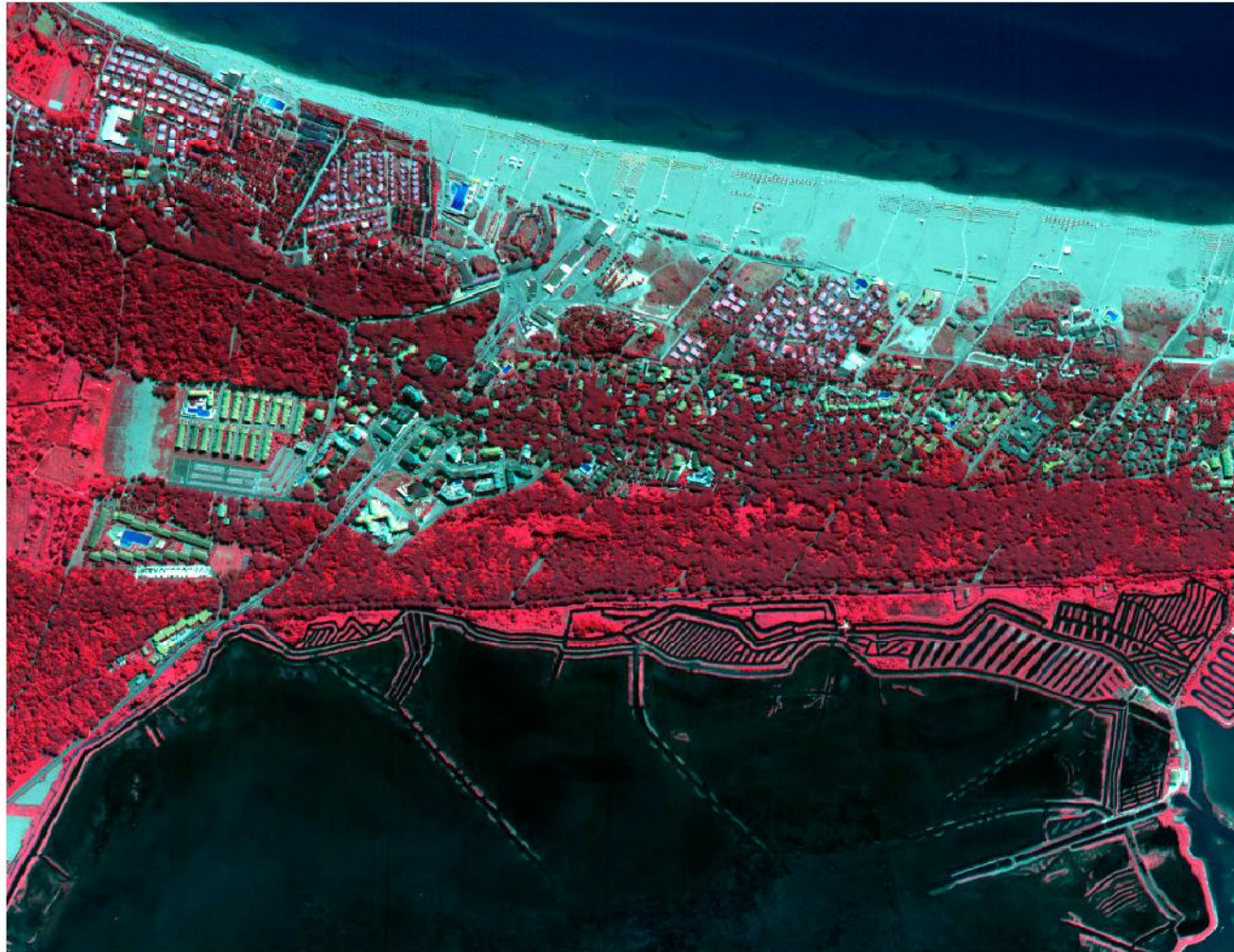
1,500 m / 4,900 ft

Flight direction:



Date: 8 June 2001

Small Scale Mapping - FCIR



Ground sample distance:

GSD \approx 15 cm / 1/2 ft

Flying height:

1,500 m / 4,900 ft

Flight direction:



Date: 20 June 2001

Mapping at all Scales

Average GSD for various map scales

| Average GSD with ADS40 | Map Scale | Map standard | | Comparable film photographs | |
|------------------------------|-------------|-------------------------|---------------------|-----------------------------|--|
| | | x-y accuracy RMSE | contour interval | photo scale | pixel size on ground of scanned film |
| 5 - 10 cm | 1 : 500 | 0.125 m | 0.25 m | 1 : 3,000 to 1 : 5,500 | 2.5 - 5 cm |
| 10 - 15 cm | 1 : 1000 | 0.25 m | 0.5 m | 1 : 5,000 to 1 : 8,000 | 5 - 7.5 cm |
| 15 - 20 cm | 1 : 1,500 | 0.4 m | 0.75 m | 1 : 6,500 to 1 : 10,000 | 7.5 - 10 cm |
| 20 - 30 cm | 1 : 2,000 | 0.5 m | 1 m | 1 : 8,000 to 1 : 11,000 | 10 - 15 cm |
| 25 - 35 cm | 1 : 2,500 | 0.60 m | 1.25 m | 1 : 8,500 to 1 : 13,000 | 12.5 - 17.5 cm |
| 30 - 50 cm | 1 : 5,000 | 1.25 m | 2.5 m | 1 : 12,000 to 1 : 18,000 | 15 - 25 cm |
| 40 - 60 cm | 1 : 10,000 | 2.50 m | 5 m | 1 : 17,000 to 1 : 27,000 | 20 - 30 cm |
| 50 - 70 cm | 1 : 20,000 | 5 m | 10 m | 1 : 25,000 to 1 : 35,000 | 25 - 35 cm |
| 50 - 80 cm | 1 : 25,000 | 6.25 m | 12.5 m | 1 : 28,000 to 1 : 42,000 | 25 - 40 cm |
| 50 - 100 cm | 1 : 50,000 | 12.5 m | 20 m | 1 : 40,000 to 1 : 60,000 | 25 - 50 cm |
| 50 - 100 cm | 1 : 100,000 | 25 m | 50 m | 1 : 60,000 to 1 : 90,000 | 25 - 50 cm |

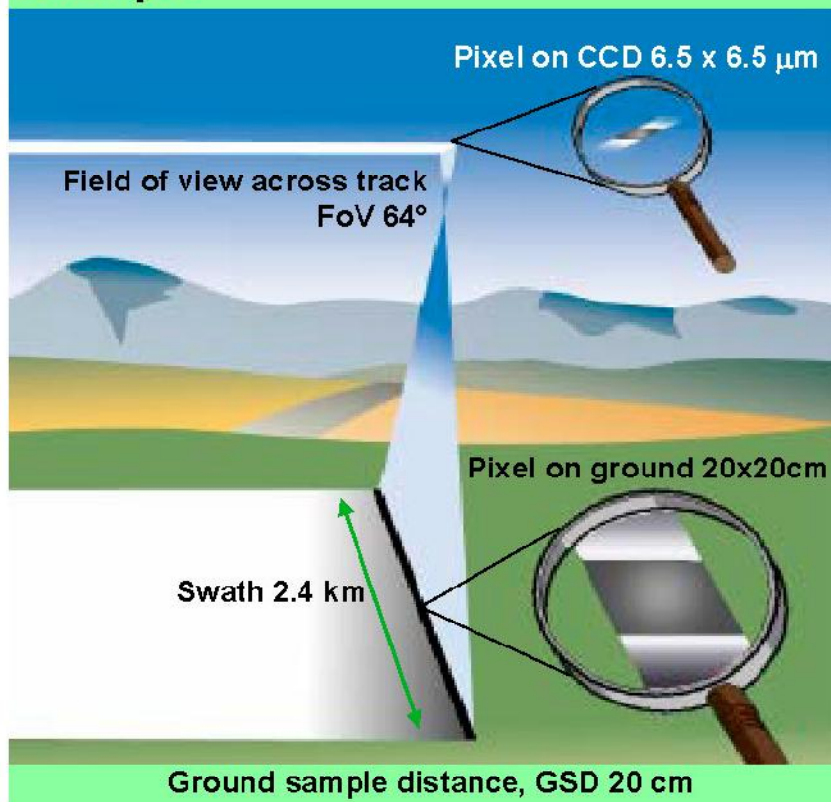


Principle of pushbroom scanner ADS40

Terminology

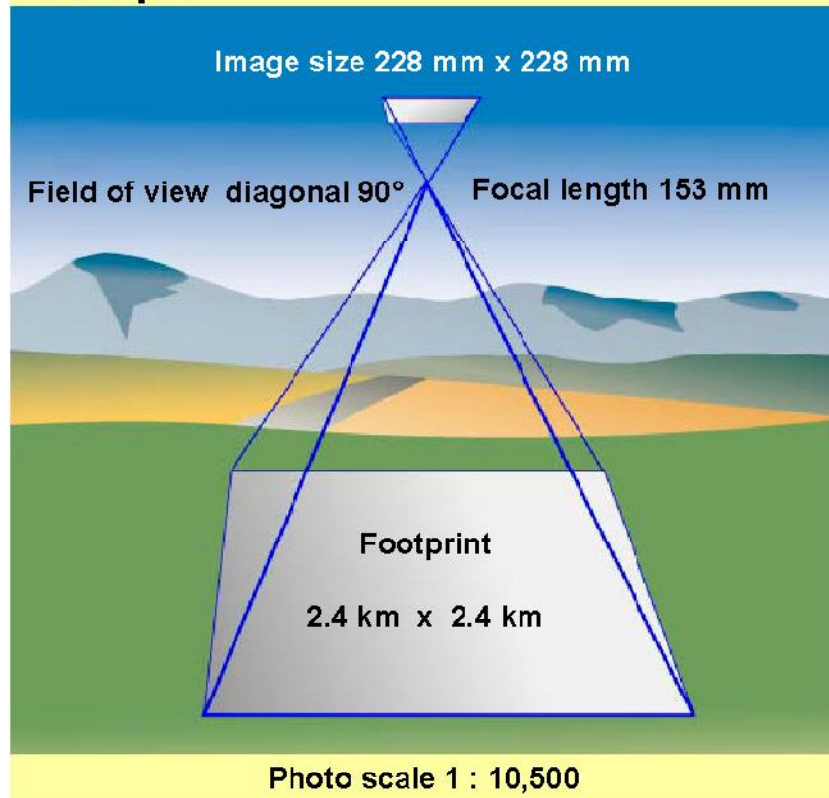
Parallel Line Perspective

Example



Central Perspective

Example



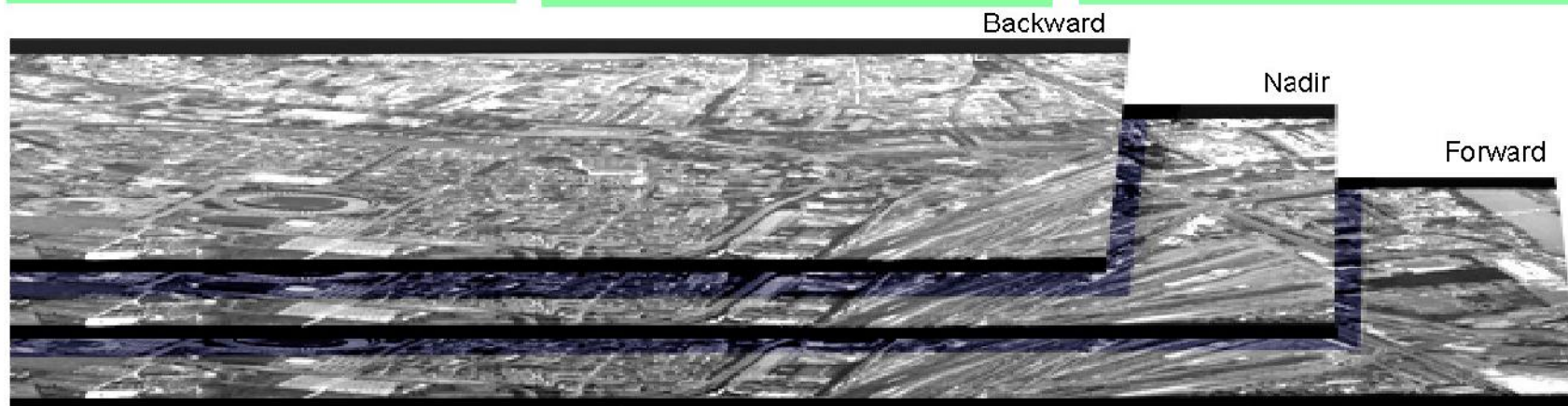
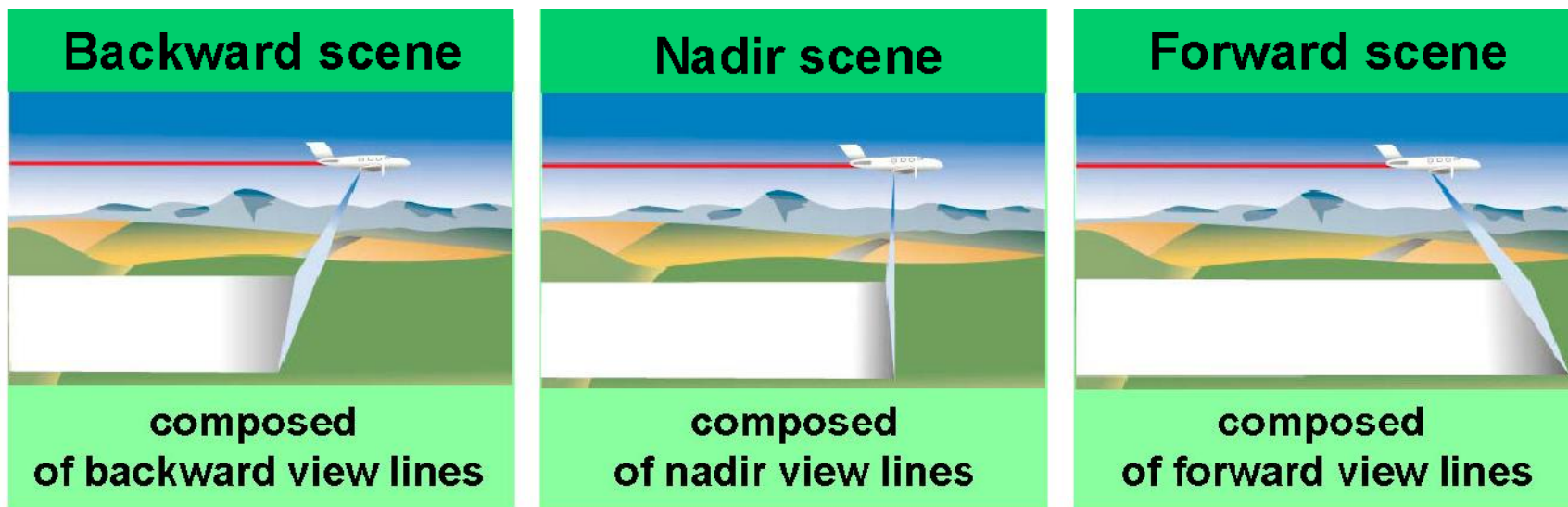
Terminology

| Digital imagery | Film |
|---------------------------------------|-------------------------------------|
| Pixel size on CCD Number of pixels | Resolution lens/film Image size |
| Field of view across track | Field of view across and along |
| Swath width Pixel carpet length | Footprint width Footprint length |
| Ground Sampling Distance (GSD) | Photo scale |

For direct digital image acquisition the term 'Photo Scale' should never be used to characterize the image or the image quality of the sensor's application range. Because in this context the term 'Photo Scale' does not take into account the many variations of the pixel size, nor the dimensions, of the CCDs which are available in the market.

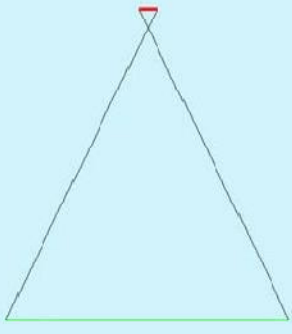
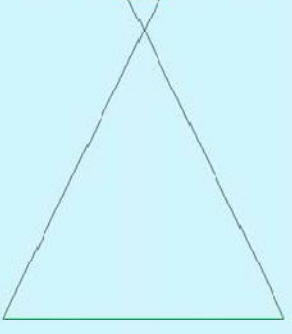
Characterizing direct digital images by 'Photo Scale' is as misleading as if scanned film images were characterized without indicating the Scan Resolution.

Three-line pushbroom scanner

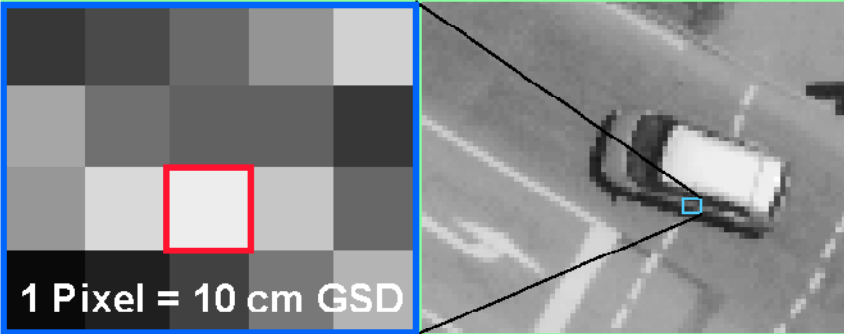
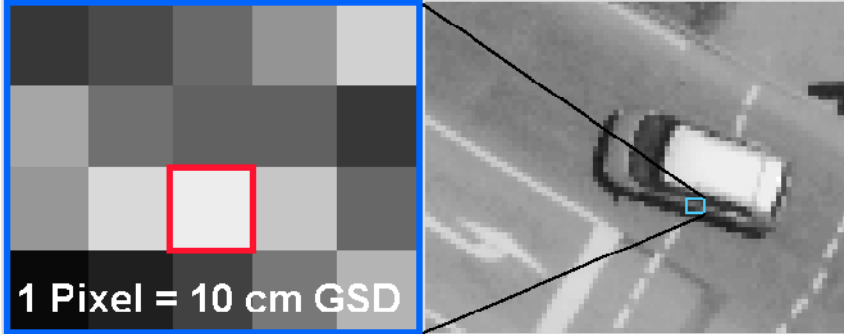


Three-line pushbroom principle, proven in satellites and adapted to aircraft platform.

Irrelevance of photo scale for direct digital images

| ADS40 6.5 μm CCD | Sensor with 12 μm CCD |
|--|---|
|  <p>Sensor data CCD: 12,000 pixels @ 6.5 μm Lens: $f = 63 \text{ mm}$, FOV 64°</p> <p>Flight data for 10cm GSD Flying height 965 m 'Photo' Scale 1 : 15,384 Swath 1,200 m</p> |  <p>Sensor data CCD: 12,000 pixels @ 12 μm Lens: $f = 120 \text{ mm}$, FOV 62°</p> <p>Flight data for 10cm GSD Flying height 1,000 m 'Photo' Scale 1 : 8,333 Swath 1,200 m</p> |

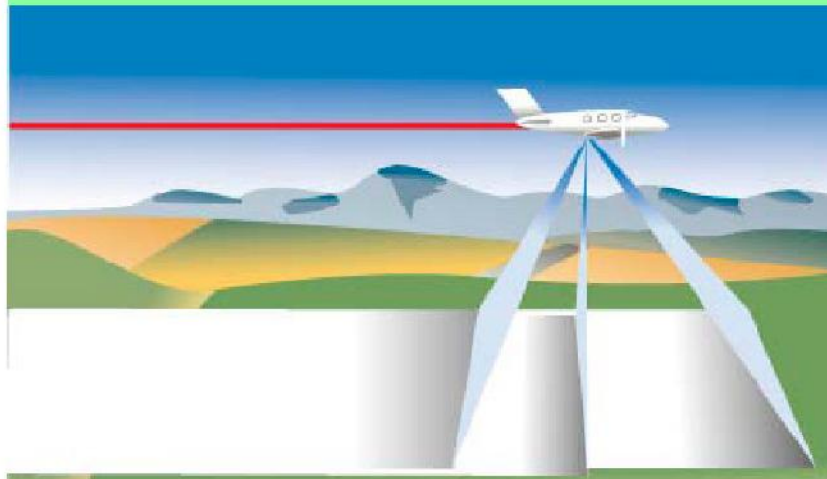
Equal GSD at different image scales - even when the CCD pixel size is different

| Digital image 12,000 pixels across track | Digital image 12,000 pixels across track |
|--|---|
|  <p>1 Pixel = 10 cm GSD</p> <p style="color: red;">Swath on ground 1200 m</p> |  <p>1 Pixel = 10 cm GSD</p> <p style="color: red;">Swath on ground 1200 m</p> |

Imaging Geometry concepts

Pushbroom Scanner

Parallel Line Perspective



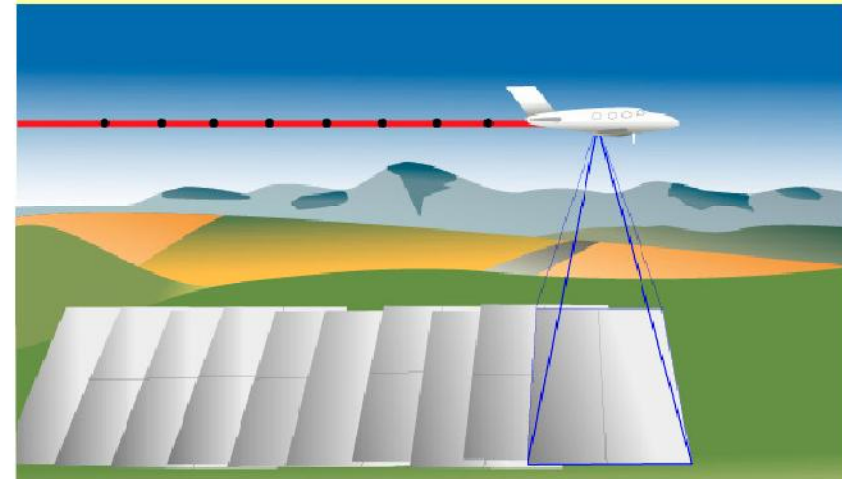
forward view

nadir view

backward view

Digital Frame Camera

Patched Central Perspective



overlapping frame images

Imaging Geometry concepts



Patched Central Perspective

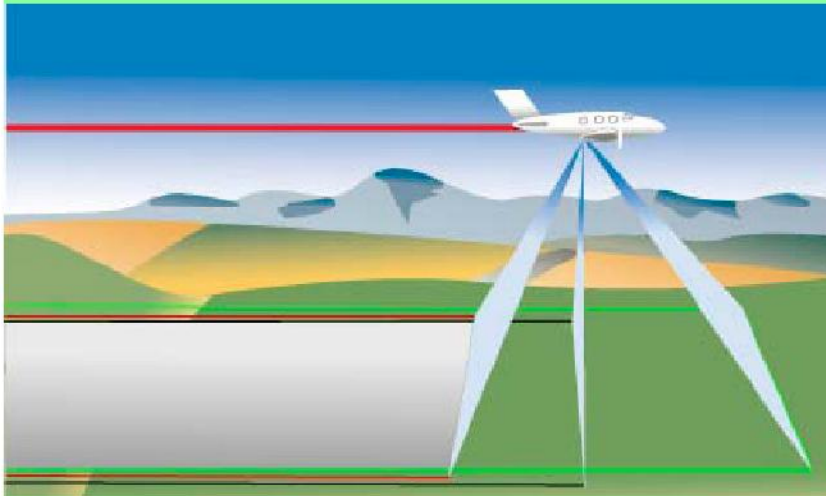


Parallel Line Perspective

Image overlap

Parallel Line Perspective

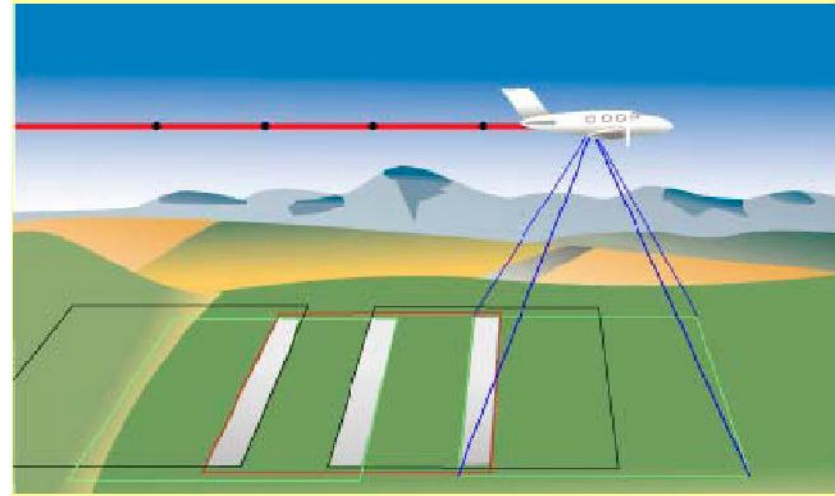
All objects recorded 3 times



100% overlapping scenes

Patched Central Perspective

Not all objects recorded 3 times

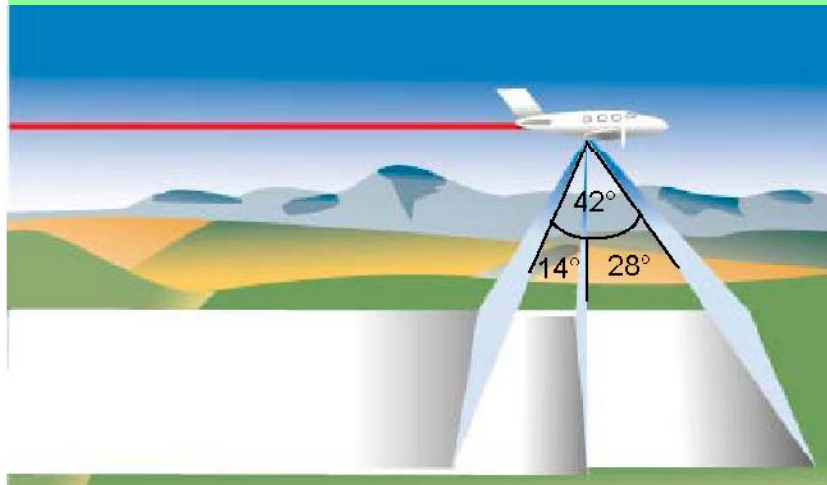


Flying with 60% overlap only 50% of all objects are on 3 photographs

Height accuracy

Parallel Line Perspective

Seamless continuous pixel carpets
100% overlapping

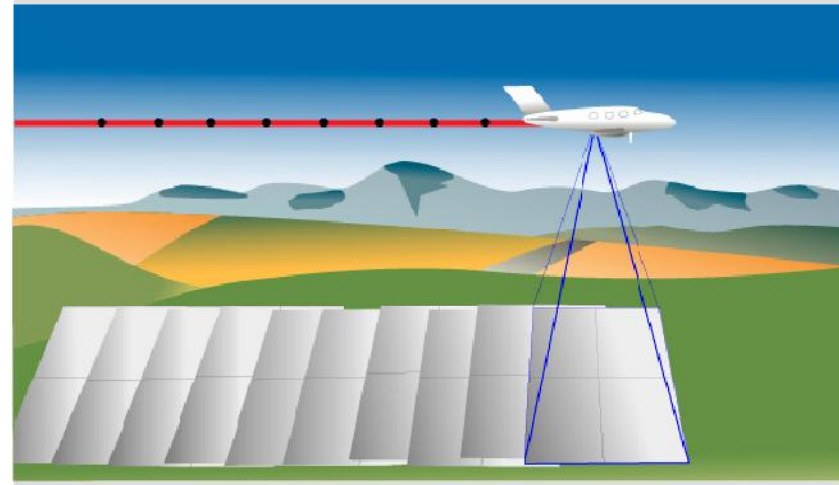


Stereo angles 14°, 28° and 42°
Height to Base ratio = 1.26

Patched Central Perspective

Multiple images form patched ,frame'

DMC: 4 images form a ,frame'
UltraCam: 9 images form a ,frame'



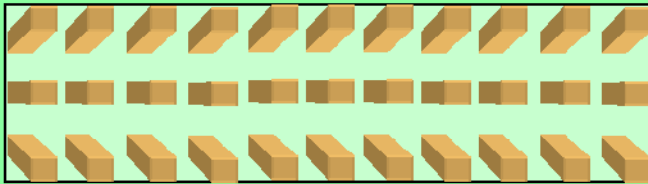
Stereo angle 17.5°, 15.5° at 60% fw. overlap
Height to Base ratio = 3.2, 3.7

The smaller the h/b ratio the better the height accuracy

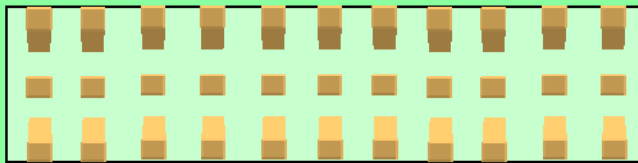
Effect of imaging perspective

Parallel Line Perspective

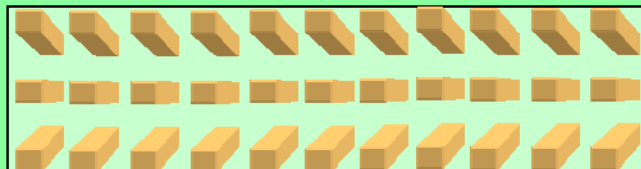
Forward parallel line perspective



Nadir Parallel Line Perspective

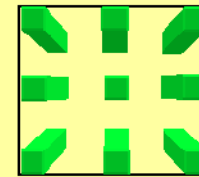


Backward parallel line perspective

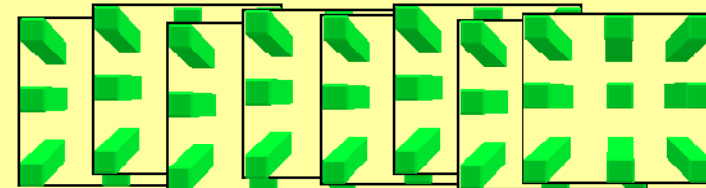


Central Perspective

Photograph with central perspective



Flight line with overlapping photographs



Filter transmission characteristics

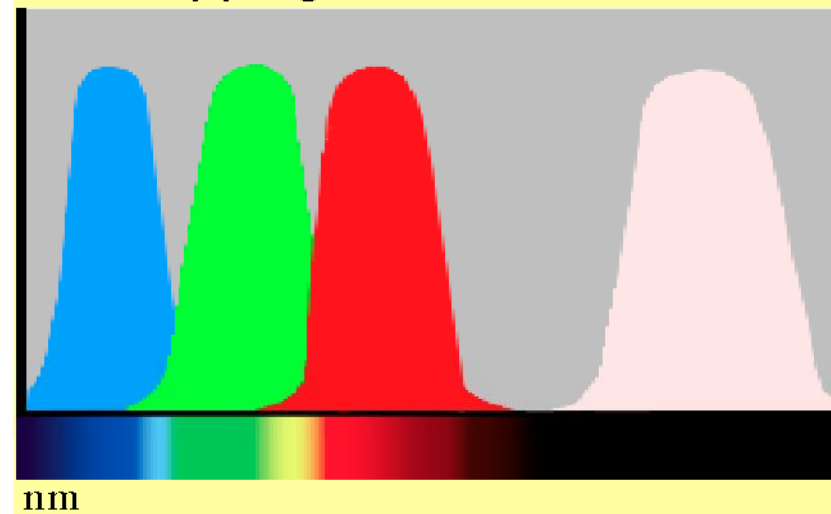
Interference filters Used in ADS40

Non-overlapping narrow bands



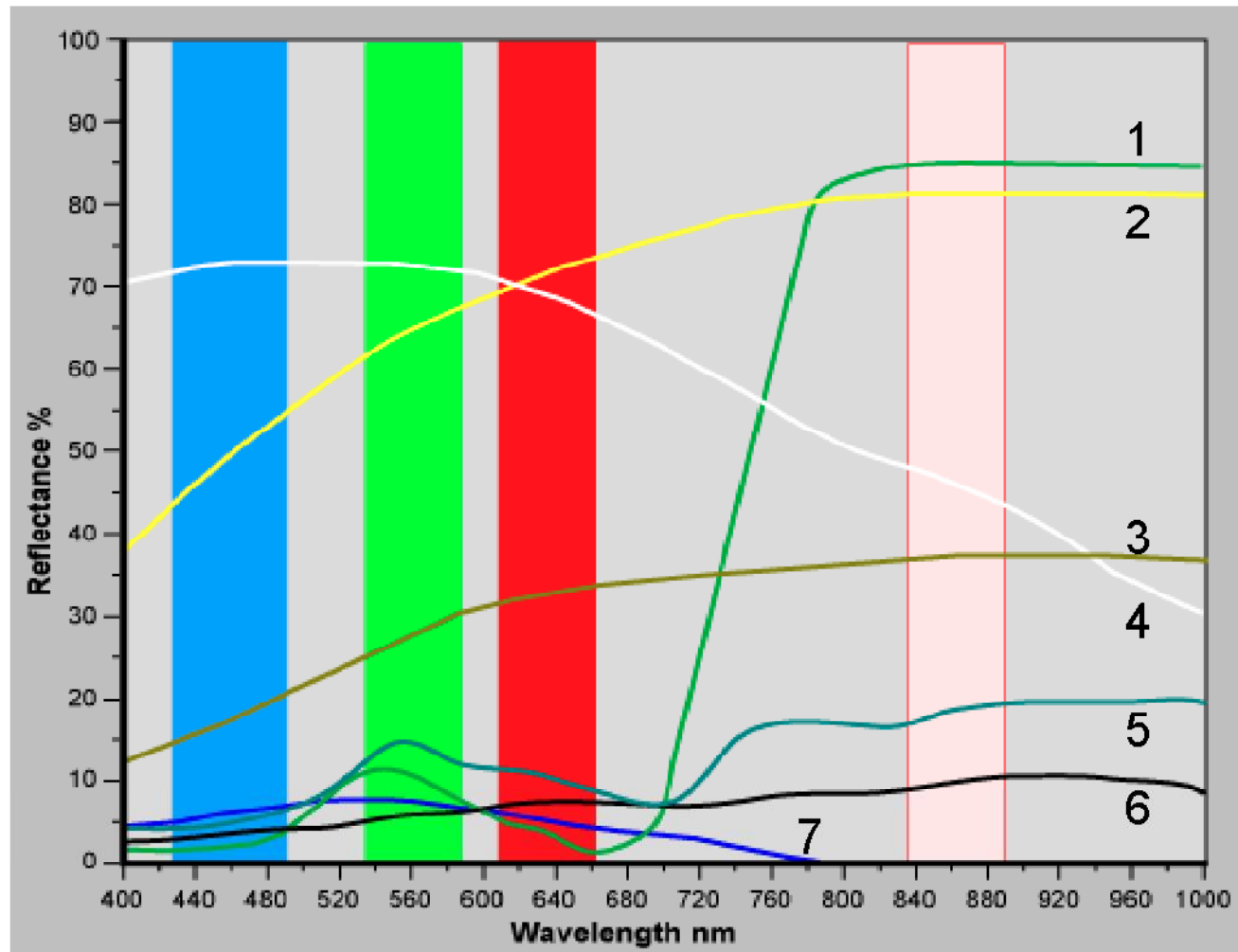
Absorption filters Used in digital frame cameras

Overlapping bands



Only interference filters are suitable for remote sensing applications where response in non-overlapping narrow bands is evaluated

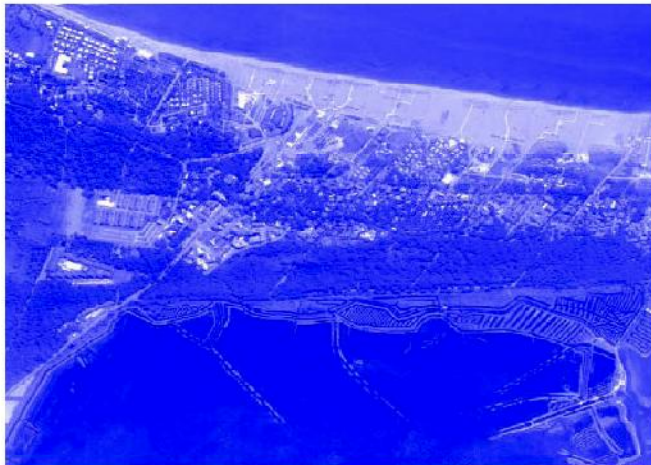
Spectral band filters



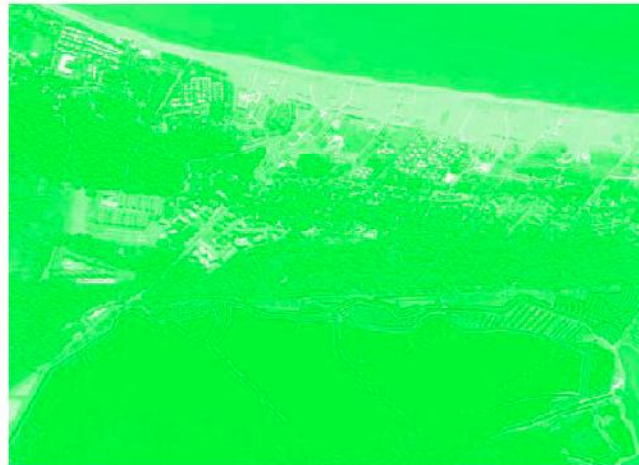
Legend

- 1 Grass
- 2 Lime Stone
- 3 Sand, dry
- 4 Snow, old
- 5 Fir tree
- 6 Asphalt, wet
- 7 Water

Narrow band multi-spectral imagery



Blue 430 - 490 nm



Green 535 - 585 nm



Red 610 - 660 nm



Infra-red 835 - 885 nm

Ground sample distance:

GSD \approx 15 cm / 1/2 ft

Flying height:

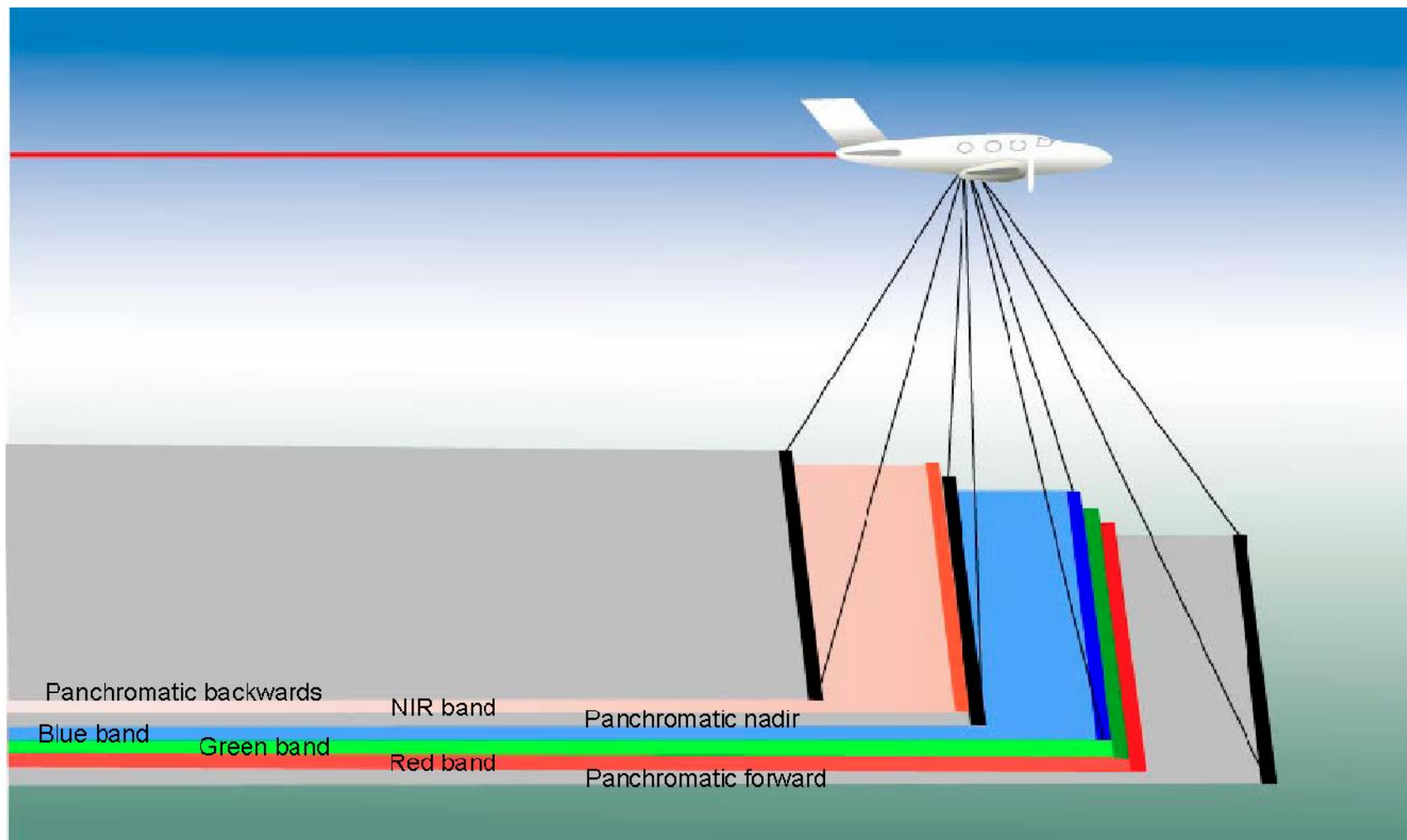
1,500 m / 4,900 ft

Flight direction:

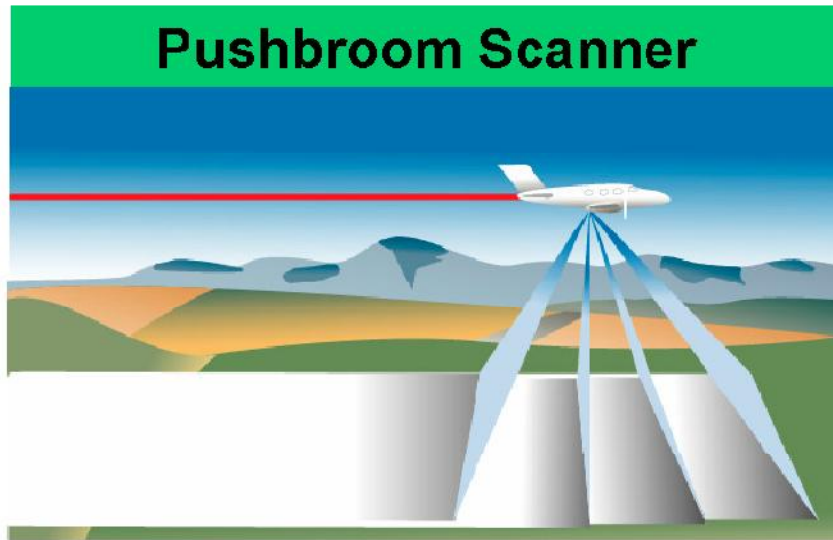


Date: 20 June 2001

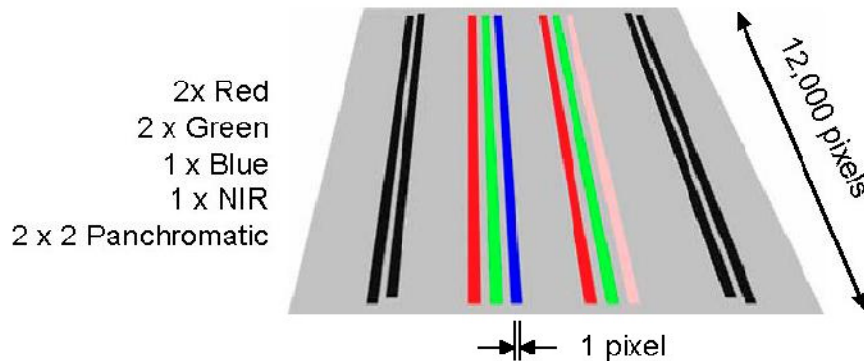
Original bands in ADS40 Focal Plate



New Focal Plate of ADS40



Single lens with a focal plate with 10 CCD lines.
Trichroid features co-registration of spectral bands.





ADS40 - Advantages of Sensor Head concept



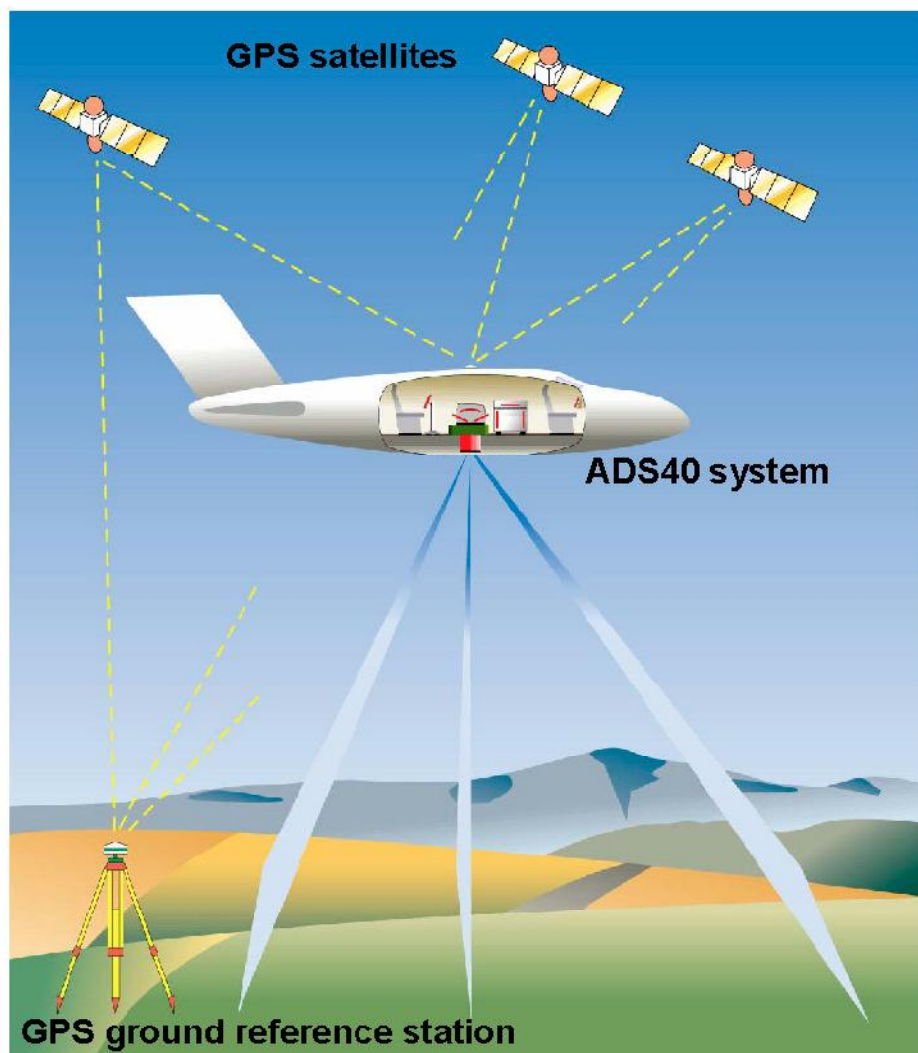
SH40 Sensor Head

- **Single lens for all 10 image sensors on same focal plate**
 - **All lines are mechanically aligned precisely to one another**
 - **Orientation of each line known**
 - **Calibrated pixel carpets**
- **Identical high resolution image sensors**
 - **10 x CCD lines with 6.5 μ m pixel**
 - **12,000 pixels swath width for each panchromatic and multi-spectral lines**
- **Forward motion compensation inherent in pushbroom principle**



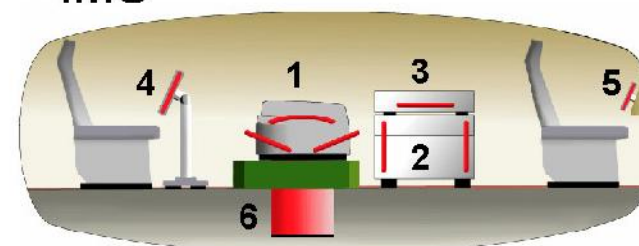
Components of the ADS40

Airborne ADS40 system



ADS40 System

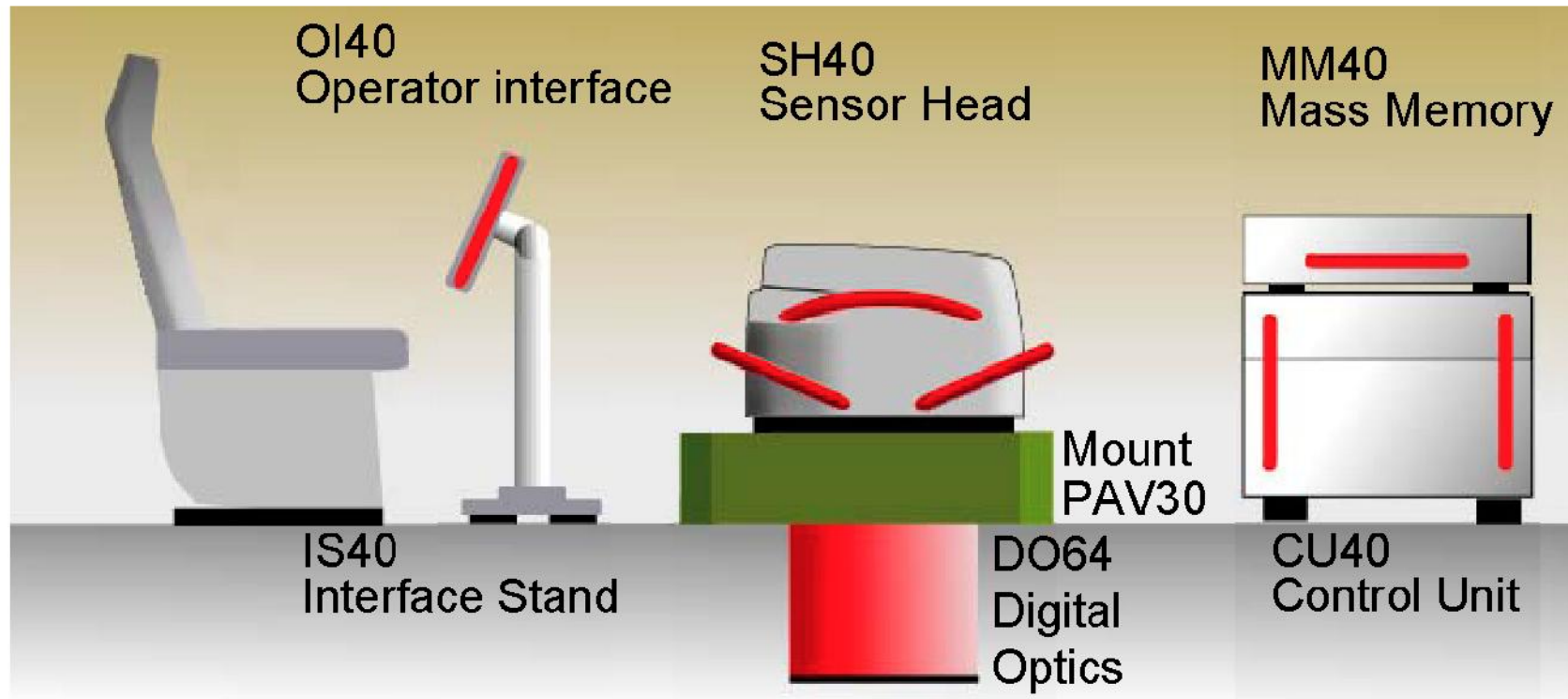
- 1 Sensor head SH40 with:
 - Digital optics DO64
 - IMU



- 2 Control unit CU40 with:
 - position & attitude computer POS or IPAS
- 3 Mass Memory MM40
- 4 Operator interface OI40
- 5 Flight guidance GI40/OC50
- 6 Mount PAV30



ADS40 - system components



- IMU integrated in Sensor Head SH40
- GPS integrated in Control Unit CU40
- FCMS Flight Control Management System (software)
- POS / IPAS Position and Attitude computer integrated in CU40
- PAV30 gyro-stabilized mount with attitude control from POS or IPAS



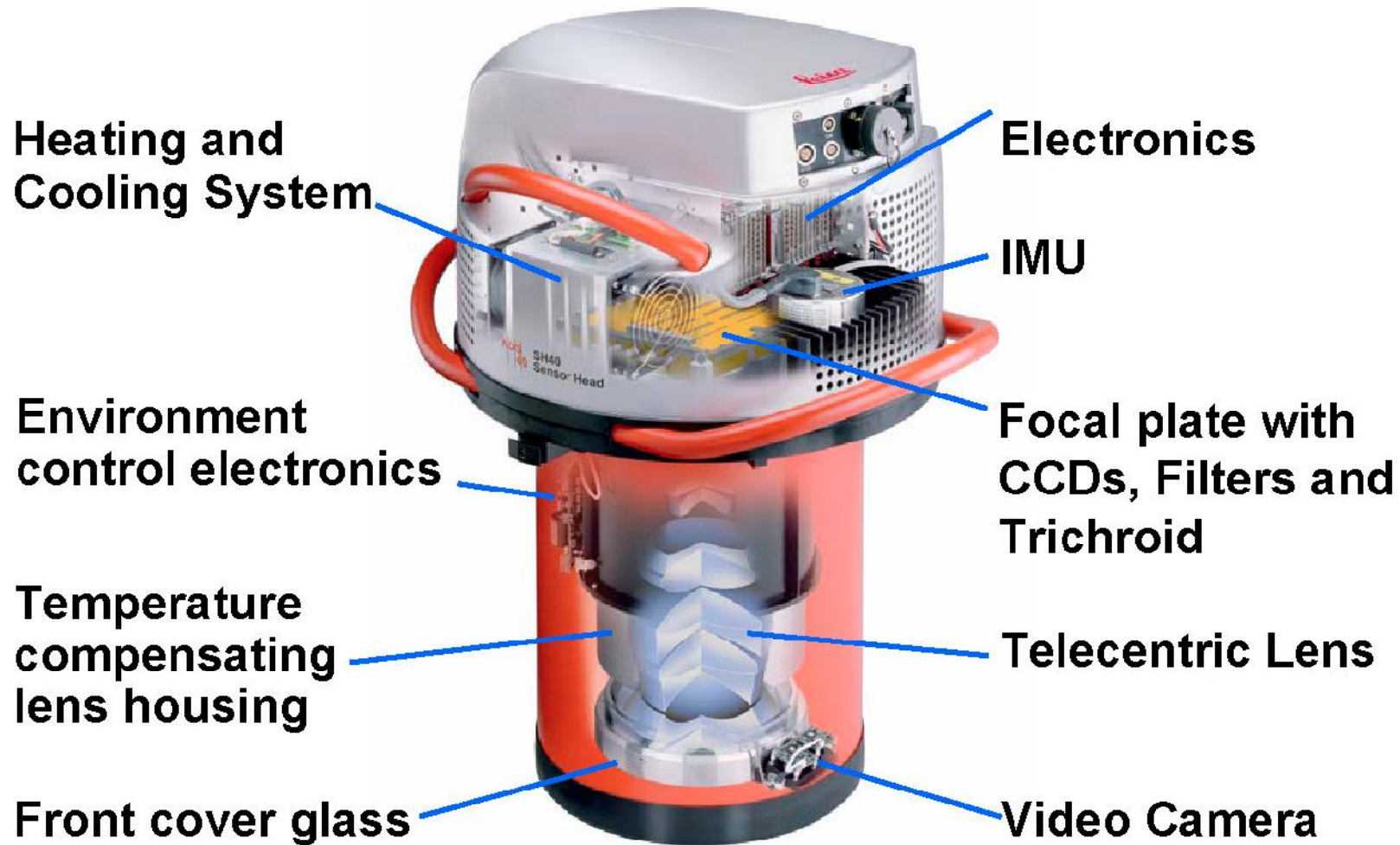
Sensor Head SH40



- 3 panchromatic CCD lines each 2 x 12,000 pixels, staggered by 3.25 μm
- 4 multispectral CCD lines, each 12,000 pixels
- Pixel size: 6.5 μm x 6.5 μm
- Field of view (FoV) or swath angle: 64°
- Focal length: 62.77 mm
- Stereo angles: 14°, 28°, 42°

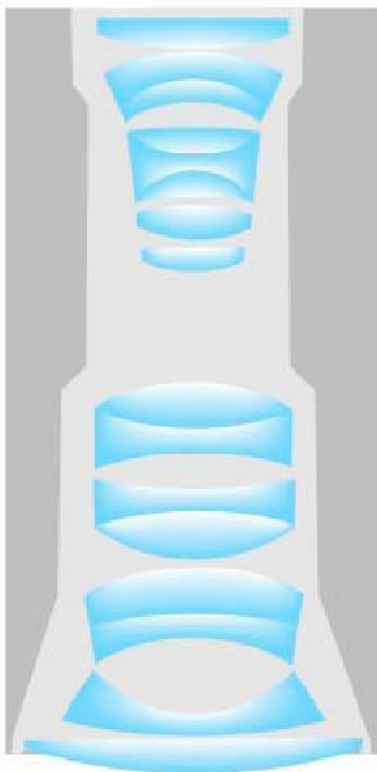


Sensor Head SH40

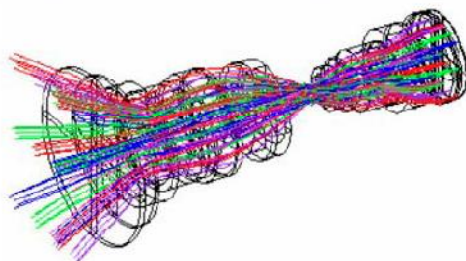




Digital Optics DO64



- 64° large FoV (Swath angle)
- f-number: 4
- 420-900 nm spectral range
- Resolution ~ 130 lp/mm
- Registration accuracy 1 μm
- Thermic & pressure stabilization in high accuracy range from +10°C to +30°C



Telecentric design

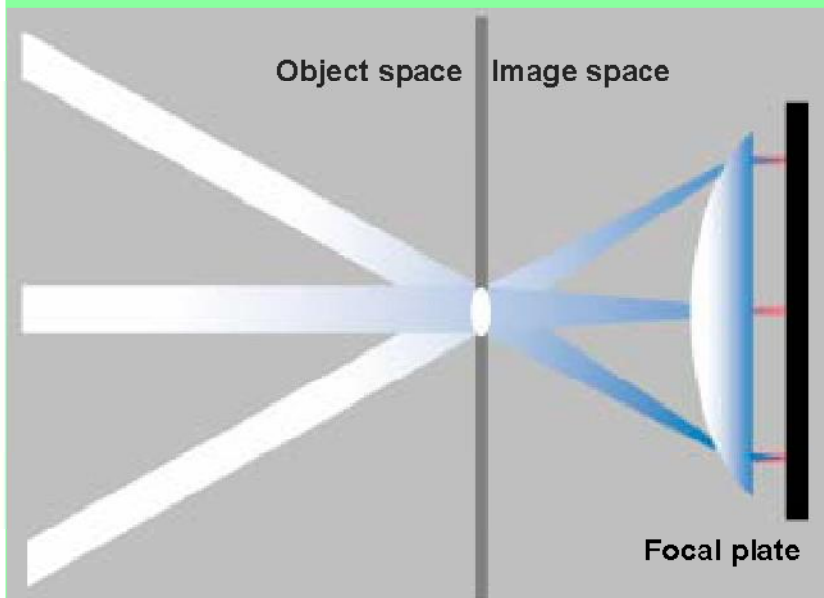
- Maintains position and width of all filter edges over the whole FoV



Telecentric optics design

Telecentric optics design ADS40

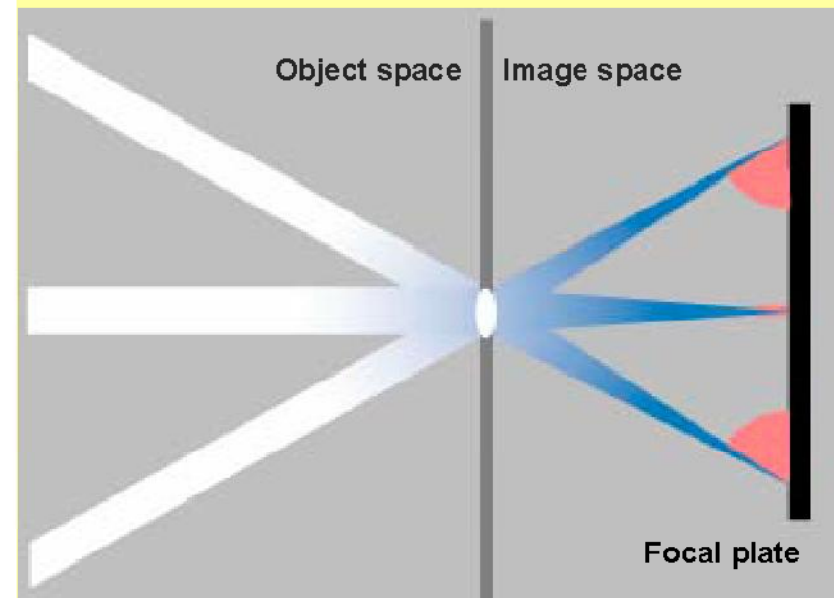
Vertical incidence of all ray bundles



Interference filter and Trichroid can be used.

Conventional optics design

Vertical incidence only for ray bundle on the optical axis



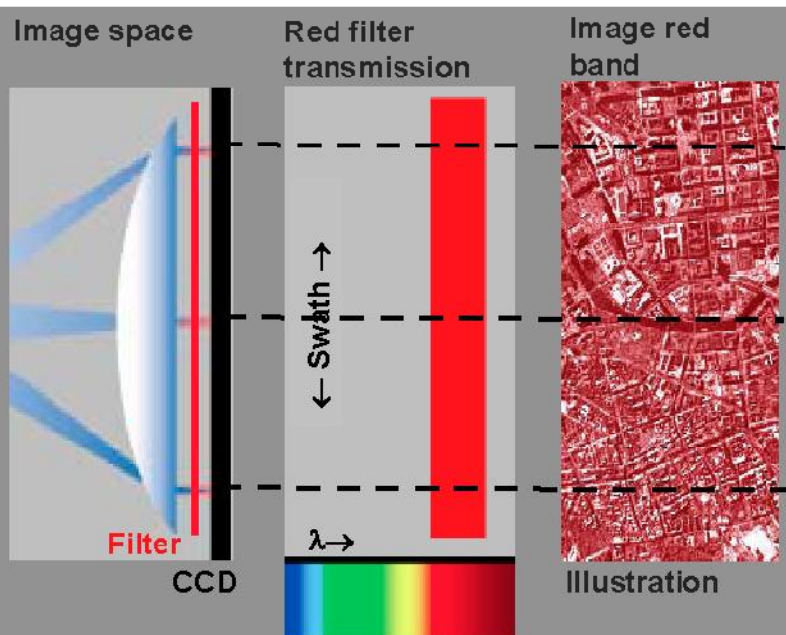
Absorption filters must be used.
NOT suitable for remote sensing.



Spectral transmission of interference filters

Telecentric optics design ADS40

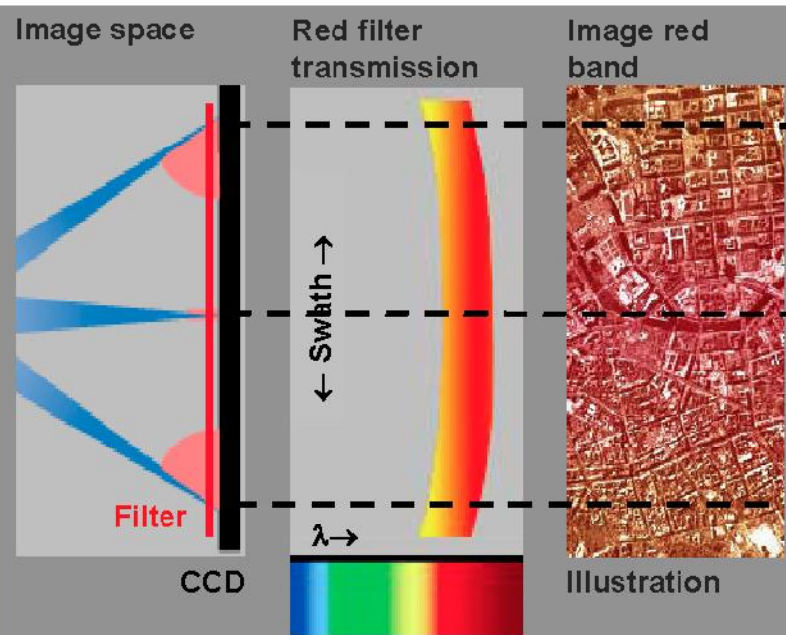
Interference filter transmission equal across whole FoV



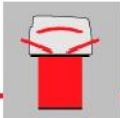
Suitable for remote sensing

Conventional optics design

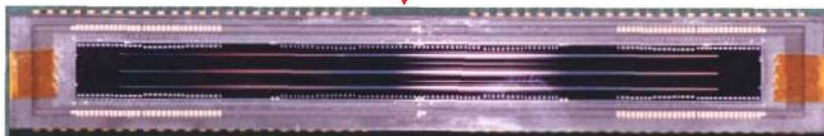
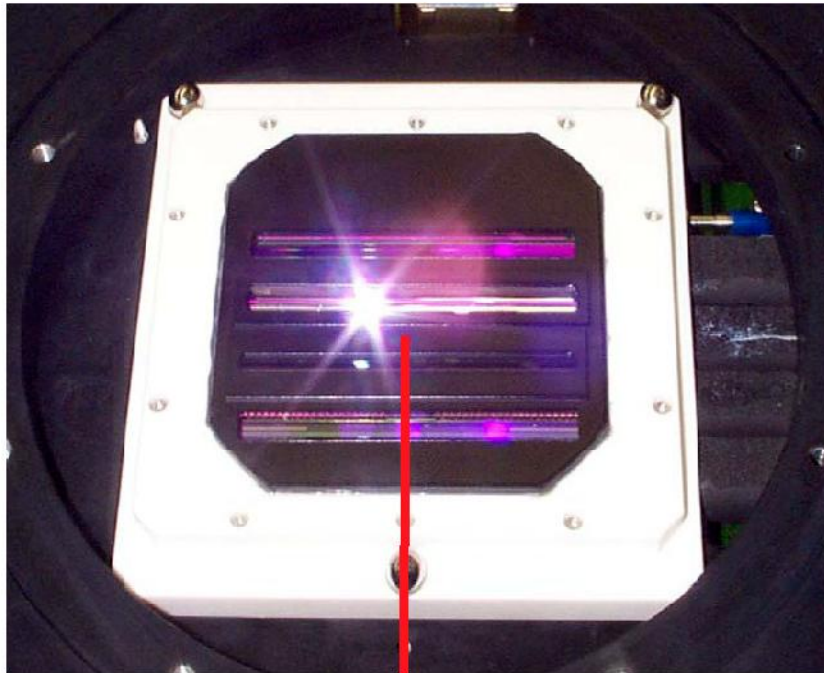
Interference filter transmission not equal for whole FoV



Not suitable for remote sensing



Temperature controlled focal plate



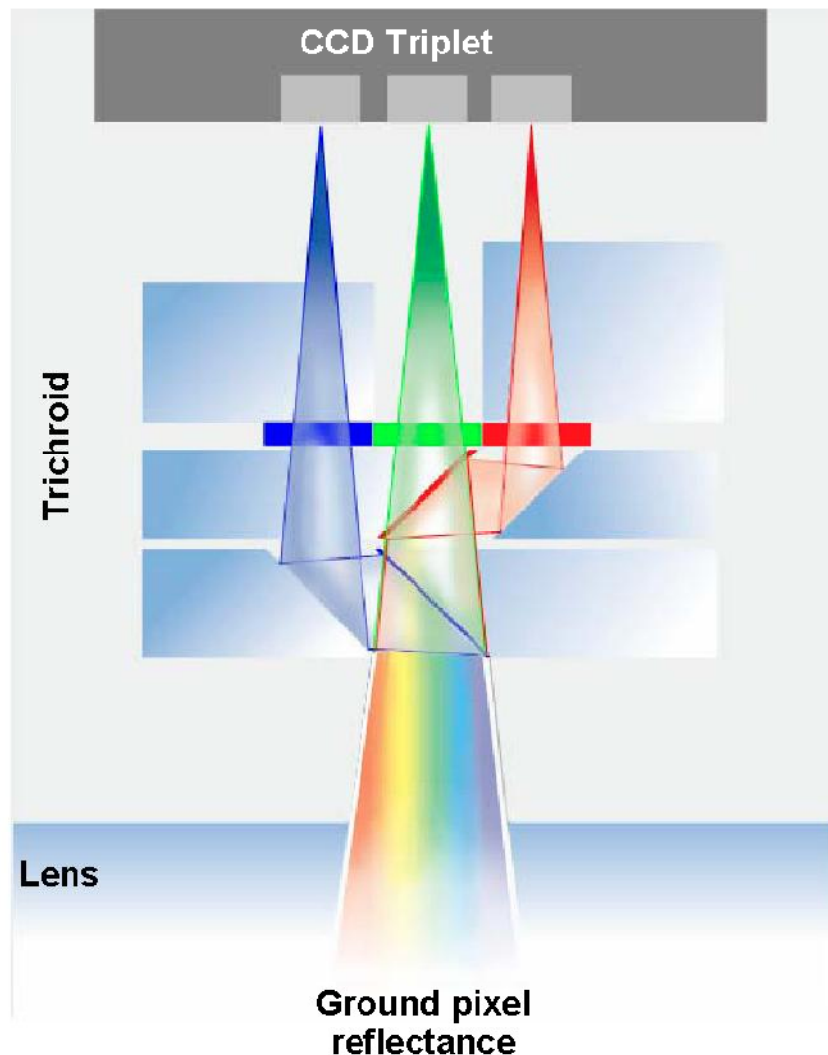
Triple CCD device

Focal plate

- The “heart” of the ADS40
- 2 single and 2 triple CCD devices with 7 channels
- 3 panchromatic channels , each with 2 x 12K elements in a staggered arrangement
- 4 multispectral channels, R,G,B,NIR each with 12K elements
- Peltier cooling system



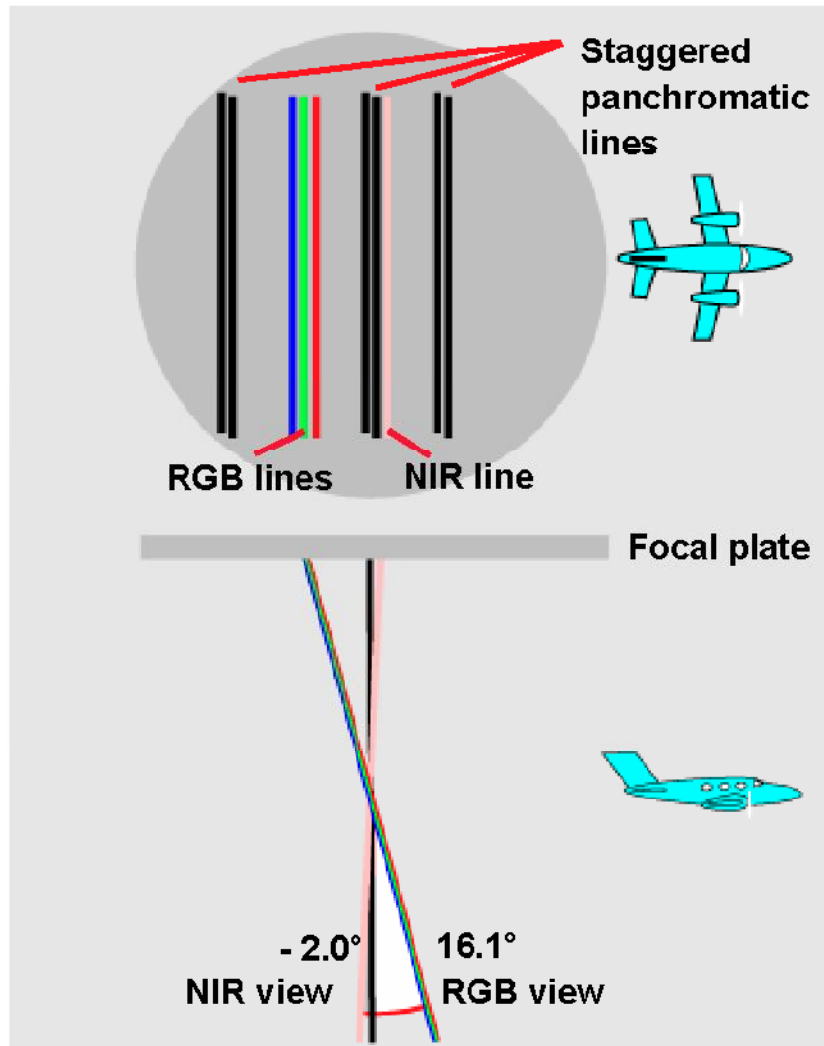
Trichroid



- Optical RGB pixel co- registration device
- Cascaded dichroitic beam splitters
- Energy conservation due to spectral light splitting
- Metal interference filters
- Between optics and CCDs

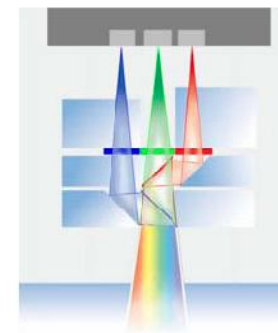


Incidence angles of spectral channels



Features

- All RGB channels with same incidence angle due to co-registration by Trichroid



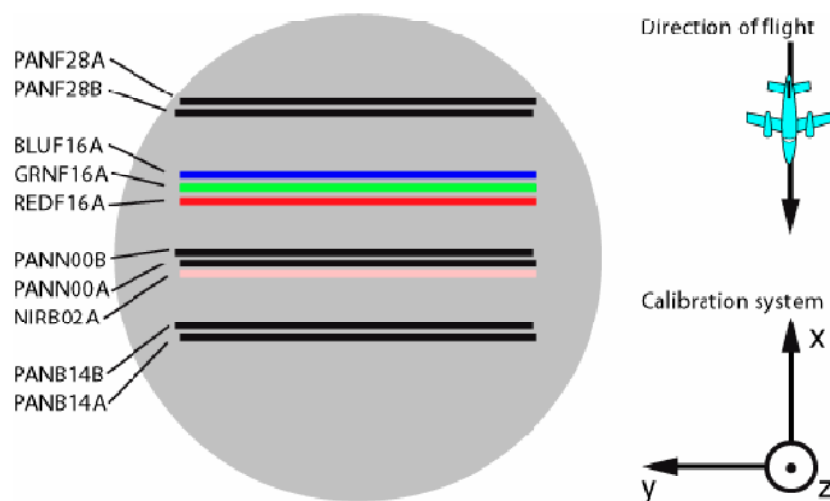
Trichroid

- NIR channel close to nadir



ADS40 focal plates

Standard FPM

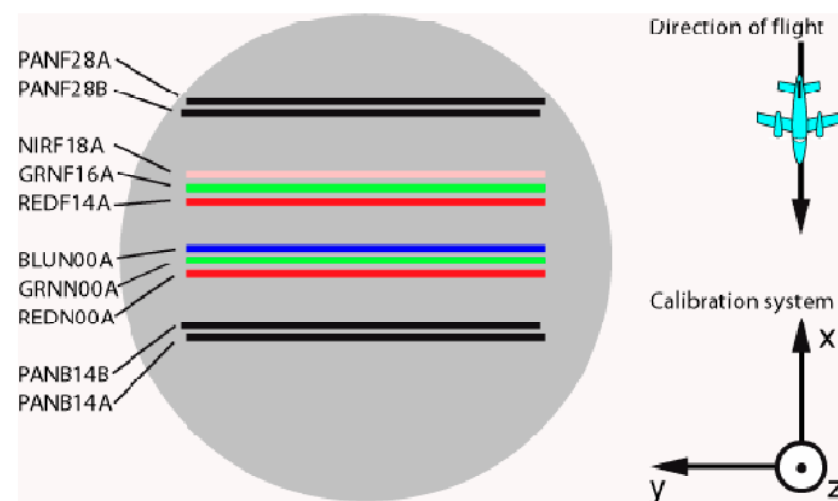


Staggered panchromatic line in Nadir

Excellent digital surface models

Original configuration - still available

New RGB-Nadir / RGN16



Panchromatic Nadir line is substituted by Green line

RGB in Nadir is perfect for true orthos

Co-registered false color bands

POS and IPAS



- **Applanix POS or Leica IPAS**
- **IMU integrated into Sensor Head SH40**
- **GPS integrated in CU40**
- **High short term IMU attitude accuracy, $\sigma < 4''$ after linear correction**
- **200 Hz IMU readout frequency**

IPAS - Inertial Position and Attitude System

IPAS completes Leica's data acquisition solution

- **IPAS10 stack for ADS40**
- **IPAS10 standalone system for ALS50**
- **LN-200 or uIRS Inertial Measurement Unit**
- **Real-time software**
- **IPAS Controller software**
- **IPAS Pro – post processing software**



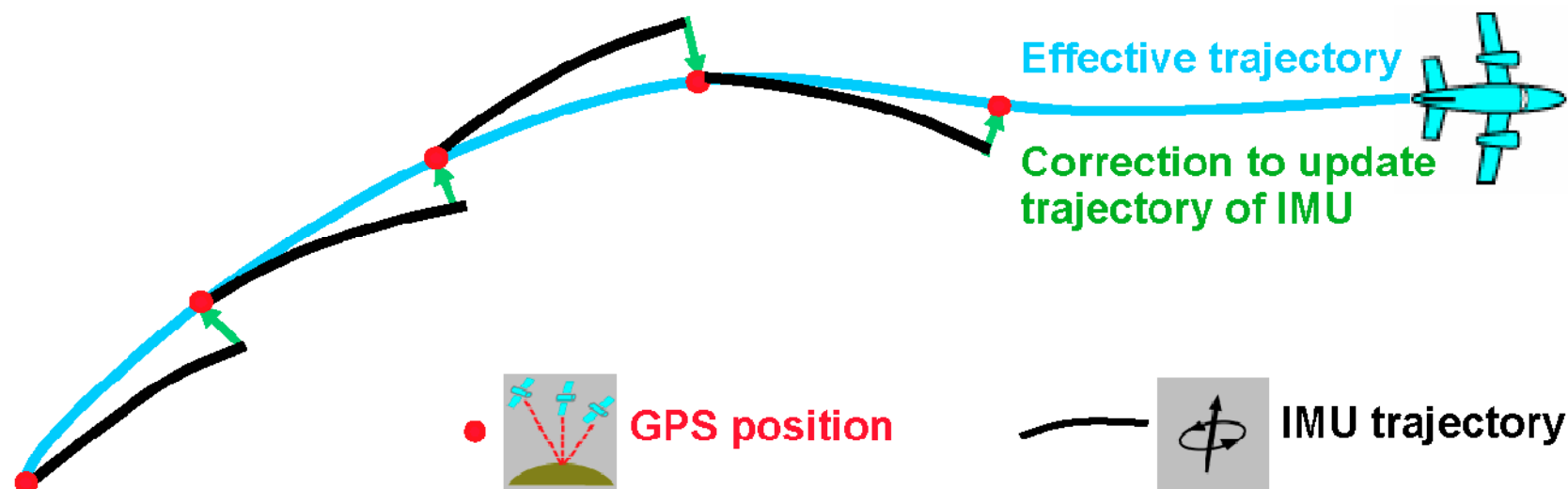
IMU/GPS System for ADS40 - the principle

The GPS sensor generates an absolute position at 2 Hz

The IMU sensor generates a relative position and a precise orientation of pitch, roll and drift at 200 Hz

Trajectory given by IMU is updated with absolute position given by GPS.

The post-processed trajectory is then interpolated to generate position & orientation at 800 Hz (1.2 ms interval)





Control Unit CU40



- Fiber optic link to SH40
- Integrated POS or IPAS
- Integrated GPS receiver
- High data throughput to MM40 up to 50 MB/sec
- Embedded Microsoft Windows Operating System
- Real-time extensions



Mass Memory MM40



- Disk array 580 GB
- Exchangeable between flight lines
- Portable, 20 kg
- Pressurized, 25,000 ft
- Temperature control
- Shock mounted

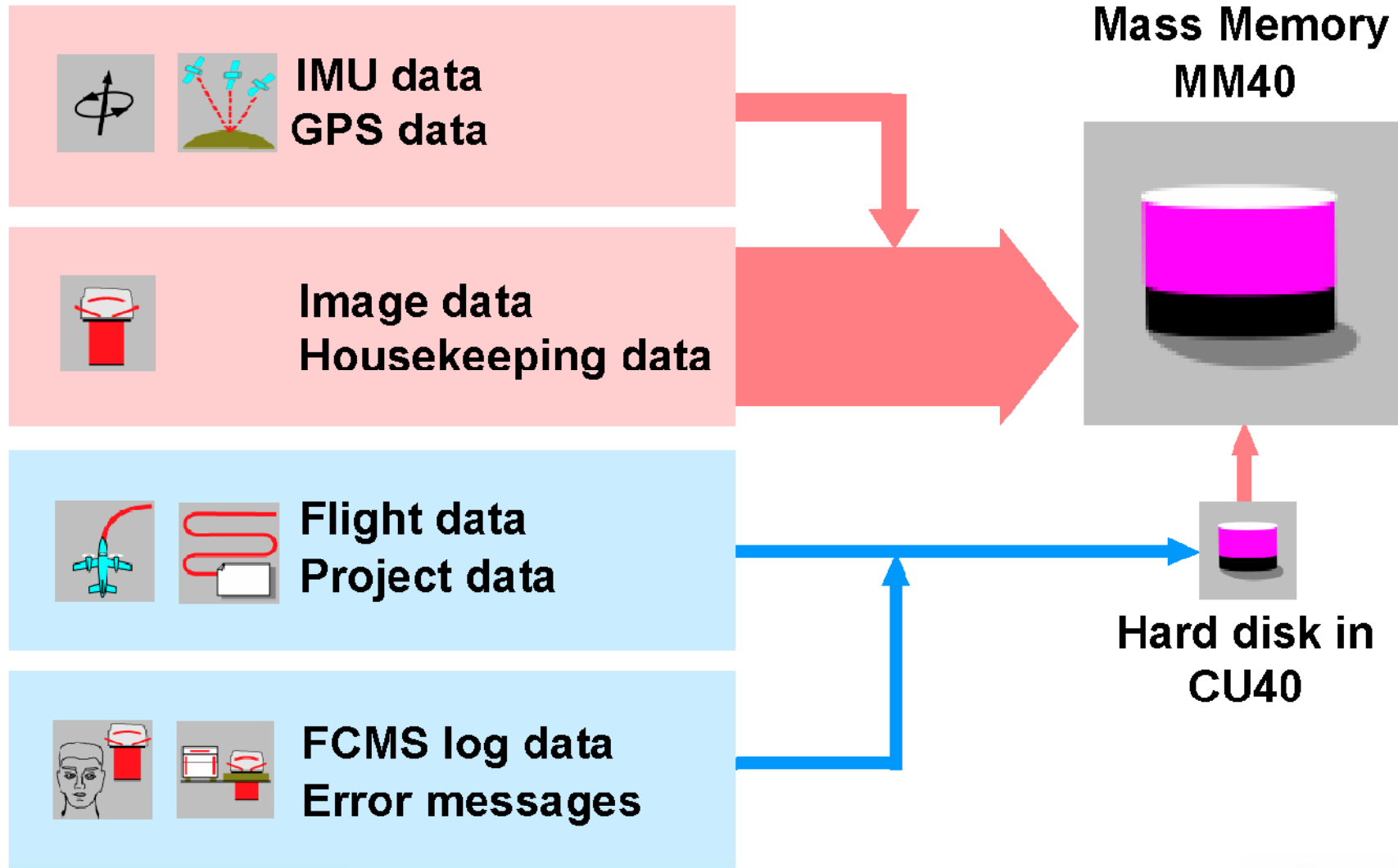
Area coverage on MM40 with capacity of 580 GB

| Configur- ation | GSD cm | GSD ft | Area km² | Area mi² |
|----------------------------|-------------------|-------------------|--------------------------------|--------------------------------|
| 3 Pan 4 MS | 15 | 1/2 | 3'635 | 1'400 |
| | 20 | 2/3 | 6'445 | 2'485 |
| | 30 | 1 | 14'430 | 5'570 |
| | 50 | 1 1/2 | 39'655 | 15'310 |
| 3 Pan | 15 | 1/2 | 8'395 | 3'240 |
| | 20 | 2/3 | 14'830 | 5'725 |
| | 30 | 1 | 32'955 | 12'720 |
| | 50 | 1 1/2 | 89'350 | 34'495 |
| 1 Pan 3 MS | 15 | 1/2 | 6'325 | 2'440 |
| | 20 | 2/3 | 11'190 | 4'320 |
| | 30 | 1 | 24'950 | 9'630 |
| | 50 | 1 1/2 | 68'035 | 26'265 |

Square area flown with 15% side lap, ADS Data format compressed by 1.25 x



Data storage in ADS system



Download hardware setup

DA45 Download Adapter



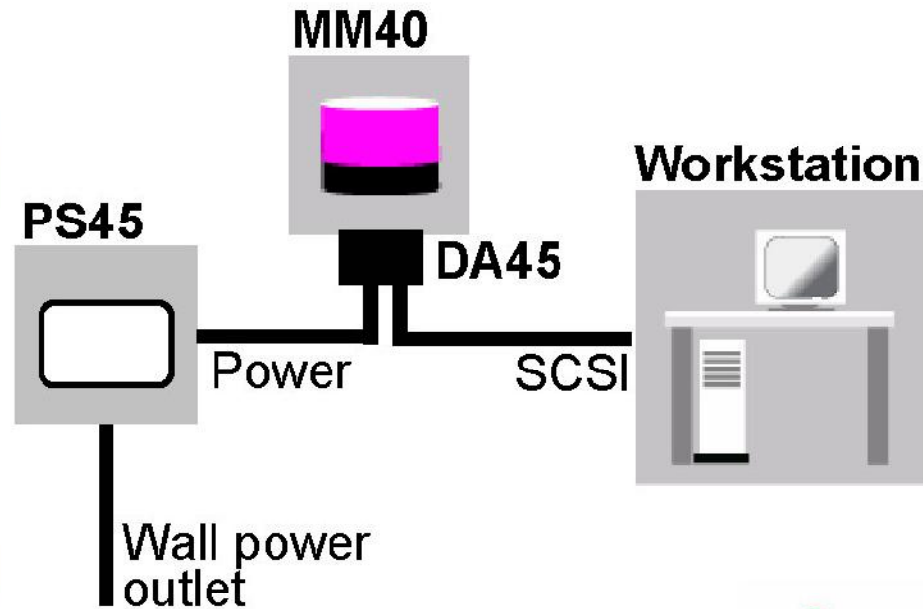
DA45 connection to MM40



PS45 Power Supply



Data download





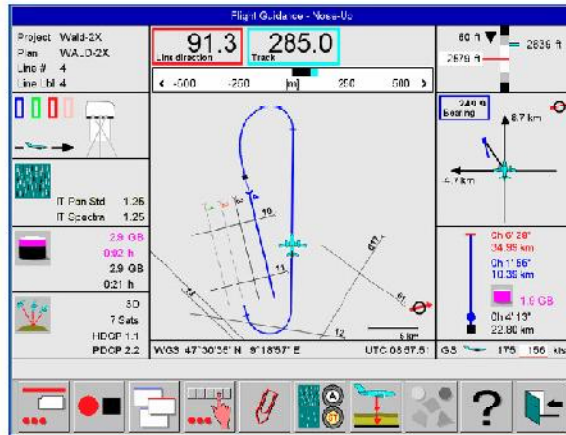
Operator Interface - OI40



- High contrast, LCD color, pressure sensitive touch screen
- 1024 x 768 pixels
- Ergonomic positioning
- Shock absorbing suspension
- Removable
- OI40 mounts onto Interface stand IS40
- Stand fits into PAS12 mounting holes

FCMS v2.0 replaces Leica ASCOT system

FCMS
v2.0



OC50

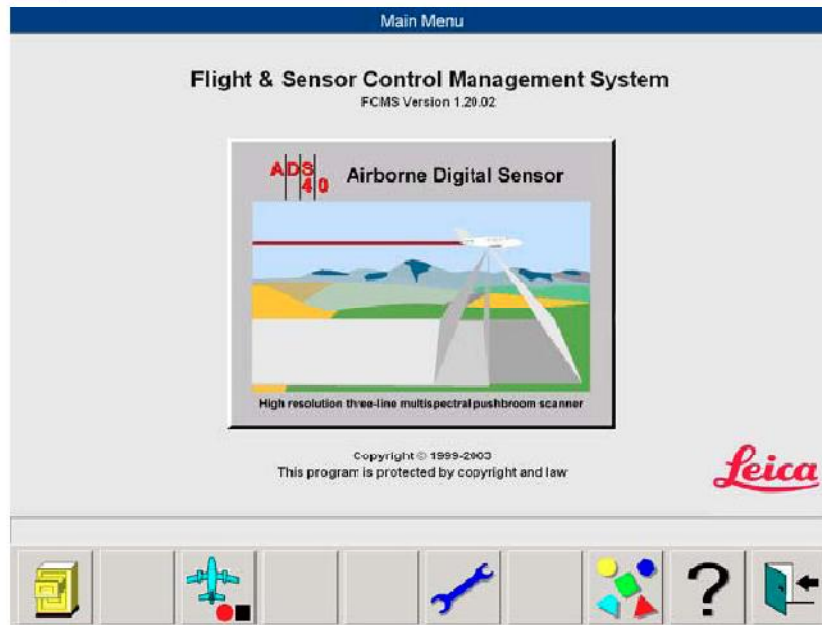


GI40

- FCMS) v2.0 replaces ASCOT
- Flight plan made with FPES can be ingested directly by FCMS v2.0
- Survey flight executed directly from Operator Interface OI40
- Two new flight guidance displays available for pilot – GI40 and/or OC50



FCMS

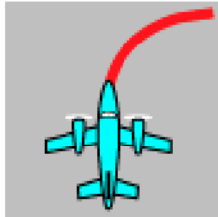


Flight & Sensor Control Management System

- Flight guidance
- Sensor control
- System management
- Graphical user interface
- Online help system
- Self diagnostics

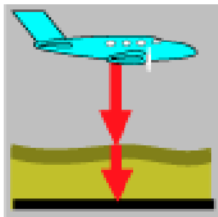


Graphical user interface



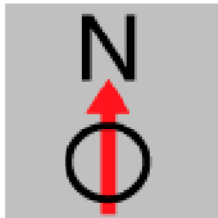
- **Figurative language on large buttons**

- **Simple touch screen interface**

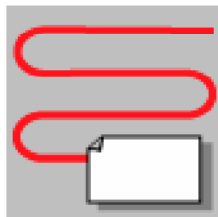


- **Pre-defined system configurations**

- **Quick navigation within the menu-tree**



- **System fully configurable for different users**



- **Easy to learn operation**

- **Integrated tutorial**



FCMS - ADS40 system status

Sensor Status

| | | | | | |
|-------|----------------------------------|---|---|--------------|--|
| ADS40 | | | | | |
| | 0 GB 0:00 h 0 GB 0:00 h | | N/A 0 Sats 0.0 0.0 | | |
| | 0.00 GB 0:00 h | 15 Jan 05, 1989 11 : 40 : 00 AM | User Defined Correction +1.5 High Compression Std | | |
| | | | | | |

capture --- reference --- measure --- analyze --- present
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FCMS - Sensor Head spectral channel status

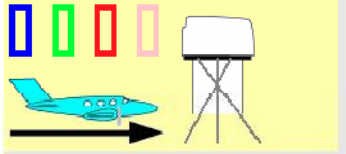
Sensor Head Configuration: Std-All-2.5

| Pan | Spectral | Swath Pan | Swath Spectral |
|------------------|---|---|------------------------------|
| | | | |
| ON/OFF | <input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/> | Height, Altitude and GSD Configuration set: 20cm GSD | |
| GSD | 20 cm | Flying height: 6'299 ft / 1'920 m | Altitude: 7'612 ft / 2'320 m |
| Integration Time | 2.50 ms | GSD: Std 20, High 10 cm | Terrain height: 400 m |
| | | Target speed over ground: 155 kts | |



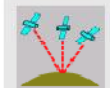



FCMS - Video View

Video View



Standard



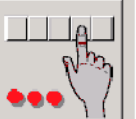

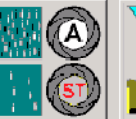
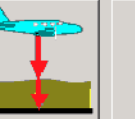

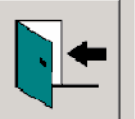
 **313 GB**
725 GB
0:00 h
 9°37'13" N
47°24'32" E
471 m
 3D
8 Sats
HDOP 1.9
PDOP 3.4



▲ 6'066 ft 7'612 ft
✈ 1'546 ft

Project 20030508104022_
Plan UNNAMED_PLAN
Line # 0
Line Lbl

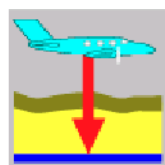
➡ SOG 0 kts

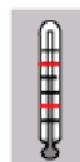
capture --- reference --- measure --- analyze --- present
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Characteristics of the ADS40



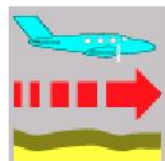
Non pressurized
Up to 25,000 ft
7,620 m



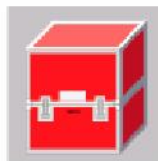
+55°C
-20°C



25,000ft
Non pressurized
aircraft



GSD 3" / 7.5 cm: < 120 kn
GSD 1/2 ft / 15 cm: < 240 kn
GSD 1 ft / 30 cm: < 480 kn
GSD 2 ft / 60 cm: < 970 kn



+70°C
-40°C
+85°C
-40°C



95% rH
0% rH
According ISO 7137



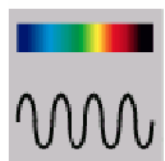
Data channel 16 Bit
Resolution A/D converter 14 Bit
Dynamic range of CCD 12 Bit



Total
224 kg



2x20A or 1x33A
< 750W/28VDC



Radiometric resolution
of compressed data 8 Bit,
adapted to signal level
Recording interval > 1.2ms



ISO 7137
RTCA DO-160D
FCC Part 15



EN 50082-2
EN 55022



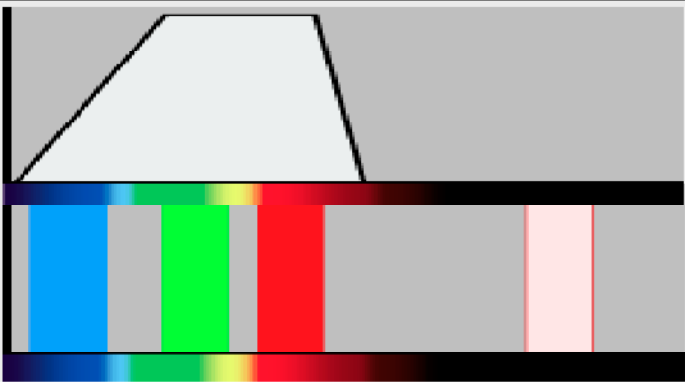
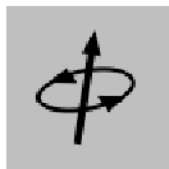
580 GB for up to 9h recording at
2.5 ms with 3 pan and 4 spectral
Data modes: raw data, compressed
Data compression: 1.5x - 25x



FAR § 25.561

Characteristics of the ADS40

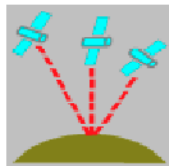
| Bands | | at $\lambda=50\%$ | |
|---------------------------|-------|-------------------|--|
| Panchromatic, trapezoidal | | 465 nm - 680 nm | |
| Spectral, rectangular | Blue | 430 nm - 490 nm | |
| | Green | 535 nm - 585 nm | |
| | Red | 610 nm - 660 nm | |
| | NIR | 835 nm - 885 nm | |

Inertial measurement system from APPLANIX

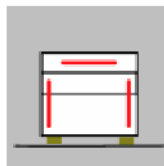


Sensor head SH40
Fits PAV30 mount



IMU integrated in SH40

GPS and POS integrated in CU40

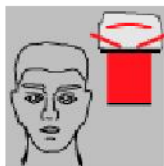


Control Unit CU40

Shock mounted stand alone or 19" rack mountable



Forward Motion Compensation (FMC or TDI)
Inherent in ADS40 due to pushbroom scanning principle



Operator Interface OI40

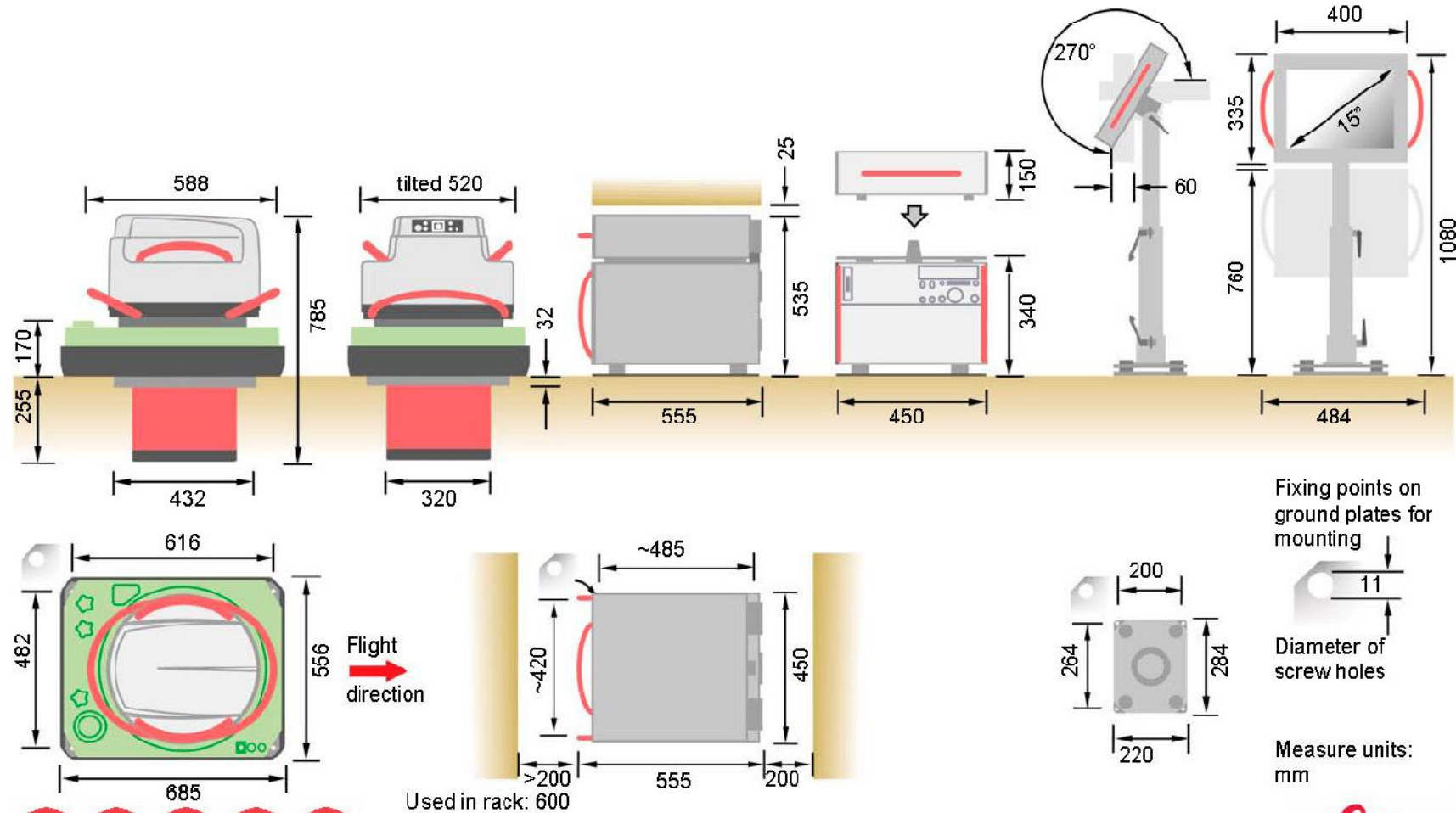
IS40 collocates in RC30 Nav-sight installation location

Dimensions of ADS40 system components

Sensor head SH40
Gyro-stabilized mount PAV30

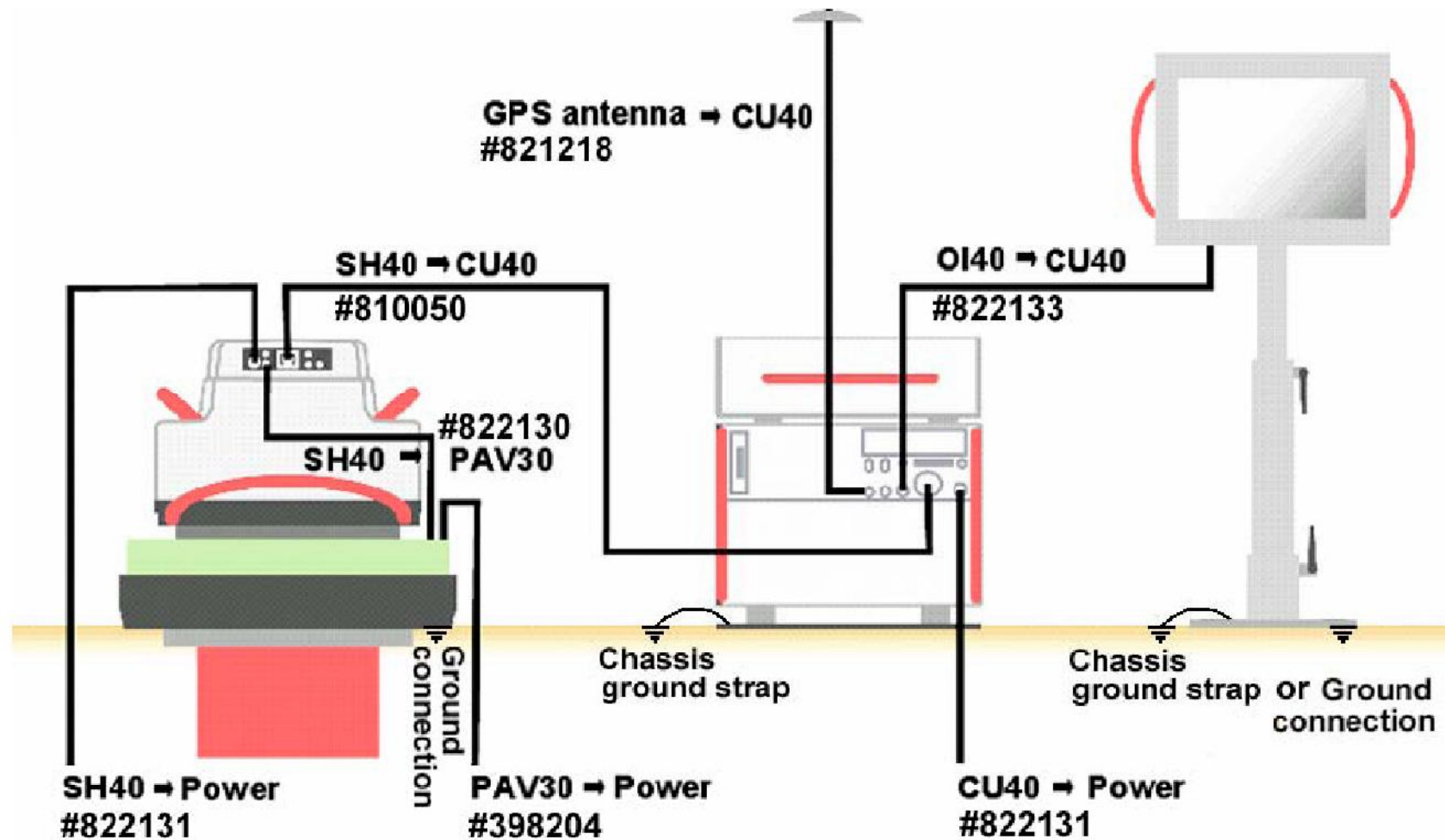
Control unit CU40
Mass memory MM40

Operator interface OI40
Interface stand IS40



capture reference measure analyze present
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Cabling of airborne system components of ADS40





Leica Geosystems GIS & Mapping

Advantages of Pushbroom Principle



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Benefits of the ADS40 features

- **Three sensors in one: black and white, color and false color images**
- **Wide area coverage for savings in flight lines and flying time**
- **Common lens and focal plate, combined with uniform sensor model, simplifies co-registration of multispectral information**
- **Perfect RGB co-registration through unique Trichroid device**
- **High quality DTMs derived from three-line stereo sensor data**
- **Reduced ground control due to tight integration of focal plate, IMU and GPS and the complete absence of film errors**
- **End-to-end digital flow line; no more photographic processing or scanning**

Advantages of ADS40 pushbroom concept

| Leica ADS40 | Large format frame sensors |
|--|---|
| Continuous pixel carpets of 100% overlapping Pan & RGBN image strips | Large format is a patchwork made from 4 or 9 small frames and mosaiked to form strips |
| Best base/height (b/h) ratio in the industry for good height accuracy | Reduced image size in flight direction results in worst b/h ratio |
| All images captured through only one calibrated high performance lens | Images taken with eight different lens cones of different focal length |
| 100% error free CCDs | Surface array CCDs have defective pixels. Pixel extrapolation is required |
| No shutters in lens – no mechanical service parts in the whole system | Eight shutters require service and have limited life |
| FMC inherent in pushbroom principle | Requires FMC or TDI |
| Proven components of airborne acquisition technology incl. GPS and IMU are all integrated for ease of use | Not all of today's proven components are integrated or are supplied from a single source |

Advantages of ADS40 pixel carpets

| Leica ADS40 | Large format frame sensors |
|---|--|
| Pixel carpets as long as the flight line. Only seven , three panchromatic and four spectral, pixel carpets per flight line to manage | Large number of panchromatic and spectral images to cover a flight line. Additional effort required to manage all this individual data |
| No spectral distortion because pan-sharpening process is not required | High spectral distortion because during pan-sharpening process up to 22 pan pixels are colorized by the information of one color pixel. |
| Narrow band filters extend flying hours and give outstanding color images suitable for Photogrammetry and Remote Sensing | Pan-sharpened color image from overlapping spectral bands. Not suitable for Remote Sensing |
| GSD of spectral data is equal in area to the high resolution panchromatic GSD | Spectral data are recorded at an area resolution of 9 to 22 times worse than the panchromatic data |

Superior ADS40 image data quality

| Leica ADS40 | Large format frame sensors |
|---|--|
| <p>Compact sensor with a single lens. Optimized for the characteristics of the CCDs. <i>Built with components specially designed for the airborne environment.</i> The high signal-noise ratio gives perfect image data.</p> | <p><i>Built with off-the-shelf components</i> which are originally designed for applications with lower performance than required for an airborne imaging sensor.</p> |
| <p>A line sensor like the ADS40 does not use the whole image area of the lens cone. Only image data from the <i>part of the lens with best resolution</i> is taken for the pixel carpets.</p> | <p>Frame sensors make use of the whole image area of a lens cone. In most lenses the <i>four corner areas have a much lower image quality.</i></p> |
| <p>Non-overlapping narrow-band filters result in <i>well separated color images where haze penetration is much better than with traditional film like separation.</i></p> | <p>Overlapping color filters, which are similar to the separation of a traditional color film, <i>do not result in color images that take full advantage of the digital approach.</i></p> |