IEEE

DIGEST

VOLUME II

REMOTE SENSING: EXTENDING MAN'S HORIZON

1983 INTERNATIONAL GEOSCIENCE AND
REMOTE SENSING SYMPOSIUM (IGARSS '83)

August 31 - September 2, 1983
San Francisco, California

IEEE Catalog No. 83CH1837 - 4

FUTURE IMAGING SENSOR CAPABILITIES

K. R. Carver
Box 3449
New Mexico State University
Las Cruces, NM 88003

K. J. Ando
Code EL-4
NASA Headquarters
Washington, DC 20546

Abstract

Imaging sensor technologies being developed for future NASA earth observations missions include the multi-linear array (MLA), the shuttle imaging spectrometer (SIS) and the shuttle imaging radar (SIR).

Keywords: SAR, SIR, MLA, imaging spectrometer

Introduction

Imaging sensors for future NASA earth observation missions will utilize advanced multi-linear array (MLA), imaging spectrometer, and synthetic aperture radar (SAR) designs which will exploit the synergism of the visible, infrared and microwave portions of the electromagnetic spectrum for remote sensing applications. This paper describes some of the imaging sensor technologies being developed by NASA for earth observations missions of the late '80's and early '90's. These next generation sensors will be the successors to MSS, RBV and TM imagers (Landsat 1-4) in the optical spectrum and to SEASAT, SIR-A, and SIR-B SAR imagers in the microwave spectrum.

Visible sensors (e.g. Landsat MSS) are primarily sensitive to surface chemistry, infrared sensors (e.g., AVHRR) to surface temperature, and microwave sensors (e.g., SIR-A) to surface geometry. The synergism inherent in the merger of optical/microwave images (e.g., TM and SAR) is thus a result of differing sensitivities in surface physical properties in these widely separated parts of the electromagnetic spectrum. For these merged image data sets to be most meaningful, each should have approximately the same resolution, generally from 10 - 30 m. For mapping mode applications, a wide swath is desired, typically greater than 150 km; however, for many research purposes, swath widths in the 10-50 km range are adequate. Finally, for remote sensing of such time-varying phenomena as vegetation, soil moisture, oceanic winds, etc., it is highly desirable that both optical and microwave data be acquired simultaneously.

This poses challenging instrument and mission design problems such as how to deal with high power consumption, very high data rates, the need for advanced digital processing techniques, coregistration, calibration, etc. Although this paper does not specifically address these issues, it does present a description of the next generation of microwave and optical imaging sensor designs which can be used in future multi-sensor earth observation missions.

In the next several years, the Shuttle will be used as a platform for many of NASA's remote sensing experiments and for the testing of new imaging sensor technologies. These will include the Shuttle Imaging Spectrometer (SIS) and the Shuttle Imaging Radar (SIR) series, and will be flown at orbital altitudes from 250-350 km with inclinations from 57° to polar. These missions will allow the determination of optimum wavelength bands, look angles, and polarizations for a variety of scientific and applications purposes Free-flyer imaging sensor missions will begin in the late '80's or early 90's and will include the multi-linear array (MLA) and free-flying imaging radar experiment concepts.

Optical Remote Sensing Systems

Land remote sensing in the optical spectrum has matured considerably since the launch of Landsat-1 in 1972. Data from the Landsat satellites are used on a routine basis for monitoring and characterizing the earth's surface cover. A large user and research community has developed throughout the world for Landsat data fostered, in part, by the widespread availability of Landsat data at modest cost on a non-discriminatory basis. Research and analysis during this period led not only to a development of a wide range of applications but also to the requirements for a more advanced sensor and a pressing need for a higher throughput ground data processing system for a more timely data access. These requirements led to the initiation of the development of the Thematic Mapper (TM) in the mid-1970's culminating in its successful experimental operation on Landsat-4 in 1982. The late 1980's and early 1990's will see the deployment of other quasi-operational advanced land remote sensing systems including the French SPOT system, ESA's ERS-1, and Japan's MOS-1 system.

NASA's optical remote sensing R&D program is currently focused on developing an advanced sensor technology and research base not only to support the development of a potential successor to the Landsat series but also to improve our observational capabilities and understanding of the earth's physical and chemical features. Results from the Space Shuttle borne Shutte Multispectral Infrared Radiometer (SMIRR) experiment, TM, and airborne sensors have demonstrated that the visible, shortwave infrared and thermal spectral regions still contain significant information of utility for remote sensing. In particular, recent airborne spectrometer and the SMIRR results have shown that direct identification of mineral types, improved vegetation stress determination and classification can be obtained from high spectral resolution data in this spectral domain.

MLA Imaging Sensors

To address our future needs, advanced instrument concepts for Shuttle, free flyer and potential platform missions are currently under study. One such new instrument concept which has evolved from these studies is the Multispectral Linear Array (MLA) sensor. The MLA design characteristics are summarized in Table 1. The MLA instrument concept provides a significant improvement in performance over the TM particularly in the area of higher spatial/radiometric sensitivity and versatility and is representative of the solid-state pushbroom sensors which will supplant the mechanically scanned sensors, such as the TM, in the late 1980's. The high density SWIR linear arrays are the most challenging technology for the implementation of the MLA instrument. In recognition of this need, NASA is currently funding several development efforts to design, fabricate and

TABLE I. MLA INSTRUMENT SPECIFICATIONS

- Orbits: 283 through 705 km
- Spatial Coverage: 185 km cross-track [at 705 km altitude]
- Spectral Coverage: 0.45 through 12.5 μm [same as TM]
- Spectral Resolution:
  7 bands: 3 visible
  1 near infrared — Same as TM
  2 short-wave infrared
  1 thermal infrared
- Spatial Resolution (IFOV):
  4 - 6m bands 1 through 6 [283 km Orbit]
  32 - 48 m band 7
  10 - 15m bands 1 through 6 [705 km Orbit]
  80 - 120m band 7
- Radiometric Resolution:
  0.5% NEΔρ Bands 1 through 4
  1% NEΔρ Bands 5, 6
  0.5°C NEΔT Band 7
- Imaging Modes:
  Nadir view
  Cross-track 0 through ± 30°
  Fore-aft stereo ± 26°
- Quantization Levels: 256 or 1024 [Selectable 8 or 10 bit encoding]
- Uncompressed Data Rate:
  260 mbps [15m IFOV, 10 bits, 705 km]
  570 mbps [6m IFOV, 8 bits, 283 km]

  Data rate varies with orbit altitude, quantization accuracy and data-compression ratio.
- On-Board Signal Processing:
  Data compression, radiometric correction

test prototype SWIR focal plane arrays for the MLA instrument. Prototype arrays will become available in the next few years from these development efforts with their first use being a series of Shuttle MLA experiments planned in the late 1980's.

Imaging Spectrometers

A second concept currently under development which will find many applications in the 1990's is the imaging spectrometer concept. The imaging spectrometer concept is an extension of the basic pushbroom approach and utilizes two-dimensional area arrays. Each line of data is spectrally dispersed by a spectrometer section and then read out through a two-dimensional focal plane array. The imaging spectrometer approach offers a number of significant advantages over the linear array pushbroom approach including higher spectral resolution, inherent spectral registration and spectral selectability through editing and summing on the focal plane prior to readout. Imaging spectrometer instruments will provide the order of magnitude increase in spectral specificity and coverage needed to enhance the capability to differentiate and identify specific mineral and vegetation classes on the earth's surface on the basis of their subtle spectral signatures.

The imaging spectrometer will first be developed as a Shuttle instrument for flight in the late 1980's. A conceptual design of this instrument, the Shuttle Imaging Spectrometer-A (SIS-A), has been completed. Table II summarizes the design characteristics of SIS-A. This design was developed as a basic instrument which incorporated the major technology elements and retained the intrinsic performance of this concept but dispensed with the wide swath width coverage and on-board data processing to reduce complexity and cost. The key long-lead technology elements for the SIS-A are currently under development including the 64x64 element SWIR hybrid HgCdTe arrays, cooler and optics design, and advanced data processing techniques for high-dimensional image data. Supporting the SIS-A effort is the experimental flights of the airborne imaging spectrometer (AIS). Recent AIS flights have successfully tested the SIS-A concept and acquired the first high dimensionality SWIR spectral data for the research community.

TABLE II. SIS-A FUNCTIONAL DESCRIPTION

• IFOV	30 m
• SWATH	11.52 km
• COVERAGE WITH STEERABLE MIRROR	250 km
• SPECTRAL SAMPLE INTERVAL:	
- VIS/NIR	10 nm
- SWIR	20 nm
• SPECTRAL RANGE	0.4 - 2.5 m
• RAW DATA RATE (8 BITS)	98.4 mbps
• OPTICS	
- Focal Length	41.6 cm
- Effective Aperture	11 cm
- Focal Ratio	F/3.8
• FOCAL PLANE	
- Format	128 Spectral 384 Spatial
- VIS/NIR	Silicon CCD
- SWIR	HgCdTe/CCD Multiplexer module
• SPACELAB PALLET MOUNTED	
• MECHANICAL COOLER - 120 K, 1 WATT	
• STEERABLE POINTING MIRROR ± 30° CROSS TRACK	
• SIZE	1.3 m x 0.7 m x 0.6 m
• WEIGHT	180 - 230 kg
• POWER	150 W Electronics 200 W Focal Plane Cooling

A second design which evolved from the design studies is the higher performance SIS-B concept. SIS-B is characterized by a larger swath width, smaller footprint, larger aperture and longer focal length in comparison to SIS-A. The design and the triple-Schmidt Litrow prisms optical configuration are summarized in Table III and Figure 1, respectively. The SIS-B concept is representative of a possible first-generation free flier or space platform system for the 1990's. The technology requirements for the implementation of SIS-B are formidable challenges, particularly in the areas of optical fabrication and alignment, focal plane and data processing.

TABLE III. SIS-B FUNCTIONAL DESCRIPTION

• IFOV*	VIS 10 m SWIR 20 m
• SWATH*	61.44 km
• SPECTRAL SAMPLE INTERVAL	20 nm
• SPECTRAL RANGE	0.4 - 2.5 μm
• RAW DATA RATE (UNEDITED)	> 100 mbps
• OPTICS	
- Focal Length	1.6 m
- Effective Aperture	30 cm
- Focal Ratio	F/5.33
- Field of View	15°
• FOCAL PLANE	
- Format	128 spectral 6144 spatial
- Pixel Size	40 x 40 μm
- VIS/NIR	96 butted 64 x 64 silicon CCDS
- SWIR	96 butted 64 x 64 HgCdTe/CCD multiplexer modules
• SIZE	2.5 m x 2.0 m x .5 m
• WEIGHT	> 300 kg
• POWER	> 600 W

*At a design altitude of 400 km

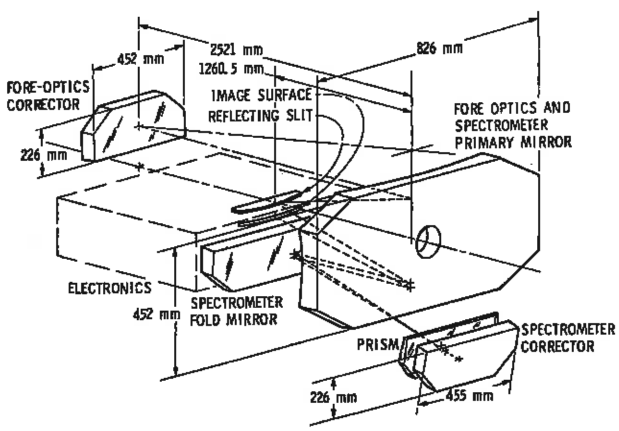

Fig. 1. SIS-B optical sensor configuration

Radar Remote Sensing Systems

Spaceborne imaging radar remote sensing of the earth began on June 26, 1978 with the launch of Seasat into a 108° inclination orbit at an altitude of 786 km. During the 100-day lifetime of Seasat, its L-Band SAR collected 42 hours of data equivalent to 100 million square kilometers area coverage of the earth. Seasat used a 20° look angle, provided images with a swath width of 100 km, and had a resolution of 25 m. Nearly all of the Seasat data were optically processed and certain scenes were also digitally processed at JPL and elsewhere.

The Shuttle Imaging Radar-A (SIR-A) was the next imaging radar experiment and was the major payload on the OSTA-1 experiment pallet carried by the second Space Shuttle (STS-2), launched on November 12, 1981 into a circular orbit at a 38° inclination and 260 km altitude. During its brief 2-day mission, the L-Band HH-polarized SIR-A optically recorded nearly eight hours of data, equivalent to 10 million square kilometers areal coverage. SIR-A images had a swath width of 50 km, a resolution of 40 m (6 looks), and used a 47° look angle. All of the SIR-A data were optically processed at JPL.

The hardware of a synthetic aperture radar consists of a transmitter, modulator, receiver, antenna, timing system, and an image correlator. Seasat and its derivative, SIR-A, used a solid-state transmitter with 1 kw peak power, an FM (chirped) pulse modulator, and a microstrip array antenna. The Seasat antenna consisted of eight microstrip honeycomb panels which were mechanically deployed into a single flat 10.74 m x 2.16 m array after launch. The Seasat bandwidth was 19 MHZ. The SIR-A antenna (9.4 m x 2.16 m) used the same microstrip honeycomb panel design as Seasat and consisted of seven panels mounted on a strongback truss attached to the OSTA-1 pallet. SIR-A used a 6 MHZ bandwidth, matching that of its optical recorder.

Both Seasat and SIR-A were fixed-parameter imaging radars, i.e. the frequency, polarization and incidence angle were constant.

SIR-B Mission

The next approved NASA imaging radar mission is SIR-B, scheduled for an August 1984 launch as part of the OSTA-3 experiment pallet (Fig. 2) for STS-17. The L-Band transmitter, modulator, receiver and antenna will be derived from Seasat and SIR-A. However, SIR-B will be digitized by an on-board ADC and tape recorded (HDDT) and/or relayed to ground via TDRSS for digital processing at JPL. In addition, the SIR-B antenna will be folded to a 4.4 m length for launch and landing, and during the mission will be mechanically tiltable to provide selectable incidence angles from 15° - 60°. SIR-B will provide for 25 hours of digital data recording. Due to the roughly 400:1 throughput ratio expected for the JPL digital image correlator, it will require about two years to digitally process the SIR-B images.

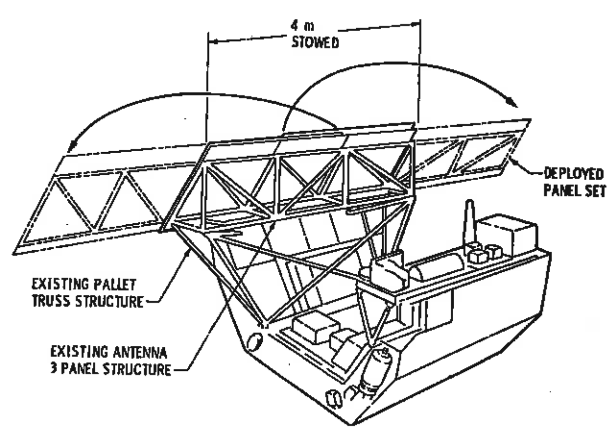

Fig. 2. SIR-B radar sensor configuration on OSTA-3 experiment pallet

SIR-B will be the first spaceborne imaging radar which can be used for systematic investigations of the dependence of radar backscatter on incidence angle. This, coupled with its digital image processing capability, will usher in a new era of quantitative radar image analysis for geoscientific research.

The mission and sensor characteristics for SIR-B are compared to SIR-A and SIR-C (see next section) in Tables IV and V.

SIR-C Mission

SIR-C is currently being planned by NASA and JPL as the next radar mission after SIR-B, and is envisioned as a dual-frequency (L-Band and C-Band) imaging sensor providing two simultaneous channels at selectable incidence angles. Multiple polarization (HH, VV, and HV) images would be available at either frequency. In order to minimize cost and complexity, the transmitter peak powers would be held to 1 kw (L-Band) and 2 kw (C-Band), as shown in Table V. This would limit the range of look angles for usable HV-polarized images to approximately 15° -30°.

SIR-C would be launched in 1987 as a part of the OSTA-7 mission, and would be the first space-based imaging radar to permit scientific research on the role of wavelength and polarization on radar backscatter. Its polar orbit, coupled with on-board high-density digital tape recorders would allow geoscientific studies of any selected zone of the earth's surface, including the polar regions.

The L-Band channel of SIR-C would reuse the SIR-B hardware and antenna support structure, except for the antenna panels. The SIR-C antenna would employ two 9-panel side-by-side arrays of dual-polarized microstrip elements, one array for L-Band and the other for C-Band. The L-Band generated chirped pulses would be up-converted to C-Band for transmission and received C-Band radar echoes would be down-converted to L-Band for reception; this would allow the re-use of the existing L-Band SIR-B STALO, modulator, and receiver designs at C-Band.

Video radar echoes would be digitized by a 32 M samples/sec A/D converter and recorded on two on-board HDDT's for later ground playback to JPL's Advanced Digital SAR Processor (ADSP) for real-time digital image processing.

Users would have a choice of two simultaneous channels with any two frequency-polarization characteristics, e.g. L(HH) + C(HH), or C(HH) + C(VV), or L(VV) + C(HV), etc.

SIR-C will be the first imaging radar to allow user selection of incidence angle, frequency, and polarization, and will allow advanced geoscientific remote sensing research in the microwave spectrum.

Free-Flying Imaging Sensor Missions

The research results obtained from the SIR and SIS shuttle missions will be very useful in designing free-flyer imaging sensor missions for the late '80's or

TABLE IV. SIR SERIES FUNCTIONAL DESCRIPTION

	SIR-A	SIR-B	SIR-C
• LAUNCH	Nov. 12, 1981	August 1984	March 1987
• EXPERIMENT PALLET	OSTA-1	OSTA-3	OSTA-7
• MISSION DURATION	2 days	7 days	7 days
• ORBITAL ALTITUDE	260 km	225 km	250 km
• ORBITAL INCLINATION	38°	57°	polar
• LOOK ANGLES	47° (fixed)	15° - 60°	15° - 60°
• FREQUENCIES	L-Band	L-Band	L-Band, C-Band
- Wavelengths	23.5 cm	23.5 cm	23.5 cm, 5.7 cm
• POLARIZATIONS	HH	HH	HH, VV, HV
• RESOLUTION			
- Range	40 m	50 m - 15 m	50 m - 15 m
- Azimuth	40 m (6 looks)	25 m (4 looks)	25 m (4 looks)
• SWATH WIDTH	50 km	50 - 20 km	120 - 35 km
• NOISE EQUIVALENT σ^o			
- (L-Band)	-32 dB	-25 dB (60°)	-23 dB (60°)
- (C-Band)	N/A	N/A	-18 dB (60°)
• IMAGE PROCESSING			
- Optical	8 hours	8 hours	N/A
- Digital	N/A	25 hours	25 hours
• RAW DATA RATE	N/A	46 Mbps	46 Mbps
• WEIGHT			
- Antenna	200 kg	324 kg	420 kg
- Sensor	198 kg	231 kg	408 kg
• POWER CONSUMPTION	785 W	865 W	2000 W

TABLE V. SIR SERIES: SENSOR DESCRIPTION

	SIR-A	SIR-B	SIR-C
• ANTENNA			
- Size	9.4 m x 2.16 m	10.7 m x 2.16 m	12 m x 2.16 m
- Launch deployment	single strongback truss, 7 panels	8 panels, 2 folded wings	9 panels, 2 folded wings
- Array size			
(L-Band)	9.4 m x 2.16 m	10.7 m x 2.16 m	12 m x 1.75 m
(C-Band)	N/A	N/A	12 m x 41 cm
- Array design			
(L-Band)	H-pol. microstrip	H-pol. microstrip	H+V-pol. microstrip
(C-Band)	N/A	N/A	H+V-pol. microstrip
• TRANSMITTER			
- Peak power	1 kw	1 kw	1 kw (L), 2 kw (C)
- Bandwidth	6 MHZ	12 MHZ	12 MHZ
- Amplifer type			
(L-Band)	solid-state	solid-state	solid-state
(C-Band)	N/A	N/A	TWT
• MODULATOR			
- Pulse width	30.4 μsec	30.4 μsec	30.4 μsec
- SAW modulation bandwidth	6 MHZ	12 MHZ	12 MHZ
- PRF	1464-1824 pps	1464-1824 pps	1200-1900 pps
• RECEIVER			
- L-Band Sensitivity	-103 dBm	-100 dBm	-100 dBm
- C-Band Sensitivity	N/A	N/A	-98 dBm (est.)
• DATA HANDLING SYSTEM			
(optical)	opt. tape rec.	opt. tape rec.	N/A
(digital)	N/A	DDHS/ADC	DDHS/ADC
No. bits	N/A	3-6 bits	3-6 bits
• DATA RATE	N/A	46 Mbps	46 Mbps

early '90's. The scientific rationale for a permanent polar-orbiting free-flyer SAR or MLA stems from the need for repeated coverage of such time-varying phenomena as (1) soil moisture diurnal, daily and seasonal variability, (2) crop canopy phenologic expressions, (3) seasonal behavior of regional geologic scenes with deciduous or mixed deciduous/coniferous forest cover, etc. Free-flyers are obviously expensive, thus requiring an intelligent choice of optimum radar sensor parameters. NASA is currently investigating several potential free-flyer multi-sensor concepts, some identified with the space station. Each of these envisions the inclusion of both MLA and SAR sensors.

Multi-Sensor Technology Challenges

Several key problems are posed by these future imaging sensor technologies, including (1) data rates, (2) power consumption, and (3) data processing.

Both the MLA and SAR sensors are inherently high data-rate devices; for example, the SIS-B generates a 100 Mbps rate and SIR-B a 46 Mbps rate. The current Shuttle Ku-band data link to TDRS is limited to 50 Mbps. This has the effect of narrowing the SIR swath to less than 40 km at the higher look angles, and of similarly constraining the SIS swath.

Both the SIS/MLA and SIR/SAR sensors consume in excess of 600 W prime power each; in fact, the SIR-C dual-frequency sensor would require 2 kw power. This severely limits the SAR's ability to acquire HV-polarized images at the larger look angles (40° - 60°), where the cross-polarized backscattered signals are roughly 10% as strong as the like-polarized echoes. To obtain HV-polarized images with a good SNR at these higher look angles (of much interest in vegetation canopy studies), an increase in transmit power of roughly 10 dB would be required. Using conventional power supplies, 20 kw prime power would be required, an impractically large number.

Finally, both SIS/MLA and SIR/SAR sensors pose challenging image processing problems in three areas: (1) throughput rates, (2) image radiometric calibration, and (3) image geometric rectification. Throughput rates of processed high-resolution image analyses are ultimately limited by human capacity to assimilate, interpret, and classify information, especially for global scale coverage such as obtained from shuttle or free-flyer imaging sensors. However, at present, SAR digital image processing is limited by the speed of available correlators; as an example, the current JPL SAR processor requires about 400 minutes of processing time for each one minute of data acquisition. By 1986, JPL expects to place their Advanced Digital SAR Processor (ADSP) into operation, which can be operated at real-time rates.

A further challenge is posed by the simultaneous acquisition of MLA (or imaging spectrometer) and SAR imagery of the earth. Whereas the SAR is a side-looking radar and can be pointed from 15° - 60°, the MLA is basically nadir viewing and can be steered cross-track from nadir to about ±30°. Thus the region of MLA/SAR common coverage would extend from approximately 15° - 30° nadir. At a 700 km altitude, this would permit simultaneous spatial coverage from 185 km - 400 km cross-track. At the higher MLA scan angles, atmospheric effects become more severe, and at the lower SAR scan angles geometric distortion becomes more severe.

Conclusions

Advanced multi-linear array, imaging spectrometer, and synthetic aperture radar designs being developed by NASA will enable a synergistic approach to the use of VIS/IR and microwave imaging sensors for remote sensing research and applications. Challenging technological problems remain, however, in the areas of data rates, power consumption, and image processing.

Acknowledgements

The authors wish to express their appreciation for technical data and other information furnished by colleagues in the SIR, SIS, and MLA programs at the Jet Propulsion Laboratory and NASA Goddard Space Flight Center.