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Shuttle Active-Microwave Experiments (SAMEX) Program

Executive Summary

July 1, 1982

NASA
National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Shuttle Active-Microwave Experiments (SAMEX)

Program Description

The Shuttle Active-Microwave Experiments (SAMEX) program consists of a series of Shuttle-borne experiments to be conducted in the 1987 to 1990 time frame. These experiments will use a modular advanced radar sensor system that can be reconfigured to acquire radar images with different microwave frequencies, signal polarizations, and observation geometries (Fig. 1).

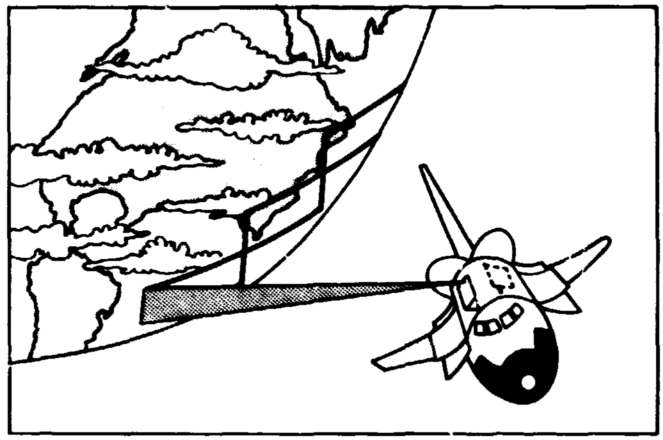

Figure 1. Artist's sketch of the SAMEX sensor in the Shuttle

Scientific Objectives

The scientific objectives of the SAMEX program are (1) to conduct research to understand the radar signature of natural surface units, features, and cover as a function of the radar parameters, (2) to conduct research in the use of multiparameter imaging radar data, in conjunction with visible and infrared data, for geoscience, botanical, and oceanographic investigations, and (3) to develop techniques to interpret radar images that will be acquired with planetary orbiters.

Technical Objectives

The technical objectives of the SAMEX program are (1) to develop the high-risk, high-payoff technology required for advanced spaceborne imaging radars that are required to meet NASA Earth-orbiting and planetary missions in the late 1980s and early 1990s, and (2) to develop and test advanced techniques that would allow improvement in the capability of using spaceborne radars for Earth observations. These include techniques such as squint and spotlight imaging.

Status

Phase A and phase B studies have been completed and a proposal has been submitted by JPL for an FY84 start of implementation. An FY84 start will lead to an FY87 first flight of SAMEX.

Role in Overall NASA Radar Program

The SAMEX program is the logical evolutionary step following the SIR-A/B program and preceding the development of a free-flying radar or space platform-borne SAR in the late 1980s or early 1990s (Fig. 2). The SAMEX program is needed both for scientific research and technical development in the spaceborne radar program.

Estimated Funding

The following cost estimate corresponds to three flights in the 1987–1990 period. In FY88 and beyond, the cost estimate corresponds to a constant level of funding, which includes the beginning of the development of a long-term platform-based radar for flight in the early 1990s.

Fiscal year	84	85	86	87	88	89	90
FY82 SM	2	5	12	14	14	14	14

The research described in this publication was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

Abstract

This Executive Summary gives a brief overview of the scientific and technological objectives of the Shuttle Active-Microwave Experiments (SAMEX) program. It also presents some of the key implementation aspects.

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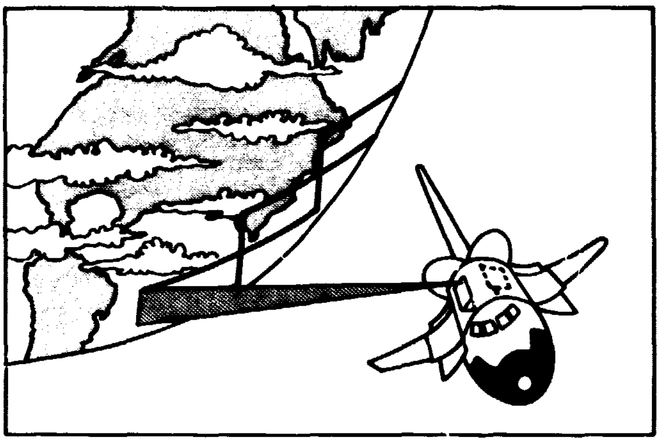

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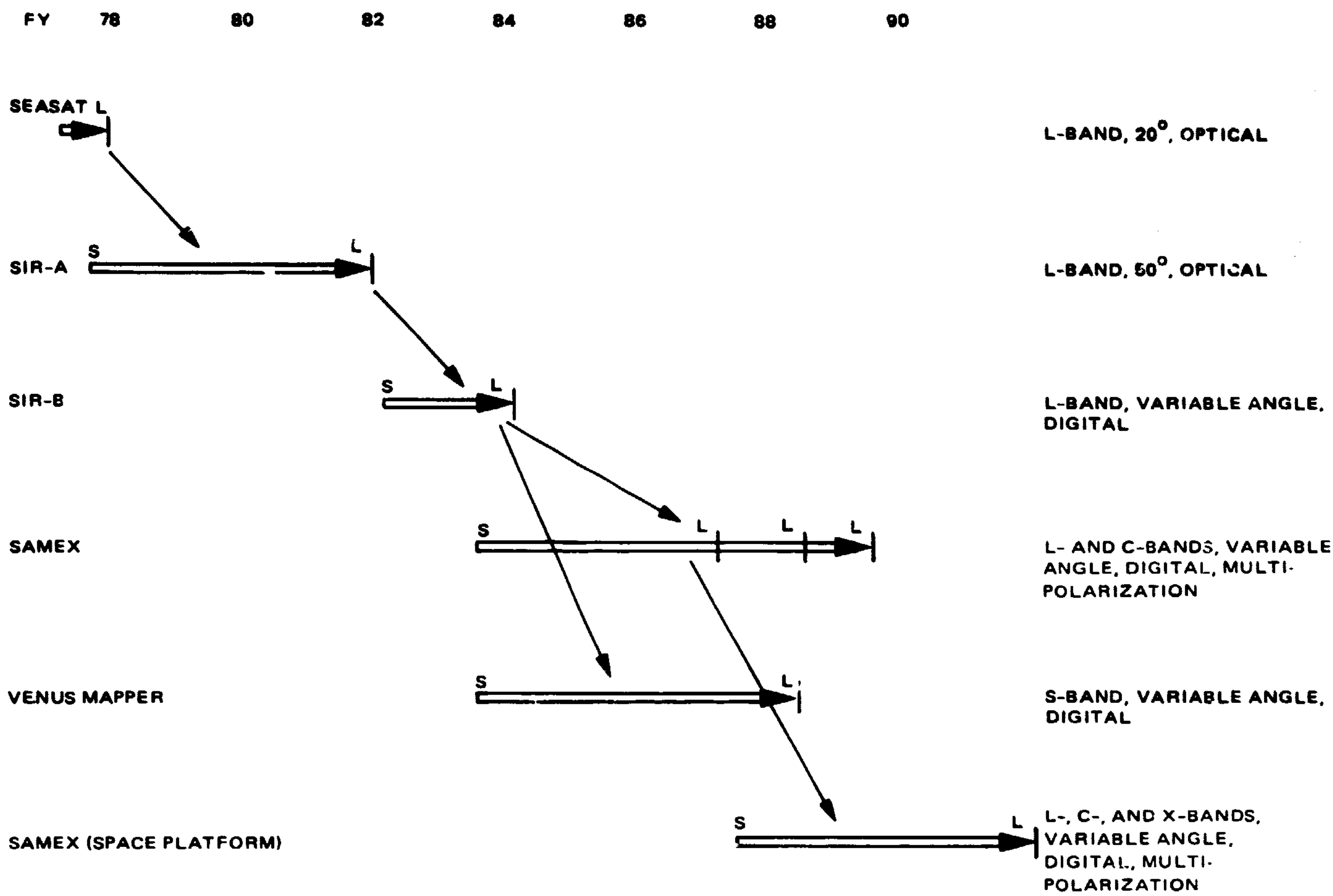

Figure 2. Spaceborne radar missions' progress relationship

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I. Science and Research

A. Objectives

The research objectives of the SAMEX program are based on the recommendation of a number of NASA-organized science working groups and research workshops. These include the Snowmass Radar Geology Workshop (1979), the ERSAR Workshops (1979–1980), the FIREX Working Groups (1981), and the Imaging Radar Science Working Groups (1982). The overall objectives are:

(1) To further our understanding of the radar signature of surface units, features, and cover as a function of radar parameters (illumination geometry, frequency, and polarization). This includes both the reflectivity and the texture signature.

(2) To assess the synergism of using multiparameter radar images with multispectral visible and infrared images.

(3) To determine and demonstrate the use of spaceborne imaging radars for geologic mapping, resource observation, and environmental observation.

(4) To develop techniques to interpret radar images that will be acquired with planetary orbiters.

More specific objectives include:

(1) To develop the capability of radar stereo for image analysis and topographic mapping.

(2) To determine the capability of multiple geometry imaging for structural mapping.

(3) To determine the capability of multifrequency observation for subsurface structural imaging in hyperarid regions, for subvegetation cover imaging in tropical regions, and for vegetation cover classification.

(4) To develop the capability to use the radar spectral albedo and textural information, in conjunction with visible and infrared imaging information, for classification and identification of surface units and cover. This includes geological as well as botanical surface properties.

(5) To determine the nature and properties of features observed on radar images of the ocean surface.

(6) To develop the capability and understanding to interpret the radar images that will be acquired with planetary orbiting radars such as the Venus Radar Mapper and the Titan Radar Mapper.

B. Rationale and Justification

A large number of remote sensors have been developed and are being used in studying the Earth's surface and subsurface. They include electromagnetic sensors (radio, microwave, infrared, visible, and ultraviolet), magnetic sensors, and gravity sensors. No single sensor can provide all the necessary information to study the Earth's surface properties. One major challenge is to find the best combination of sensors for acquiring the data needed to resolve a specific problem.

Imaging radar sensors have unique capabilities in comparison to optical and infrared remote sensors. These include:

(1) Imaging capability in a region of the electromagnetic spectrum that is strongly sensitive to some key surface characteristics such as surface roughness, soil moisture, surface slope, and man-made structures.

(2) Limited penetration capability into dry soil, thin vegetation canopies, snow, and ice.

(3) Control of the illumination geometry.

(4) All-weather, day or night capability. This is particularly important for imaging cloud-covered tropical regions, for imaging polar regions during long night periods, and for monitoring short-term dynamic phenomena (such as soil moisture, vegetation, and ocean surface), where timeliness is essential.

These capabilities are useful in general for many geoscience areas. The justification for specific cases is briefly presented below for surface morphology, rocks and soils, vegetation canopies, and surface water.

1. Surface morphology (Fig. 3). Radar backscatter is extremely sensitive to surface slope. Variations of 1° in slope can lead to a backscatter change of about 0.5 dB (i.e., 12 percent in the backscatter power). This is appreciably higher than the reflection change in the visible or infrared. This characteristic, combined with the capability of complete control of the illumination geometry, potentially gives the radar sensor a major role in the study of surface morphology. Analysis of the Seasat and SIR-A data (Ford, 1980; Baker and Lonsinger, 1980; Sabins, Blom, and Elachi, 1980; Elachi et al., 1982) clearly indicates that the radar has high potential for detecting surface structures and lineaments, particularly when they have topographic or roughness expressions. SIR-A data have also shown that subsurface structures in hyperarid regions can be imaged even if they are covered by a layer of dry sand (McCauley et al., 1982).

A number of questions, however, still have to be answered: What is the optimum geometry for detecting different surface morphologic features? Is one incidence angle sufficient? If so, which one? If not, how many are required? What is the role and capability of radar stereo? What is the role of radar frequency and polarization in detecting large-scale and small-scale surface landforms? How well can the radar map areas with different topographic texture? Most of these questions have barely been addressed so far because of the lack of a flexible system which allows trade-off studies and observation of large areas at a constant geometry. All of these questions will be directly addressed by the SIR-B and SAMEX programs.

2. Rocks and soils (Fig. 4). The radar return is sensitive to the surface roughness of rock outcrops and the size and angularity of unconsolidated rock weathering products (sand, gravel, boulders, etc.). The radar is sensitive to the moisture of the surface, which is an indicator of the porosity and permeability of the rocks. Preliminary investigations by Dellwig (1969), Daily et al. (1979), and Schaber, Elachi, and

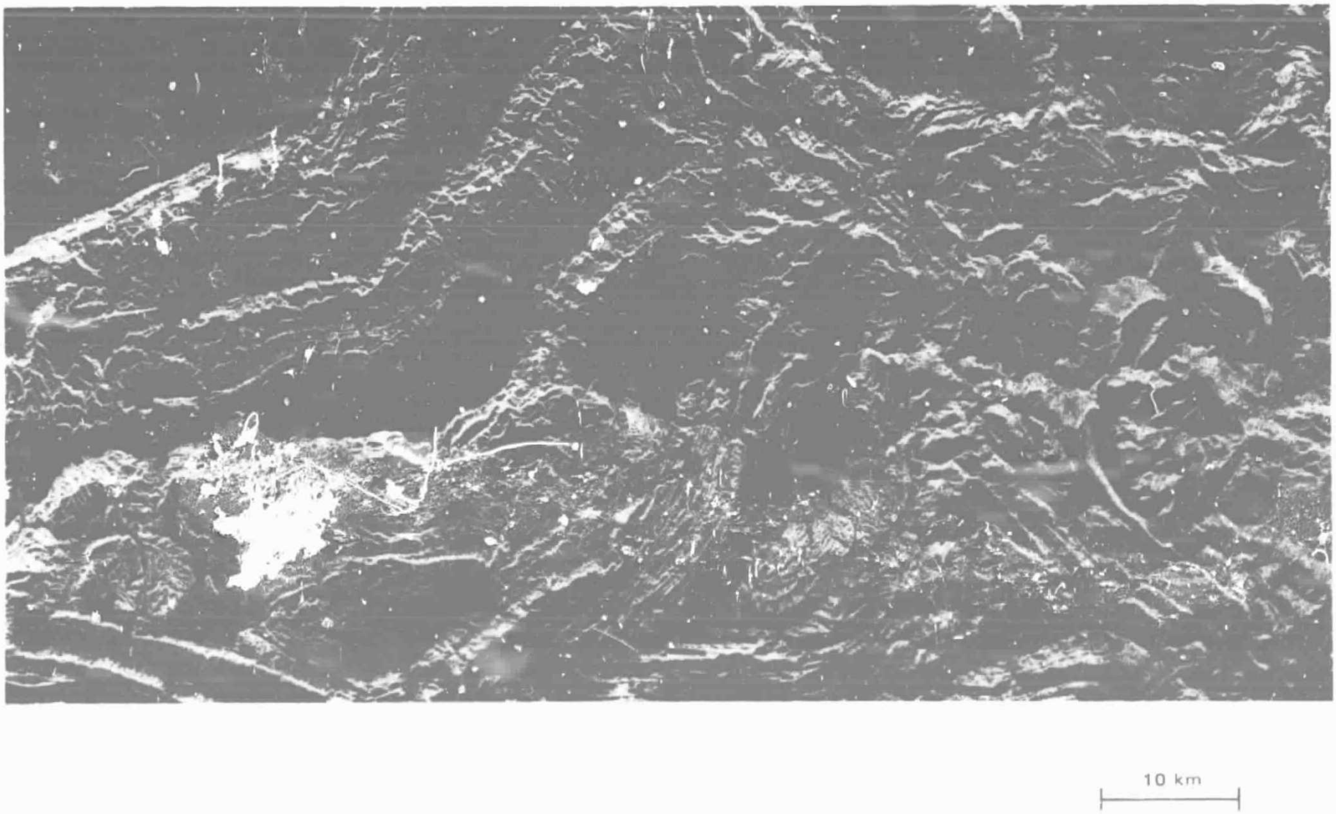

Figure 3. Folded geologic structure in Pakistan, imaged by SIR-A

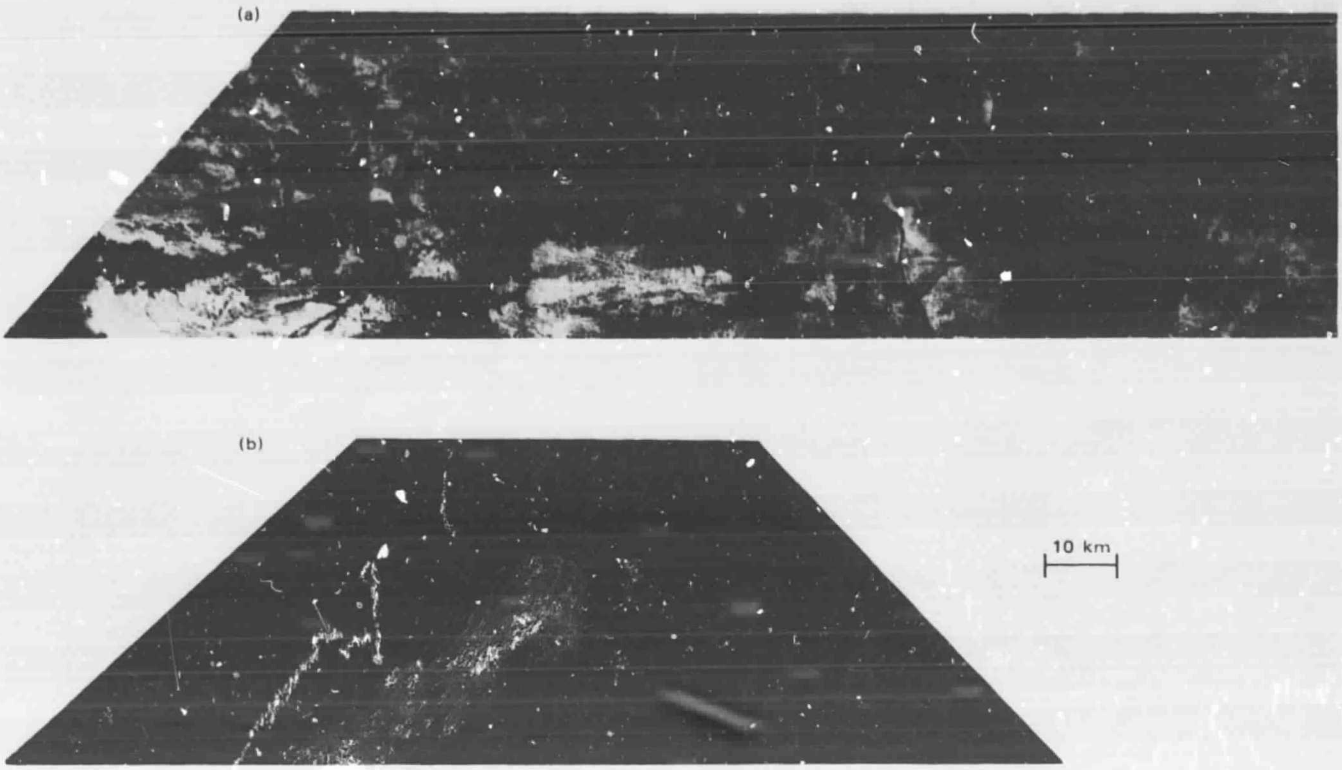

Figure 4. Images of the same area in the eastern Libyan desert in southern Egypt: (a) SIR-A; (b) Landsat. The stream patterns clearly visible on SIR-A were a result of the radar wave penetration through the sand sheet

Farr (1980) indicate that surface geologic units in some arid regions can be unambiguously classified by using multifrequency, multipolarization radar data. Analysis by Blom and Daily (1982) and Farr (1982) also indicates that texture in the radar images could be used to improve rock units' separability. However, the best frequency and polarization combinations still need to be determined to classify the different types of rocks, to determine the effects of vegetation cover, to establish the synergism of combining radar and Landsat data, and to determine the use of both the tonal and textural information in the radar image to delineate different rock units.

3. Vegetation canopies (Fig. 5). Active microwave remote sensors appear to have the potential for sensing parameters related to vegetation type as well as areal extent and condition, which may complement measurements obtained by other remote sensors. Of particular significance is the potential to determine plant canopy geometry and morphology throughout the growing season; canopy water content and distribution; extent of forest, rangeland, and wetland vegetation; and watershed runoff characteristics.

Most of the work in the past has been limited to truck-mounted and some airborne investigations, which provided limited but encouraging results. Radars with short wavelengths (C-band and X-band) and large incidence angles seem to be the most promising. A number of questions still have to be answered, among them: What is the criticality of the different radar parameters in conducting measurements related to vegetation canopies? What is the required accuracy of calibration? What algorithms are necessary for optimum use of combined radar and Landsat data? What is the importance of multitemporal radar data sets? What modifications are necessary to adapt existing pattern recognition algorithms to analyze radar data or composite radar/infrared visible data sets? Some of these questions may be addressed with airborne systems; however, it is not clear that the algorithms and techniques developed can then be extended to future spaceborne sensors. The proposed SAMEX program will provide

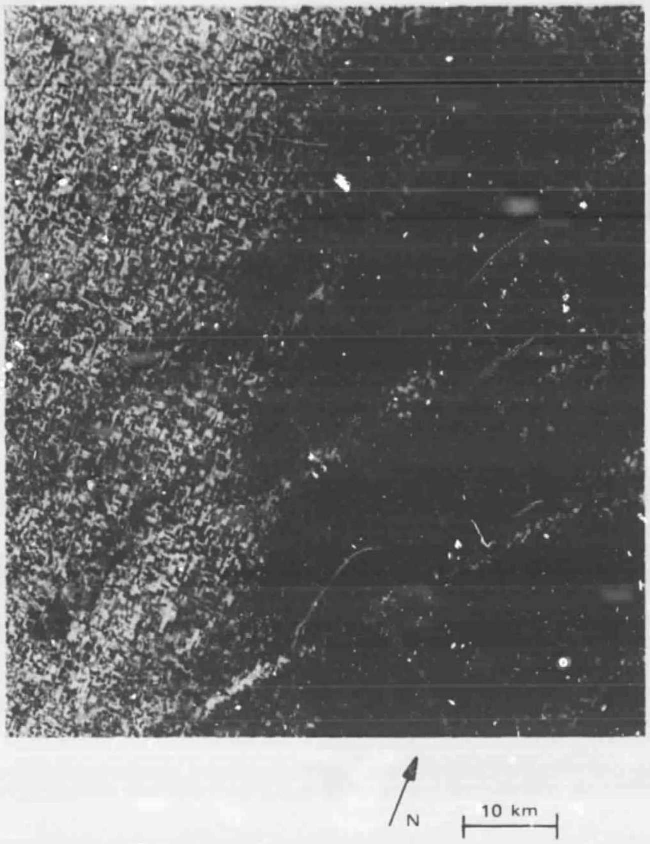

Figure 5. Seasat image over central Iowa showing the variations in the return from cultivated fields

Figure 6. Seasat image of floating ice cover in the Beaufort sea. The bright curvilinear features are ridges, the gray areas are ice floes, and the dark areas are open water channels

the necessary capability and data set, which will allow the development of the algorithms necessary to analyze future spaceborne radar data.

4. **Surface water** (Fig. 6). The measurement potential of active microwave sensors is considered to be particularly significant for studying snowpack properties (extent, depth, water equivalent, etc.), for measuring soil moisture, for mapping surface water extent, for determining floating ice type, extent, and dynamics, and for monitoring ocean surface features. Several investigations have shown that radar data are sensitive to the physical characteristics required in the above applications.

Research and experimental investigations, however, are still needed to address numerous questions, including: What are the best radar parameters (or combination of radar parameters) necessary to measure the snow, floating ice, and soil moisture properties? What is the need for periodic coverage to better estimate these properties? What are the calibration requirements? How accurately can the radar determine the extent of precipitation regions based on the resulting surface soil moisture variation measurements? Some of these questions can be answered using aircraft or truck-mounted systems; however, some of them require a space platform. An illustrative example is the Seasat SAR image of central Iowa (Fig. 5) which shows, on a regional scale, the changes in soil moisture as a result of precipitation from a storm that had just broken up.

C. Synergism With Other Sensors

The radar provides information about the surface and near-surface physical (slopes, roughness) and dielectric properties. In contrast, thermal infrared sensors provide information about the bulk thermal inertia, and visible and near-infrared sensors provide information about the surface chemical properties. Thus, a complete description of the surface and near-surface properties will require the acquisition of data over all three regions of the electromagnetic spectrum: microwave (30 to 1 cm), thermal infrared (50 to 5 μm) and visible/near-infrared (5 to 0.4 μm).

D. Needed SAMEX Capability

The surface signature is dependent on the spectral, polarization, and geometric characteristics of the illuminating wave. Thus, to get a complete signature of different surface units and features, the radar sensor must be able to illuminate the surface at different frequencies, polarizations, and illumination geometries.

The multifrequency observation allows the acquisition of information about the surface spectral roughness and extent of penetration. The multipolarization observation allows the acquisition of information about the dielectric constant and the volume scattering. The multi-illumination observation gives information about the surface morphology, slopes, and roughness.

Seasat and SIR-A provided information on a specific frequency, polarization, and geometry. SIR-B will allow observation with different illumination geometry but still at a fixed frequency and polarization. SAMEX will extend the capability to get a complete "picture" of the surface signature (Fig. 7).

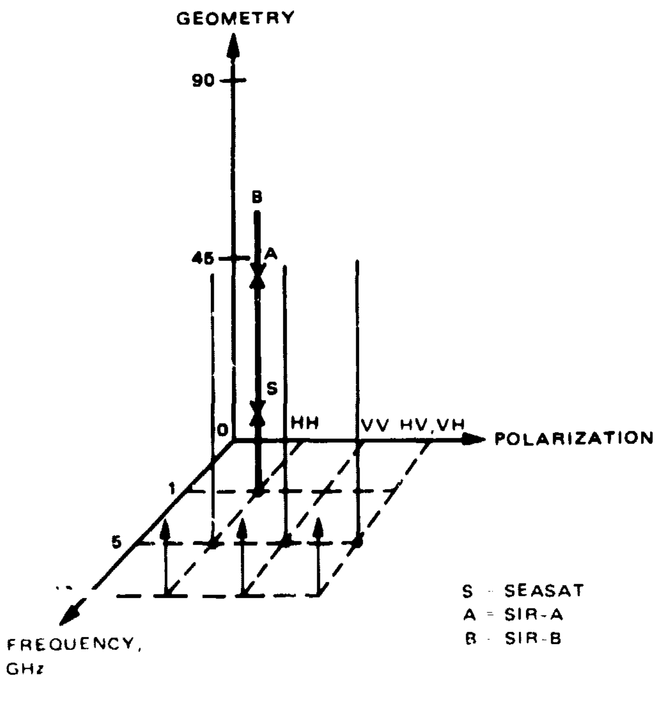

Figure 7. Needed capability

II. Technology and Techniques

The SAMEX program, in addition to the scientific research objectives discussed above, has a number of technical objectives. These are:

(1) To develop the high-risk, high-payoff technologies required for spaceborne radar systems of the 1990s. These include the development of (a) modular multispectral (L-, C-, X-bands) sensors' hardware, (b) high-power, wide bandwidth transmitters, (c) multifrequency, multipolarization large antennas, (d) real-time digital processors, and (e) post-processing techniques for data analysis. Some of these technologies are being developed under SRT tasks; however, SAMEX will use them in the space environment and under realistic operating conditions.

(2) To develop and demonstrate, from space, techniques such as squint mode, spotlight mode, burst mode, etc., which would provide more flexibility in the use of the radar sensors within orbital and spacecraft capability constraints.

III. Implementation Philosophy and Approach

A. Overall Design Philosophy—Modular Approach

A modular approach will be used to allow easy reconfiguration of and modification to the basic sensor. Frequency and polarization-independent modules will be maximized so that modifications and additions will only involve a minimum number of modules. In addition, the use of identical modules for the different channels will increase the flexibility and reliability of the total system. Figure 8 shows a sketch of the SAMEX block diagram. The approach is to use the SIR-B hardware to the maximum extent.

To illustrate, if the operating frequency needs to be changed from X-band to C-band, this can be accomplished by changing the antenna and reprogramming the up converter and down converter. Simultaneous operation at both X- and C-bands can be accomplished by using two antennas and a burst mode approach.

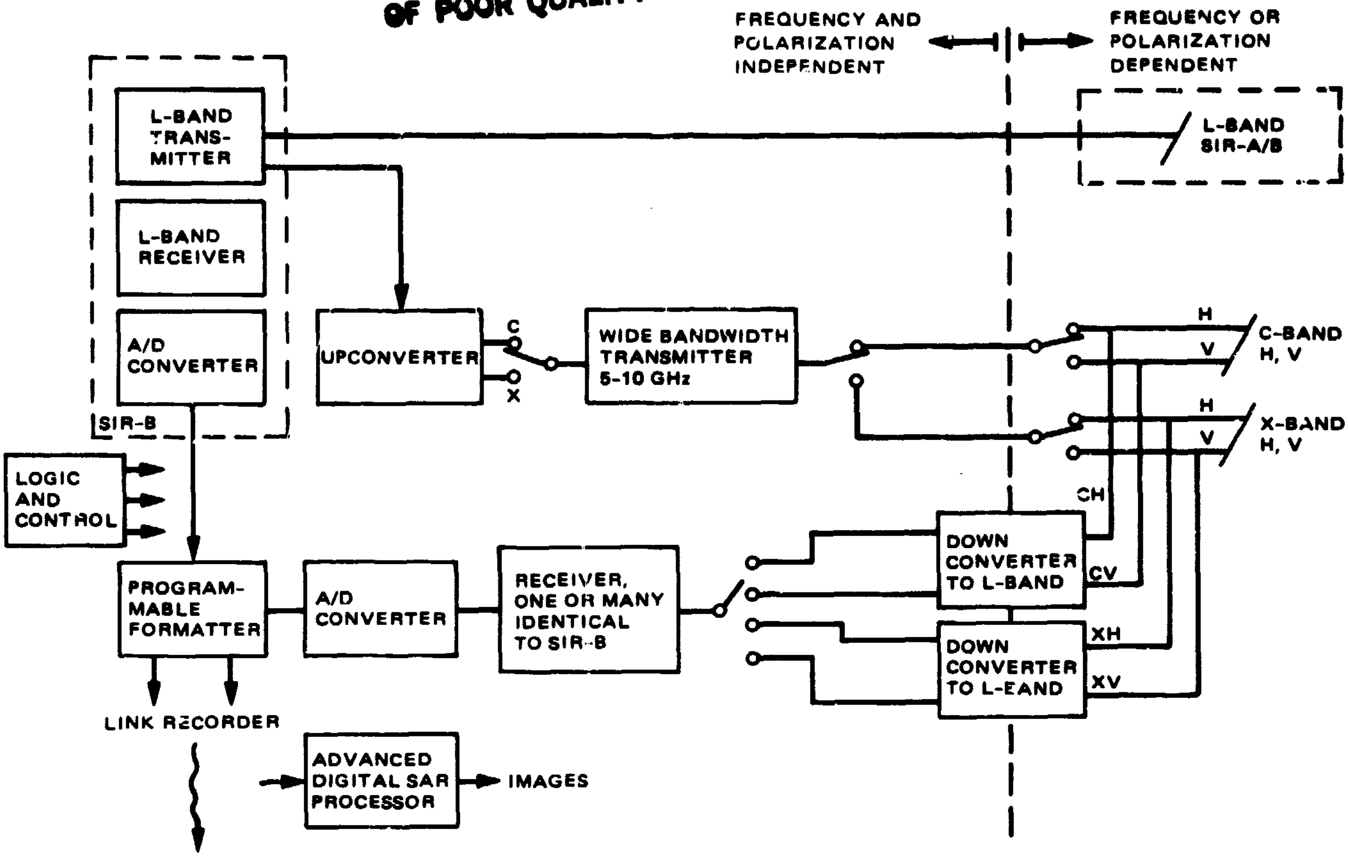

Figure 8. Overall basic system diagram

B. Overall Configuration Approach—Software Control

The SAMEX system can be operated in a variety of modes to adapt to different investigation requirements. It has a wide range of configuration flexibility and can be modified and controlled by ground commands, crew commands, or preprogrammed commands. This flexibility includes:

(1) Selectable incidence angle: from 15° to 70° with 5° steps.

(2) Ultimately three frequencies: L-band, C-band, and X-band.

(3) Triple polarization on the X-band and C-band.

(4) Extended swath. At large incidence angles, the swath width can be traded off with resolution and number of looks.

(5) Burst mode, which allows trade off between resolution, number of looks, and swath width. This flexibility is limited by the maximum bit rate that can be transmitted on the Shuttle data link (i.e., 50 Mb/s).

C. Sensor Characteristics and Expected Performance

The SAMEX sensor characteristics are described in Table 1. Some of the corresponding performance characteristics are illustrated in Figs. 9 and 10.

IV. Program Description

The proposed SAMEX program consists of three Shuttle flights to be conducted in the 1987–1990 time frame. Each flight will build and expand the technical and scientific research capability of the previous one. The nominal scenario is as follows:

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SAMEX I: L- and C-bands, single polarization. 1987 flight.

SAMEX II: L- and C-bands, multipolarization. 1989 flight.

SAMEX III: L-, C-, and X-bands, multipolarization, 1990 flight.

The approval of the total program (versus one flight at a time) will allow a more cost-efficient phasing of the development of different modules in the total system (Fig. 11) and will allow the overall system to be designed at the beginning of the program.

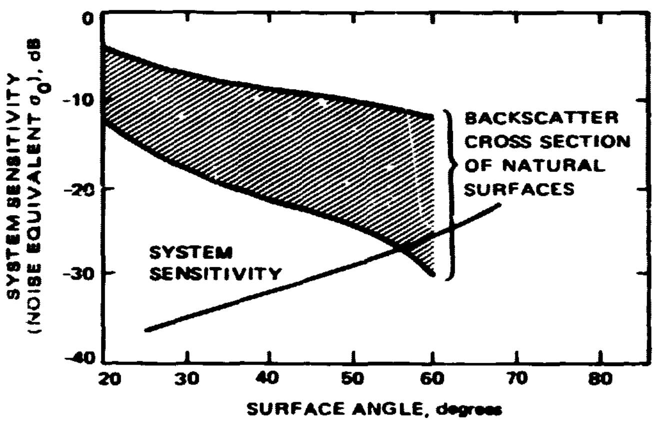

Figure 9. SAMEX system sensitivity

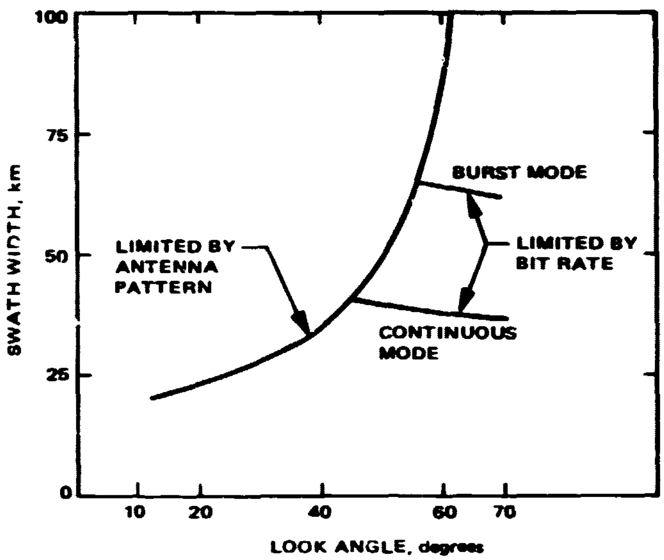

Figure 10. SAMEX swath coverage

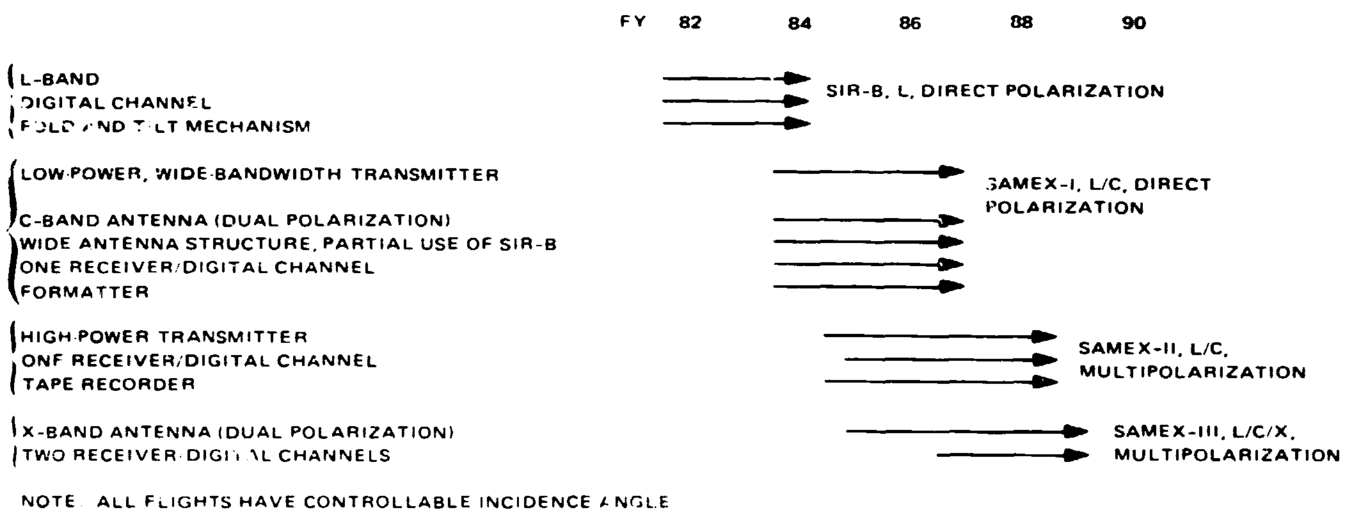

Figure 11. Possible SAMEX flight scenario and corresponding main modules' development

Table 1. SAMEX baseline characteristics

Parameter	Value		
	L-Band	C-Band	X-Band
Frequency, GHz	1.275	5.3	9.6
Wavelength, cm	24	5.7	3
Transmitted peak power, kW	1	4	4
Bandwidth, MHz	12	12	12
Incidence angle	15° - 70°	15° - 70°	15° - 70°
Resolution, m	50 - 15	50 - 15	50 - 15
Swath width, km	30 - 60	30 - 60	30 - 60
Number of looks	6 - 2	6 - 2	6 - 2
Polarization	HH	HH, VV, HV	HH, VV, HV
Antenna length, m	12	12	12
Antenna width, m	2	0.4	0.2
Operation altitude, km	200 - 400		
Data collection	Digital via TDRSS (50 Mbits link)		
Bit rate	46 Mb/s		
Calibration goal	1 dB relative during one flight and between flights		
Data collection per flight	50 h		
Data processing	Digital		
Modes and configuration control	Can be done by command or programming		

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