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DESIGN AND IMPLEMENTATION OF A SYNTHETIC APERTURE RADAR FOR OPEN SKIES (SAROS) ABOARD A C-135 AIRCRAFT

Dale W. Cooper
Sandia National Laboratories (SNL)
P O Box 5800; MS 0312
Albuquerque, NM 87185-5800
(505) 844-9451

Contributors

Greg Rimmel
Loral Defense Systems-Arizona
PO Box 85
Litchfield Park, AZ 85340-0085
(602) 925-7281

Michael Murphy and the
Special Radars Dept. of SNL
PO Box 5800, MS 0529
Albuquerque, NM 87185-5800
(505) 844-2265

ABSTRACT

NATO and former Warsaw Pact nations have agreed to allow overflights of their countries in the interest of easing world tension. The United States has decided to implement two C-135 aircraft with a Synthetic Aperture Radar (SAR) that has a 3-meter resolution. This work is being sponsored by the Defense Nuclear Agency (DNA) and will be operational in Fall 1995.

Since the SAR equipment must be exportable to foreign nations, a 20-year-old UPD-8 analog SAR system was selected as the front-end and refurbished for this application by Loral Defense Systems. Data processing is being upgraded to a currently exportable digital design by Sandia National Laboratories. Amplitude and phase histories will be collected during these overflights and digitized on VHS cassettes. Ground stations will use reduction algorithms to process the data and convert it to magnitude-detected images for member nations. System Planning Corporation is presently developing a portable ground station for use on the demonstration flights. Aircraft integration into the C-135 aircraft is being done by the Air Force at Wright-Patterson AFB, Ohio.

Key Words: Systems, Synthetic Aperture Radar, Treaty, Open Skies.

1.0 INTRODUCTION

Synthetic Aperture Radar (SAR) is one of the imaging technologies identified for use under the Open Skies Treaty. Synthetic Aperture Radar for Open Skies (SAROS) will provide an all-weather, day and night imaging capability.

SAROS is unique among Open Skies sensors in that complex signal processing is necessary to form a SAR image from the raw radar signal. Prior to April 1, 1994, the U.S. could not export modern digital SAR technology to any country that was not one of the 17 countries in the Coordinating Committee for Multilateral Export Controls (COCOM). In addition, exportable technology must pass the Defense Technology Security Administration's (DTSA) guidelines.

In order to meet these requirements, a hybrid SAR system is being designed using a 20-year-old UPD-8 analog radar, which is being refurbished to eliminate sunset and nonexportable technologies. This work is being done by Loral Defense Systems in Phoenix, Arizona.

Digital SARs, particularly those employing digital waveform generation and analog-to-digital (A/D) converters with speeds above 100 Megasamples per second, are nonexportable technologies. Sandia's digital design was required to meet these exportation standards.

By treaty, it was necessary to restrict the SAROS resolution to no more than 3 meters. To do this, it was necessary to incorporate an azimuth filter and a Litton 92 Inertial Navigation System with Global Positioning System (GPS) updates to correct for aircraft/antenna movement.

2.0 SAR IMAGING GEOMETRY

In an Open Skies mission, the C-135 aircraft will fly a straight trajectory that projects the ground track as shown in Figure 1. The SAR transmits

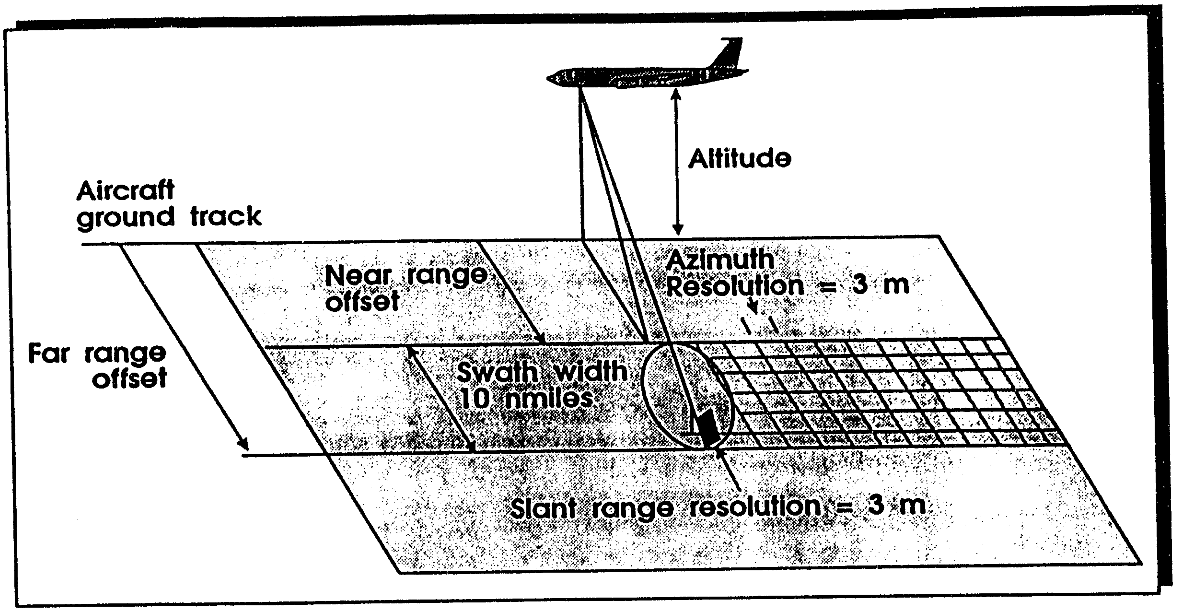

Figure 1. Imaging Geometry

X-band radar signals, as directed by its antenna, onto a ground swath of 10 nautical miles. The received signal is not an image, but a continuous voltage that is a summation of the signals from all the reflectors illuminated by the antenna. This continuous signal is referred to as the analog phase history. When this continuous signal is measured at discrete time intervals (e.g., at 100 millionth of a second intervals) and expressed numerically, it is referred to as a digital phase history. [1]

3.0 OPERATIONAL PARAMETERS

SAROS operating parameters are given in Table 1. Three operational modes are identified for this X-band radar. The first mode is low altitude, while the two remaining modes are at high altitude.

Table 1. SAROS Operational Specifications

Center Frequency: 9.6 Ghz (X-band)
Resolution: 3 m

Mode	Altitude Range (kft)	Near Offset (nmi)	Far Offset (nmi)
A	3.3 - 6	2.5	12.5
B	20 - 43	10	20
C	20 - 43	20	30

4.0 ANALOG FRONT END (AFE)

Loral modified and refurbished three complete sets of the UPD-8 radar that were taken from government inventory. Figure 2 shows a SAROS system block diagram. The components of the analog front end equipment are Line Replaceable Units (LRUs), which provide the functions illustrated in the block diagram.

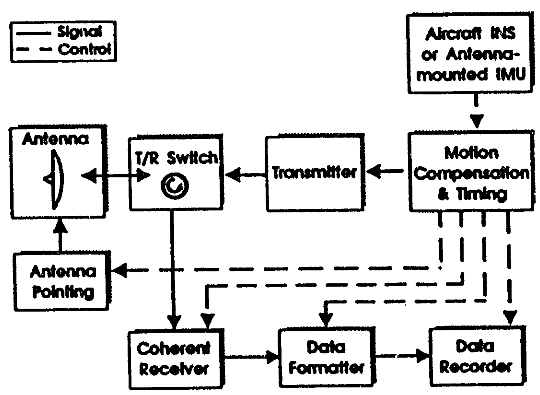

Figure 2. SAROS Block Diagram

There are right and left antenna arrays with high-pressure hydraulic pointing control assemblies that will allow radiation to either side of the C-135 aircraft. By treaty, only one side antenna can radiate at one time. The Frequency Converter Transmitter, Amplifier Modulator, and Signal Data Generator make up the transmitter and receiver sections shown in the block diagram. The Radar Set Control is the master control, which interfaces into the Distribution Box for power and signal control. The Fault Locator indicates any fault in the LRUs.

While the LRUs are still physically the same as they were in the original UPD-8 system, a significant reduction in size and weight has been made because of new technology. These reductions also have resulted in a dramatic increase in the mean time between failure (MTBF) for the system and a corresponding decrease in noise figure for the receiver from 4.5 to 2.0 dB. Sunset technology in the system was replaced wherever possible for future maintainability.

5.0 DIGITAL PROCESSOR

The SAROS Digital Processor (DP) collects mission and sensor data and stores this information on a digital recorder. It conditions the radar phase histories to limit azimuth resolution and correct for platform motion. This data is post processed to generate 3-meter SAR images.

The DP receives radar return and Intermediate Frequency (IF) reference signals from the Analog Front End (AFE). The DP-IF board generates baseband Inphase (I) and Quadrature (Q) signals from the AFE signals. An A/D board (ADC) simultaneously digitizes the I and Q channels to 6-bit digital data at an 80.4-MHz rate. It buffers the data and outputs to the remainder of the DP at 23 MHz. The digitized data is sent to the Digital Motion Compensation (DMC) board.

The DMC receives motion correction parameters from the SAROS Motion Measurement System (MMS). The DMC corrects the radar returns for platform motion and sends the data to the Azimuth Filter (AZF). The AZF filters and decimates the radar data in the azimuth direction. This limits the SAR azimuth resolution to the treaty limit of 3 meters. The processed data is sent to the Control, Interface and Annotation (CIA) board. The CIA collects the radar phase histories and mission data from various sources and records this to tape. The CIA also is an interface between the DP and the SAROS control computer. The computer configures the DP for normal operation or various self-test modes. The DP boards interface on a custom-defined 16-slot VME backplane. The boards are standard VXI-C size, approximately 13 by 9 inches. The system is powered by 28 VDC.

6.0 CONTROL COMPUTER

The SAROS system requires a control computer to communicate with other systems, to control the processing and recording subsystems, and to calculate pre-azimuth filter phase corrections. This last function is performed by a second dedicated 486 computer that shares the bus and housing with the control computer.

More specifically, the control computer performs the following functions:

1. It reads the radar set control and controls its indicators, thus providing operator interface to the SAR system.
2. It communicates with the aircraft's Data Annotation Recording and Mapping System (DARMS), initiating frame, header, and event records.
3. It initiates test and operate sequences in the Analog Front End.
4. It controls and monitors waveguide switch positions.
5. It monitors the squat switch and operates the cockpit radiate indicator.
6. It controls the operation of the digital processor and the digital recorder.
7. It formats annotation data and sends this to the digital processor.
8. It controls power to the digital recorder, digital processor, and the Uninterruptable Power Supply (UPS).

7.0 ANNOTATION

To satisfy the Open Skies treaty requirements, to provide information for correlation of radar data with other sensor systems, and to provide post-processing image formation, annotation data are written to tape. Most of the annotation data are written in character format in a block that precedes recorded radar phase histories. Each field of character data is delimited by newline characters, in order to facilitate interpretation of data dumped to a terminal. The character data are followed by binary fields containing motion compensation data from the SAR and phase corrections from the motion compensation system.

In addition to annotated radar phase histories, the tape will begin with a header block and end with a tape directory. Each continuous set of radar phase history records will be preceded by a test block. These blocks will be tagged with a file mark to provide a fast search capability. The header block contains information that identifies the mission and the cassette and that satisfies specific treaty requirements. The test block consists of a short annotation block and calibration phase histories that may be used as a range reference signal. The tape directory is written after the last valid data on the tape and provides an index to significant mission events, such as changes in SAR status, beginning of a frame, or beginning/end of a recording run. The directory will relate tape Principle Block Numbers (PBNs) to time of day, latitude/longitude, and other variables of interest.

8.0 MOTION COMPENSATION

SAROS implements real-time motion compensation to correct the phase history data for non-ideal aircraft motion before it is passed through the treaty-required azimuth filter. After the phase history data is collected, it must be passed through an azimuth filter to reduce the Doppler bandwidth of the azimuth data in order to restrict the resolution. This reduction of Doppler bandwidth also eliminates information necessary to compensate for aircraft motion and to focus the image in azimuth. The real-time motion compensation removes the effects of motion before the data is passed through the azimuth filter.

The motion compensation system is implemented in custom hardware using a Litton 92. Inertial Navigation System (LTN92) motion measurements are integrated with GPS updates. Motion measurements are received from the LTN92 through a 1553 interface at a 64-Hz rate. The motion measurement computer converts these measurements into motion corrections and resamples the corrections on time boundaries, corresponding to sample boundaries in the radar system. These corrections are passed to the radar system and sent to the digital motion compensation hardware, where the phase correction is applied to the incoming phase histories.

Critical parameters in motion measurement are resolution and measurement latency. The small wavelength of the transmitted signal (31 mm) results in the requirement for very fine motion measurements in order to remove the motion effects. The LTN92-1553 interface provides the appropriate resolution and accuracy to correct for the motion. Another critical parameter in motion compensation is the latency of the motion measurement data. The LTN92-1553 interface should provide the ability to reduce these latency errors to acceptable levels.

9.0 AIRCRAFT INTEGRATION

The SAROS system is being integrated into the C-135 aircraft by the Design, Modification and Manufacturing Facility (DMMF) at Wright-Patterson Air Force Base (WPAFB), Dayton, Ohio. Two Full Operational Capability (FOC) aircraft will be outfitted with the SAROS system.

Figure 3 illustrates the location of the various subsystems that make up SAROS. The canoe is aerodynamic in design and has X-band radome panels for radar transmission to either side. DMMF is designing the canoe and radome panels. The canoe contains the 4-foot antennas and the high pressure hydraulic servomechanism for antenna pointing.

Above the canoe, in the zero fuel cell area, there is a manual switch that, when enabled, will not allow radiation, but instead puts all radiated power into a radio frequency load. This satisfies a treaty requirement to insure that there is no emitted radiation on certain flights.

The analog LRUs and digital system reside in the passenger area directly above the canoe. This environment will increase the MTBF of the analog system because, in previous aircraft installations, the LRUs were always in unmanned areas. DMMF is responsible for cooling, wiring, and waveguide installation in the aircraft installation.

At the operator stations in the rear of the aircraft, there is an operator's control panel and Metrum VLDS cassette tape recorder. Communication between the digital system and tape recorder is made via an optical link. This arrangement allows tape changing to be done easily by the operator in the rear of the aircraft.

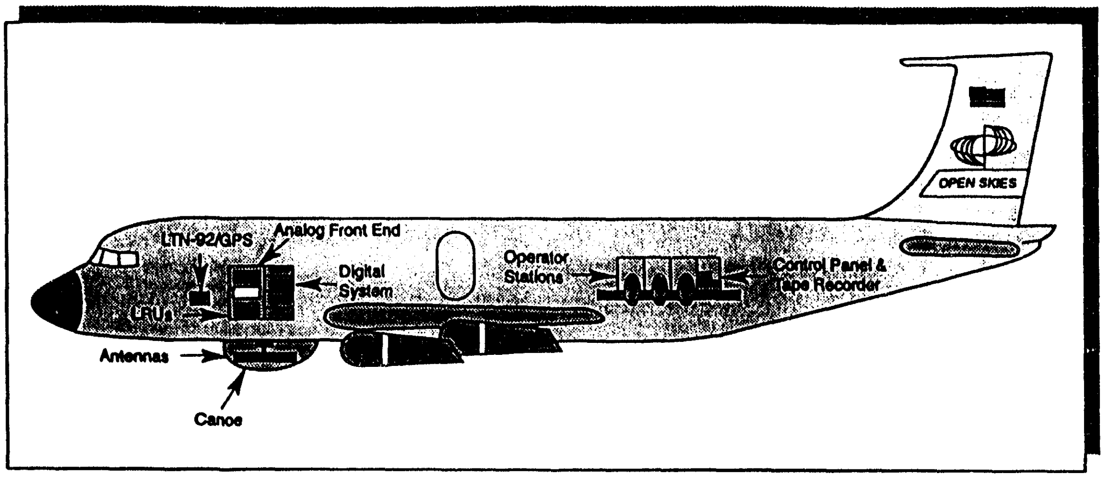

Figure 3. SAROS Aircraft

10.0 CONCLUSIONS

SAR on-the-floor integration tests are presently underway at Sandia National Laboratories in Albuquerque, New Mexico. In January, the SAROS system will be shipped to DMMF at WPAFB for aircraft integration. Initial testing and certification flights will begin in September 1995. The flight testing will be done by the 412th at Edwards AFB in California (AFFTC). In October 1995, the SAROS system will be fully operational and thereafter operated by the On-Site Inspection Agency (OSIA).

ACKNOWLEDGMENT

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