# AN OVERVIEW OF THE GEOSAR TERRAIN MAPPING SYSTEM

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## 1. THE GEOSAR SYSTEM

By the end of this century, a new tool will be available for geologists, earthquake researchers, emergency management agencies, and forestry and land use management agencies. An airborne radar system called GeoSAR, the Geographic Synthetic Aperture Radar, will generate high-resolution, three-dimensional maps to explore and study California, as well as many other areas around the globe. GeoSAR is being developed by a consortium consisting of the California Department of Conservation (CalDOC), Calgis Inc., and NASA's Jet Propulsion Laboratory (JPL), with funding provided by the Defense Advanced Research Projects Agency (DARPA).

GeoSAR consists of a dual-frequency, airborne, interferometric synthetic aperture radar (IfSAR) system that will be able to collect 240 square kilometers (93 square miles) of data per minute. Being a radar-based system, GeoSAR will be able to operate both day and night, under almost any weather condition. GeoSAR will be able to map both above and through the vegetation canopy, providing important information, such as data about landslides, in terrain that is overgrown with vegetation.

JPL will build the radar system and develop the data processing software that will be used to convert the raw radar data into digital elevation models (DEMs). Calgis Inc., a geographic information systems company based in Fresno, California, will construct a geographic information systems (GIS) work station that will convert the JPL radar images into user maps. Calgis will operate the radar system and acquire the data onboard a Gulfstream II. CalDOC will design and lead the user validation experiments during the final year of the three year project. GeoSAR will initially map areas in California with the project branching out into other states and countries as users request data.

The GeoSAR system is currently in the design and construction phase. Test flights generating initial images and DEMs are planned to begin by the end of 1998. The system is expected to become fully operational and commercially available in early 2000.

## 2. SYSTEM PERFORMANCE

### 2.1 Radar Performance

The GeoSAR radar system is a dual-side, dual frequency design using both P- and X-band wavelengths. The P-band radar, with a central wavelength of 86 cm (350 MHz frequency) will penetrate deeper into the vegetation canopy and will scatter quite differently than the X-band radar with a wavelength of 3 cm (9.7 GHz). Each frequency will be able to transmit with either an 80 MHz or 160 MHz bandwidth. The antenna beam widths and mounting angles are such that each system is expected to yield a high-resolution DEM with a swath width on each side of the aircraft of 10 km, at altitudes ranging from 5 to 10 km.

The aircraft chosen for GeoSAR is a Gulfstream II (GII) business jet. It possesses adequate room and power for the radar transmitters, receivers, controllers, data storage systems, etc. The P-band antennas will be located within pods affixed to the ends of the wings. This allows a physical P-band interferometric baseline of 20 m. Although the GII has a very stiff wing, the baseline length and orientation must be known to better than 0.5 mm and 15 arcseconds, respectively. This has necessitated the development and inclusion of an active metrology system for the P-band antennas, the Laser Baseline Measurement System (LBMS), incorporating a set of precision laser rangers and high angular resolution cameras. The X-band antennas will be mounted under the fuselage, with a physical spacing of 2.6 m. This separation distance must be known to better than 0.1 mm, and will be actively measured by the LBMS. The position and orientation of the aircraft itself will be measured by a pair of Honeywell Embedded Global Positioning System (GPS) / Inertial Navigation Units (EGIs) and a differential GPS (DGPS) system. Together, these should enable knowledge of the position and orientation of the aircraft and interferometric baselines at the 10 cm and 15 arcsec level, respectively.

The P-band system also has a polarimetric capability. A horizontally polarized transmitted beam will be received with both horizontal and vertical polarizations. The X-band system can transmit and receive with vertical polarization only. Both systems can function in a double baseline or ping-pong mode, where each antenna alternately transmits and receives its own signal, or in a single baseline mode where one antenna transmits and both antennas receive the reflected signal.

### 2.2 Mapping Performance

The 80/160 MHz bandwidth and the 1.5 m antenna lengths for both P- and X-band systems yield range and azimuth resolution and relative accuracy at the 1-3 meter level. Interferometric relative height errors are expected to be at the 0.5-3 m level or better, with absolute height errors somewhat higher (evaluated over squares 10 meters on a side). The P-band system collects dual baseline data, in both ping-pong and single transmitter mode (yielding different levels of height accuracy and phase unwrapping errors). The X-band system may be operated in one baseline mode or the other, but not both simultaneously. The DGPS and EGI systems will allow the GeoSAR generated maps to be planimetrically positioned at the 1-to-4 meter level (see Table 1 for a summary of system accuracy).

## 3. UNIQUE FEATURES

The GeoSAR system is distinguished by a number of unique features that will allow it to generate an unprecedented volume of high-resolution, high-accuracy topography. These include the dual frequencies in UHF and X bands, the dual bandwidths of 80 or 160 MHz, the dual baselines in ping-pong and single-baseline mode, and dual sided collection of data in 10 km swaths both to the right and left of the aircraft. The LBMS active baseline monitoring system, as well as the EGI-DGPS combination for inertial motion monitoring, and their data reduction techniques are also unique and provide powerful motion sensing capabilities. Radio frequency interference (RFI) is handled by notching the transmitted waveform and by filtering the raw data using an adaptive RFI rejection algorithm. There are many novel additions to the data processing and calibration schemes, a number focused on improving the performance of P-band interferometric systems, reducing multipath and other errors, and extracting canopy height and sub-canopy terrain.

GeoSAR is expected to operate as a commercial system, with users able to specify exact flight goals and requirements, and highly automated flight plan generation, data collection, and data reduction. DEMs and additional products, such as height error and slope maps, will be available in a variety of GIS formats.

GeoSAR is designed to enable terrain mapping beneath the vegetation canopy. When combined with other remote sensing data, such as Landsat multispectral information, it should be possible to determine a variety of vegetation characteristics, such as tree height, tree species, and perhaps even crown diameter. Maps created with the GeoSAR data will be used to assess potential geologic/seismic hazards, classify land cover, map farmlands and urbanization, and manage forest harvests.

**Table 1. Interferometric System Parameters**

| | X-Band | P-Band |
|---|---|---|
| DEM height accuracy | 0.5 - 1.2 m (relative) | 1-3 m (relative) |
| | 1-3 m (absolute) | 2-5 meters (absolute) |
| Planimetric accuracy (1 sigma) | 2.5 m (absolute) | 2 m @ 5 km altitude (absolute) |
| | 1 m (relative) | 4 m @ 10 km altitude (absolute) |
| Ground swath width | 20 km | 20 km |
| Wavelength at center frequency | 3 cm | 86 cm |
| Bandwidth | 80/160 MHz | 80/160 MHz |
| Polarization (V=vertical, H=horizontal) | VV | HH & HV or VV & VH |
| Baseline length | 2.6 m | 20 m |

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