THE GEOSAR AIRBORNE MAPPING SYSTEM

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INTRODUCTION

GeoSAR is a cooperative effort between JPL, the California Department of Conservation (DoC), and Calgis, Inc. to develop an airborne, radar-based, terrain mapping system for identification of geological, seismic, and environmental hazards to increase public safety and improve environmental management. The GeoSAR radar hardware and processor are being developed at the Jet Propulsion Laboratory with funding provided by the National Imagery and Mapping Agency. The main function of the GeoSAR interferometric radar-mapping instrument is the generation of digital elevation models in vegetated areas that represent the bald earth elevation. This technique is a major advancement to current mapping technology, which is unable to rapidly and accurately map sub-canopy elevations. To accomplish this goal, a dual-frequency interferometric mapping radar has been developed. One of the bands is an X-band interferometer (3 cm wavelength) which will achieve 1-2 m height accuracy but primarily maps the top of the vegetation canopy. In order to obtain bald earth elevation measurements, a second interferometer operating at P-band (85 cm wavelength) is incorporated into the GeoSAR mapping system which exploits the fact that lower microwave frequencies penetrate deeper into the canopy. Although the elevation measurements made with the P-band interferometer will be closer to the bald earth elevations, it does not measure the bald earth elevation directly due to the complex scattering mechanism of microwaves with the canopy and ground. In order to get the true bald earth elevation, it is necessary to use the interferometric correlation and semi-empirical models to convert the P-band elevation measurements to the bald earth elevation.

GEOSAR RADAR HARDWARE

The Geographic Synthetic Aperture Radar (GeoSAR) is a dual-frequency interferometric mapping radar which can be commanded to operate in either an 80 MHz or a 160 MHz bandwidth mode. A Block Floating Point Quantization (BFPQ) data encoding scheme is used to reduce data rate in the 160 MHz chirp bandwidth mode. GeoSAR is capable of collecting radar interferometric mapping data from both the left and right sides of the aircraft simultaneously. The four X-band antennas are mounted to the underside of the aircraft with an approximate 2.6 meters separation. Two X-band antennas are located on the left side of the aircraft, one looking left and one looking right. The other two antennas are located on the right side of the aircraft, one looking left and one looking right. The four P-band antennas are mounted in pods attached to the end of the wings of the aircraft and provide an approximate physical baseline of 20 meters. Two antennas are located on the left side of the aircraft, one looking left and one looking right. The other two antennas are located on the right side of the aircraft, one looking left and one looking right. A summary of the GeoSAR system parameters for the P-band and X-band radars can be found in Table 1.

In the 160 MHz bandwidth mode, the X-band radar generates a FM linear chirp waveform from 9.63 GHz to 9.79 GHz at a peak power level of 8 KW. The transmit waveform is routed to one of four antennas to be transmitted in vertical polarization, and the reflected energy from the target is received in vertical polarization from the two antennas looking at the same side as the transmit antenna. The received echo energy is down converted to baseband and sampled at 360 MHz prior to storage on high density digital tape.

In the 160 MHz bandwidth mode, the P-band radar generates a FM linear chirp waveform from 270 MHz to 430 MHz at a peak power level of 4 KW. The transmit waveform is routed to one of four antennas to be transmitted in horizontal polarization, and the reflected energy from the target is received from two antennas either both in horizontal polarization or one in horizontal and one in vertical polarization. In addition, two of the four P-band antennas are configured for reception in both horizontal and vertical polarizations. Cross polarization data are collected to aid in classification studies and sub-canopy height reconstruction. The received echo energy is down-converted to baseband and sampled at 360 MHz prior to storage on high density digital tape.

In order to achieve accurate height maps using radar interferometry, precise knowledge of the interferometric baseline is required. Therefore, the relative position between the two interferometric antennas must be measured extremely accurately. In addition, absolute position accuracy of the resultant digital elevation models (DEM) is limited not only by the relative antenna phase center position but also knowledge of the absolute location of the aircraft. In order to meet these stringent requirements, the GeoSAR system is equipped with a motion measurement system consisting of two Honeywell H764 Embedded Global Positioning System / Inertial Navigation Units (EGI), a Laser Baseline Metrology System (LBMS), and a differential GPS receiver.

The EGI is a self-contained, all altitude navigation system providing outputs of linear and angular acceleration, linear and angular velocity, position, attitude, magnetic and true heading, altitude, body angular rates, time tags, and Universal Coordinate Time (UTC) and GPS time. Aircraft position, velocity, and attitude are measured by the EGIs every 64 Hz and recorded on optical disc onboard the aircraft. Although the velocity and attitude data are accurate enough to meet the GeoSAR mapping requirement, better position knowledge is desired. The EGI has the capability of measuring the absolute position of the aircraft to about 5-10 m whereas the desired position accuracy is sub-meter. A differential GPS is included to refine the aircraft position to the 50 cm level. In order to get accurate knowledge of the P-band antenna phase center locations, the LBMS is used. The LBMS is a complex optical measurement system consisting of 5 laser ranging units, 8 transverse cameras, and the wing-tip pod-mounted reflectors and beacons. The observations produced by these systems consist of range measurements from the laser ranging units to the pod-mounted reflectors and angular deflection measurements from transverse camera systems that image the pod-mounted beacons. The primary requirement of the LBMS is to determine the length and orientation of the interferometer baseline (i.e., wing pod mounted P-band antennas) within an aircraft body-fixed reference frame. The LBMS provides platform-referenced three-dimensional position information for targets mounted on the wing pod antennas. Four targets per pod are monitored for each side of the aircraft. Two targets have their full three-dimensional positions monitored, while two only have two components of their position vectors monitored. There is also a separate laser ranging unit system to measure the X-band antenna separation. These data are measured at a 256 Hz rate and recorded on optical disc onboard the aircraft for subsequent processing.

Because of the frequencies over which the P-band radar operates, there are a number of systems that could potentially be affected by the GeoSAR P-band high power transmissions. As a result, the GeoSAR chirp waveform generation electronics was designed to incorporate the ability to notch any number of frequency bands within the 270 MHz to 430 MHz spectrum. For each frequency that one desires to notch, the width and depth of the notch in the chirp waveform can be programmed. Thus the individual notches in the P-band transmit spectrum can be adjusted to optimize operation in proximity to the systems that share the P-band spectrum. An example of a GeoSAR notched transmit waveform is provided in Figure 1.

The platform selected for the GeoSAR airborne collection system is the Gulfstream II aircraft chosen for its combination of available power, volume and lift capacity suitable for accommodating the GeoSAR radar mapping instrument. These capabilities coupled with adequate flight range, ability to operate at the desired altitudes, and low cost of flight operation made the Gulfstream II aircraft the platform of choice. The majority of the GeoSAR hardware is located in the cabin of the Gulfstream II. The X-band antennas, P-band antennas, and the motion measurement system are all located outside the cabin as illustrated in Figure 2.

GEOSAR PROCESSOR

The GeoSAR processor is a series of programs designed to process and calibrate radar interferometry data collected by the GeoSAR radar mapping instrument. The GeoSAR processor consists of the following major programs:

- Data transfer software to move data from the high density recorder to disc.
- Motion measurement processor to combine the motion measurement data and compute most of the time varying parameters that affect the processing.
- X-band processor to generate digital elevation models (DEM) from X-band raw signal data.
- P-band processor to generate digital elevation models (DEM) from P-band raw signal data.
- Program to extract the true ground surface elevation from the P-band and X-band data.
- Calibration software for calibrating the X and P-band interferometric mapping radars.

The DEM generation portion of the processor consists mainly of the Motion Measurement Processor (MMP) and the Interferometric Processor (IP). The primary function of the MMP is to reformat and condition the time varying radar parameter data in a manner suitable for the IP. The IP takes the data generated by the MMP together with raw radar signal data to generate a strip map DEM, a correlation map, ortho-rectified imagery, a height error map, and an ancillary processor output annotation file.

An example of the GeoSAR processor output products is provided as Figure 3. This view of the northern edge of the Tehachapi Mountains was created with data collected on the first interferometric flight of GeoSAR on April 15, 1999. The area viewed is east of Interstate 5, near Grapevine, California. Clearly visible in the image is a pumping plant used to pump water from the California Aqueduct into a tunnel under the Tehachapi Mountains. The greyscale indicates the amount of energy backscattered to the radar. Flat, smooth areas appear dark in the image, such as the water in the California Aqueduct. Areas which are rough compared to the X-band 3 cm wavelength or oriented to scatter power back toward the radar appear bright. The pumping plant, for example, with its many reflecting, differently oriented surfaces appears light. Small clumps of trees appear as bright dots on the hillsides. This image, posted with 5 m pixels, was obtained with the GeoSAR interferometric 80 MHz bandwidth X-band system. The area mapped is approximately 4.5 km by 4.5 km in size. Superimposed on the greyscale image is color indicating the height at that location. The colors in the image represent topographic contours, or elevation levels, in repeating color cycles. A single color cycle, from green to green for example, represents 500 meters of elevation. The DEM has 10 cm to 1 m statistical vertical accuracy.

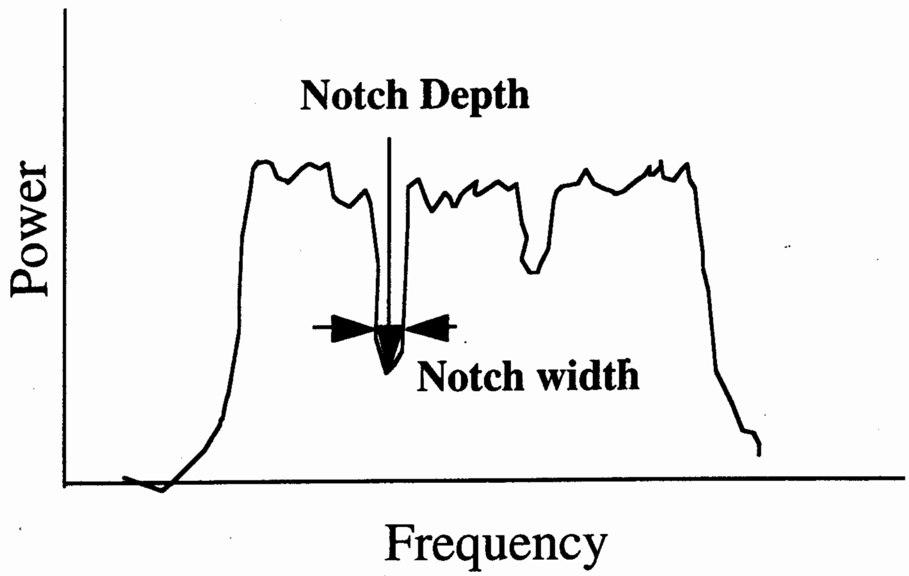

Figure 1. Notched Waveform Example

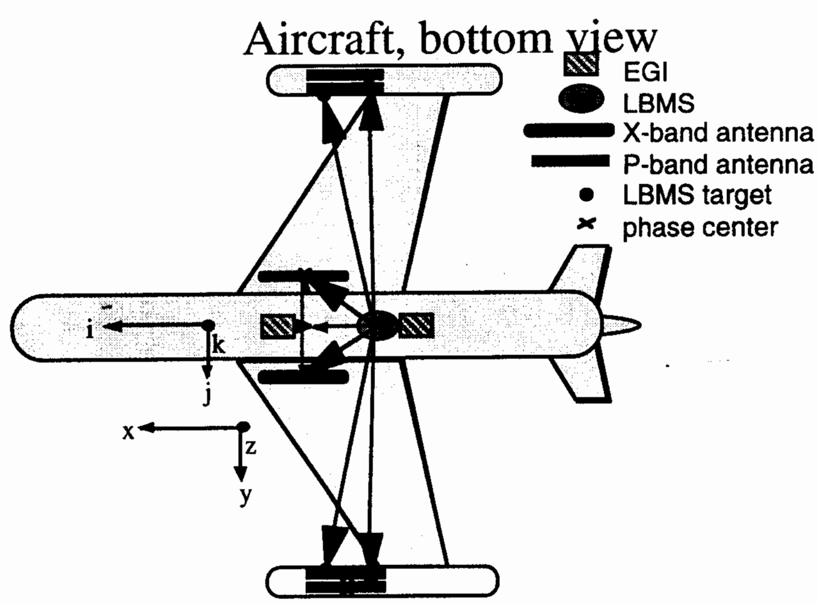

Figure 2. Locations of Antennas and Motion Measurement System on the GeoSAR Gulfstream II Aircraft

Figure 3. GeoSAR X-band image of the Tehachapi Mountains

SUMMARY

This paper provides an overview of the GeoSAR radar hardware and processor structure. An example DEM is also shown to demonstrate the capability of the X-band radar. This imaging system was designed to be a robust and automated mapping system. Test flights are flown to verify the flight planning software and the automatic radar controller that automates the radar operations. Phase III of the project includes the completion of instrument testing, automation and calibration, system level analysis of phase unwrapping and motion compensation effects on terrain mapping performance, and long wavelength foliage penetration studies.

REFERENCES

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P-band Parameter	Value	X-band Parameter	Value
Peak Transmit Power	4 KW	Peak Transmit Power	8 KW
Bandwidth	80/160 MHz	Bandwidth	80/160 MHz
Pulse Length	40 μSec	Pulse Length	40 μSec
Sampling	8/4 BFPQ @ 160 MHz 8 bit for 80 MHz	Sampling	8/4 BFPQ @ 160 MHz 8 bit for 80 MHz
Antenna Size	1.524 m x 0.381 m	Antenna Size	1.5 m x 0.035 m
Ant. Gain @ Boresight	11 dBi	Ant. Gain @ Boresight	26.5 dBi
Antenna Look Angle	27 – 60 Deg.	Antenna Look Angle	27 – 60 Deg.
Antenna Boresight	60 Deg.	Antenna Boresight	60 Deg.
Wavelength at Center Frequency	0.86 m for 160 MHz 0.97 m for 80 MHz	Wavelength at Center Frequency	0.031 m for 160 MHz or 80 MHz
Center Frequency	350 MHz	Center Frequency	9.71 GHz
Baseline Length	20 m/40 m	Baseline Length	1.3 m/2.6 m
Baseline Tilt Angle	0 Deg.	Baseline Tilt Angle	0 Deg.
Platform Altitude	5000 m – 10000 m	Platform Altitude	5000 m – 10000 m

Table 1. GeoSAR System Parameters Overview