

# The Interferometric Data Calibration for the AIRSAR PacRim II Mission

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**Abstract-** This paper focuses on the cross-track interferometric data calibration results and height accuracy analysis. We also present the key elements of the calibration techniques for cross-track interferometric SAR processed with the AIRSAR Integrated Processor.

## I. INTRODUCTION

During July through October 2000, the NASA / Jet Propulsion Laboratory Airborne Synthetic Aperture Radar (AIRSAR) collected over 60 hours of AIRSAR data for the Pacific Rim II mission.

The AIRSAR Integrated Processor (AIP) is used to generate co-registered multi-frequency (C-, L-, and P-band) images which are projected and terrain-corrected onto the DEM generated by a single pair of interferometric channels. The calibration procedure consists of two steps to calibrate the cross-track interferometric data (TOPSAR) data. The first step is to verify and recover the raw echo data, auxiliary data and motion data. Anomalies in the raw data, such as saturation pulses, byte-shift within a range line, and phase jitter are detected and a linear fit is applied to the motion data. The second step is the primary goal to calibrate the TOPSAR data for each pair of interferometric channels to generate the digital elevation models (DEMs). The baseline between the two antennas and the differential phase is calibrated using corner reflectors ground truth position information.

## II. PRE-PROCESSING

The first step of performing the calibration procedure is to verify and recover the raw echo data, auxiliary data and motion data. In this procedure, the raw echo data is scanned and fixed line by line for anomalies in range samples extraction and range sample shifting, and for Radio Frequency Interference (RFI) filtering. For the PacRim II data, the rate of

contaminated pulses was less than 0.1%. An Ashtek Differential Global Position System (D-GPS) was incorporated into the AIRSAR during the PacRim II mission along with the H764G Embedded GPS Receiver in an Inertial Navigation System (INS) (EGI) and the stability of motion data was increased from previous years.

## III. INTERFEROMETRIC CALIBRATION

The height errors in an interferometric radar DEM (Digital Elevation Map) can be classified into two types, relative and absolute errors. The relative error comes from the pixel-to-pixel uncorrelated phase noise which cannot be compensated by a calibration technique. The absolute error is a systematic error caused by various error sources such as the differential phase due to channel imbalance and baseline estimation errors. Unlike the relative error, the absolute error can be compensated by using ground control points if these errors are stable in time.

The interferometric calibration procedure starts with co-registration of two images. We accomplish this co-registration by applying a complex correlation technique to two single look complex SAR images. After this co-registration process, two images are usually co-registered to an accuracy much better 1/10 of a pixel. The second step is to remove a slant range bias. This is done by measuring the round trip time from an antenna to the surveyed targets whose locations are known accurately. The slant range bias is caused by incorrectly estimated radar electronic delay time including both electronic delay inside the radar and true round trip time. We have used corner reflectors a Rosamond lakebed to perform this slant range calibration. In this process, tropospheric refractive index variations must be considered since the round trip time is determined by the optical path length rather than the physical length.

The next step is to evaluate the receiver channel imbalance, especially in phase. Even though two interferometric receive channels are designed to be identical, both amplitude and phase characteristics of two channels usually are different. The phase

difference can be measured by injecting the same calibration tone signal to both receiver channels. However, any imperfections associated with the calibration tone measurement may cause a differential phase estimate error. This error also can be removed by comparing the radar DEM with height of the surveyed corner reflectors.

In order to do interferometric data processing, the location of the two antennas must be known accurately. For the TOPSAR case, the baseline length and attitude must be known to an accuracy better than 1 mm and 0.01 degrees, respectively. The separation of the two antennas was surveyed accurately prior to SAR data collections. The baseline vector estimation bias can be calibrated using the known height of surveyed corner reflectors. The aircraft attitude measurement bias can be estimated by comparing the Doppler centroid derived from the aircraft motion data with the radar phase history data.

The baseline between the two antennas and the differential phase are calibrated using corner reflectors ground truth position information. The C-band interferometry upper and lower antennas are separated by 2.5 meters with a roll angle of 50 ° and a baseline yaw angle of -0.5°. The L-band antennas are separated by 1.9 meters with a roll angle of 69° and a yaw angle of -2°. The calibration parameters are determined by fitting errors in corner reflector positions using the known sensitivity of the target position to calibration parameter errors. Given the airplane position  $\mathbf{P}$  vector, line of sight  $\mathbf{n}$  and slant range  $\rho$ , the position to the corner reflectors ( $\mathbf{T}$ ) can be obtained from  $\mathbf{T}=\mathbf{P}+\rho\cdot\mathbf{n}$ . The error in the interferometric measurement and interferometric phase can be written as (1) (2),

$$\delta T = \delta P + \rho \cdot \delta n + \delta \rho \cdot n \quad (1)$$

$$\delta \phi = (-4\pi/\lambda)[(\rho_1 - \rho_2) \cdot \mathbf{n}] \quad (2)$$

where  $\rho_1$  and  $\rho_2$  are slant range from upper and lower antennas, respectively.

From [1], the interferometric phase and DEM height can be expressed as below (3) (4),

$$\delta \phi = (4\pi / \lambda) \cdot B \cdot \sin(\theta - \alpha) \quad (3)$$

$$Z = h - \rho \cos(\theta) \quad (4)$$

For the interferometric phase, we estimate the baseline vector and differential phase by using the flat portion of the Rosamond lakebed with 663 meter site height in the WGS-84 projection. When a common flight track is used for

processing both interferometric channels, the interferometric phase  $\delta\phi$  [2] can be rewritten as (5).

$$\delta\phi = (-4\pi / \lambda) \cdot (\hat{n}_t - \hat{n}_r) \cdot \bar{B}_t - \frac{4\pi}{\lambda} \hat{n}_r \cdot \bar{b} + \Delta\phi + 2\pi m + \phi_e \quad (5)$$

where  $\lambda$ =wave length,

$n_t$  = true unit look vector,

$n_r$  = reference unit look vector,

$B_t$  = true baseline vector,

$b$  = baseline error vector,

$\Delta\phi$  = differential phase,

$m$  = absolute phase number, and

$\phi_e$  = phase due to earth curvature.

When the reference flat height is the same as the true height, the first term of (5) becomes zero. After the earth curvature corrected and the phase ambiguity number ( $m$ ) are determined, the resulting phase  $\phi_c$  can be written as (6).

$$\phi_c = \delta\phi - \phi_e = -\frac{4\pi}{\lambda} \hat{n}_r \cdot \bar{b} + \Delta\phi \quad (6)$$

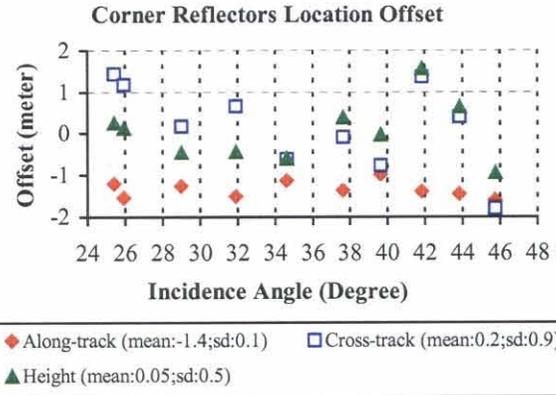
Using the TOPSAR data, we can determine the baseline error vector ( $b$ ) and differential phase ( $\Delta\phi$ ) with a least square error technique.

For the PacRim II, the relative height accuracy of the TOPSAR data is within 2 to 5 m for C-band and 5 to 10 m for L-band.

The plot shown on this page at right side bottom is the locations offset of the Rosamond corner reflectors for C-band 40 MHz TOPSAR data with heading 350 degrees and the mean of the location error is around 3 meters.

#### IV. TIE-POINT PROCESSING

If there are other error sources that have not been modeled in the calibration procedure, our estimation



will be biased. As an example, multi-path can cause such a bias since the multi-path sources are usually unknown and it is difficult to model this multiple scattering from a complex structure like an aircraft. This calibration bias results in height errors when other areas are imaged. Sometime, the motion data can be corrupted as well. In the quality assurance processing [3], we developed a tie-point processing by using ground points for absolute phase determination. Hence, we wrote a program to determine two parameters. The height error  $\delta h$  is expressed as (7)

$$\delta h = \Delta h + C_\phi \delta \phi \quad (7)$$

Where  $\Delta h$  is a constant height bias and  $C_\phi$  relates the differential phase  $\delta \phi$  including  $2\pi m$ .  $C_\phi$  will be saved from the integrated processor and  $\Delta h$  and  $\delta \phi$  are estimated using a separate program. We found that a couple of automated iteration is required to estimate two parameters accurately.

In the Fig. 1, it shows the height construction ( $h$ ) derived from the angle  $\alpha$ . The angle  $\alpha$  is the function of the baseline geometry ( $B_x, B_y, B_z$ ), attitude (roll, yaw, pitch) and interferometric phase ( $\phi$ ). Equation (8) can be derived from equation (4) as shown below:

$$h = Z - r\sqrt{(1 - n_x^2)} \cdot \sin \alpha \quad (8)$$

Where:  $\rho = r\sqrt{(1 - n_x^2)}$  is zero Doppler slant range,  $\sin \alpha = \cos \theta$ ,  $r$  is slant range,  $Z$  is altitude plus antenna location correction,  $n_x$  is a unit look vector component in  $x$ .

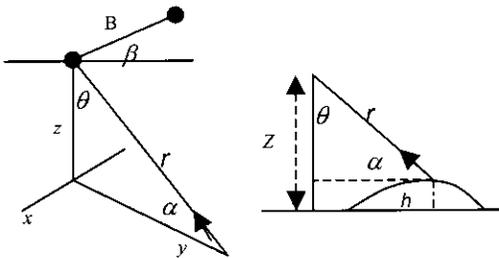


Figure 1 Geometry of height ( $h$ ) construction

## V. Absolute Gain Calibration

For the interferometric data, the backscatter measurement utilizes an external trihedral corner reflectors to correct the residual amplitude for the absolute gain of the radar system. In calculating the correlator gain, we use the theoretical expression for triangular trihedral corner reflector cross-section (9) found in Ruck et al[4]

$$\sigma = \frac{4\pi}{\lambda^2} l^4 \{ \cos \theta + \sin \theta (\sin \phi + \cos \phi) - [\cos \theta + \sin \theta (\sin \phi + \cos \phi)]^{-1} \}^2 \quad (9)$$

Where:  $l$  is the length of corner reflector sides,  
 $\lambda$  is the radar wavelength,  
 $\theta$  is radar wave incident angle, and  
 $\phi$  is corner reflector azimuth angle.

For PacRim II, the TOPSAR image absolute calibration is within 3 dB.

## VI. CONCLUSIONS

In this paper, we present the results of raw echo data analysis with error recovery and the calibration results of AIRSAR interferometric modes. All AIP products are calibrated and corrected geometrically and radiometrically. A number of precision image data sets will be presented to demonstrate the calibration for the PacRim II data.

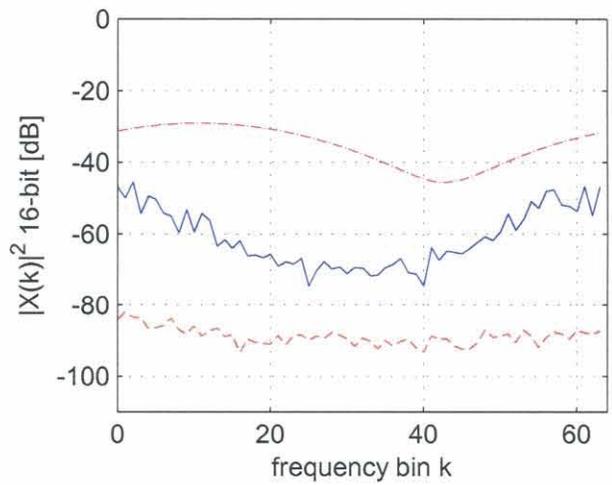
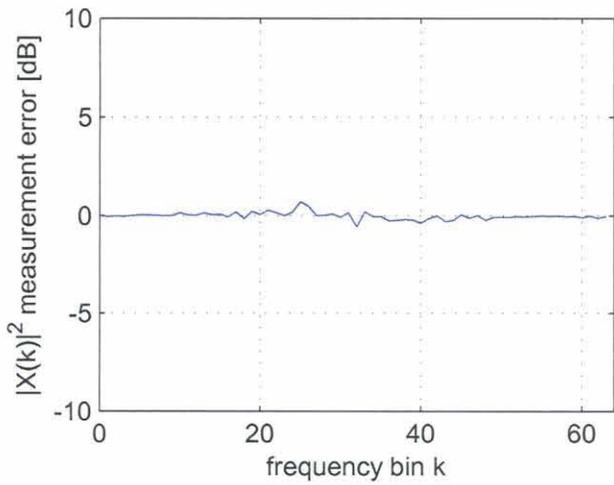
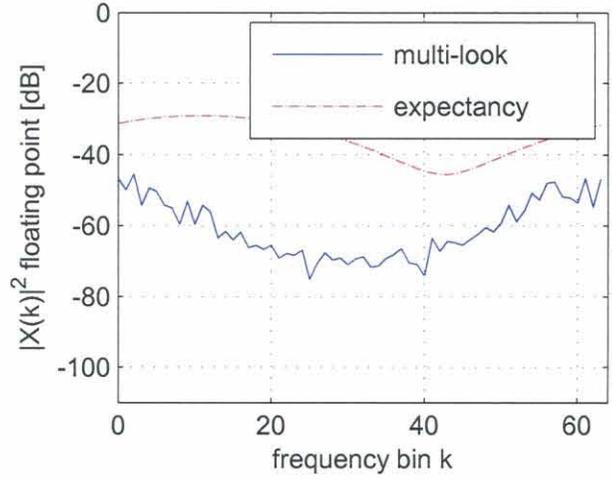
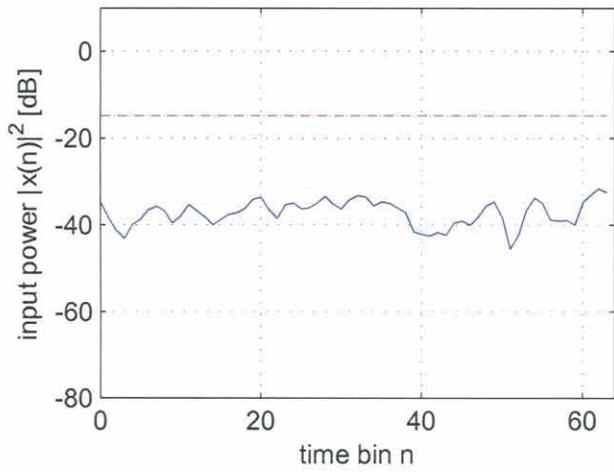
## ACKNOWLEDGMENT

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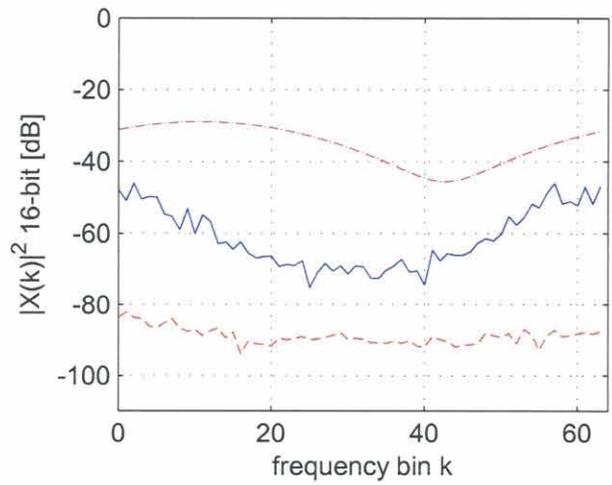
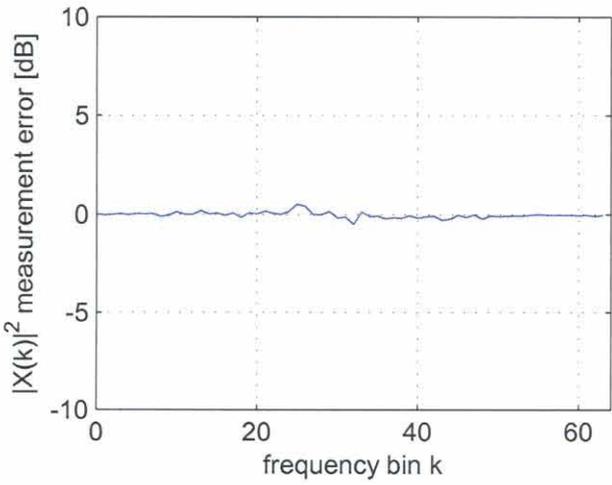
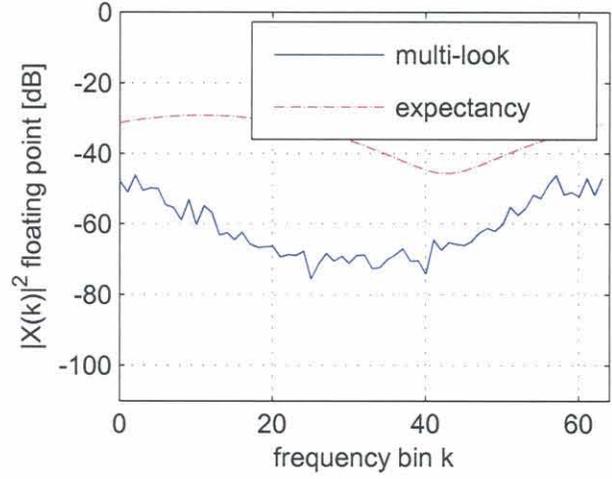
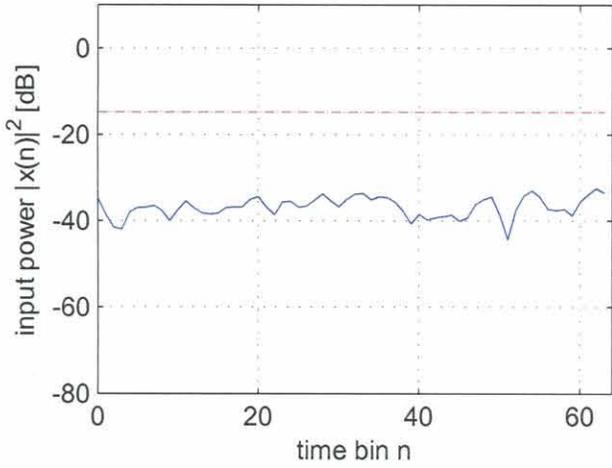
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