Internal Calibration of SRTM C-Band Radar System

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This paper describes the specific internal calibration design implemented in the Shuttle Radar Topography Mission radar system to allow for compensation (in ground data processing) of errors due to drift in the relative transfer function of the two interferometric receive channels. The paper will provide an overview of the radar internal calibration scheme for both inboard and outboard antenna channels through receiver/down-converter/digitizer electronics. A phase-locked optical link used to translate a phase reference to the outboard antenna located at the end of the 60m mast will be described. The error budget, and evaluation of the overall calibration link operation over the mission, will be given.

For an interferometric synthetic aperture radar (IFSAR) designed specifically for topography generation such as the one flown in SRTM, the interferometric phase (or phase difference) between two interferometric channels is one of the critical measurements which enable height derivation. The accuracy by which the interferometric phase can be measured affects the height accuracy attainable. Two kinds of phase errors limit the accuracy of phase measurements. The first kind is phase uncertainties in the resultant images caused by thermal noise and speckle noise, both of which are typical and intrinsic in SAR imagery. The second kind of phase errors is caused by different characteristics of the two interferometric channels when they cannot be made to track each other in practice, and whose effect cannot be removed completely. This uncorrectable phase imbalance between the two interferometric channels will be embedded as part of the interferometric phase measurements, leading to undesirable errors in height construction. Obviously it is crucial to keep this phase imbalance as small as possible. For SRTM design, the uncorrectable phase imbalance was allocated and required to be $\leq 8°$ (1.6σ), which translates to 7.6m of height error, about 1/3 of the overall system single-pass height error allocation of 22.6m.

Removing system variation so that the "calibrated" measurements are devoid of errors introduced by the measurement system is certainly not new. And removing such variation among different channels in a multi-channel system is not limited to an IFSAR system. A polarimetric SAR needs to eliminate such channel imbalance. What's challenging in SRTM is the above mentioned tight residual phase imbalance requirement and that fact the electrical signal path of the two receive channels is separated by about 100m (additional length of cables is required over the 60m physical separation of the two antennas). In contrast, for SIR-C, which is a polarimetric SAR, the relative phase error between the polarimetric channels was ±25° as a goal and the signal path of these polarimetric channels was approximately equal in length.

Conventionally, calibration approaches are classified as either internal calibration or external calibration and they are usually complementary to each other. Internal calibration refers to flight system calibration which relies specifically on engineering data self-generated within the flight system. External calibration, on the other hand, refers to utilizing data which are acquired through interaction with "external" known targets or scenes. For SRTM, a combination of internal and external calibration is used to remove biases in the final height products. Together with a set of external calibration schemes, the above phase imbalance requirement was imposed over 40 minutes (between coastal crossings) during which the uncorrectable phase imbalance had to be $\leq 8°$. Internal calibration is used to reduce the residual (e.g., temperature-related) phase imbalance between each pair of interferometric receive channels.

For SRTM, the inboard antenna, located in the shuttle cargo bay, provides the transmit beam and together with the outboard antenna, located 60m away at the tip of the mast, receives the reflected echoes as an interferometer. The inboard antenna uses SIR-C vintage C-band phased array transmit/receive panels, whereas the outboard antenna is a receive-only design new for STRM. The outboard antenna also includes down-conversion from C-band to L-band to reduce RF signal losses along the mast coax cables used to route the outboard signals back to the cargo bay, and to take advantage of the SIR-C L-band receivers. Thus, the two receiver channels used to form an interferometric pair are not at all matched.

To allow for relative phase calibration of inboard and outboard channels, a coherent caltone is generated at C-band, and routed for injection into each receiver. The frequency of the caltone is chosen to be within the bandwidth of the radar echo spectrum. For the inboard antenna, the injection path is along a short coax cable to a coupler in the antenna panel feed network. For the outboard antenna, in order to eliminate the large thermal drift associated with the long mast cables, a fiber-optic link, with feedback to form a phase-locked loop, is used to route the caltone for injection. This particular design was the result of trades over several alternatives, all of which were determined unfeasible. With this phase-locked loop, the caltone generated by hardware located at inboard side would provide a stable reference at the injection point at outboard side. Maintaining caltone stability at the outboard injection point is important in that the stable caltone signal would traverse through the same electrical path as would the echo signals received by the outboard antenna.

In order to completely calibrate a phased array, injection of the caltone along every active-element path would be required at the cost of greater, and ill-afforded, complexity. For the SRTM system, this added complexity was determined to be unnecessary. A single receive path through an "extra" receive module for each polarization for the outboard antenna channels, and a single path through the panel feed network only for each polarization for the inboard antenna channels were deemed to be sufficient.

Since the caltone frequency is within the echo bandwidth, the level of caltone signals has to be set against the level of average radar echo signals so that the caltone does not overwhelm the radar echo, but with sufficient level for post-mission extraction. The caltone level setting, its co-presence with the echo and thermal noise, and the averaging required to gain sufficiently accurate estimates, made this calibration process less than perfect in that the residual phase imbalance cannot be made to zero all the time. However, through this specific design, the residual phase imbalance, after applying the internal calibration, was within allocation.

Given the large fraction of height error attributed to the residual phase imbalance, it is clear that to improve height accuracy beyond what SRTM has attained, one of the efforts has to be reducing this residual phase error further for the future IFSAR missions.

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