Precision Boresight Measurement for Doppler Radar Systems Measured on a Near-Field Range

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Abstract

Airborne Doppler Velocity Sensors require precise boresight information in determining a Doppler solution. Far-field ranges have been extensively used to provide this boresighting capability. This paper discusses an empirical investigation to determine the feasibility of using near-field techniques to fulfill the boresighting requirement.

Keywords: Boresight, Doppler, Velocity

1. Introduction

Doppler Velocity Sensors (DVS) are Ku band radar sets that provide velocity information to onboard navigation computers. This information consist of heading (down range), drift (cross range) and vertical velocities. An integral part of DVS is a multi-beam antenna, which is boresighted at a Litton far-field range in San Diego, California. In the DVS context, boresighting is the measurement of the angular coincidence between the electrical centroid of each of the four beams of each of two planar waveguide antennas with their common mechanical/structural reference plane. Boresight data is collected, exercised within a Litton algorithm to develop boresight coefficients and the resultant information stored within an EPROM to provide in-flight correction. The far-field range provides highly accurate and consistent data on beam position. The following paragraphs discuss a joint investigation conducted by Litton Guidance & Control Systems (Litton) and Nearfield Systems Inc. (NSI), to determine the feasibility of performing boresighting on a near-field range, where feasibility meant that similar results could be achieved on the two ranges.

2. Antenna Description

The antenna used for this investigation was a production APN-218 DVS antenna. The APN-218 DVS is found on B1B, B52, KC135 and C130 aircraft. The antenna consists of side-by-side planar waveguide arrays. The transmitter array (TXA) is a traveling wave structure, whereas the receiver array (RXA) is a standing wave configuration. Transmission occurs by continuously stepping through the TXA four beam positions at a sixty-four millisecond rate. The receiver array creates four simultaneous beams. Aligning of the transmit and receive patterns of each of the four beams is implicitly part of the pattern product, forming the "two-way" measurement, which reflects operational use. Boresighting addresses the antenna in the two-way mode, rather than measuring the arrays separately. Gain of the antenna is greater than 56 dBi and the beams are displaced in both the down range and cross range directions with respect to vertical incidence (reference Figure 1). The beams are tilted approximately twenty degrees in the fore/aft plane (χ) and approximately 11 degrees in the port/ starboard plane (Λ).

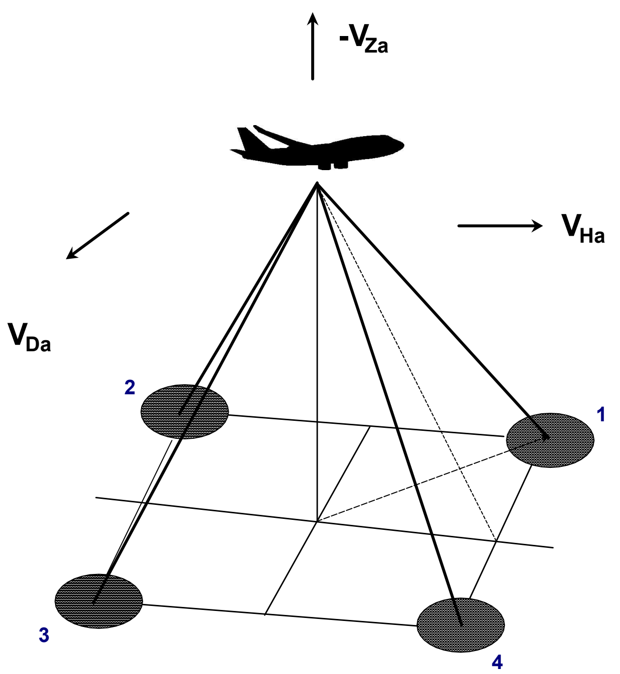

Figure 1: Beam Geometry

3. Far-field Range Description and Problems

The Litton Boresight facility is an elevated Ku band (12-18 GHz) antenna range, consisting of a primary and a secondary tower. Each of the towers is approximately forty feet high and the towers are separated by 288 feet [3]. Reference Figure 2 for a view of the secondary tower, from the pouch of the primary tower. The positioner is an elevation over azimuth of special construction mounted on a massive stone block, which is attached to the top of a rigid tower floated from the surrounding building. Typical facility measurements include gain, sidelobe levels, beamwidths and beam separation (position). The latter measurement requires a high degree of accuracy and is the primary purpose of this facility. Two modes are tested. One-way measurements where the antenna is tested in the receive mode, and two-way where the antenna is tested as it would be in its operational configuration. It is this two-way test which dominates the measurements on the range and was the format used for the near-field investigation.

Figure 2: View of secondary tower and positioner

The San Diego range has been in service for almost thirty years, and suffers from both facility and equipment issues associated with continuous use over that period of time. Repair time (facilities and equipment) is becoming a large percentage of overall range time. Additionally, since the antennas are built in Northridge and tested twice at different times (first and final boresight) in San Diego, a significant logistics problem also exist. It is for these reasons that Litton was seeking an alternative means of boresighting antennas and this in turn led to the near-field investigation.

4. Near-field Range Description

The DVS antenna was measured at the Nearfield Systems Incorporated facility in Carson, Ca. It was tested using an NSI Model 200V-3x3 planar scanner with granite base option, which provides a 3x3 ft scan area. Figure 3 shows the antenna and scanner.

Figure 3: DVS antenna and nearfield scanner

The four transmit beams were measured in separate tests, while the receive beam was measured in each of these tests to facilitate data processing. A PIN diode switch was used to multiplex the data. To reduce multipath errors, the nearfield data was collected at 2 Z-positions spaced by 0.25 wavelength [4]. Measurement of each nearfield data set (receive beam plus one transmit beam) took approximately 17 minutes.

The boresight for each beam was calculated using custom sequence files for data processing. The 2-way pattern was formed by multiplying the far-field patterns of the transmit beam and the receive beam. Then the initial boresight was determined by finding the peak. To achieve better angular resolution, an azimuth cut was generated in a narrow span around the initial peak location, then an elevation cut at the azimuth peak. This iteration process was repeated 2 times, after which the peak location was found to have a numerical accuracy of better than 3 arcseconds.

5. Near-field Range Challenges For Accurate Boresight Measurements

For the tests at NSI, an indication of boresight accuracy was obtained by measuring the antenna at Phi = 0° and Phi = 180° and comparing the results. It was found that accurate alignment of the antenna to the scan plane was crucial in getting accurate boresight results.

The alignment of the AUT in Phi was verified by touching

2 reference pins on the side of the antenna with a dial indicator mounted to the RF probe. Alignment in azimuth and elevation was checked by touching 3 marked locations on the front of the antenna. The ultimate alignment accuracy was approximately ±0.001", corresponding to a boresight uncertainty of ±15 arcseconds.

Other error terms that contribute to boresight errors were:

- X and Y positioning errors. These were calibrated using a laser interferometer system.
- Scanner planarity errors. A granite-based 3x3 ft scanner was chosen for these tests since it offers improved accuracy and stability. The planarity is better than 0.001" RMS.
- RF cable flexing effects, which were minimized by using a high-quality flexible cable.
- Mutual coupling errors; these were reduced by measuring at 2 probe Z positions and coherently processing the data [4].
- Truncation errors. The 3x3 ft scan area proved to be only just enough to measure this antenna and it was concluded that a larger scanner would provide more accurate results.

6. Measured Near-field Data

As an example, Figure 4 shows the nearfield greyscale plots for transmit beam 1.

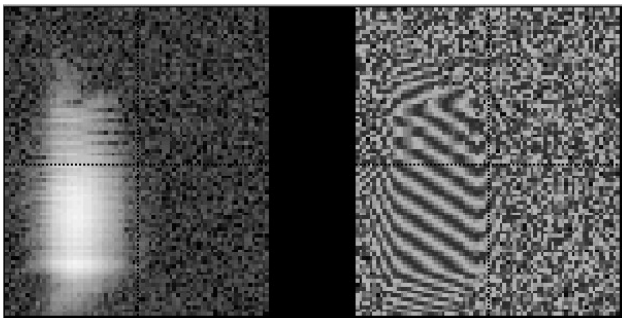

Figure 4: Nearfield amplitude (left) and phase (right) greyscale plots

Figure 5 shows the boresight results for each of the four 2-way beams, at Phi=0° and Phi=180°. The maximum difference in azimuth values is 0.06° or 216 arcsec. The maximum difference in elevation is 0.03° or 108 arcsec. Note that these results are for uncorrected data.

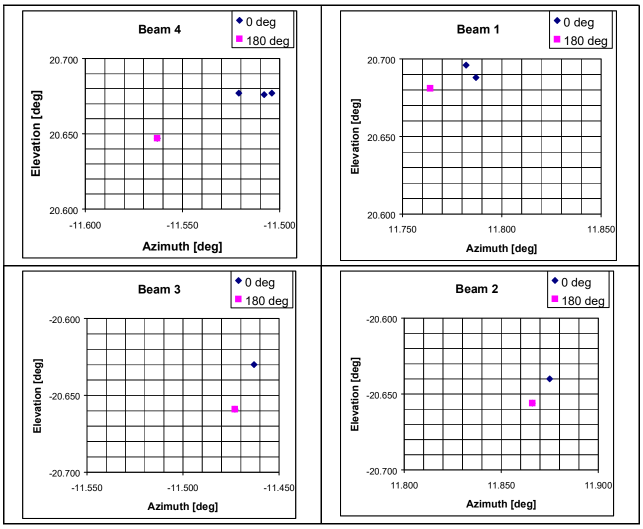

Figure 5: Boresight results for all 2-way beams

7. Comparison Between Near-field and Far-field Boresight Data

Antenna testing occurred in three phases. The first phase took place at the San Diego facility where the test article was measured in the automatic (normal) configuration, then in a manual configuration, and a manual, three-point configuration with the antenna first mounted in its normal orientation and then in a orientation 180 degrees from the normal. This original set of uncorrected data was exercised within the Litton algorithm (ABS), which compensates for frequency, temperature, pressure and humidity variances. The test antenna was then shipped to NSI for the second phase. Here data was collected for both of the manual three-point configurations. This raw data was then turned over to Litton, along with frequency, temperature, pressure and humidity inputs, to be exercised by the ABS. Finally, the antenna was returned to San Diego and all phase one testing repeated.

Based on a total system error of 0.13% of ground speed and the boresight contribution to the overall system error budget, the allowable RMS error in boresight of the average of the four χ angles is 45 arc-seconds, and for Λ, the allowable RMS error is 90 arc-seconds [2]. Historically, Litton has consistently been able to demonstrate repeatability on the order of 30 arc-seconds for χ and 75 arc-seconds for Λ, and it was these magnitudes of angular difference we were hoping to achieve on the near-field range. Table-1 indicates the results of this investigation with respect to the down range angle (χ). The data contained in Table-1 is referenced to the phase one corrected results [1].

Table-1: Site Differences in χ (arc-seconds)

	χ_0	χ_{180}
San Diego-1	0	0
NSI	-30	-26
San Diego-2	-15	17
Allowable RMS Error	45	45

Table-2 contains the results of the cross range (Λ) comparison.

Table-2: Site Differences in Λ (arc-seconds)

	Λ_0	Λ_{180}
San Diego-1	0	0
NSI	58	35
San Diego-2	0	-32
Allowable RMS Error	90	90

As can be seen from the tables, the near-field data met our established criteria for both angles. The tables also indicate the high degree of repeatability between far-field measurements.

8.0 Conclusions

The primary reason for Litton maintaining a far-field range in San Diego is the high degree of accuracy and repeatability provided by that facility in terms of boresighting Doppler antennas. Litton was seeking an alternative approach to the far-field facility in San Diego. Research of available databases, discussions with various antenna houses and near-field range equipment manufacturers failed to provide hard evidence that a near-field range could provide similar performance. Thus, this joint Litton and NSI effort was undertaken to furnish that evidence.

Through a thorough understanding of all the near-field errors and proper near-field alignment techniques, this effort resulted in data that indicated that a near-field range could be a viable replacement for a far-field range with respect to antenna boresighting. As a result of this effort, Litton has purchased a NSI 300V-8x8 scanner that will be on-line and providing redundant antenna data in the fall, and is tentatively scheduled to become the primary boresighting facility in January, 1999.

References

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