Getting aHead(ing) with eLoran

Presented By

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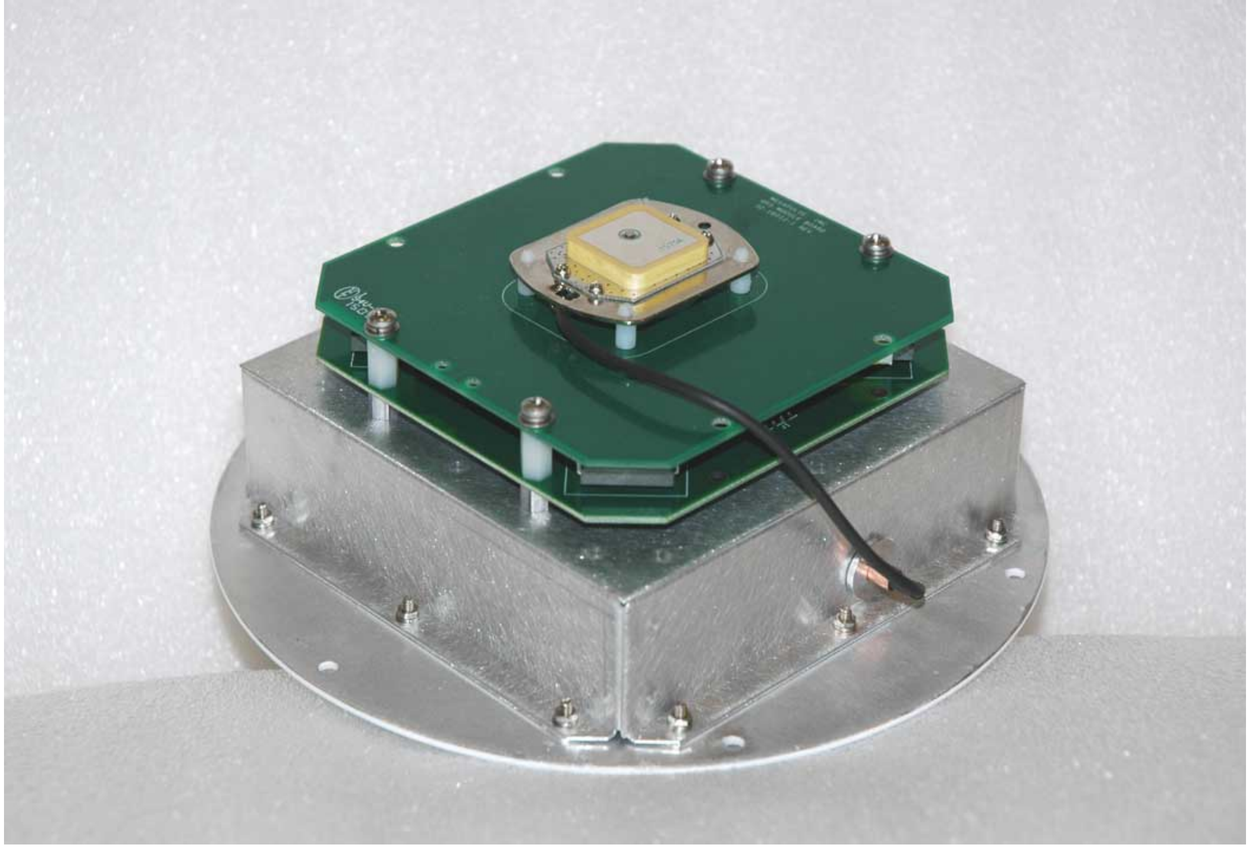
Overview

- Development of eLoran Sensor
- Manufacturing Issues
- Position Fixing Characteristics
- Heading Characteristics
- Observations and final thought

A Commercial eLoran Sensor

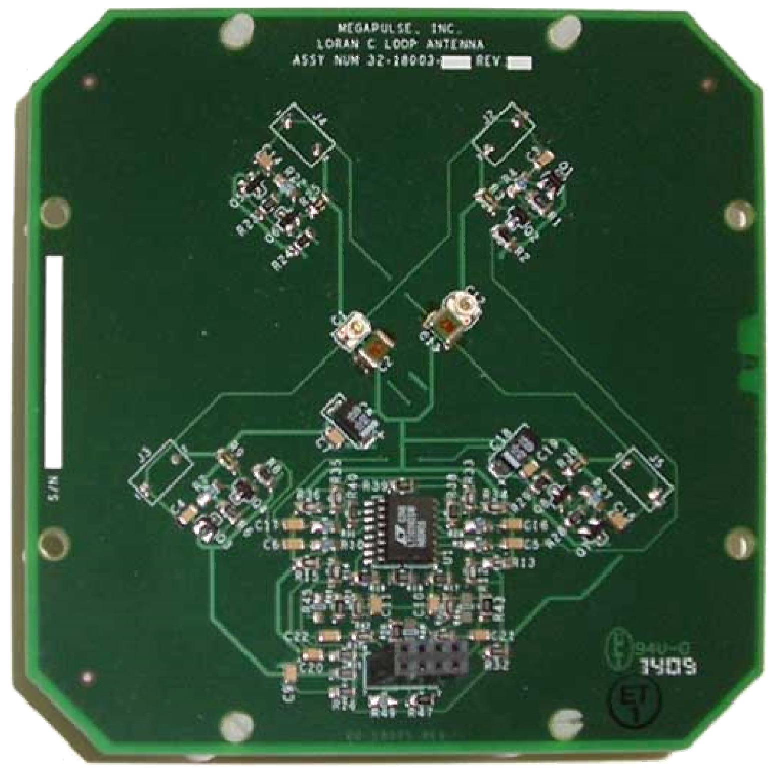
- Goals as presented … Tokyo
  - Integrated … eiver using H field an… ower in, data …
  - Int…
  - S…
  - P… Apr 2005
  - Ma… ost s… s end-user pricing of le… an $1,000

Design Challenge – Easy to Build



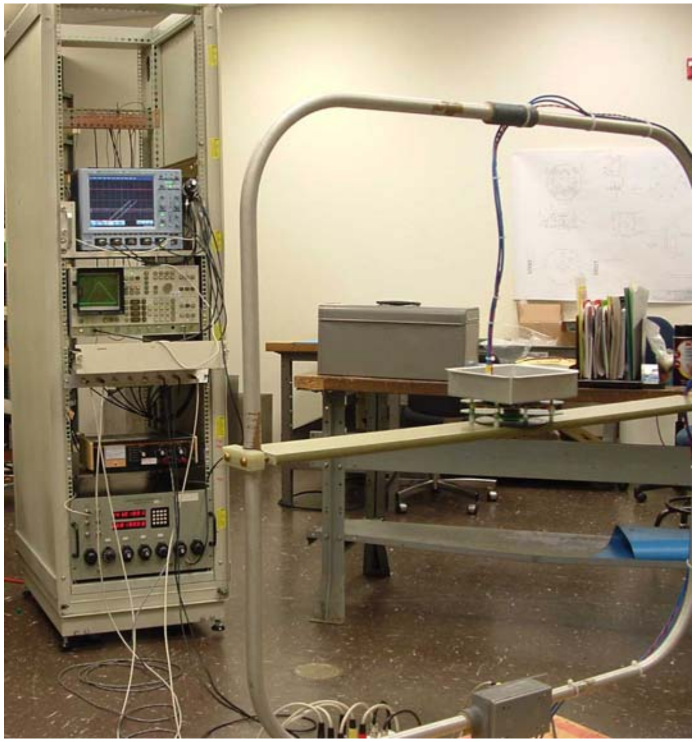
Design Challenge – Reproducible Antennas

- Minimizing efield pick-up
  - Main preamp below winding termination
  - Instrumentation amp for common mode rejection
- Minimizing cross coupling
  - Double shield eliminates parasitic p/u from preamp to opposing windings
  - Critical runs w/i shield layers



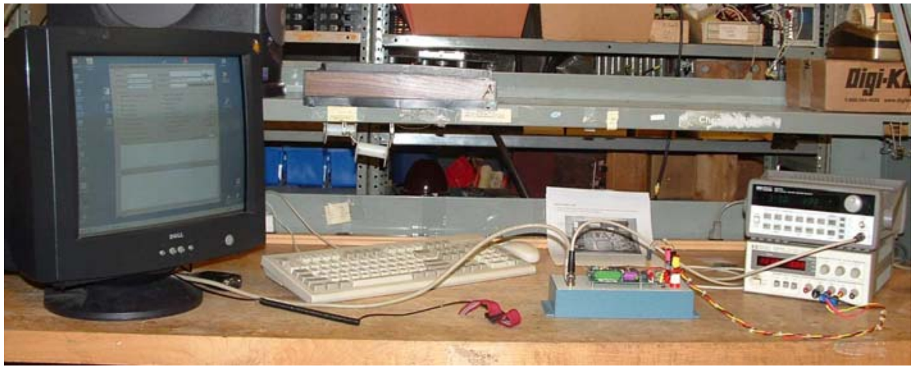
Manufacturing Test – Antenna Bd

- Purpose:
  - Tuning to equalize response from each loop
- Equipment:
  - LSG and Antenna, Spectrum Analyzer, O'scope, Channel Selectors
- Procedure:
  - *Step 1*: Loops independently coarsely tuned to 100 kHz (± .5kHz)
  - *Step 2*: Zero crossings (~6^{th}) fine tuned to ±5nsec

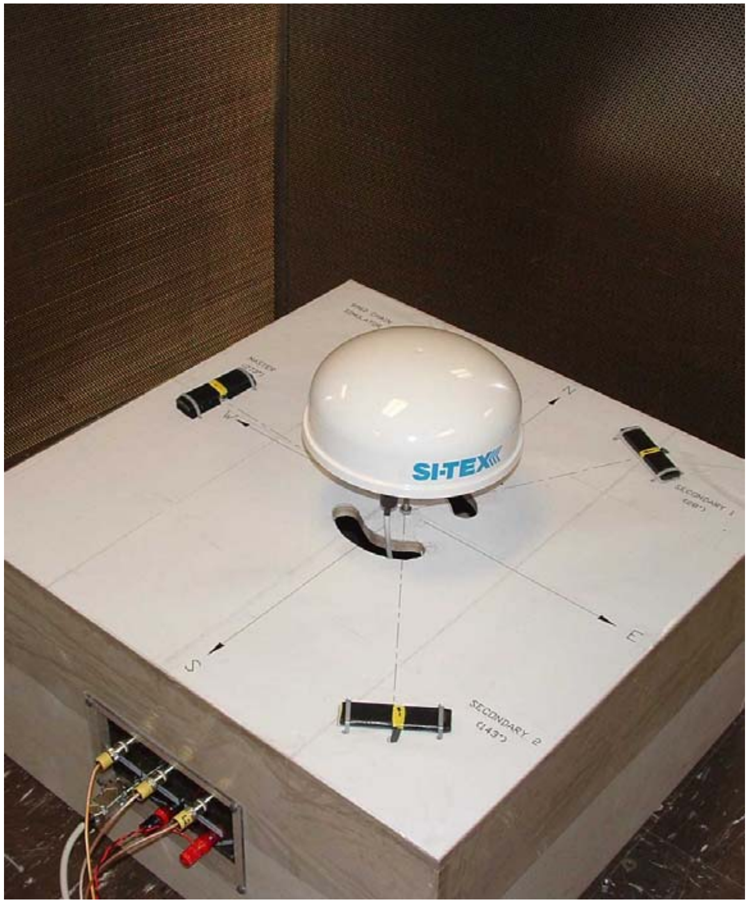


Manufacturing Test – DSP/MoBo

- Purpose:
  - Verify performance of A/Ds, DSP, other logic chips, loads firmware
- Equipment:
  - Reelektronika Test Software and Hardware Box, Function Generator
- Procedure:
  - Fully automated custom test program click to start, Pass/Fail response



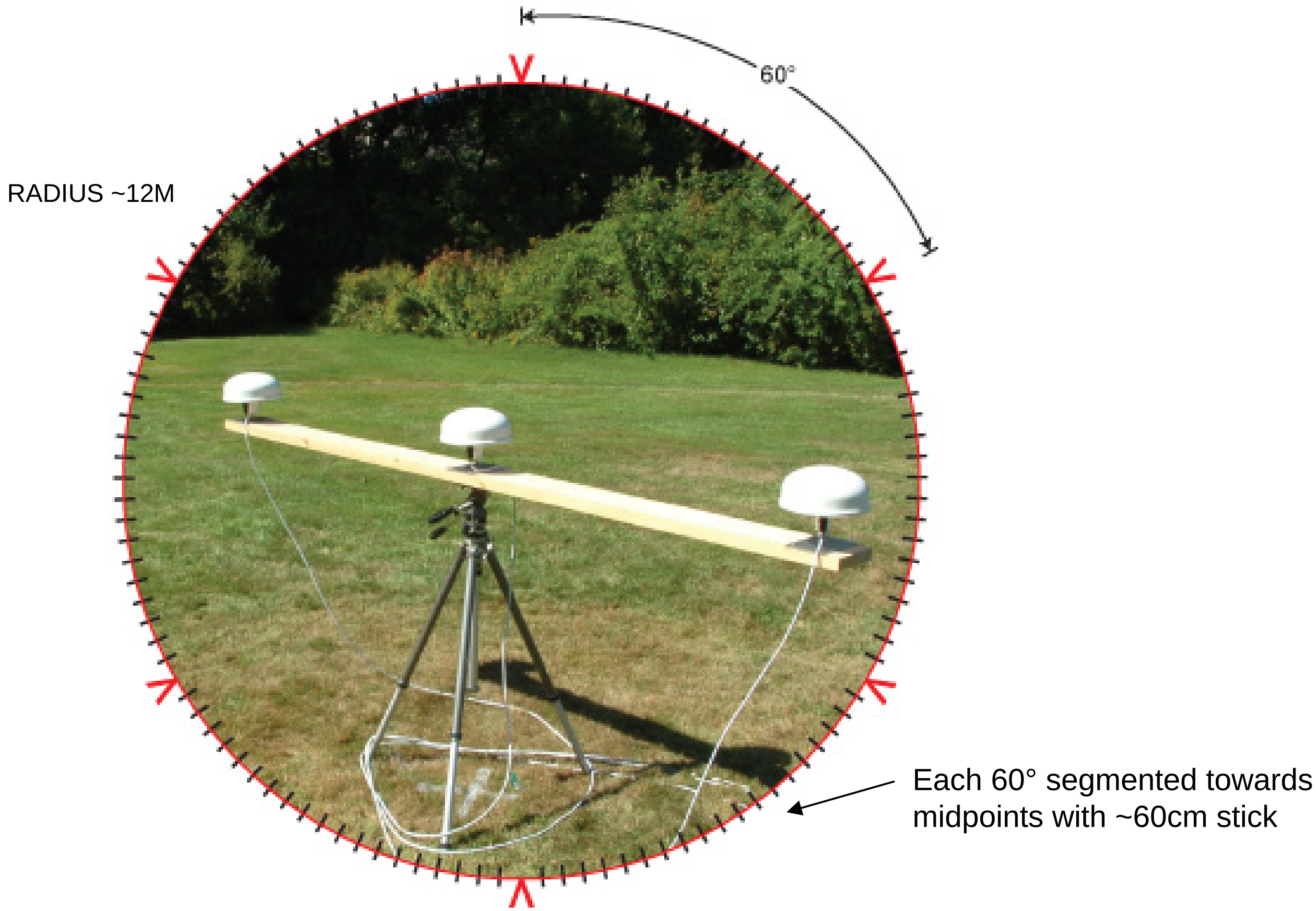
Manufacturing Test – Unit Assembly



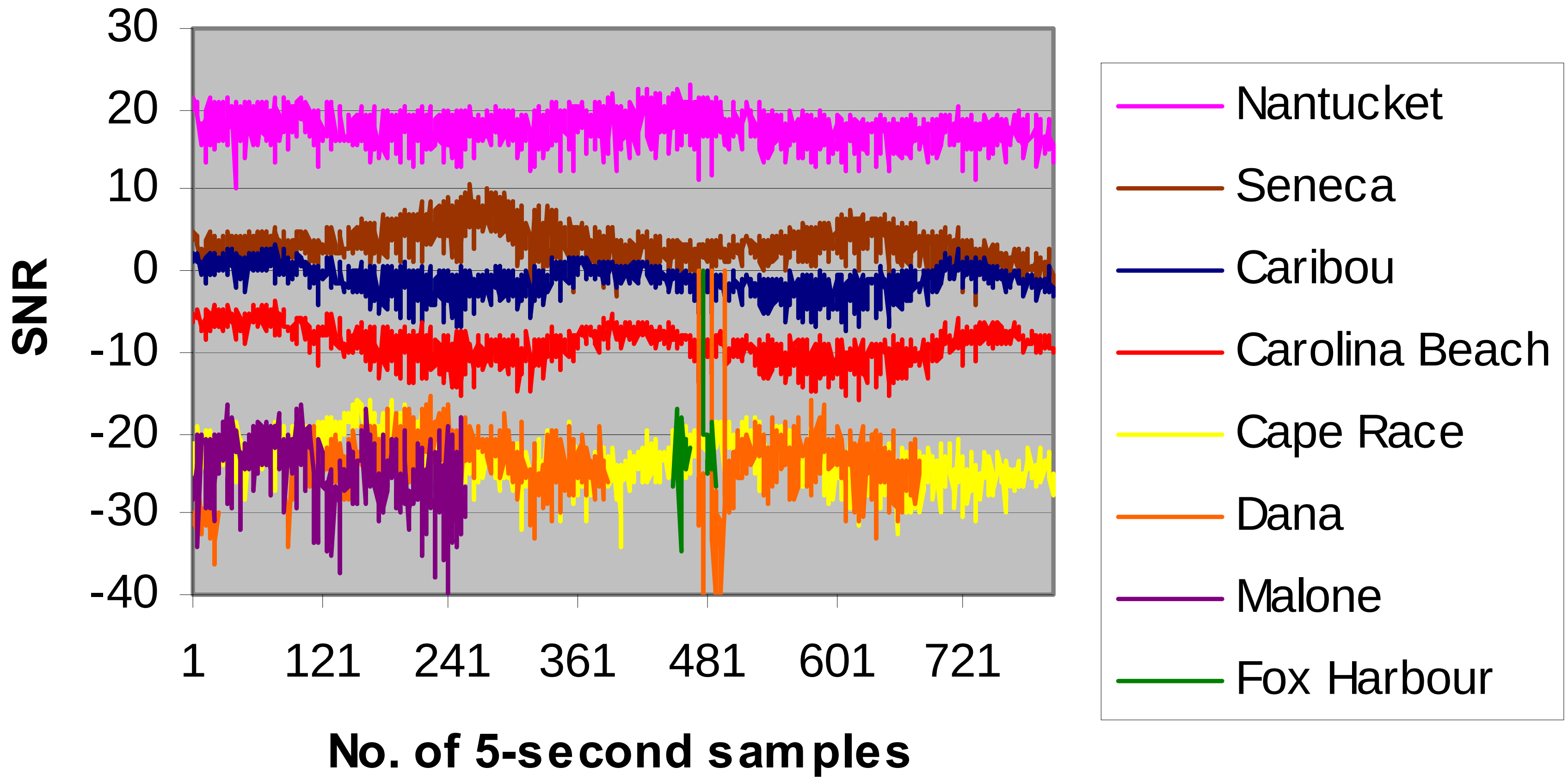
- Purpose:
  - Verify full signal processing capability
- Equipment:
  - Loran Signal Generator and antennas (Chain Simulator), GPS Reradiator, PC w/LERX
- Procedure:
  - 3 orientations N & ±45, verify compass and positional accuracy/ stability

Field Testing of Integrated Antenna

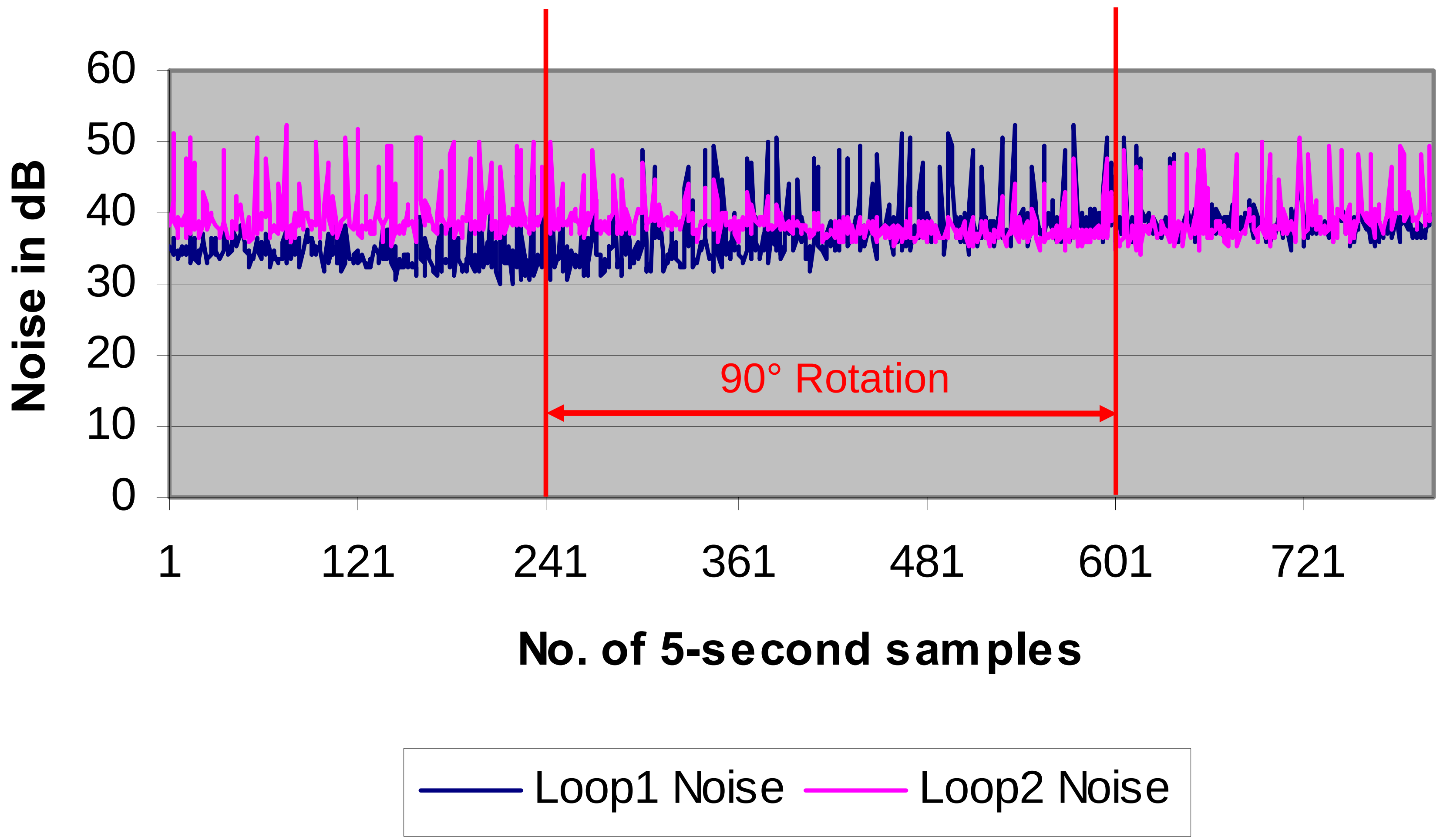
- Tests were performed in September 2005 to validate manufacturing processes are resulting in uniform performance of units.
- Measurements of position and heading for:
  - Stationary vs rotated
  - Split vs integrated
  - Different H-field designs
  - Repeatable and Absolute Accuracies
  - Dynamic and Challenging


60°
RADIUS ~12M
Each 60° segmented towards
midpoints with ~60cm stick

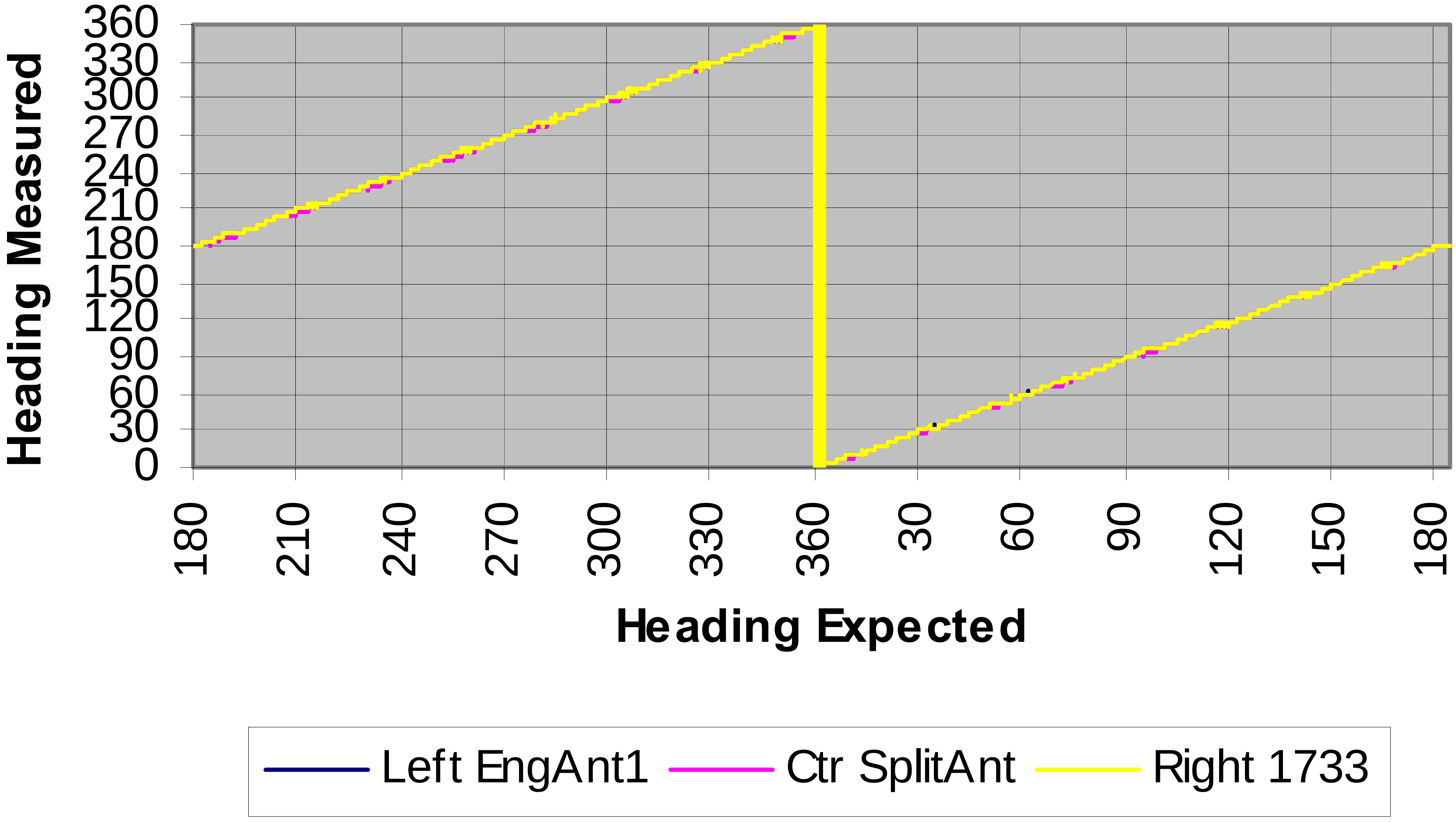
Ant Rotation 6: Signal Environment



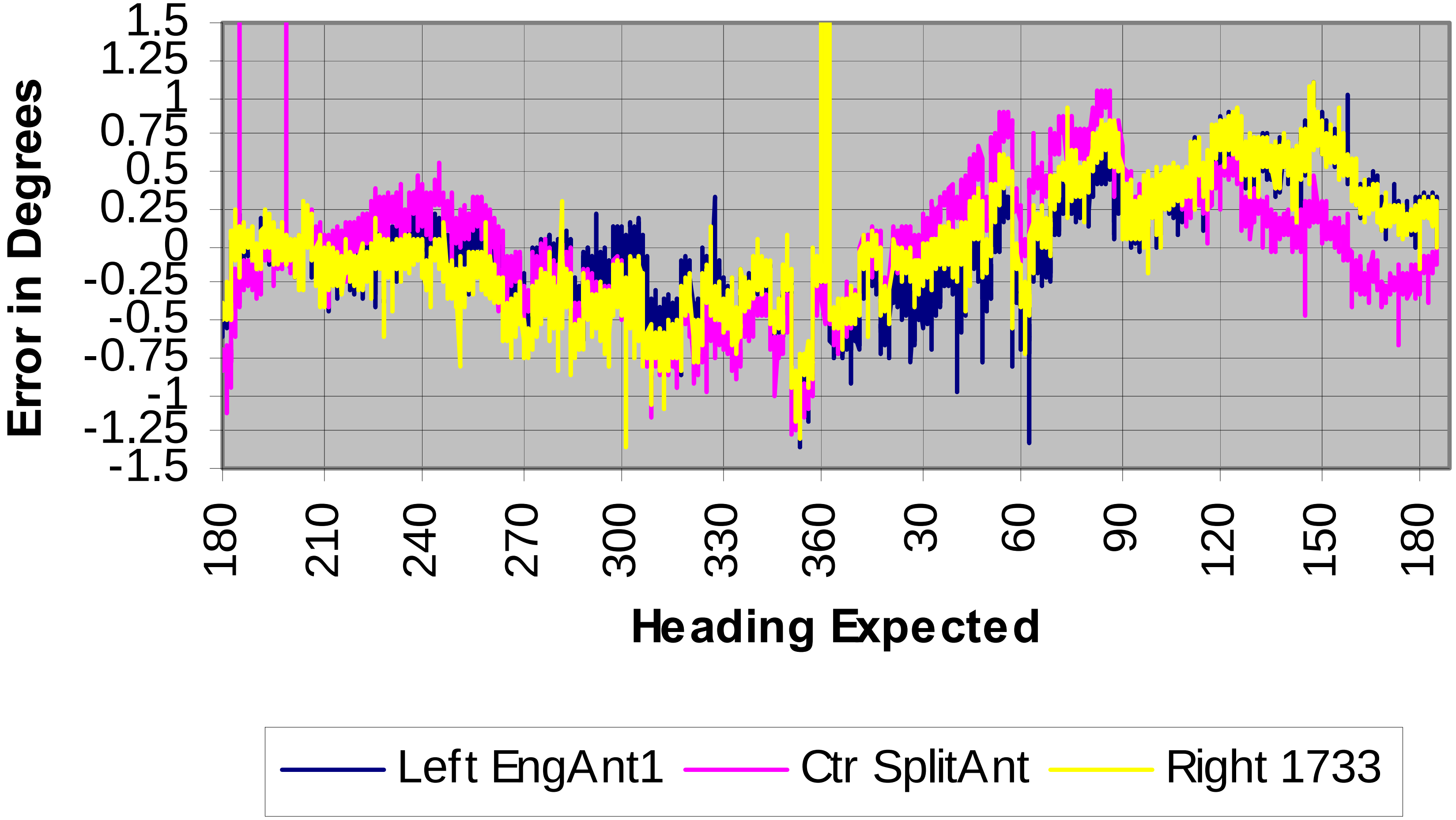
Ant Rotation 6: Loop Noise Values



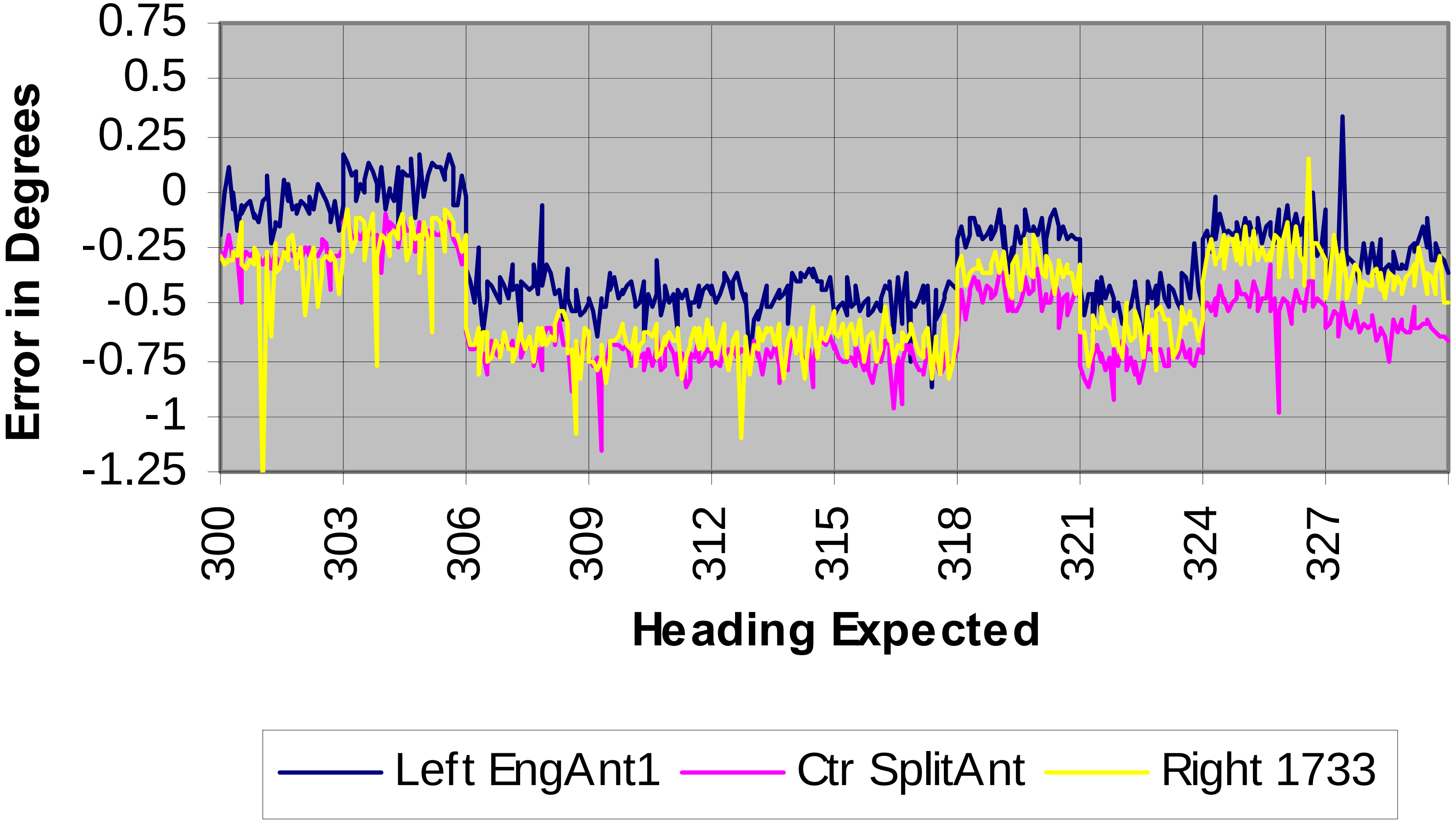
Ant Rotation Test 6&7: 3 degree increments



Ant Rotation 6&7: Measured Error

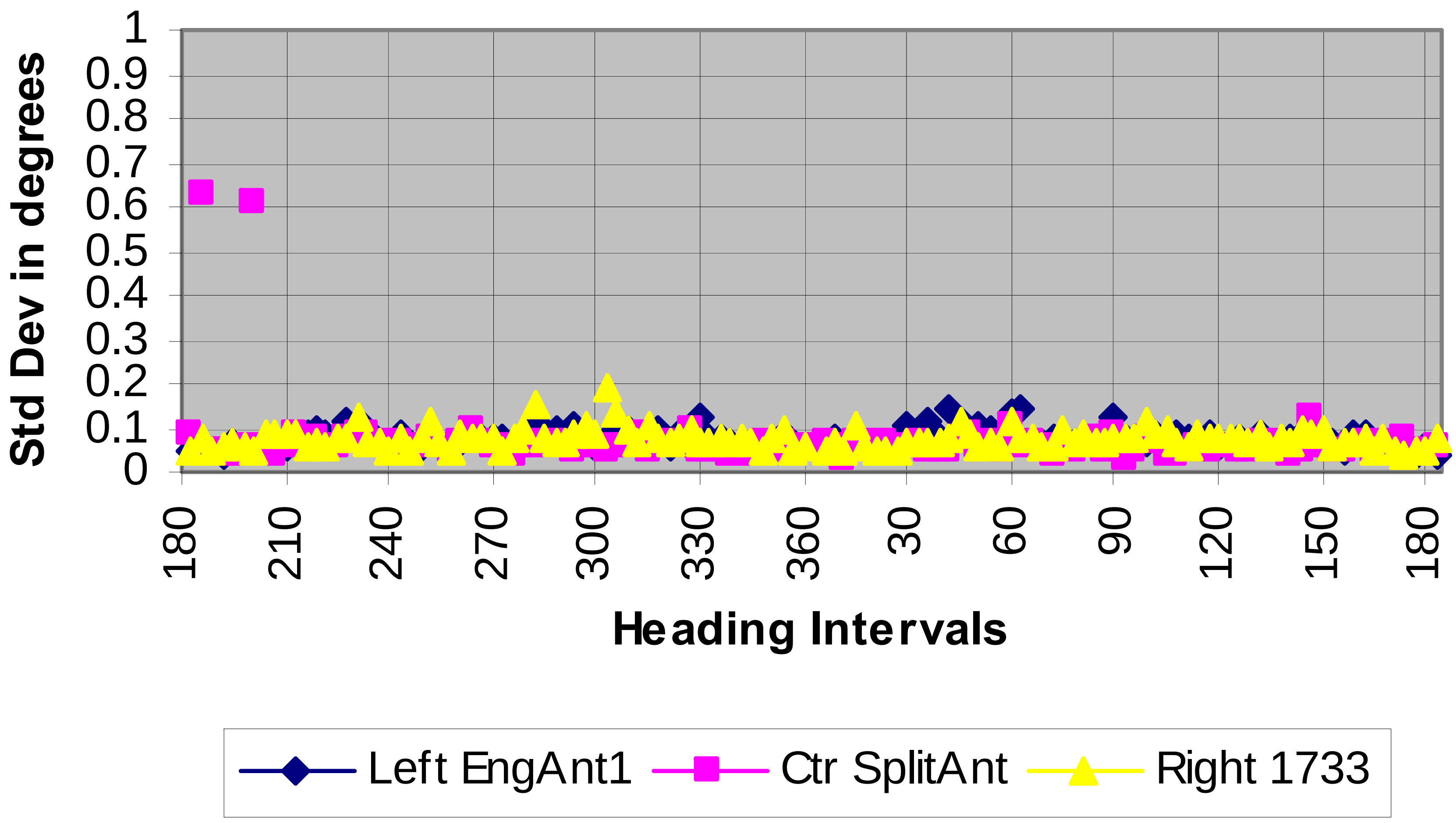


Ant Rotation 6&7: Error Close-up

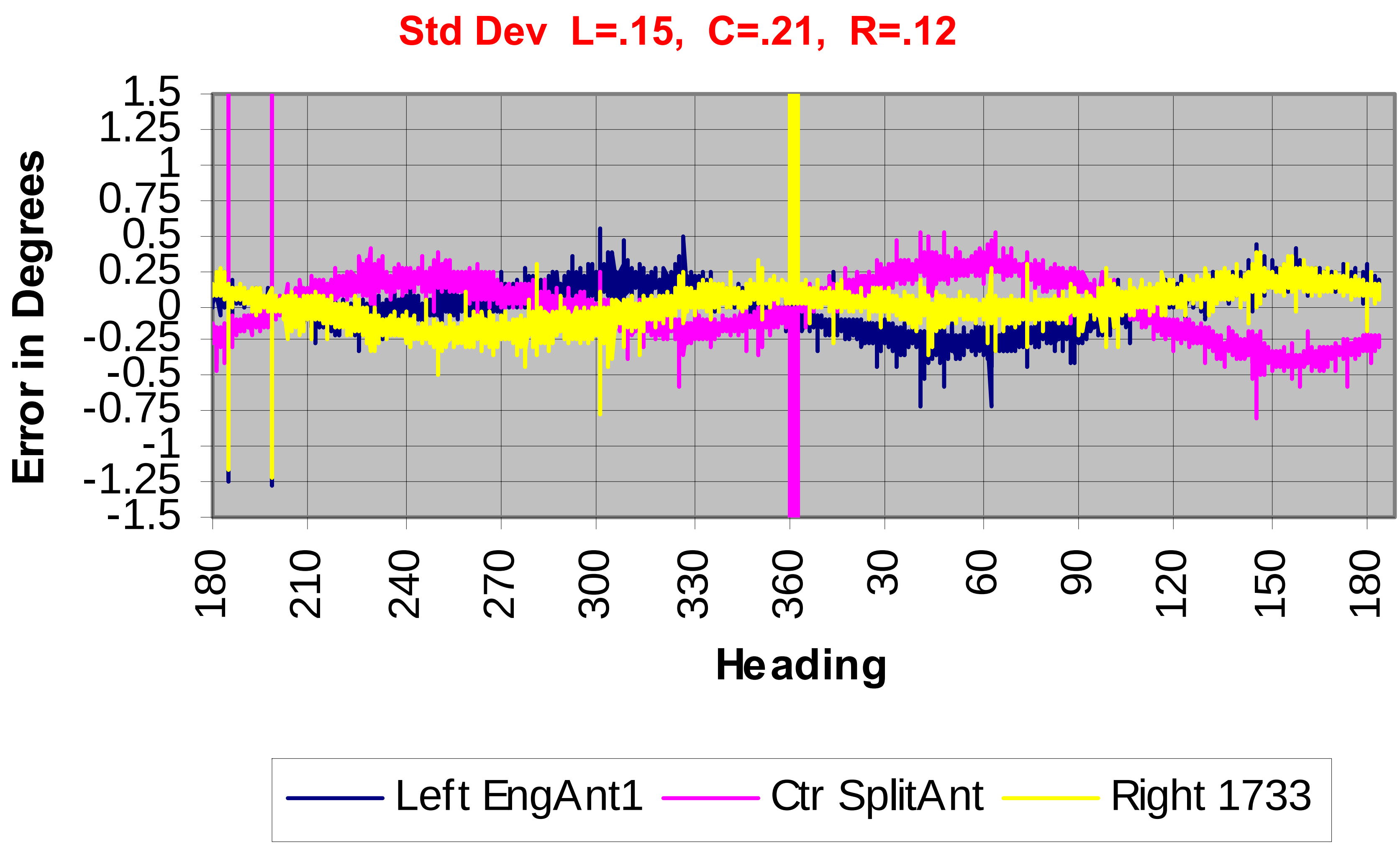


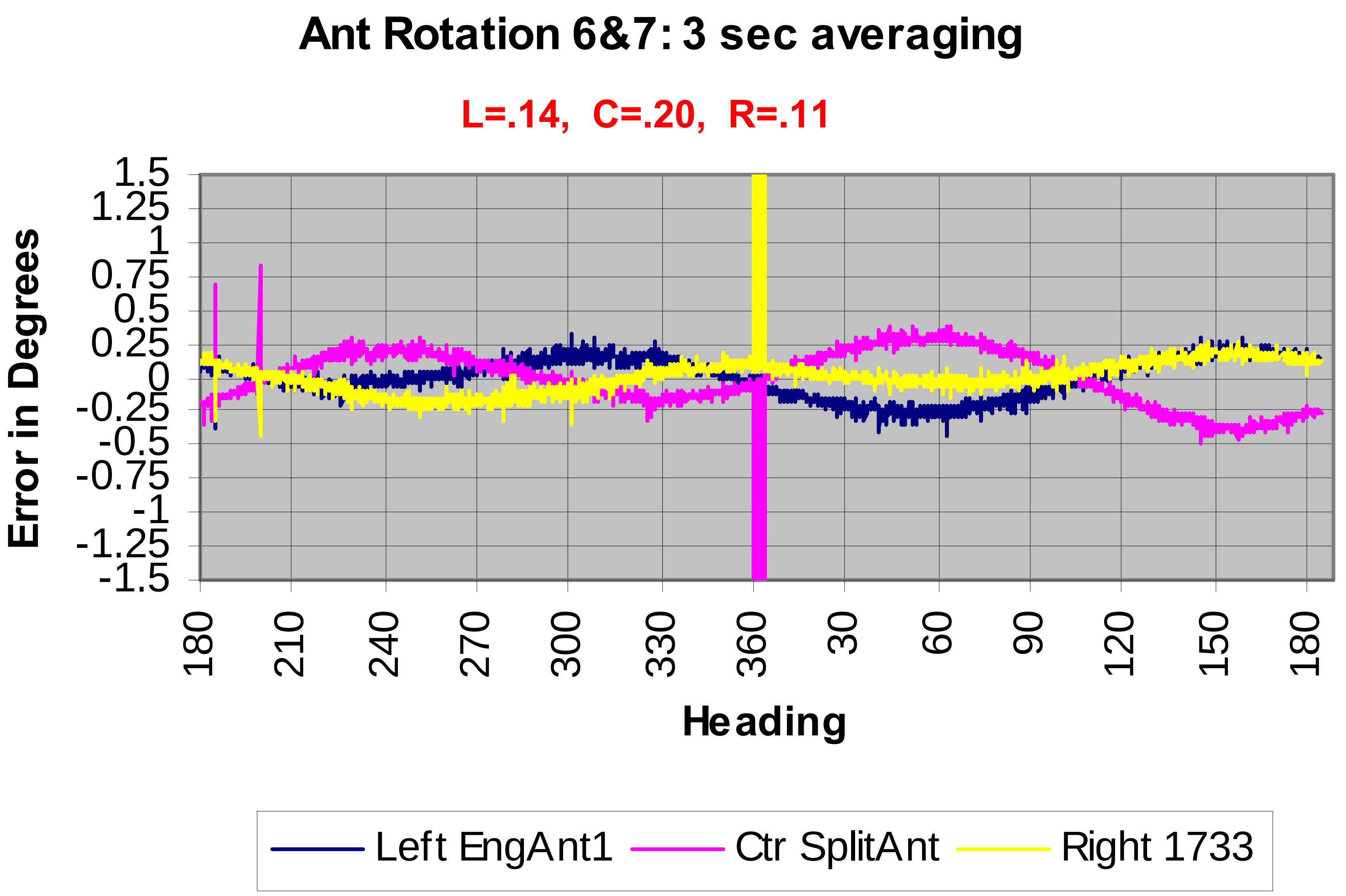
Ant Rotation 6&7: Heading Stability

Ave Std Dev L=.08, C=.07, R=.08



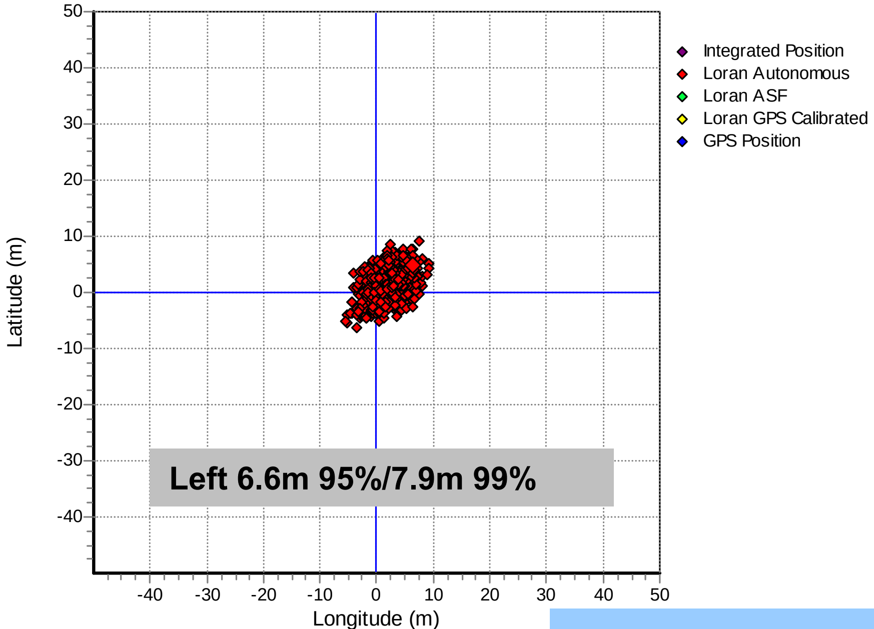
Ant Rotation 6&7: 1Hz Dev fr Mean

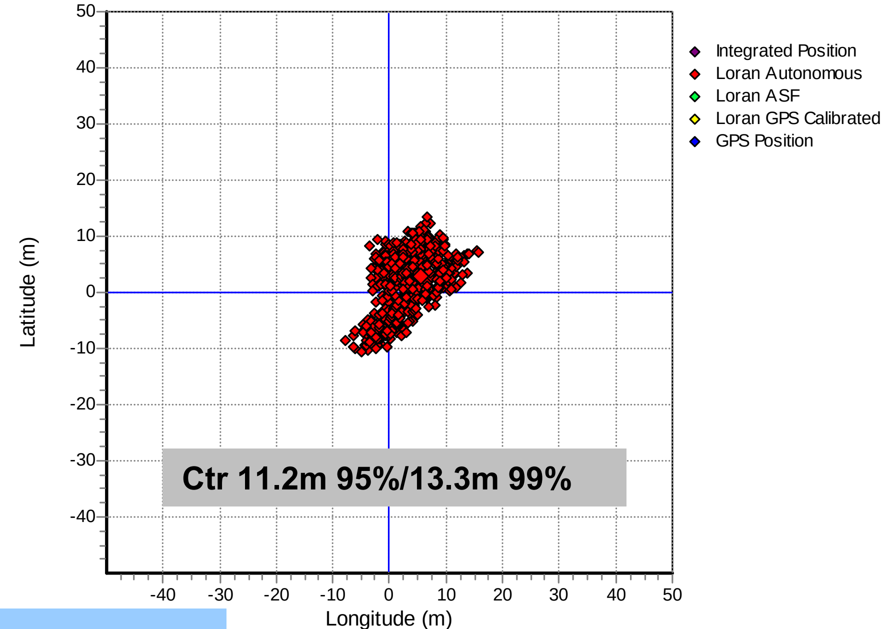


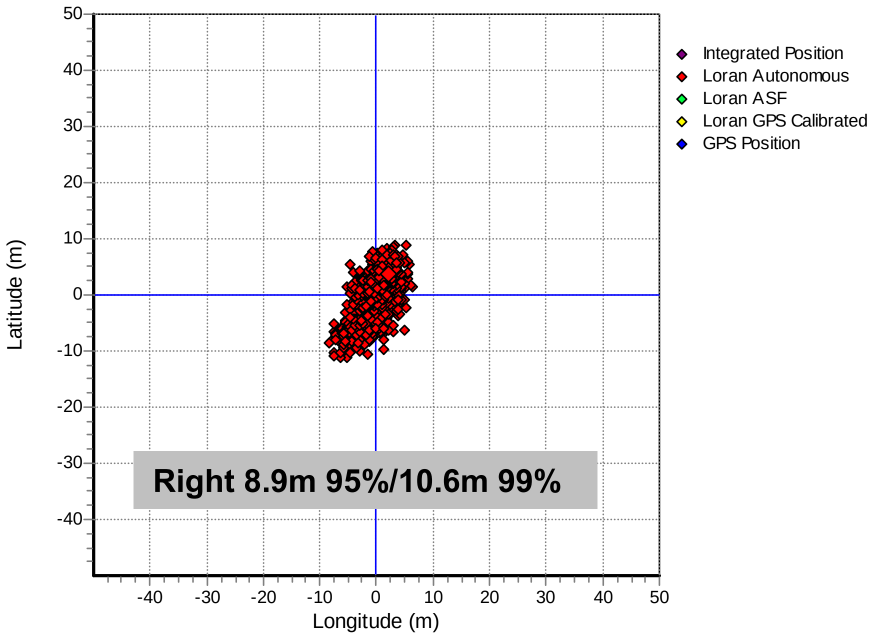


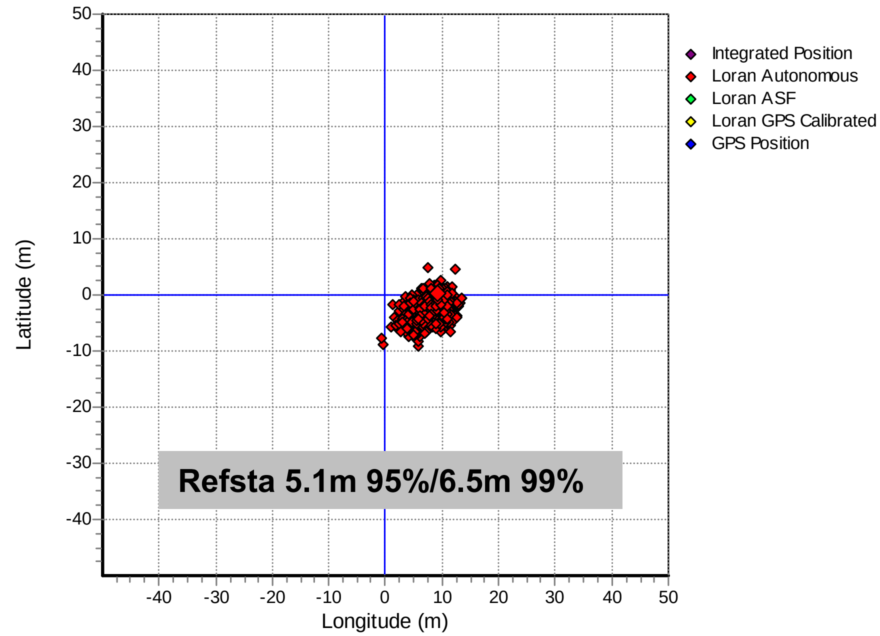
Ant Rotation 6&7: 3 sec averaging
L=.14, C=.20, R=.11
Error in Degrees
1.5
1.25
1
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-1
-1.25
-1.5
180
210
240
270
300
330
360
30
60
90
120
150
180
Heading
Left EngAnt1
Ctr SplitAnt
Right 1733

Antenna Rotation Test 6

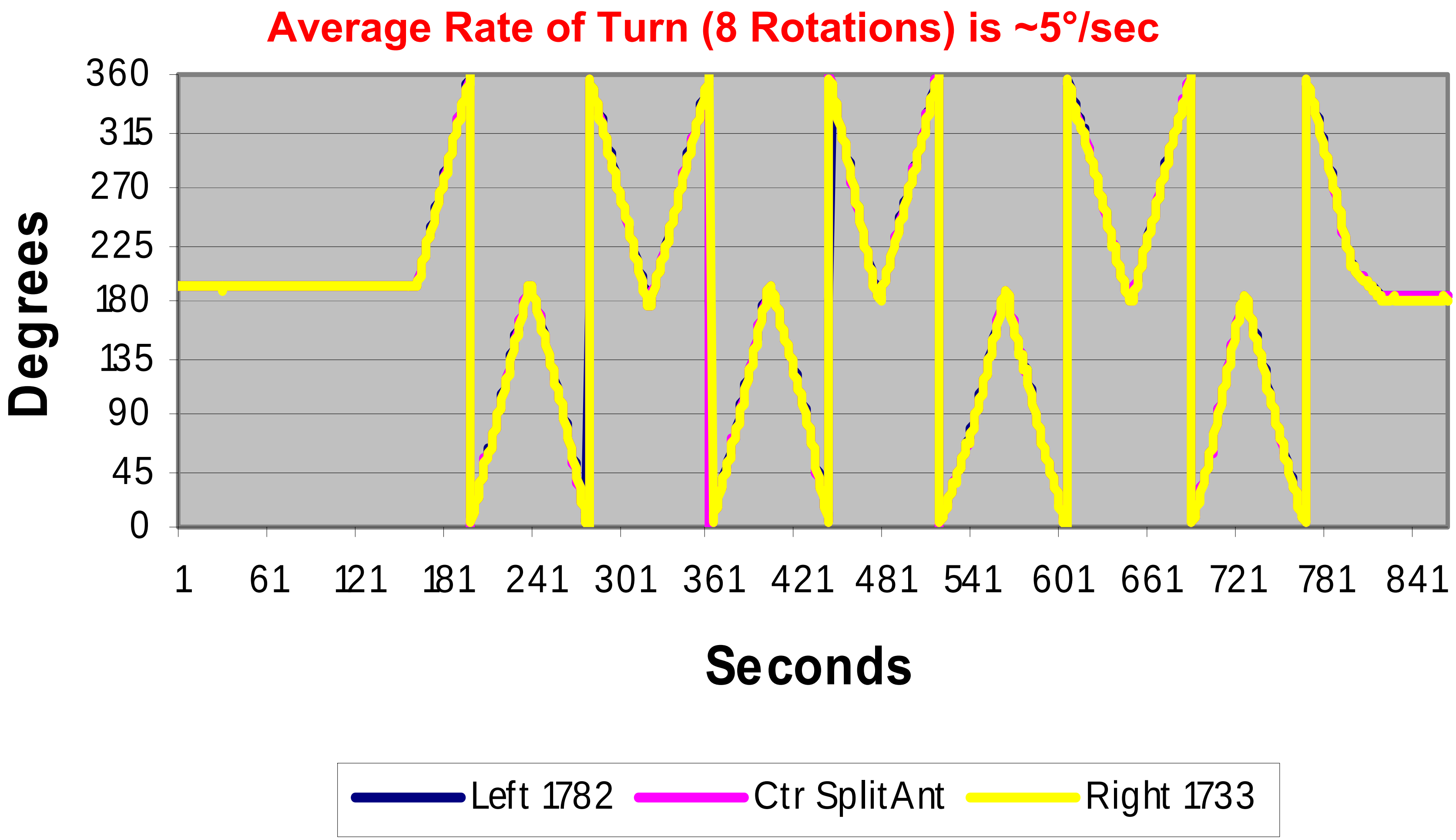




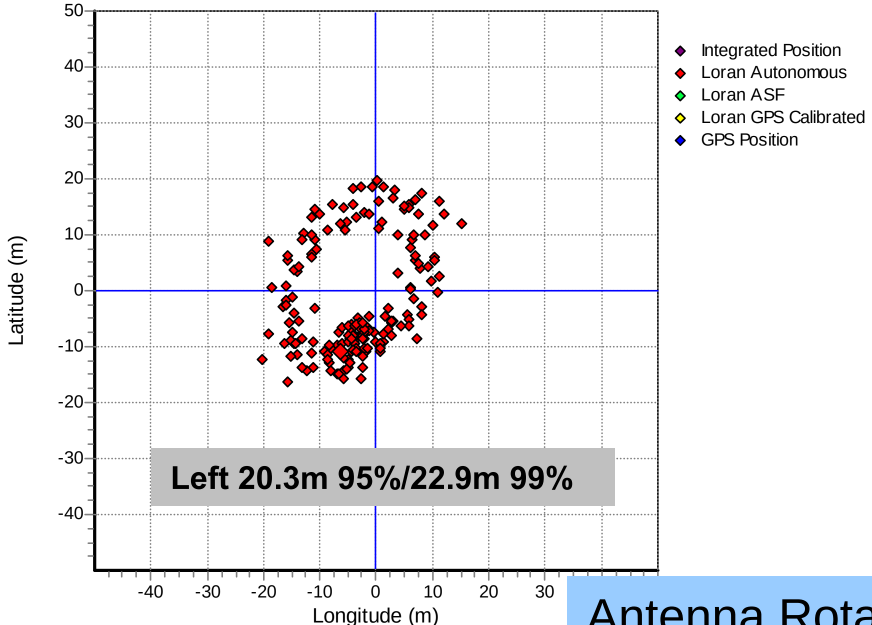


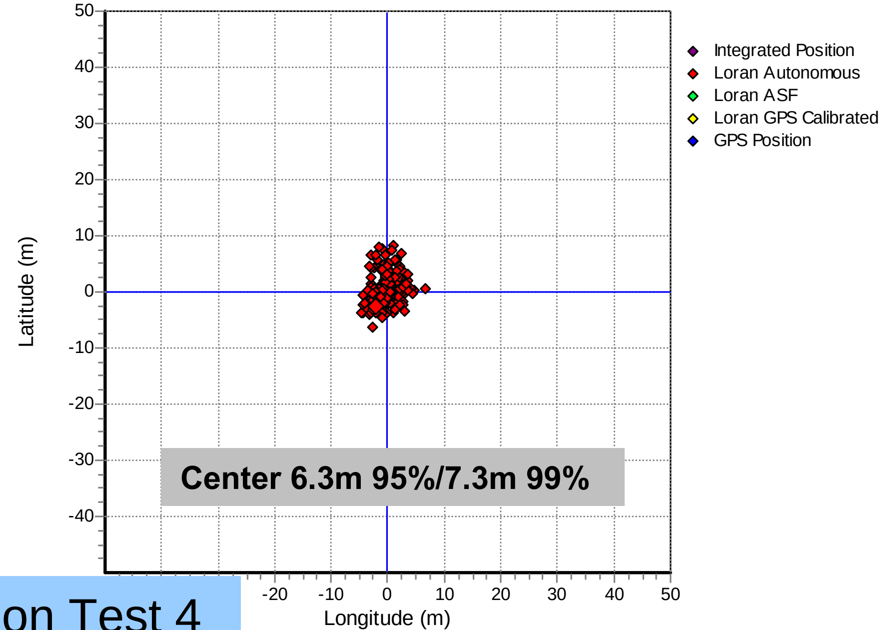


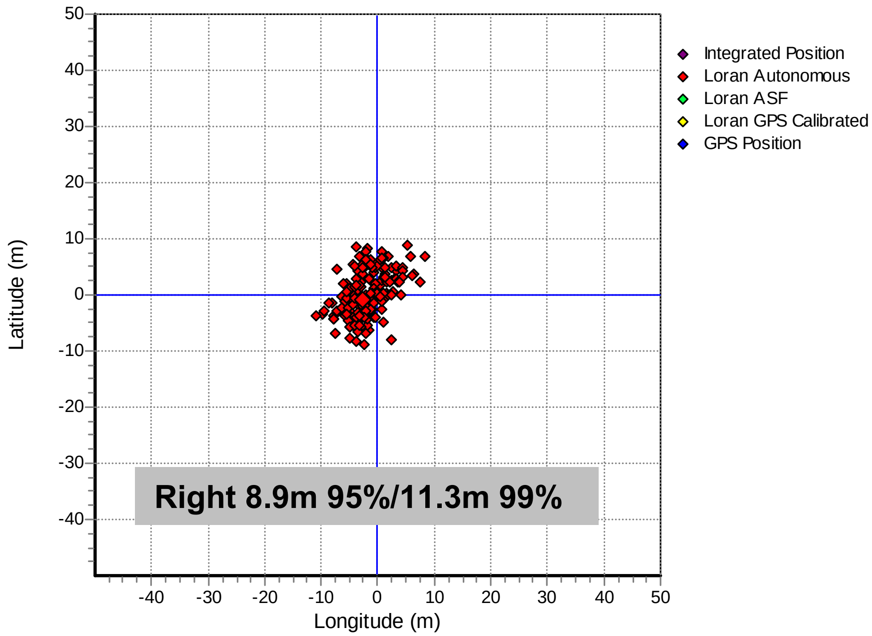
Antenna Rotation Test 4

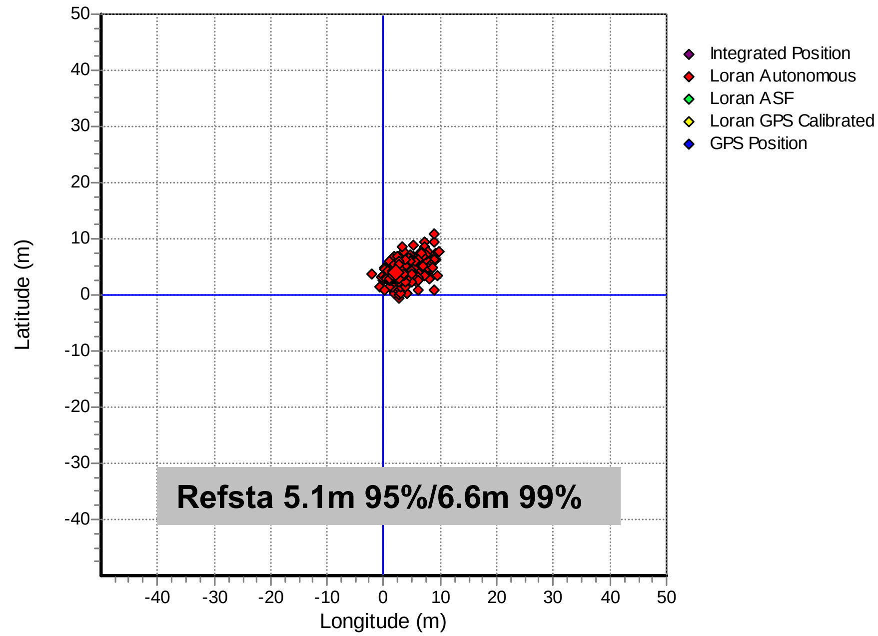


Antenna Rotation Test 4

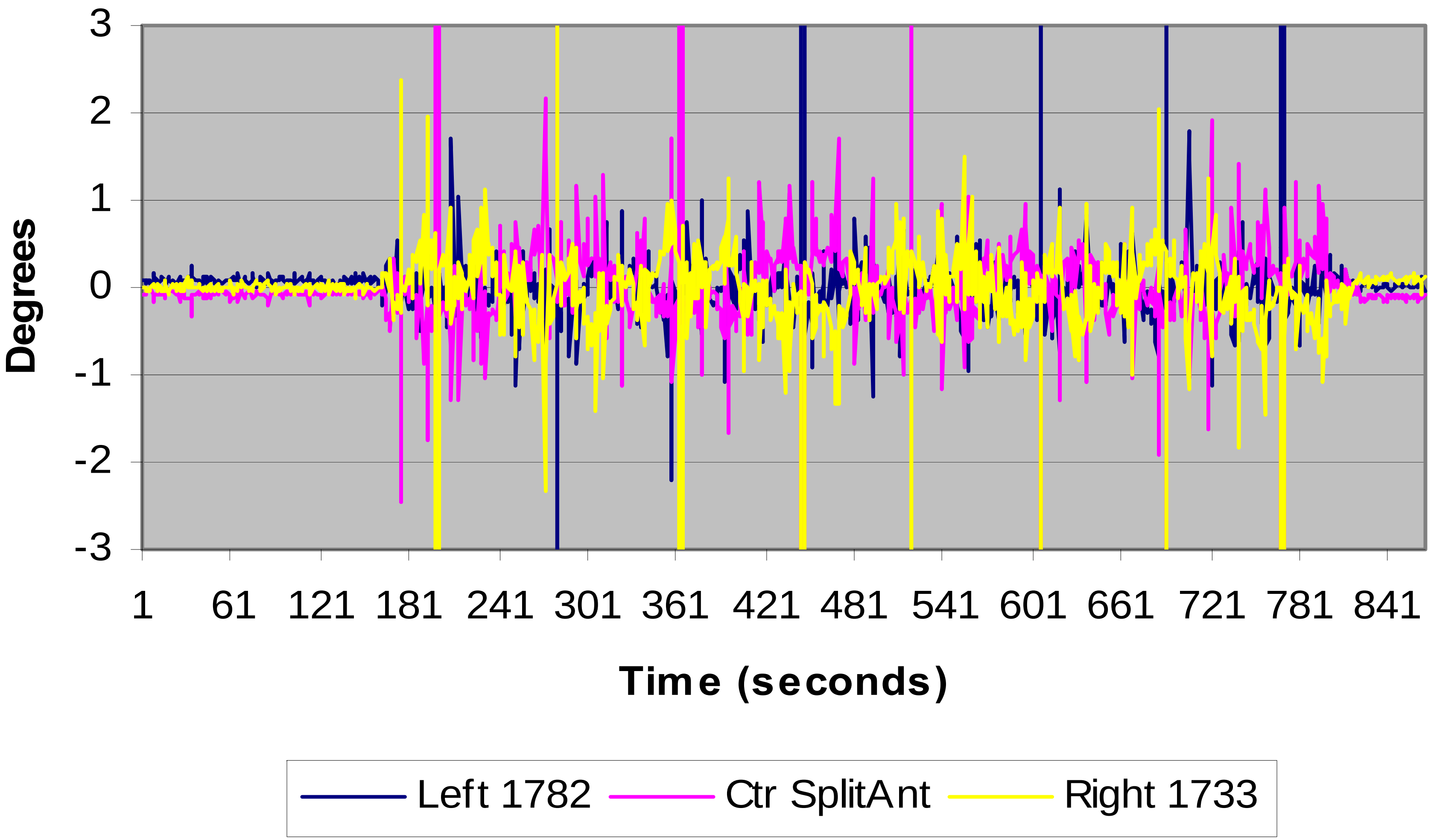




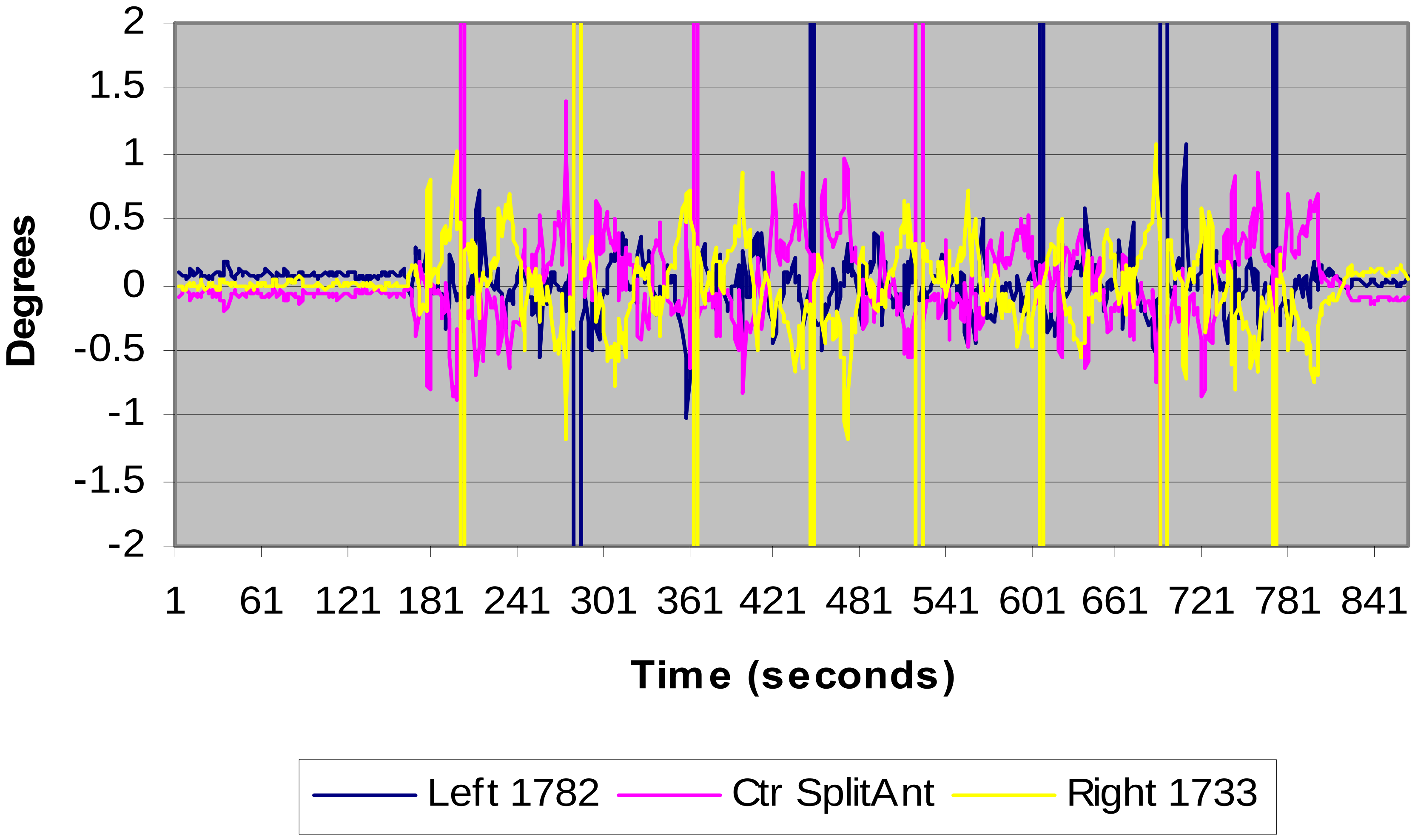




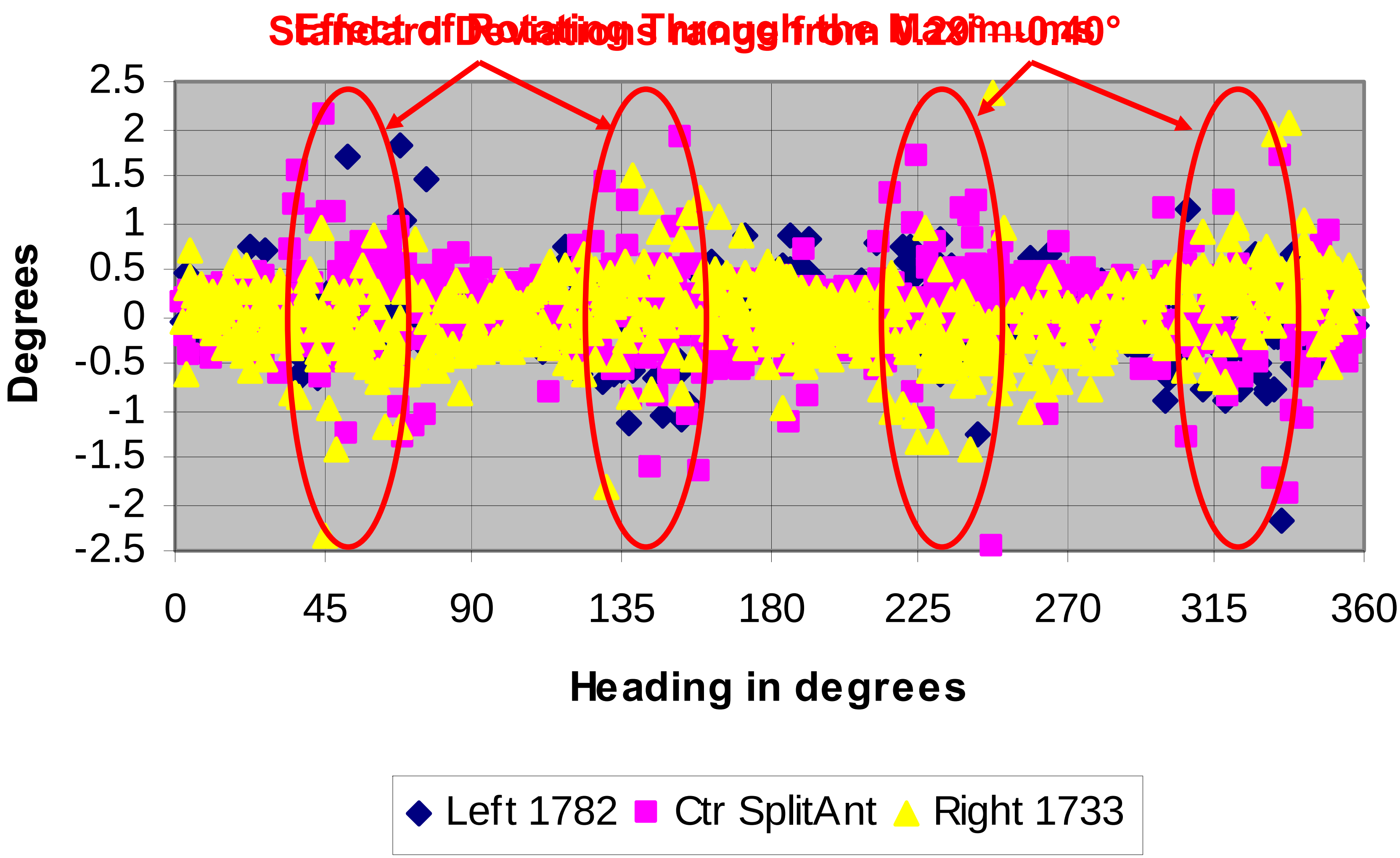
Ant Rotation Test 4: Raw 1Hz Output



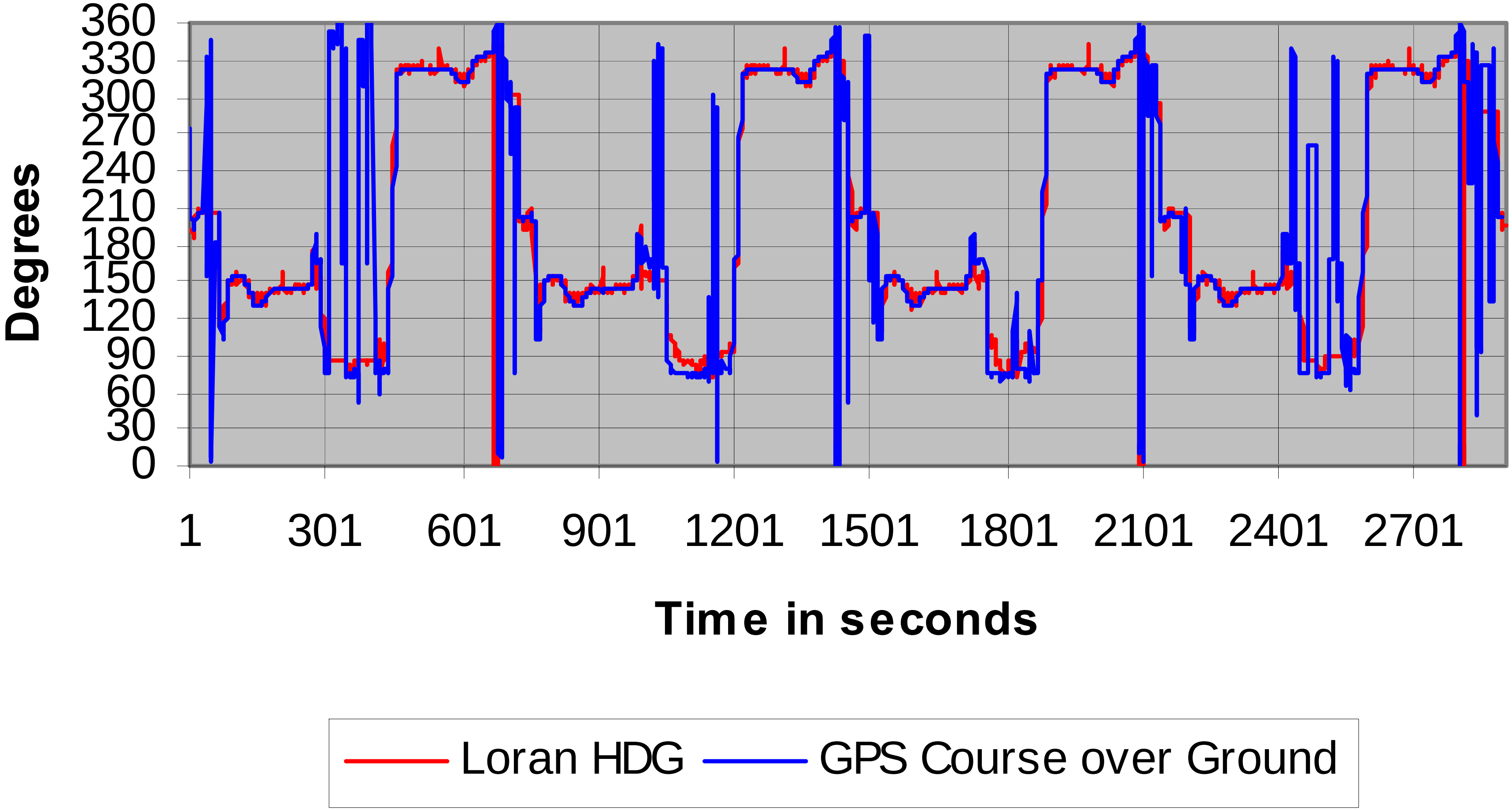
Ant Rotation Test 4: 3 second averaging

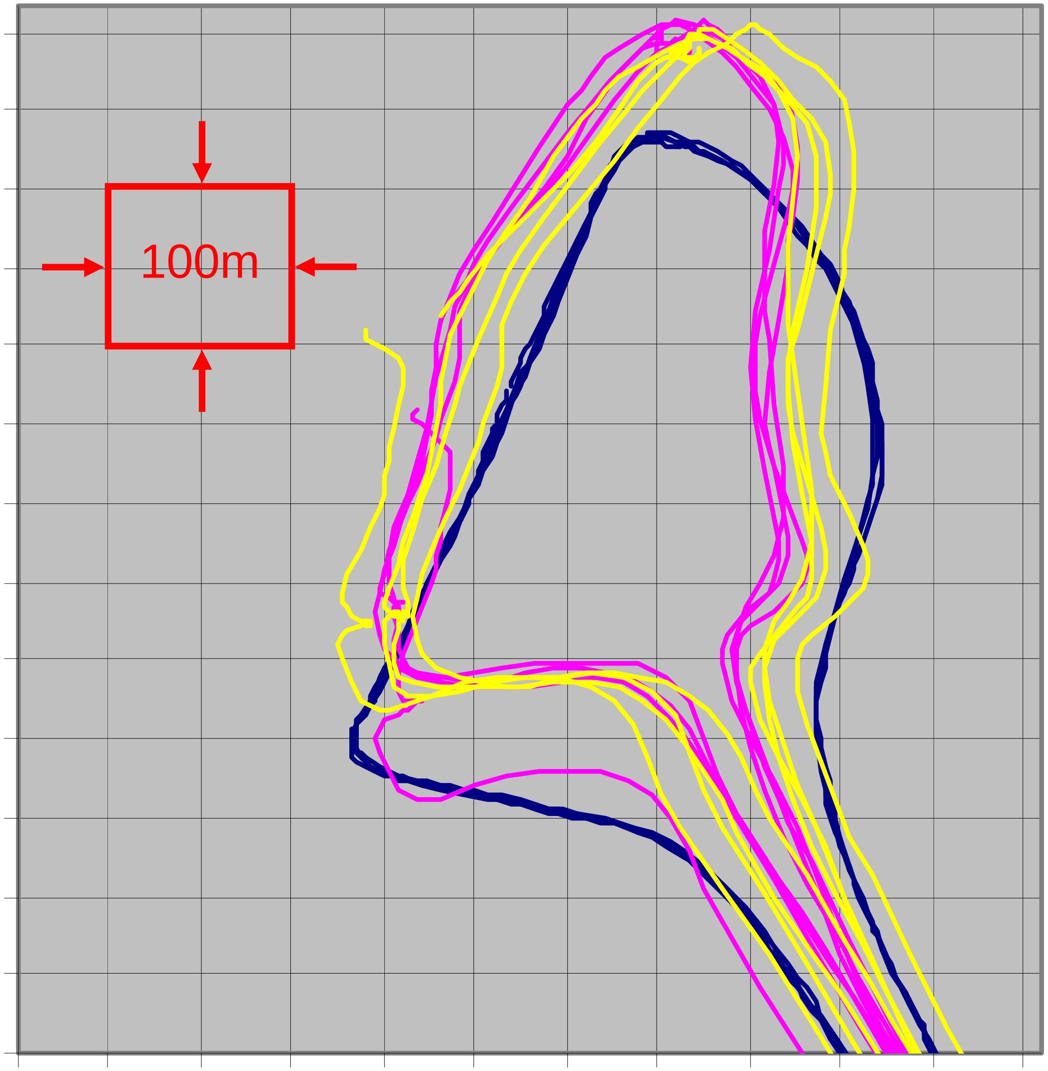


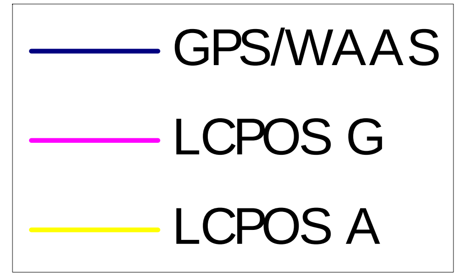
Ant Rotation Test 4: Heading error (1 Hz)



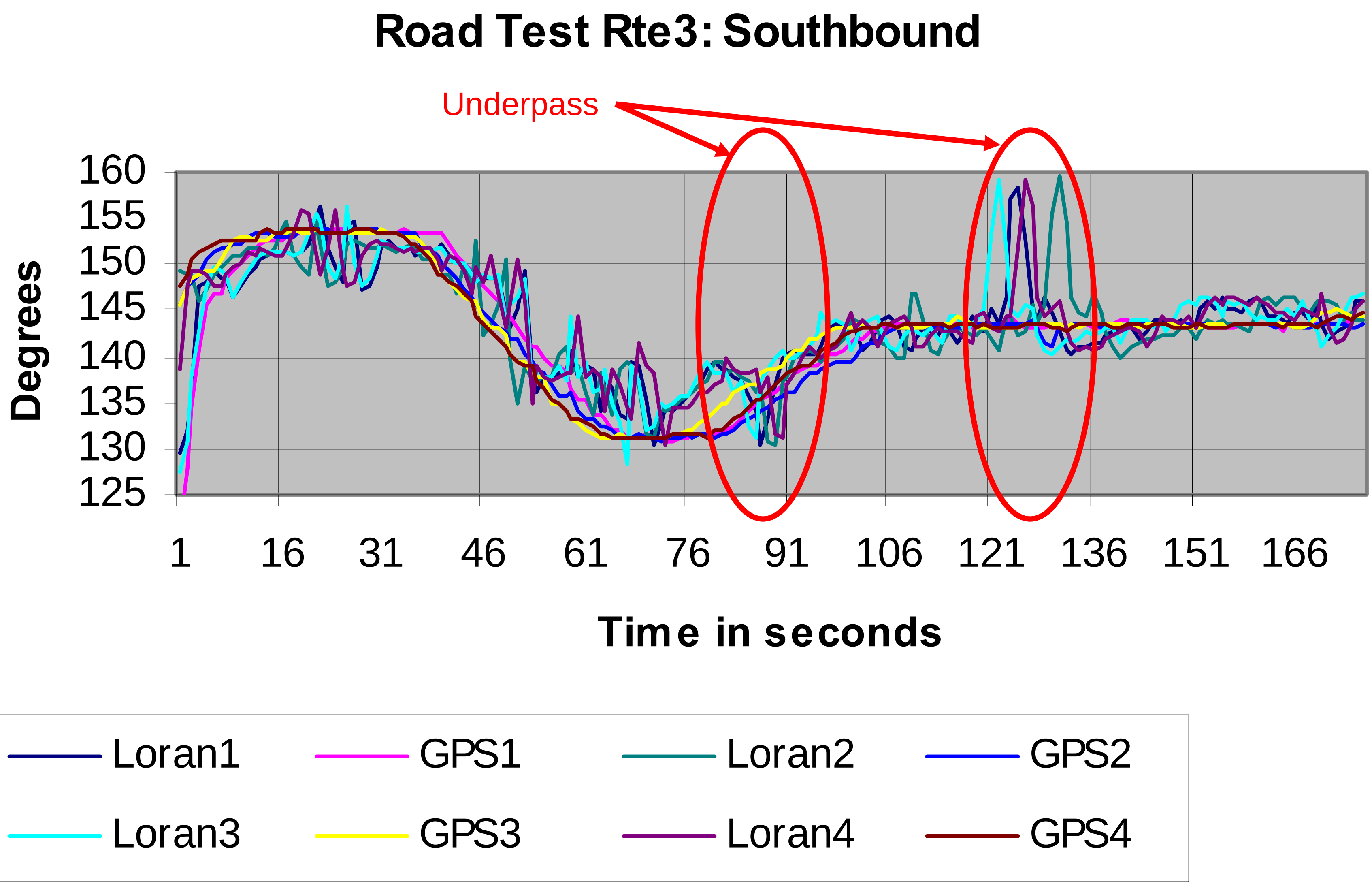
Road Test Rte3: Loran Hdg vs GPS CoG

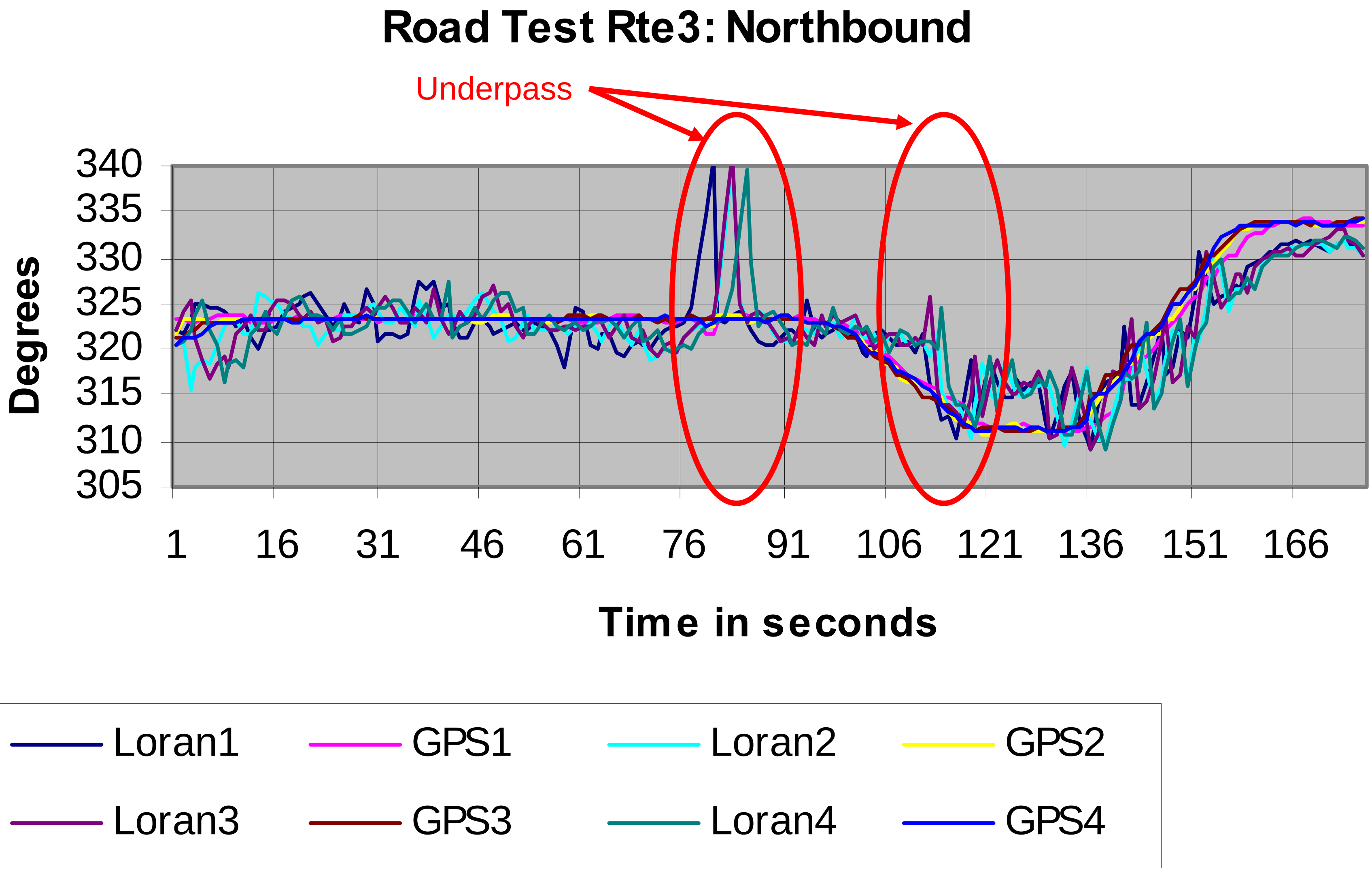




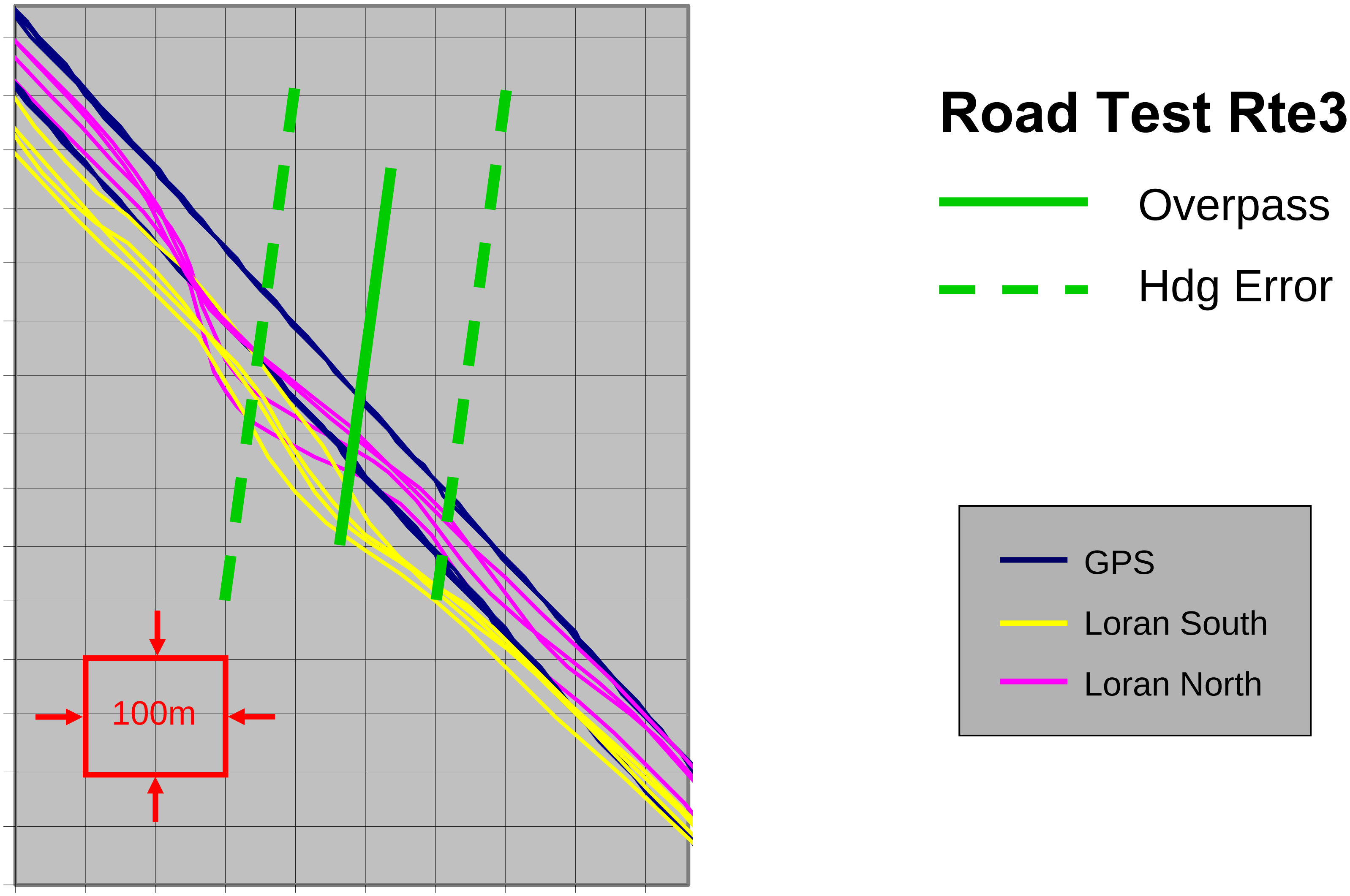


Road Test Rte3

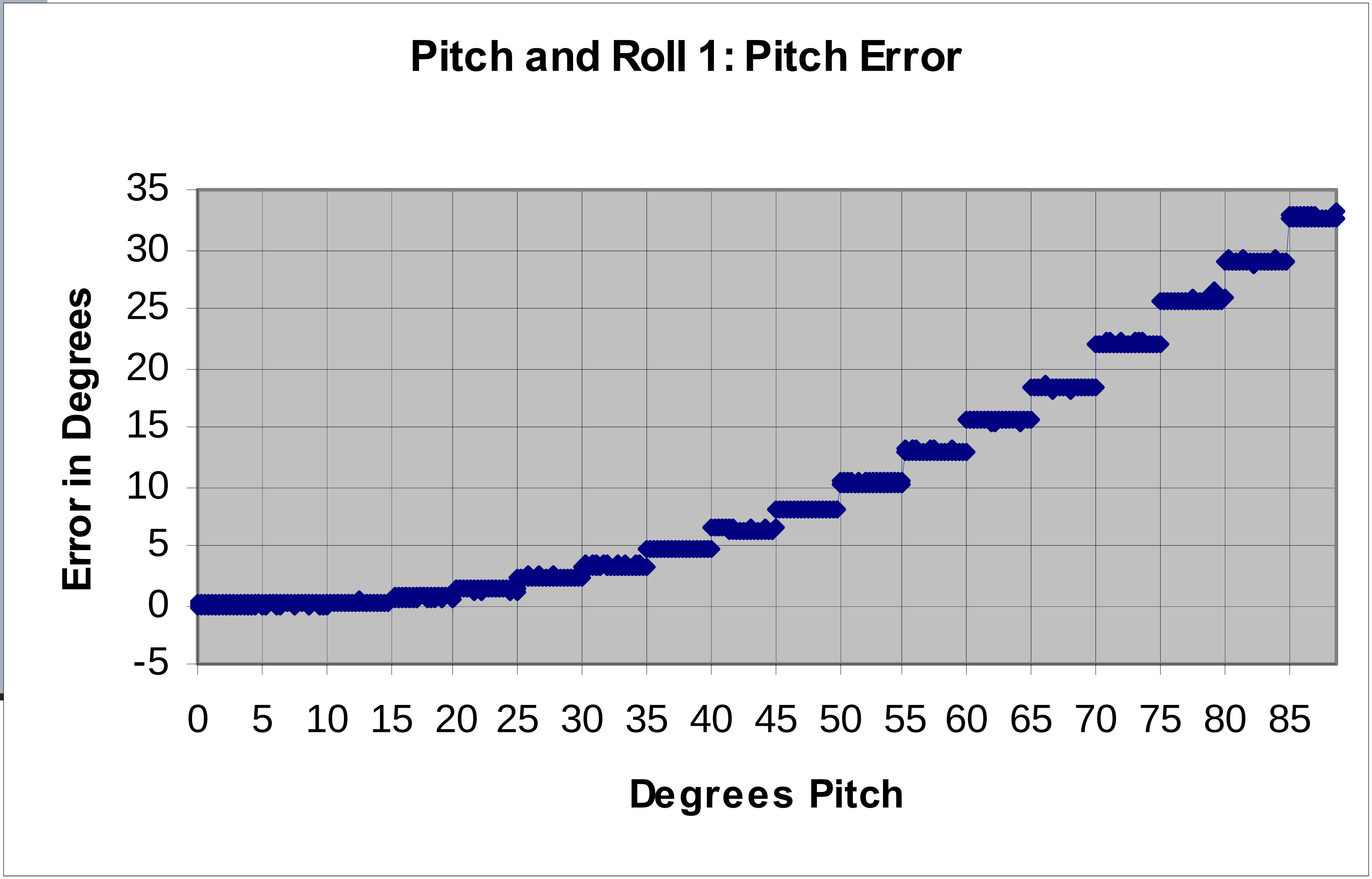

Road Test Rte3: Southbound
Underpass
Degrees
160
155
150
145
140
135
130
125
1
16
31
46
61
76
91
106
121
136
151
166
Time in seconds
Loran1
GPS1
Loran2
GPS2
Loran3
GPS3
Loran4
GPS4


Road Test Rte3: Northbound
Underpass
Degrees
340
335
330
325
320
315
310
305
1
16
31
46
61
76
91
106
121
136
151
166
Time in seconds
Loran1
GPS1
Loran2
GPS2
Loran3
GPS3
Loran4
GPS4

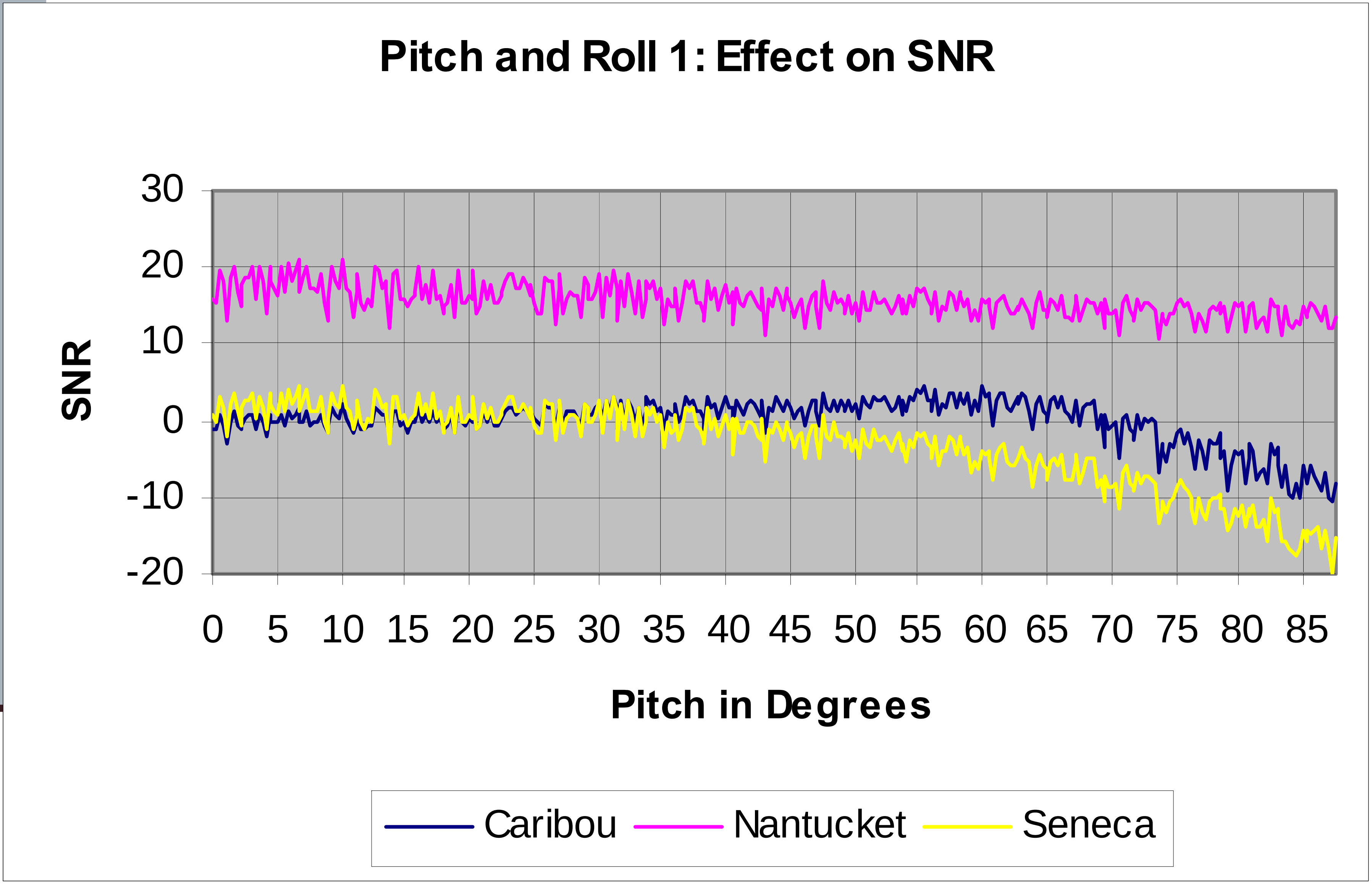
Road Test Rte3

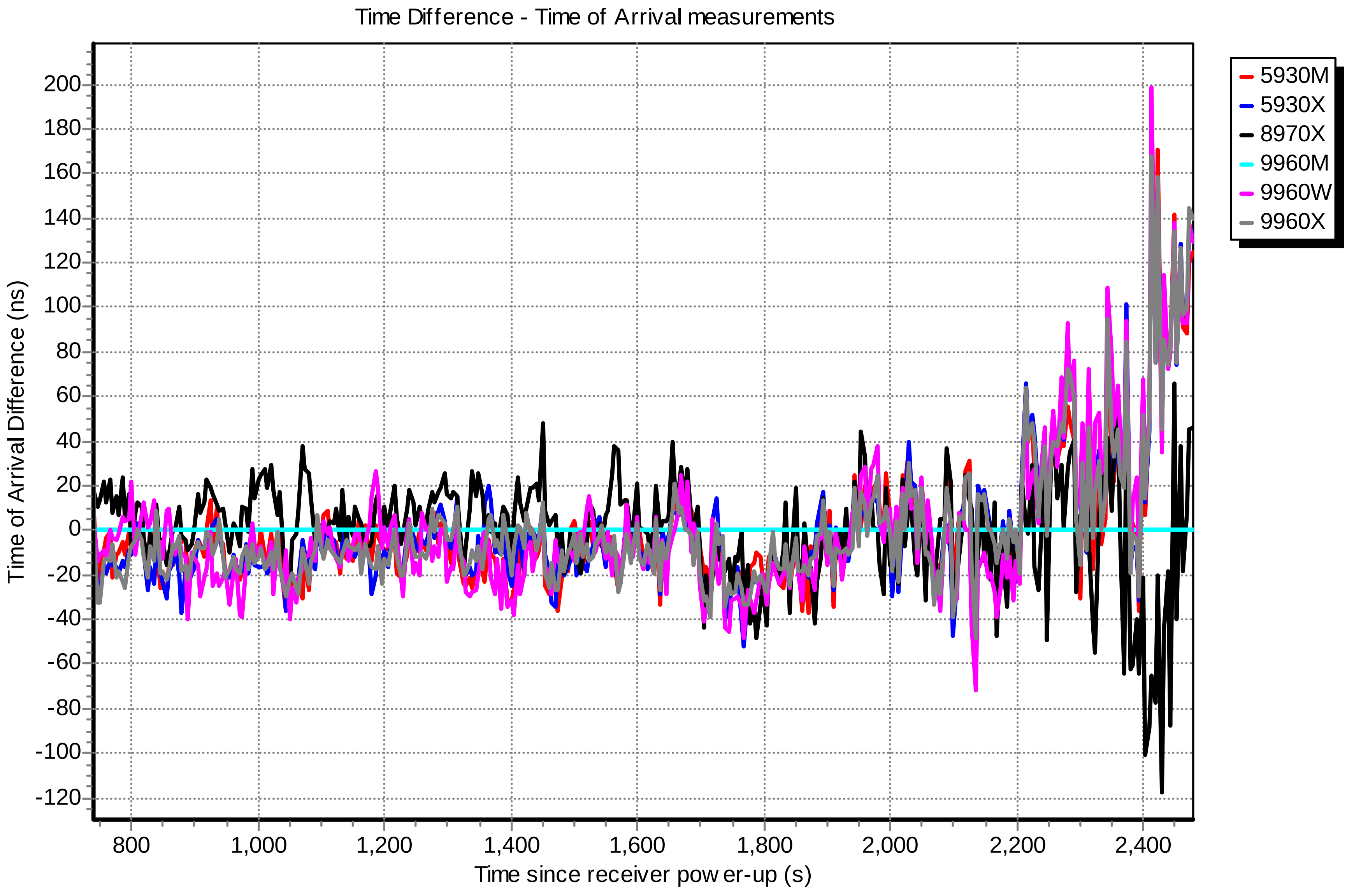


Pitch and Roll Fixture

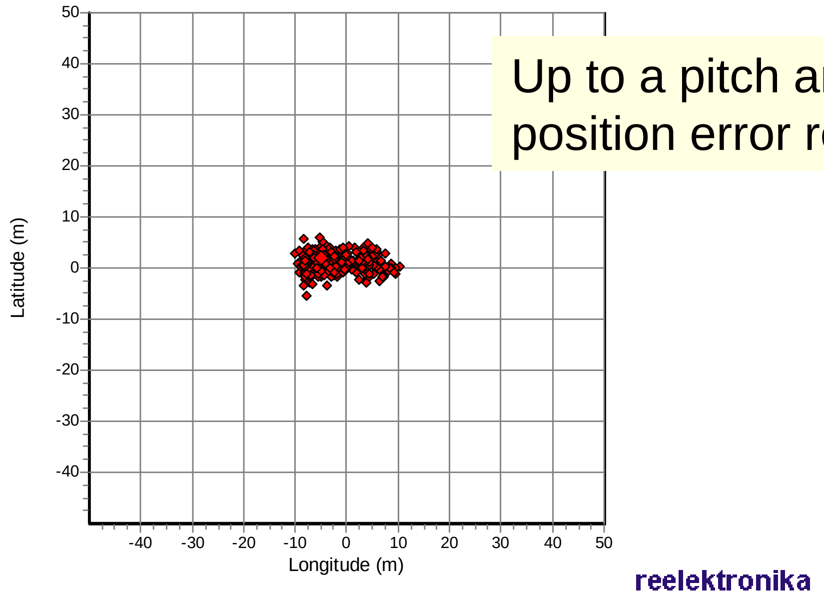


Pitch and Roll 1: Pitch Error
Error in Degrees
35
30
25
20
15
10
5
0
-5
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85
Degrees Pitch

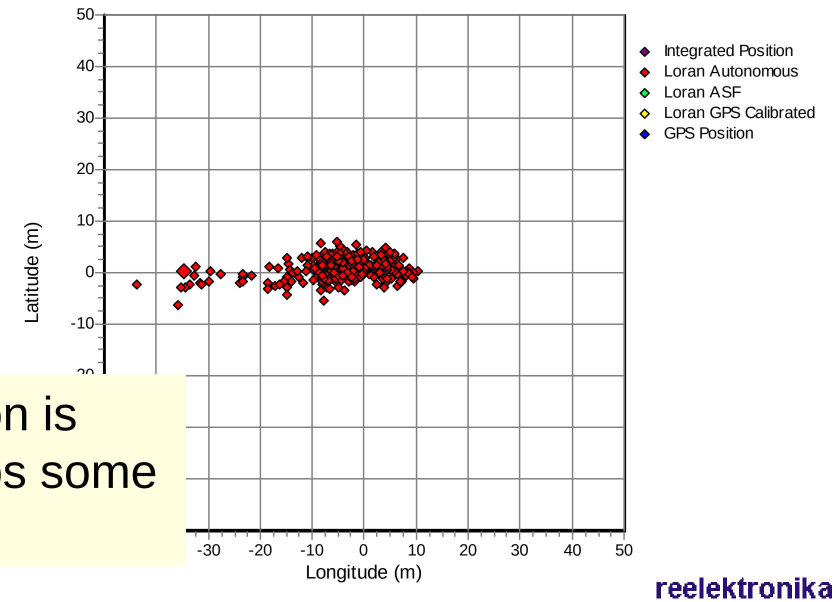

Pitch and Roll 1: Effect on SNR
SNR
30
20
10
0
-10
-20
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
Pitch in Degrees
Caribou
Nantucket
Seneca


Time Difference - Time of Arrival measurements
Time of Arrival Difference (ns)
200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
800
1,000
1,200
1,400
1,600
1,800
2,000
2,200
2,400
Time since receiver pow er-up (s)
5930M
5930X
8970X
9960M
9960W
9960X

Pitch and Roll Test 1: Positional Accuracy



Up to a pitch angle of 70 degrees, the position error remains under 10m, 95%.



Beyond 70 degrees, the position is offset, due to noise and perhaps some e-field.

Observations on Test Results

- Rotational test is an easy indicator of quality of antenna balance.
- Standard deviations of less than quarter degree exceeded the accuracy of test set-up, pitch effect?
- Minimal benefit (some reduction of outliers) from averaging independent 1Hz outputs.
- Dynamic rate of turn shows limitations of 1 Hz update rate.

Observations on Test Results (cont'd)

- System effects such as LPAs, Patco loops, etc. have greater impact on positional accuracy than rotation.
- Road testing shows benefit of Loran when stationary or near zero. Heading perturbations present opportunities.
- Pitch and roll result in predictable (heading dependent) heading errors. Position errors occur only at extreme angles.

A Final Thought…

- Heading – The fourth information utility after position, velocity and time.

  Given a known position (i.e. GPS) only a single, strongest station is required. This implies that very small (handheld) and inexpensive compasses (and/or timing sensors) can be developed. Maritime small boat AIS is an ideal application. More demanding applications such as aviation will likely incorporate tilt sensors. Heading information from one or more stations can likely be used to improve position fixing accuracy and integrity.

Thank You!