RF Compatibility tests of DORIS Simulator with VLBI Broadband Antenna at GGAO

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The Space Geodesy Project

Establish and operate a prototype next generation space geodetic station with integrated next generation SLR, VLBI, GNSS (and DORIS) systems, along with a system that provides for accurate vector ties between them.

Develop a Project Implementation Plan for the construction, deployment and operation of a NASA network of similar next generation stations that will become the core of a larger global network of modern space geodetic stations.

Demonstration by August 2013.

NRC Recommendation: “In the near term, the United States should construct and deploy the next generation of automated high-repetition rate SLR tracking systems at the four current U.S. tracking sites: Haleakala, Hawaii; Monument Peak, California; Fort Davis, Texas; and Greenbelt, Maryland. It also should install the next-generation VLBI systems at the four U.S. VLBI sites: Greenbelt, Maryland; Fairbanks, Alaska; Kokee Park, Hawaii; and Fort Davis, Texas.”
Prototype Geodetic Station at GGAO

• Goddard Geophysical and Astronomical Observatory (GGAO) is located 5 km from Goddard Space Flight Center in the middle of the Beltsville Agricultural Research Center. GGAO is one of the few sites in the world to have all four geodetic techniques co-located at a single location.
Vector Tie System (VTS)

- Accurate measurement of inter-station vectors is an essential aspect of an integrated space geodesy site.
- Measurements provide closure between terrestrial reference frames derived from different space geodesy techniques.
- Tests of technologies and currently available systems underway at GGAO.
Space Geodesy Project (SGP) and RFI

- Modeling the GGAO environment and VLBI2010 susceptibility before & after the trees came down
- Measuring the DORIS Beacon, and the NGSLR radars in South, radar masks & DORIS path loss provide mitigation
- Measuring 12m side lobes with a standard gain horn simulator ≥100m away
- Mitigate RFI with masks, filtering, and shielding
- Measure the effectiveness of an all-weather blocker to reduce the RFI of a DORIS Test Transmitter placed 136 meters away
- Measure the multi-path effects of the blocker on DORIS
  - Different distances and heights of blocker
  - Different angles of blocker
S-Band Filtering

- S- Band (2-5 GHz) is transferred separately to avoid saturation from RFI in the fiber optic link
RF Compatibility Methodology
Measurement of Transmitter Radiation Properties in 2010-2011

**MOBLAS 7 Summary**

<table>
<thead>
<tr>
<th>Location</th>
<th>Expected Power (+/- 2 dB)</th>
<th>Measured Power</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No Obstruction</td>
<td>Radome</td>
</tr>
<tr>
<td>Loc #2</td>
<td>-4.1 dBm</td>
<td>-4.9 dBm</td>
<td>-7.0</td>
</tr>
<tr>
<td>GODE</td>
<td>-1.0 dBm</td>
<td>-0.8 dBm</td>
<td>-5.9</td>
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</table>

**NGSLR Summary**

<table>
<thead>
<tr>
<th>Location</th>
<th>Expected Power (+/- 2 dB)</th>
<th>Measured Power</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No Obstruction</td>
<td>Radome</td>
</tr>
<tr>
<td>Loc #2</td>
<td>-3.0 dBm</td>
<td>-3.6 dBm</td>
<td>-0.7</td>
</tr>
<tr>
<td>DORIS</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**DORIS Summary**

<table>
<thead>
<tr>
<th>Location</th>
<th>Expected Power</th>
<th>Measured Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>DORIS Pad</td>
<td>-1.3 dBm</td>
<td>-1 dBm</td>
</tr>
<tr>
<td>Observatory Pad</td>
<td>-29.5 dBm</td>
<td>-27.6 dBm</td>
</tr>
</tbody>
</table>

- DORIS and SLR radar power levels were measured using S and X-band standard gain horn antennas
- SLR Radar Power Level Measurement Memo:

DORIS beacon characteristics

- DORIS barrier must be considered for two frequencies
- Barriers modeled for 6 degrees in azimuth and elevation
## Tradeoffs to RFI Mitigation Techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Current Implementation</th>
<th>Current results/limitations</th>
<th>Next steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masking</td>
<td>MOBLAS 7/ 20°</td>
<td>May 16th, 2012 geodetic test lost targets due to mask</td>
<td>Masks will be removed when absorber/reflectors go up</td>
</tr>
<tr>
<td></td>
<td>NGSLR / 30°</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>VLBI/ 40° and 30°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filtering</td>
<td>2-5 GHz lowband filter separating high band 4-14 Ghz on optical fiber from lowband on coaxial wire</td>
<td>No limitations due to high band / low band separation. Additional complication in design. DORIS at GGAO will not saturate VLBI.</td>
<td>Combination of high pass filter and isolation with tailored dynamic range. Notch at DORIS frequencies a possibility</td>
</tr>
<tr>
<td>Shielding</td>
<td>Radars are blocked by GGAO buildings</td>
<td>Radar platform guard rail occupies space. Metal guardrails re-resonate</td>
<td>Deliberate shielding must control back reflection</td>
</tr>
<tr>
<td>Absorbing</td>
<td>No absorber currently deployed</td>
<td></td>
<td>Cover guard rails</td>
</tr>
<tr>
<td>Shielding/Absorbing</td>
<td>Further experiments necessary. 35 degree above horizontal experiment – must be all weather</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Next Steps – RFI Mitigation at GGAO

- When radar and VLBI are past SGP Prototype validation milestones conduct another coordinated blocker test
  - From both positions on two lines of sight
  - With all weather, moderate wind materials used in construction of blocker
- Conduct Blocker effectiveness tests with DORIS
- Full Characterization of on and off-campus RFI at GGAO
The requirements are:

- No metallic object must be located within the envelope volume (except for the DORIS antenna nominal support).
- Nothing must stand within the visibility cone, apart from the antenna itself.

This implies:

- The barrier should be placed at 5m from the antenna and
- The barrier should raise a height that does not exceed the limit of the visibility cone.
- Rem. : A derogation could be made to take a value slightly higher for the visibility cone (between 5 and 8°).
DORIS Test transmitter at GGAO

Figure 1: DORIS Beacon setup in GNSS Equipment Building, A temperature controlled room

Figure 2: DORIS Antenna view, The DORIS Beacon Coaxial cables leave the GNSS building on the lower left. The VLBI Line of Sight is on the right.
Profile Geometry of the DORIS-VLBI Test Range

Common horizontal reference
DORIS Test antenna ~ 136 m from Standard Gain Horn at IOA

136 m away, 1 degree above IOA

-29.4 dBm received
15.1 dB cable loss

-44.5 dBm on SA
DORIS test as measured at VLBI antenna.

September 5\textsuperscript{th}: With blocker (-49.2 dBm) and without (-35.7 dBm), blocker measured at IOA with Standard Gain Horn. At – 40 dBm is where the VLBI LNAs would saturate.

September 22\textsuperscript{nd}: With blocker measured by the 12 meter (Marker 1: Test DORIS=-54.3 dBm, Marker 2: Operational DORIS=-50.6 dBm)
S-Band RFI spectra

- S- Band RFI as measured at various elevation sweeps and 300 degrees azimuth - Northwest

**Graph Description:**
- **Title:** GGAO 12m H-pol S-band spectra at 300 deg azimuth and selected elevations
- **X-axis:** Frequency (GHz)
- **Y-axis:** Power (dBm) in 3 MHz BW
- **Legend:**
  - 07 deg elev
  - 10 deg elev
  - 20 deg elev
  - 45 deg elev
  - 87 deg elev
- **Note:**
  - DORIS frequency indicated in the graph.
Comparison of VLBI Tsys with and without DORIS Test transmitting

Spectra for September 8th, 2036186350-2036286350 Hz VLBI looking North at 40 degrees elevation
Raising the blocker to 4 meters blocks lines of sight to all positions of the VLBI subreflector.
VLBI Sidelobe Tests on 9/25 and 10/8

- Tests above 60 degrees elevation were conducted on October 8th
- Tests on September 25\(^{th}\) (day 268) were conducted without radars operating
  Includes Azimuth angles that are usually masked out below 40 degrees including DORIS test beacon line of sight

Data Dropouts are due to the spectrum analyzer re-calibrating

October 8\(^{th}\) tests were conducted with the mask up and the SLR radars likely raise the noise floor
DORIS test beacon – 10/13- 10/21
Summary of 2014 DORIS-VLBI Tests

• At 136 meters a DORIS test beacon was placed at GGAO and required RFI mitigation not to saturate the VLBI

• A stainless steel blocker that was 3m wide and 4m high and placed 7 meters away introduced 10-15 dB attenuation. This allowed linear operation of VLBI over the entire hemisphere

• Multipath effects of the stainless steel blocker are still being investigated by the DORIS team

• Thank you to CNES, Haystack Observatory, and NASA GSFC for your efforts on these tests
Backup Charts – 2012-2013 Tests at X-band
DORIS Test
antenna location

<table>
<thead>
<tr>
<th>Desc</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Ellip. Ht. ( M)</th>
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<tbody>
<tr>
<td>Temp. DORIS Antenna</td>
<td>39° 01' 14.86116&quot;</td>
<td>076° 49' 38.50753&quot;</td>
<td>20.84</td>
</tr>
<tr>
<td>Feed Horn ( @ VLBI 2010 antenna)</td>
<td>39° 01' 19.28129&quot;</td>
<td>076° 49' 38.29029&quot;</td>
<td>18.37</td>
</tr>
</tbody>
</table>

Point to Point Inverse Using Ellipsoidal Heights. Added Azimuth & Elevation Angles

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>AZ</th>
<th>EL</th>
<th>Ellipsoidal Distance (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Horn ( @ VLBI 2010 antenna)</td>
<td>Temp. DORIS Antenna</td>
<td>182° 11' 44.1506&quot;</td>
<td>1° 2' 12.32&quot;</td>
<td>136.41</td>
</tr>
<tr>
<td>Feed Horn ( @ VLBI 2010 antenna)</td>
<td>NGSLR Radar</td>
<td>183° 36' 19.8639&quot;</td>
<td>1°28'36.12&quot;</td>
<td>202.77</td>
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<tr>
<td>Feed Horn ( @ VLBI 2010 antenna)</td>
<td>MOB 7 Radar</td>
<td>194° 57' 31.6373&quot;</td>
<td>2°07'25.64&quot;</td>
<td>160.53</td>
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### DORIS Test

#### Standard Gain Horn-calculations

<table>
<thead>
<tr>
<th>freq (GHz)</th>
<th>T/R pol</th>
<th>Tx power (dBm)</th>
<th>range (m)</th>
<th>Tx gain (dBi)</th>
<th>gain (dBi)</th>
<th>path loss (dB)</th>
<th>cable loss IOA to SA</th>
<th>Rcv at Spectrum Anal</th>
</tr>
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<tbody>
<tr>
<td>2.036</td>
<td>C/C</td>
<td>39.8</td>
<td>136.40</td>
<td>3.0</td>
<td>15.5</td>
<td>81.31</td>
<td>15.10</td>
<td>-41.1</td>
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<tr>
<td>2036236.0 KHz</td>
<td>assign marker 1</td>
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<tr>
<td>C/H</td>
<td>36.8</td>
<td>136.40</td>
<td>3.0</td>
<td>15.5</td>
<td>81.31</td>
<td>15.10</td>
<td>-44.1</td>
<td></td>
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<tr>
<td>DORIS-op at 2036250 KHz, from azimuth 193° 21' 05.2064&quot; assign Marker 2</td>
<td></td>
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<td></td>
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<tr>
<td>36.8</td>
<td>222.80</td>
<td>3.0</td>
<td>12.5</td>
<td>85.58</td>
<td>15.10</td>
<td>-51.4</td>
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DORIS Test

Standard Gain

Horn-calculations

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<td>-56.7</td>
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<td>222.80</td>
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<td>15.10</td>
<td>-77</td>
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DORIS Test

Standard Gain

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<td>81.31</td>
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<td>-57.6</td>
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<tr>
<td>2.036</td>
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<td>222.80</td>
<td>3.0</td>
<td>15.5</td>
<td>81.31</td>
<td>15.10</td>
<td>-77</td>
</tr>
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</table>
12 Meter X-band and C-Band side lobe characterization at GGAO

antenna gain vs. angle between 12-m boresight and transmitter. The data have been binned by angle into 40 bins equispaced in log(angle). The 4 "curves" are
red  100th percentile in each bin (i.e., max gain)
green 90th percentile
blue  50th percentile (i.e., median gain)
black ITU-R SA.509 standard for the 90th percentile of the far-field gain of a large antenna

12 m Sidelobe views it peripherally in the North
Beacon in the East
Sidelobe Measurement of 12 meter antenna - with beacon deployed near NGSLR LHRS phase center
Comparison to ANSI sidelobe envelope

Figure 1: ITU-5009 antenna sidelobe envelope model incorporated in numerical RFI-compatibility studies.
Loss of the Southern sky must be planned around due to radar masks at GGAO

- **Oct 4th →**
- **These observing plans were specially prepared with knowledge of VLBI mask avoidance**

- **Oct 5th**
- **← These observing plans were opened up to the full sky through coordination with NG SLR and MOB7**
Profile and Link Budget for Far Field RFI Mitigation between NG SLR LHRS radar and VLBI

86.7 m (284 ft)

<table>
<thead>
<tr>
<th>dataset</th>
<th>nail</th>
<th>freq GHz</th>
<th>T/R pol</th>
<th>Tx power dBm</th>
<th>range ft</th>
<th>range m</th>
<th>Tx gain dBi</th>
<th>electronic SGH Rcv ant gain dB</th>
<th>path loss dB</th>
<th>dBi-dBm 250 m</th>
<th>Fiber loss dB</th>
<th>20 ft Recvd power dB</th>
<th>VNA Noise floor dBm</th>
</tr>
</thead>
<tbody>
<tr>
<td>NG SLR range</td>
<td>ZX60-14012L-9.410 S+</td>
<td>10.0</td>
<td>200.00</td>
<td>35.0</td>
<td>22.0</td>
<td>97.93</td>
<td>30.93</td>
<td>35.0</td>
<td>10.00</td>
<td>-75.9</td>
<td>-80.00</td>
<td></td>
<td></td>
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</tbody>
</table>
Results of subreflector blocker on NG SLR and MOB7 line of sight to VLBI

◆ April 17th, 2013 Test
  – 10’ x 15’ Blocker in NG SLR line of sight
  – Standard Gain Horn from ground was surrogate for radar

◆ April 26th, 2013 Test
  – 10’ x 15’ Blocker in MOB7 line of sight
  – Standard Gain Horn from ground was surrogate for radar