Approaching the finish line with GeoSTAR

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GeoSTAR Development History

Decadal survey: PATH mission

PATH applications

- **Weather forecasting**: All-weather soundings, in cloudy and stormy scenes
- **Synoptic rapid-update soundings**: Forecast error detection; 4DVAR applications
- **Hurricane & severe-storm diagnostics**: Location, intensity & vertical structure of deep convection
- **Tropospheric wind profiling**: 1000-300 mb; very high temp.res.; in & below clouds
- **Climate research**: Stable & continuous MW observations

Constraints on models for boundary layer, cloud, and precipitation processes

- **PATH**: High frequency, all-weather temperature and humidity soundings for weather forecasting and SST

<table>
<thead>
<tr>
<th>PATH</th>
<th>GEO</th>
<th>MW array spectrometer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$450 M</td>
</tr>
</tbody>
</table>

= GeoSTAR
Severe storms may be getting worse

Weather Fatalities

- Flood: 2010 - 103, 10 Year Average (2001-2010) - 92, 30 Year Average (1981-2010) - 71
- Tornado: 2010 - 29, 10 Year Average (2001-2010) - 55, 30 Year Average (1981-2010) - 45
- Hurricane: 2010 - 0, 10 Year Average (2001-2010) - 47, 30 Year Average (1981-2010) - 116
- Cold: 2010 - 34, 10 Year Average (2001-2010) - 25, 30 Year Average (1981-2010) - 42
- Winter: 2010 - 33, 10 Year Average (2001-2010) - 41, 30 Year Average (1981-2010) - 43
- Wind: 2010 - 64, 10 Year Average (2001-2010) - 43, 30 Year Average (1981-2010) - 56

- Tornado tracks
- Wind > 65 knots
- Hail > 2 inches
- Hurricanes
- Tornado watch

MAX = 16, Several Counties in southeast MS and southwest AL
GeoSTAR timeline

• Concept development
  – NRC white paper (2005)
  – NRC Decadal Survey (2007)

• ESTO technology development
  1. IIP-03 (2003-2006): Proof-of-concept prototype
  2. ACT-05 (2006-2008): MIMRAM receivers
  3. IIP-07 (2008-2011): Key technology

• Space implementation
  – Venture mission (before 2020?)
  – PATH mission (~202X?)
GeoSTAR Development – IIP-03
Proof of concept

STAR concept and key technologies developed & tested

Compact receivers
Low-power MMICs
Innovative array layout

Spatial resolution | Frequency band | 50 GHz | 89 GHz | 115 GHz | 135 GHz
--- | --- | --- | --- | --- | ---
150 km
| Number of elements | → 3×32 → | → 3×32 → | → 3×32 → | → 3×32 → |
| Arm length | 0.7 m | 0.4 m | 0.3 m | 0.2 m |
| Power | 75 W | 75 W | 75 W | 75 W |
| Mass | 0.1 kg | 0.1 kg | 0.1 kg | 0.1 kg |
100 km
| Number of elements | → 3×48 → | → 3×48 → | → 3×48 → | → 3×48 → |
| Arm length | 1.0 m | 0.6 m | 0.45 m | 0.3 m |
| Power | 115 W | 115 W | 115 W | 115 W |
| Mass | 100 kg | 100 kg | 100 kg | 100 kg |
75 km
| Number of elements | → 3×96 → | → 3×96 → | → 3×96 → | → 3×96 → |
| Arm length | 1.5 m | 0.8 m | 0.4 m | 0.4 m |
| Power | 150 W | 150 W | 150 W | 150 W |
| Mass | 125 kg | 125 kg | 125 kg | 125 kg |
50 km
| Number of elements | → 3×192 → | → 3×192 → | → 3×192 → | → 3×192 → |
| Arm length | 2.0 m | 1.1 m | 0.85 m | 0.6 m |
| Power | 225 W | 225 W | 225 W | 225 W |
| Mass | 200 kg | 200 kg | 200 kg | 200 kg |
30 km
| Number of elements | → 3×384 → | → 3×384 → | → 3×384 → | → 3×384 → |
| Arm length | 3.4 m | 1.9 m | 1.4 m | 0.8 m |
| Power | 400 W | 400 W | 400 W | 400 W |
| Mass | 300 kg | 225 kg | 190 kg | 130 kg |

Partnership with NOAA: Mission study

NOAA mission

Compact receivers
Low-power MMICs
Innovative array layout

Correlator: Efficient, Redundant, OK for ASICs
Feedhorns: Low mutual coupling

First images at 50 GHz by aperture synthesis
GeoSTAR Development – ACT-05
183-GHz technology

Breakthrough MMIC performance

Design innovations

Calibration, performance verification

First images at 50 GHz by aperture synthesis

NOAA observations

Innovative array layout

STAR concept and key technologies developed & tested

Compact receivers

Low-power MMICs

Phase switching system: Ultrastable operation

Correlator: Efficient, Redundant, OK for ASICs

Feedback: Low mutual coupling

Innovative array layout

STAR sounder concept

Aerowave Inc.
183-GHz receiver (fab 50 samples)

- Conversion gain 10 dB
- Power consumption <60mW
- Mass <3g
- Physical size .375"x.3"x.2"
GeoSTAR Development – IIP-07

New antenna design (demo)

- Develop 50 low-noise 183-GHz receivers
- Develop 3 2x8-element receiver sub-array modules
- Develop low-power Application-Specific Integrated Circuit (ASIC) correlator chips
- Develop low-mass/power signal distribution system
- Develop functional 183-GHz 2D STAR prototype

Sharply bounded FOR

 ↔

Large alias-free region
NEDT < 1/3 K
GeoSTAR Development – IIP-07

Antenna subarray assemblies
GeoSTAR IIP-10: Correlator, Part 1

Small 5x5 design demo chip
Correlator ASIC development

A 5x5 digitizer/correlator and evaluation board was built to provide risk reduction for the development of the larger A/D correlator ASIC.

- Test A/D and correlator cells together to uncover design or implementation flaws
- Determine crosstalk between channels

Initial tests indicated problems, but design was fixed, chip re-spun and tested

Tested for rad-hardness: OK
Chip and test board

Chip (2.4 mm square)

Test board, with chip heat sink

Substrate carrier (3/4” square)
GeoSTAR IIP-10: Correlator, Part 2

Chip orientation

- Die Photo -

- Layout (M9, AP) -

24x24 = 529 pins
GeoSTAR IIP-10: Correlator, Part 3

Specs & power consumption

<table>
<thead>
<tr>
<th>Parameter</th>
<th>This work</th>
</tr>
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<tbody>
<tr>
<td># of Channels</td>
<td>128</td>
</tr>
<tr>
<td># of Correlators</td>
<td>4096</td>
</tr>
<tr>
<td>Channel Bitwidth</td>
<td>2</td>
</tr>
<tr>
<td>On-Chip ADCs</td>
<td>yes, 128</td>
</tr>
<tr>
<td>Logic Family</td>
<td>static</td>
</tr>
<tr>
<td>Correlation Efficiency (%)</td>
<td>&gt;90% @ &gt;30dBm</td>
</tr>
<tr>
<td>Isolation (dB)</td>
<td>-42.4</td>
</tr>
<tr>
<td>Technology</td>
<td>65nm</td>
</tr>
<tr>
<td>Total Power (W)</td>
<td>1.44 @775mV, 1GHz</td>
</tr>
<tr>
<td></td>
<td>3.73@1V, 1.5GHz</td>
</tr>
<tr>
<td>Energy per Correlation (pJ/correlation/cycle)</td>
<td>0.35 @775mV, 1GHz</td>
</tr>
<tr>
<td></td>
<td>0.61 @1V, 1.5GHz (2b corr + ADC)</td>
</tr>
<tr>
<td>Core Area (mm²)</td>
<td>5.9</td>
</tr>
<tr>
<td>Chip Area (mm²)</td>
<td>17.9</td>
</tr>
<tr>
<td>Max Performance (T correlation/s)</td>
<td>6.14 @1V, 1.5GHz</td>
</tr>
</tbody>
</table>

*a: a 1-bit correlation is just XOR*
GeoSTAR IIP-10: Correlator, Part 3

Max clock rate 1.6 GHz (1 GHz required)
Excellent correlation efficiency

![Graph showing correlation efficiency vs input power. The graph includes a line for r=100%, r=10%, and r=1%. The y-axis represents correlation efficiency in percentage, ranging from 0% to 100%. The x-axis represents input power in dBm, ranging from -40 dBm to -10 dBm. The graph shows that as input power decreases, correlation efficiency increases.]
GeoSTAR IIP-10: Final phase

- Further testing of correlator ASIC
  - Complete full correlator board hosting new chip
  - Full functional testing of new chip
- System testing
  - Assemble small 183-GHz antenna array
    - Using miniature ultra-low-power MIMRAM receivers
  - Integrate full system with correlator
  - Characterize system performance
  - Imaging demonstration
GeoSTAR will make similar measurements from GEO as AMSU currently does from LEO, but every 15 minutes vs. 2 times per day. High-intensity events can be sampled in 5 minutes or less.

GeoSTAR will uniquely provide measurement of **Temperature/moisture/clouds; Wind; Precipitation** simultaneously, continuously and in 3 dimensions.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Horizontal</th>
<th>Vertical</th>
<th>Temporal</th>
<th>Precision</th>
<th>Accuracy</th>
<th>Thermodyn.</th>
<th>Microphys.</th>
<th>Dynamics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brightness temperatures</td>
<td>25 - 50 km</td>
<td>N/A</td>
<td>5-20 min</td>
<td>0.5-1.5 K</td>
<td>0.5 K</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Temperature</td>
<td></td>
<td></td>
<td></td>
<td>1.5-2.5 K</td>
<td>0.5 K</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water vapor</td>
<td></td>
<td></td>
<td></td>
<td>25-40%</td>
<td>10%</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind vector (u,v)</td>
<td>25 - 50 km</td>
<td>2-3 km</td>
<td>10-20 min</td>
<td>8 m/s</td>
<td>2 m/s</td>
<td></td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Reflectivity</td>
<td></td>
<td></td>
<td></td>
<td>4-6 dBZ</td>
<td>2 dBZ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rain rate</td>
<td></td>
<td></td>
<td></td>
<td>5 mm/hr</td>
<td>2 mm/hr</td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>LWP</td>
<td></td>
<td></td>
<td></td>
<td>25%</td>
<td>10%</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IWNP (IWP)</td>
<td></td>
<td></td>
<td></td>
<td>25%</td>
<td>20%</td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
</tbody>
</table>

Precision & accuracy reflect performance of MIRS (except for reflectivity).
Pre-PATH mission

We are approaching readiness for space mission

Ready for Venture-class mission now

- Timeline: Start development ~2014 → Launch ~2018
- Objective: PATH science subset demonstrator
- Instrument: “GeoSTAR-lite” – all key technologies @ TRL 6
  - Correlator baseline: Omnisys 32x32 ASIC (TRL 6: has been rad tested)
    - meets science requirements
Pre-PATH mission

Swedish 32x32 correlator
Tested and verified
Pre-PATH mission

Radiation test results: No susceptibility of concern

Integrator cross section analysis

Integrator errors

Readout logic errors

Single event rate (errors/device/day)

AI thickness (cm)
Summary

• STAR concept demonstrated in IIP-03
  – Developed a functional 50-GHz STAR demonstrator

• Key technologies developed in IIP-07
  – Developed miniature low-power 183-GHz MMIC receivers
  – Developed new alias-rejecting antenna array design

• Ready for PATH mission after IIP-10
  – Full-size 64x64 correlator ASIC is a success!
  – Can start development ~2015 → launch ~2020

• We have advanced the technology from Tier-3 level to Tier-1 level – a major achievement