A New 449 MHz Wind Profiler Radar: Antenna and Amplifier Design

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Current Profiling Capability

- Three deployable boundary layer 915 MHz Wind Profilers with RASS
- Winds to ~3 km (virtual temperature to ~1 km)
  60-100 m height resolution
- Options: MAPR, Mobile-ISS, ship-borne, sodar, ceilometer
- 44 ISS deployments since 1992
- 30-min time resolution with ISS
- 1-min time resolution with 915 MHz MAPR spaced antenna system

Integrated Sounding System (ISS)
New Wind Profiler Improvements

• Use 449 MHz frequency because it is more sensitive to clear air turbulence than 915 MHz. This will allow sensing beyond 3 km.
• Design (NOAA) and evaluate (NCAR) new antenna with better sidelobe performance
• Explore high power amplifier solutions
• Upgrade other components such as circulators and LNAs
Modular Antenna System: Easily Scalable

Nine antennas could make 3 Boundary Layer profilers, Power x Aperture for 4km Max. Range

Or 7 antennas could make 1 Mid-Troposphere profiler 7km Max. Range
Background

- Single Pulse Radar Equation for SNR for Bragg scatter from a clear air target can be written as

\[
SNR = \frac{0.21 P_t \varepsilon_a A \Delta R^2}{4 \lambda^{1/3} \pi c R^2 LkT_{sys}} C_n^2 \propto P_t A
\]

Doviak and Zrnic

- Single pulse SNR is very low, coherent pulse integration and spectral averaging are used to increase SNR
# Radar Specifications

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>Frequency</strong></td>
<td>449 MHz</td>
</tr>
<tr>
<td><strong>First range gate</strong></td>
<td>100-150m</td>
</tr>
<tr>
<td><strong>Last range gate</strong></td>
<td>4km to 7km (depending on power x aperture)</td>
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<tr>
<td><strong>Pulse code</strong></td>
<td>4-bit complementary code (phase modulation)</td>
</tr>
<tr>
<td><strong>Range resolution</strong></td>
<td>150m</td>
</tr>
<tr>
<td><strong>Velocity precision</strong></td>
<td>1 m/s</td>
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<tr>
<td><strong>Time resolution</strong></td>
<td>1 minute</td>
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<tr>
<td><strong>RF power</strong></td>
<td>6 kW or more</td>
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<tr>
<td><strong>Antenna</strong></td>
<td>54 or 162 circular patch array</td>
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<tr>
<td><strong>Vertical velocity method</strong></td>
<td>Doppler</td>
</tr>
<tr>
<td><strong>Horizontal velocity method</strong></td>
<td>Spaced Antenna</td>
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MAPR 64 Square Patch Array (915 MHz)

- Theoretical array factor pattern, assumes no mutual coupling
- Edge of plot is at horizon, center is zenith
- Sidelobe level: 20 dB down from main beam at horizon
New 449 MHz 54 Circular Patch Array

449 Antenna

Array Layout

- Sidelobe level: 40 dB down from main beam at horizon
Patch Antennas

- Copper patches on foam dielectric with aluminum ground plane
Antenna Verification

Modular Profiler Antenna Sidelobe Levels (Receiver polarization oriented horizontally)

Sidelobes at Horizon at least 33 dB down

449 MHz antenna sidelobe measurements

Sidelobes at horizon are at least 33 dB lower than main beam
Prototype 449 MHz antenna and 915 MHz DBS profiler comparison

Clear air reflectivity from a single prototype 449-MHz antenna panel and a 915-MHz system.

Higher reflectivity clear-air signals from the 449 MHz system after normalizing the two systems during precipitation
3-Channel System Design

Existing Amplifier: 2 kW, Class-C, $30,000

HPA

~ -150 dBm

Three Panel Spaced Antenna
High Dynamic Range Front End
Jim Jordan
July 1, 2008
Rev. 0
Amplifier Strategy: Use Low Cost LDMOS Transistors and Class-E mode of operation

- High efficiency has benefit of less dissipated heat in transistor
- Higher reliability
- More portable, less heat sink weight

<table>
<thead>
<tr>
<th>Class of Operation</th>
<th>Theoretical Efficiency</th>
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<tbody>
<tr>
<td>A</td>
<td>50%</td>
</tr>
<tr>
<td>AB</td>
<td>78%</td>
</tr>
<tr>
<td>C</td>
<td>90%</td>
</tr>
<tr>
<td>E</td>
<td>100%</td>
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Class-E design process

Class-E ideal circuit

Switch closed: Vout = 0
Switch open: Ic > 0

Class-E output match approximation, include open circuit at 2nd harmonic

Open circuit at 2nd harmonic helps create high efficiency “soft-switching” waveforms

\[
Z_{net} = \frac{0.28}{\omega_s C_s} e^{j 49.05^\circ}
\]

(AGR09045E LDMOS transistor output capacitance is 23 pF)

f = 449 MHz

\[
Z_{net} = 2.8 + 3.2 j \Omega
\]
Lindseth, et al.

Class-E transmission line design

Layout of output network using design from Agilent ADS
Low impedance Class-E match and open circuit stub at second harmonic on Rogers 4350B substrate

\[ Z_{net} = 2.8 + 3.2j \text{ Ohms} \]
449 MHz Low power 1W Class-E amplifier evaluation, Low cost transistors, 80% efficiency.

449 MHz 40W LDMOS amplifier based on a Triquint AGR09045E transistor in Class-E mode. First results: 65% efficiency. ~1 watt per dollar. Expect ~%80 in final design.

\[ Z = 2.8 + 3.2j \text{ Ohms} \]
Power Sweep of 449 MHz AGR09045E Power Amplifier Vds=18V

- Gain
- Output Power
- PAE

Preliminary data, 10W out at 65% PAE and 10 dB gain
• Currently evaluating Freescale LDMOS devices. ~$35 per 60W transistor. Less than $1 per watt in parts cost. Preliminary data above, 66% PAE, 25W, 11.8 dB gain
• Future work will combine two transistors to make a >100W amplifier module
Future Modular Amplifier Configuration

- Amplifier behind each of the 54 patches
- 100W per patch
- 5.4 kW total over whole array
- 54 * $35 = $1890 in transistor cost, estimate $10,000 total cost vs. $30,000 for commercial amplifier
Summary

• New antenna design for 449 MHz confirmed with measurements
• High power amplifier alternatives are being evaluated, with efficiencies up to 80%
• System performance compared to 915 MHz DBS system
• Future work:
  • Demonstrate spaced antenna horizontal winds with three antenna system (54 elements)
  • Demonstrate high efficiency high power amplifier, 80% PAE and 100W per module
  • Demonstrate 54 antenna-amplifier element array
• Cost: Under $10,000 in parts cost for 54 100W amplifiers