Antenna systems: dipoles/groundscreen & analog beamformer

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# General specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunable frequency range</td>
<td>80-300 MHz</td>
</tr>
<tr>
<td>Instantaneous frequency range</td>
<td>$\geq 32$ MHz</td>
</tr>
<tr>
<td>Collecting area</td>
<td>$\geq 10$ m$^2$ over as much of frequency range as possible</td>
</tr>
<tr>
<td>Field of view</td>
<td>As wide as possible (within constraints of collecting area &amp; physics)</td>
</tr>
<tr>
<td>Polarization</td>
<td>Dual</td>
</tr>
<tr>
<td>System temperature</td>
<td>Sky noise dominated</td>
</tr>
</tbody>
</table>
Key design features

- 16 dual-polarization, bowtie antenna elements over a ground screen
- Elements arranged in compact planar array with $\lambda/2$ spacing at 140 MHz ($= 1.07$ m)
- Low-noise amplification integral to each element
- Analog RF beamformer with PCB tapped delay lines
Block diagram of electronics for one tile

One section of 5 sections of switchable delay line – lengths differ by factors of 2

Identical circuit for Y signals
Prototype antenna element used in ED tiles
Low-noise amplifier

- Balanced design using two ATF-54143 HEMTs
- Measured noise temperature 14-17 K with 50 ohm loads on inputs, in agreement with simulation
- Measured OIP2 > +63 dBm, OIP3 = +27 dBm
- With LNA connected to prototype element, simulated noise temperature < ½ x sky temperature
Simulated receiver noise temperature (antenna-LNA impedance mismatch included)
Receiver noise temperature from ED1 data

Top to bottom:
- 100 MHz
- 120 MHz
- 140 MHz
- 160 MHz
- 180 MHz
- 200 MHz
Single element power patterns

Single element: 110 MHz, E-plane

-25.0
-20.0
-15.0
-10.0
-5.0
0.0
5.0
10.0
-90.0 -45.0 0.0 45.0 90.0
Zenith angle (degrees)
Power (dB)
Simulated
Measured

Single element: 110 MHz, H-plane

-25.0
-20.0
-15.0
-10.0
-5.0
0.0
5.0
10.0
-90.0 -45.0 0.0 45.0 90.0
Zenith angle (degrees)
Power (dB)
Simulated
Measured

Single element: 200 MHz, E-plane

-25.0
-20.0
-15.0
-10.0
-5.0
0.0
5.0
10.0
-90.0 -45.0 0.0 45.0 90.0
Zenith angle (degrees)
Power (dB)
Simulated
Measured

Single element: 200 MHz, H-plane

-25.0
-20.0
-15.0
-10.0
-5.0
0.0
5.0
10.0
-90.0 -45.0 0.0 45.0 90.0
Zenith angle (degrees)
Power (dB)
Simulated
Measured
Single element power patterns (cont’d)

Single element: 300 MHz, E-plane

Single element: 300 MHz, H-plane
RF analog beamformer

- 4-channel prototype board constructed using coplanar waveguide in 4-layer PCB with 10-ns max delay
- Isolation > 40 dB between channels and between switched lines within a channel
- Delay reproducible between channels to ~0.1 ns (1σ)
- Gain reproducible between channels to ~0.3 dB (1σ)
- Gain independent of delay selected to <1 dB
Prototype LOFAR HBA beamformer: measured gain and delay for minimum delay

![Graph showing measured gain and delay for minimum delay](image)

### Delay (ns)

### Gain (dB)

### Frequency (MHz)

- 50
- 114
- 166
- 222
- 275
- 330
- 384
- 438
- 492
- 546
- 600

- Delay
- Gain
- Frequency
Prototype LOFAR HBA beamformer: measured gain and delay for maximum delay
Prototype LOFAR HBA beamformer: measured gain and delay differences, max - min delay

![Graph showing gain and delay differences in a frequency range of 60 Hz to 600 Hz. The graph plots delay (ns) on the x-axis and gain (dB) on the y-axis.]
Simulated antenna tile patterns for beam steered to zenith

- **80 MHz**
  
  - E plane
  
  - H plane

- **153 MHz**
Simulated antenna tile patterns for beam steered to zenith (cont’d)

227 MHz

E plane

H plane

300 MHz
Measured antenna tile patterns for five steering directions

110MHz, Eplane, 1.07m spacing, 4x4

110MHz, Hplane, 1.07m spacing, 4x4

200MHz, Eplane, 1.07m spacing, 4x4

200MHz, Hplane, 1.07m spacing, 4x4
Looking ahead toward CDR....

- The primary (& secondary & tertiary &...) challenge is to meet the cost targets.

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity per tile</th>
<th>Total cost ($US)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual-polarization antenna element</td>
<td>16</td>
<td>$500</td>
</tr>
<tr>
<td>LNA (using ATF-55143)</td>
<td>32</td>
<td>$300</td>
</tr>
<tr>
<td>LNA → beamformer cable</td>
<td>32</td>
<td>$50</td>
</tr>
<tr>
<td>Beamformer boards</td>
<td>2 delay line + 1 digital interface</td>
<td>$500</td>
</tr>
<tr>
<td>Beamformer chassis, power supply &amp; final amps</td>
<td>1</td>
<td>$100</td>
</tr>
<tr>
<td>Groundscreen</td>
<td>1</td>
<td>$50</td>
</tr>
<tr>
<td>Shipping</td>
<td></td>
<td>$100</td>
</tr>
<tr>
<td>Assembly / installation</td>
<td></td>
<td>$300</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>$1900</strong></td>
</tr>
</tbody>
</table>
Antenna/groundscreen issues

- Antenna + groundscreen (+ LNA?) must be redesigned to minimize cost of manufacture, shipping, & installation.
- May support bowties with 5-cm-high dielectric posts between the groundscreen & lower tips of bowties.
- How is the groundscreen supported?
  - Lay it directly on the ground → cheap!
  - Support it above ground → other advantages.
- Working with two U.S. antenna companies to develop new design.
  - RDI Inc.
  - Seavey Engineering
Beamformer: technical issues

Is the frequency dependence of the BF delay acceptable?
Beamformer: technical issues (cont’d)

- Should the max delay be increased from 10.6 ns to 13.1 ns, to allow observations with all 16 elements down to 60° ZA for all azimuths?
Beamformer: technical issues (cont’d)

- Can the delay lines be packed closer together, while maintaining acceptable crosstalk, in order to fit all 16 channels and a 16-way combiner on one board?
  - Presently laying out a test PC board with closer packed lines
Monitor/control: functions

- Monitor functions:
  - Beamformer internal temperature
  - Beamformer DC voltage levels?

- Control functions:
  - Set delay line switches and on/off switch for each polarization of each antenna element
  - Set $0^\circ/180^\circ$ phase shift for each polarization

- Rely on satellite RFI to monitor health of LNAs and BF.

- Deuterium Array experience with similar LNAs:
  - Zero failures in $\sim2000$ HEMTs over $\sim3$ years
  - Only failures were in passive components, e.g., inductors
Monitor/control: implementation

- Use CPLD.
- What communication standard with node? RS-xxx?
- During observations, put logic to sleep, to avoid RFI.
- Walsh function signals must be handled separately.
  - Switching rates < 1 kHz.