Antenna systems: dipoles/groundscreen & analog beamformer

Brian Corey
MIT Haystack Observatory

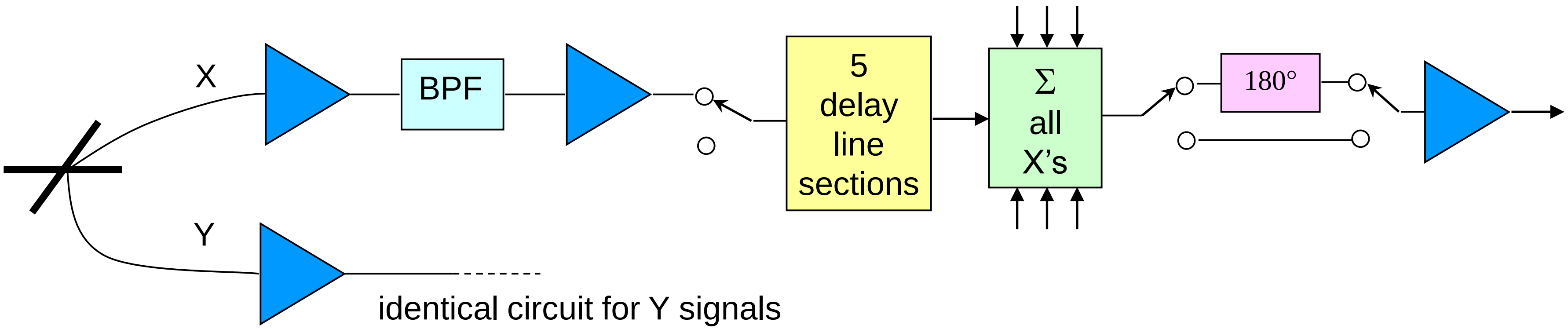
General specifications

Tunable frequency range	80-300 MHz
Instantaneous frequency range	≥ 32 MHz
Collecting area	≥ 10 m^2 over as much of frequency range as possible
Field of view	As wide as possible (within constraints of collecting area & physics)
Polarization	Dual
System temperature	Sky noise dominated

Key design features

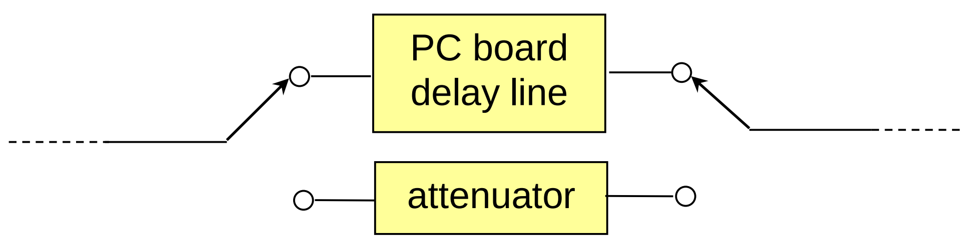
- 16 dual-polarization, bowtie antenna elements over a ground screen
- Elements arranged in compact planar array with $\lambda/2$ spacing at 140 MHz (= 1.07 m)
- Low-noise amplification integral to each element
- Analog RF beamformer with PCB tapped delay lines

Block diagram of electronics for one tile

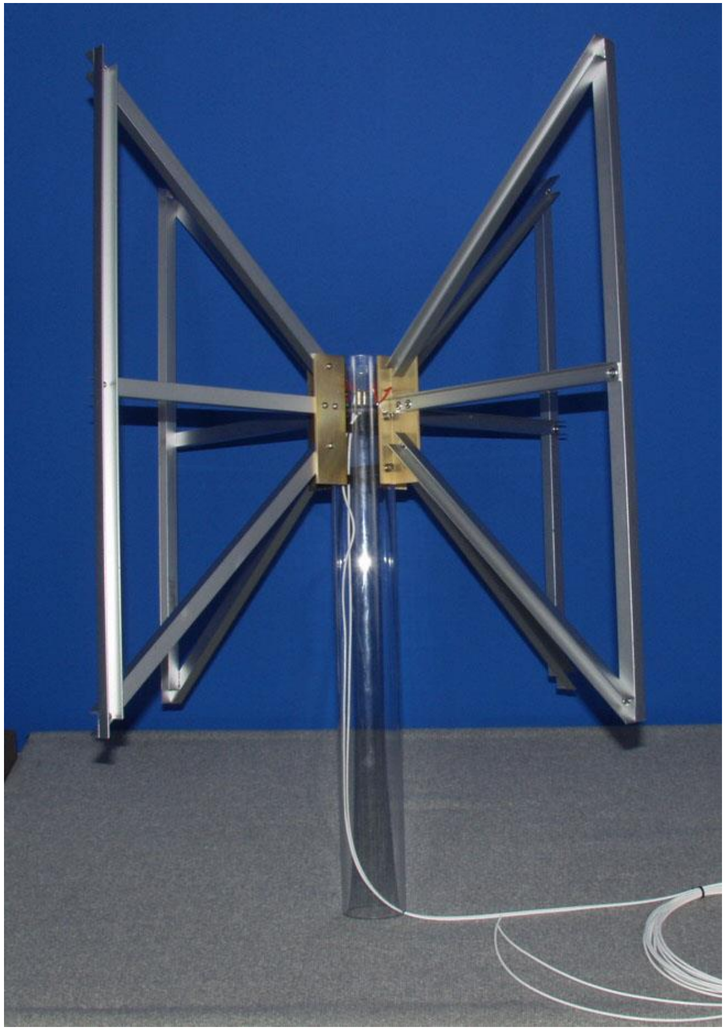


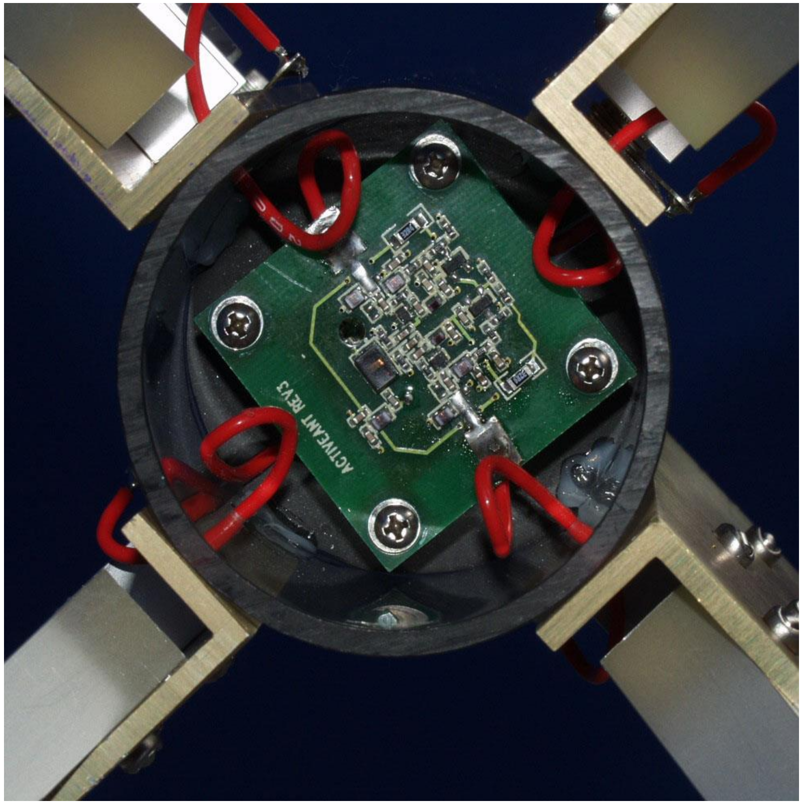
identical circuit for Y signals

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



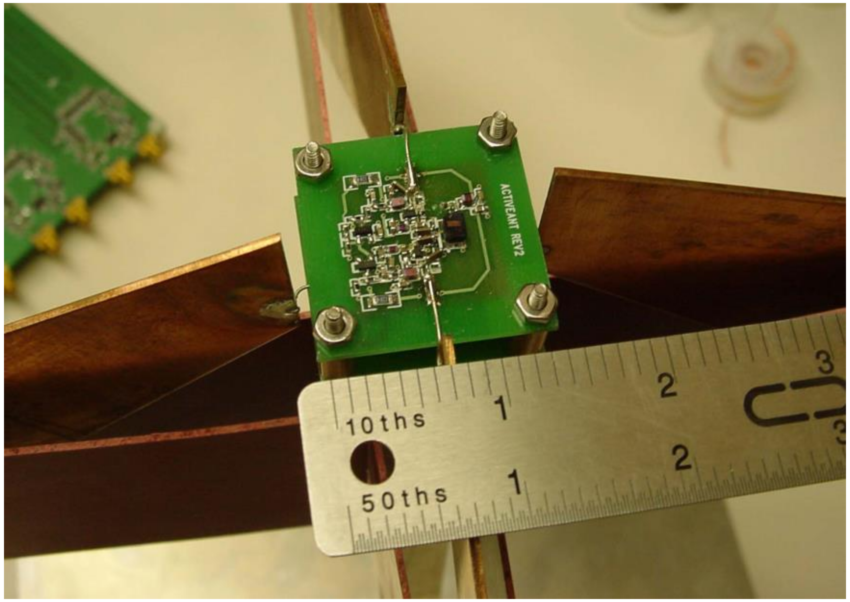
Prototype antenna element used in ED tiles



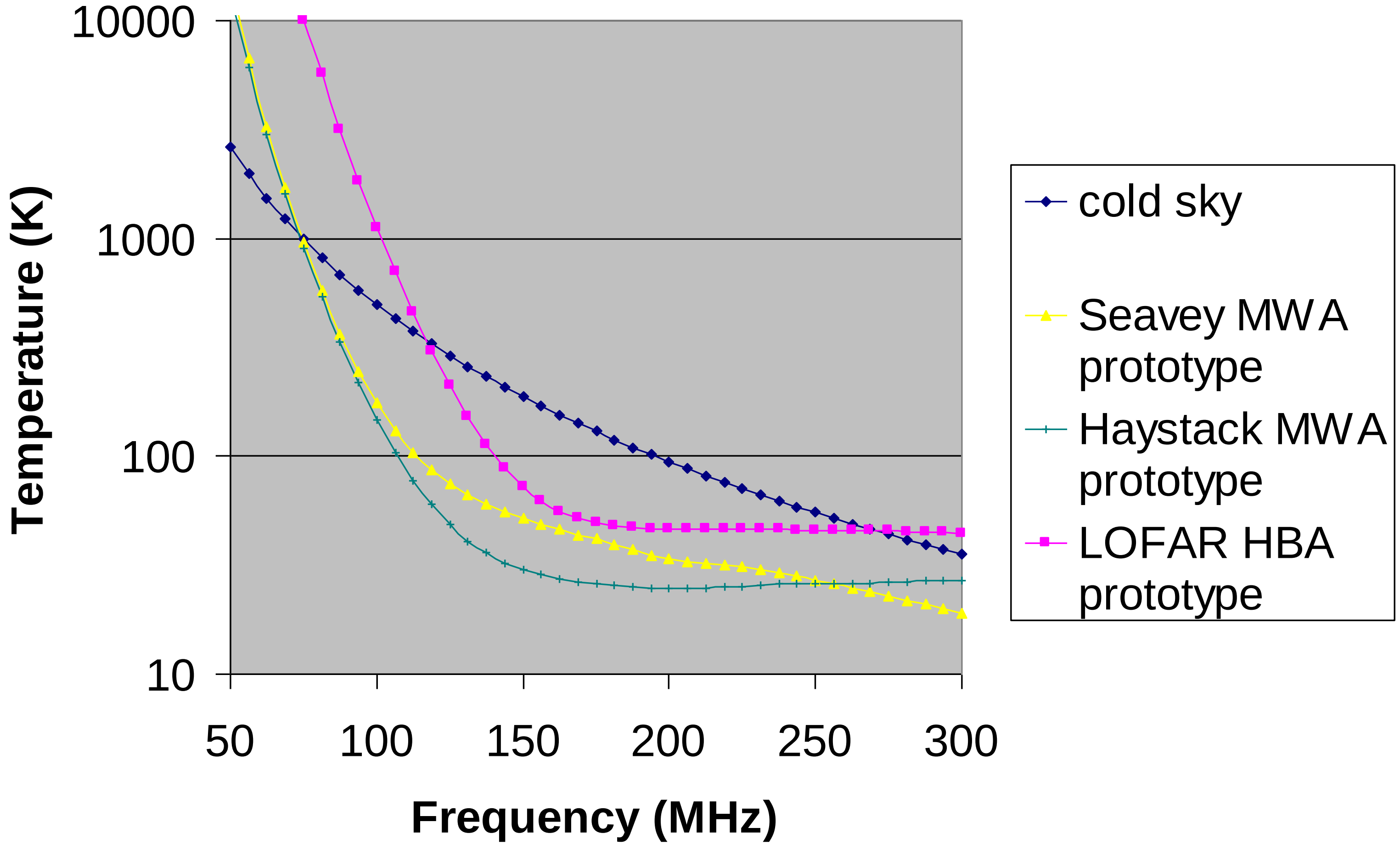


Low-noise amplifier

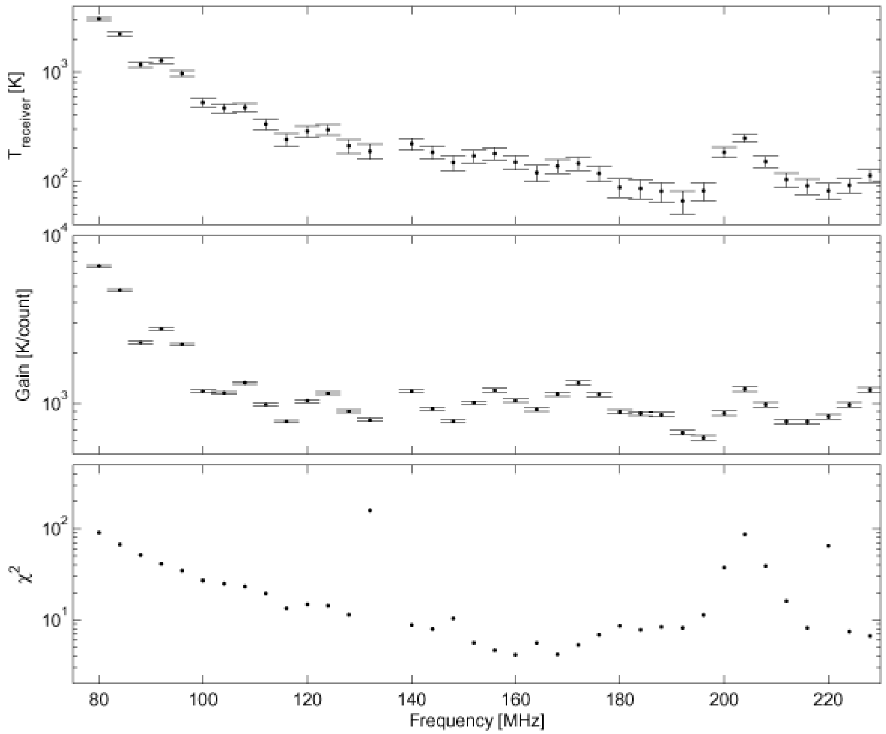
- Balanced design using two ATF-54143 HEMTs
- Measured noise temperature 14-17 K with 50 ohm loads on inputs, in agreement with simulation
- Measured OIP2 > +63 dBm, OIP3 = +27 dBm
- With LNA connected to prototype element, simulated noise temperature < ½ x sky temperature

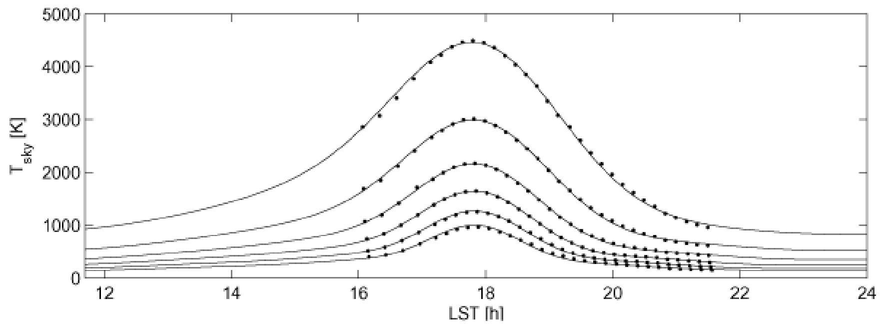


Simulated receiver noise temperature (antenna-LNA impedance mismatch included)



Receiver noise temperature from ED1 data

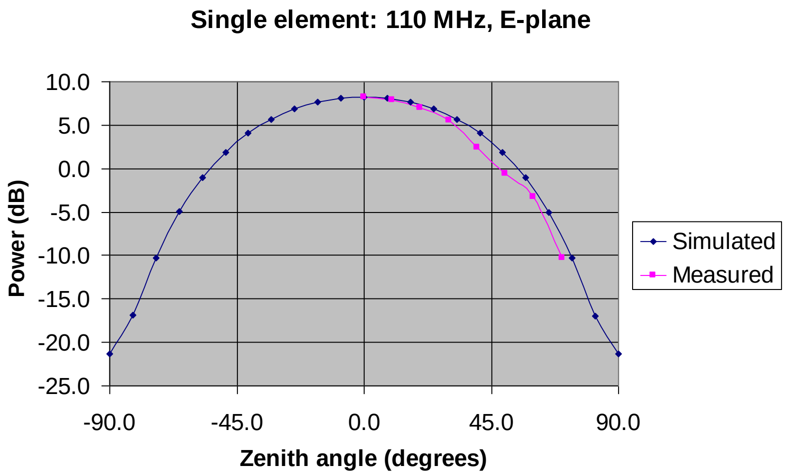


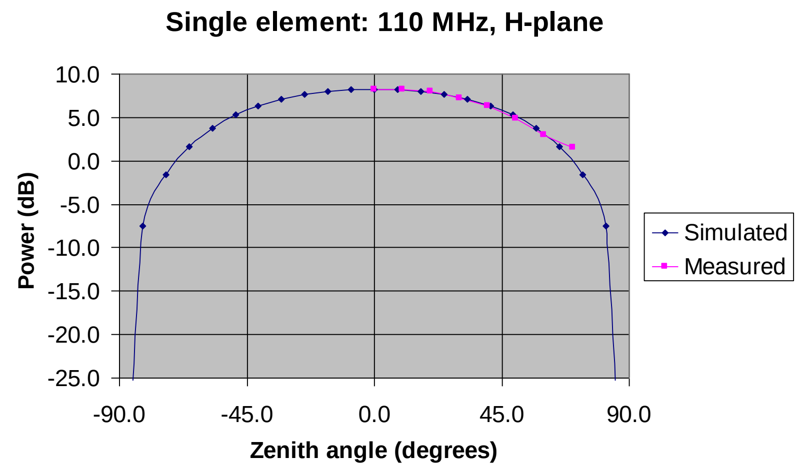


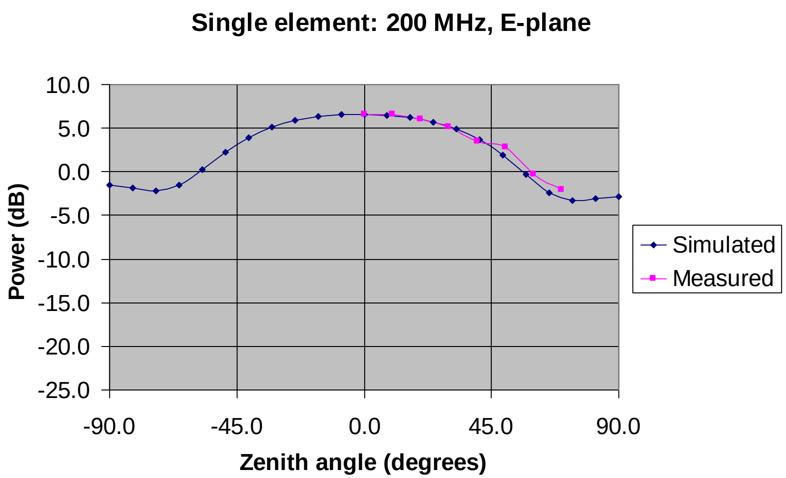
Top to bottom:

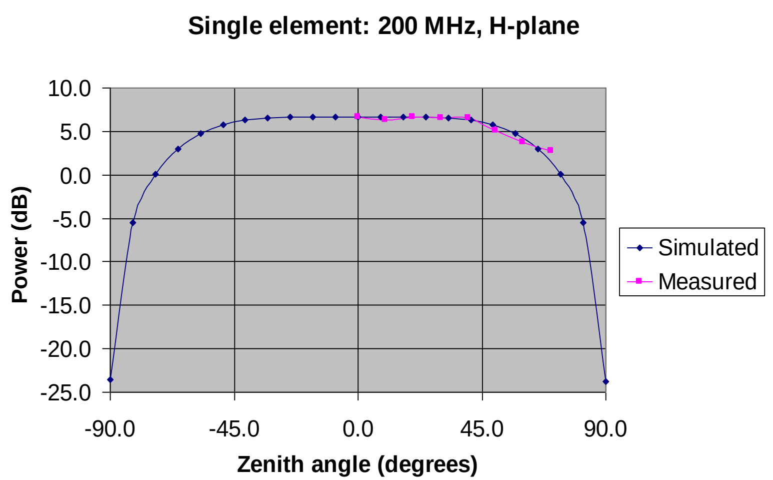
100 MHz
120 MHz
140 MHz
160 MHz
180 MHz
200 MHz

Single element power patterns

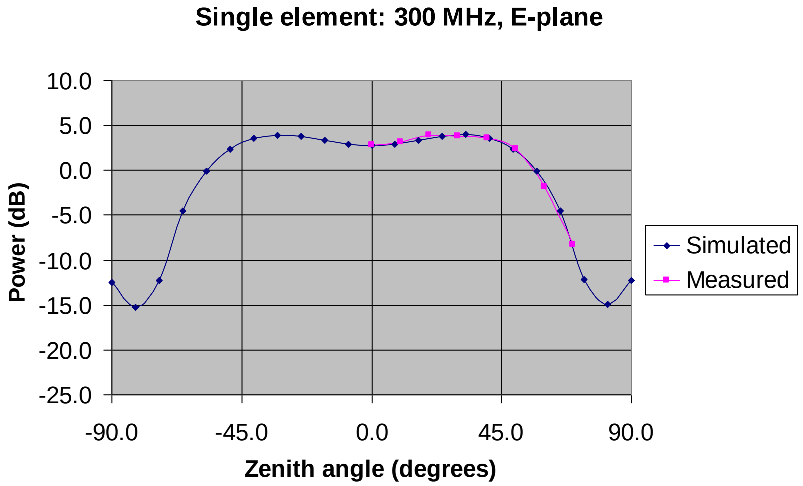


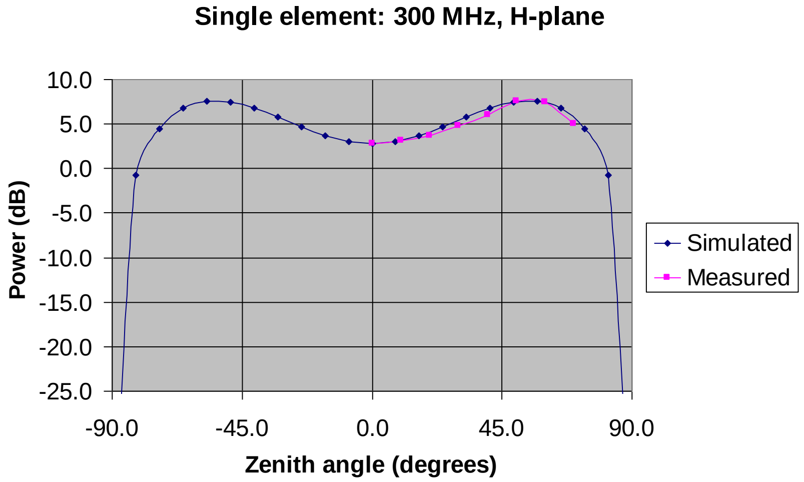






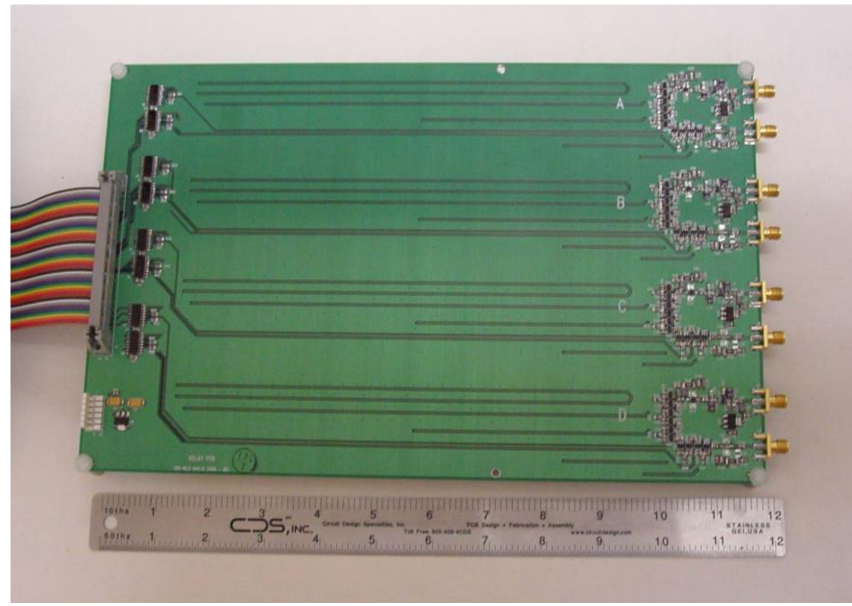
Single element power patterns (cont'd)



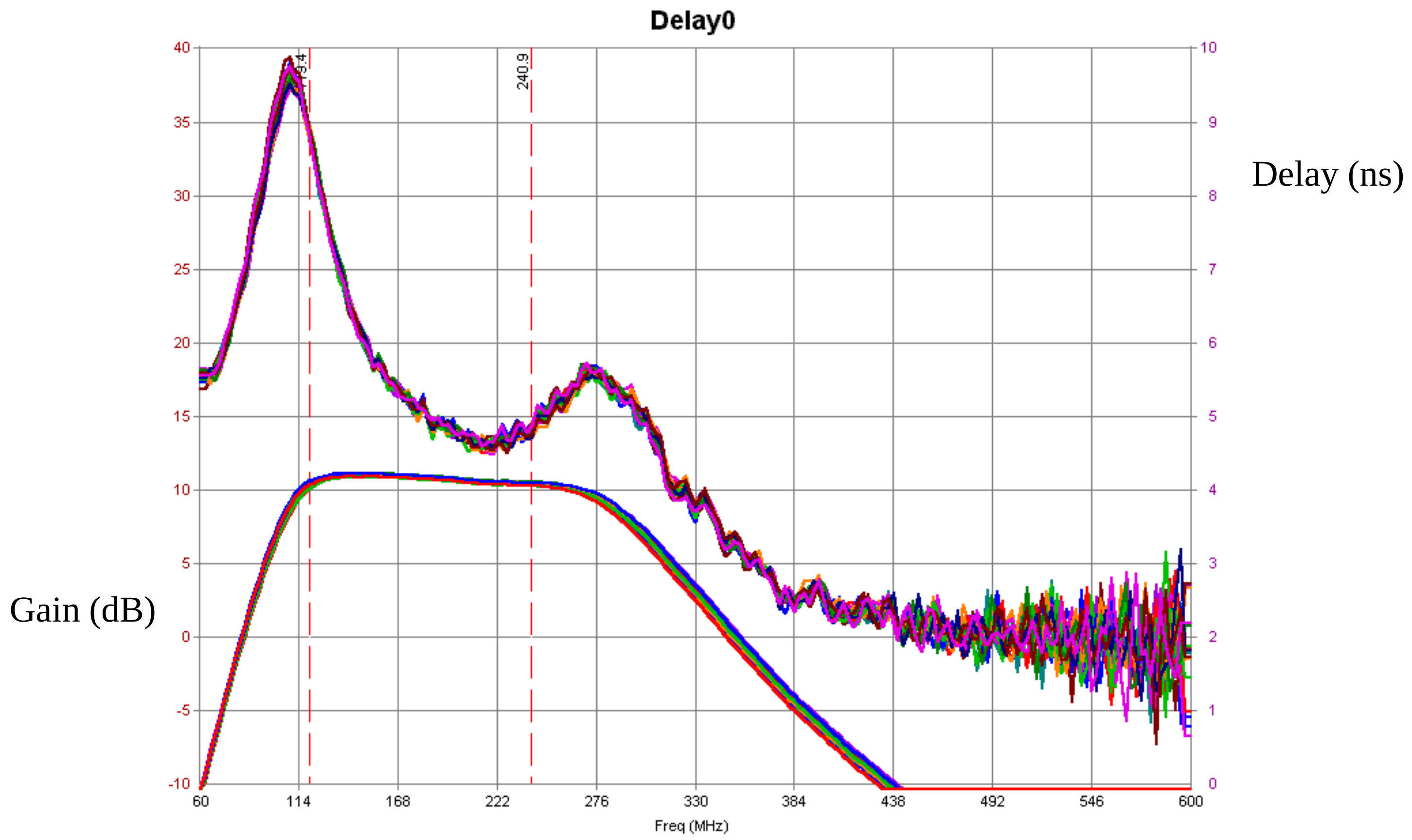


RF analog beamformer

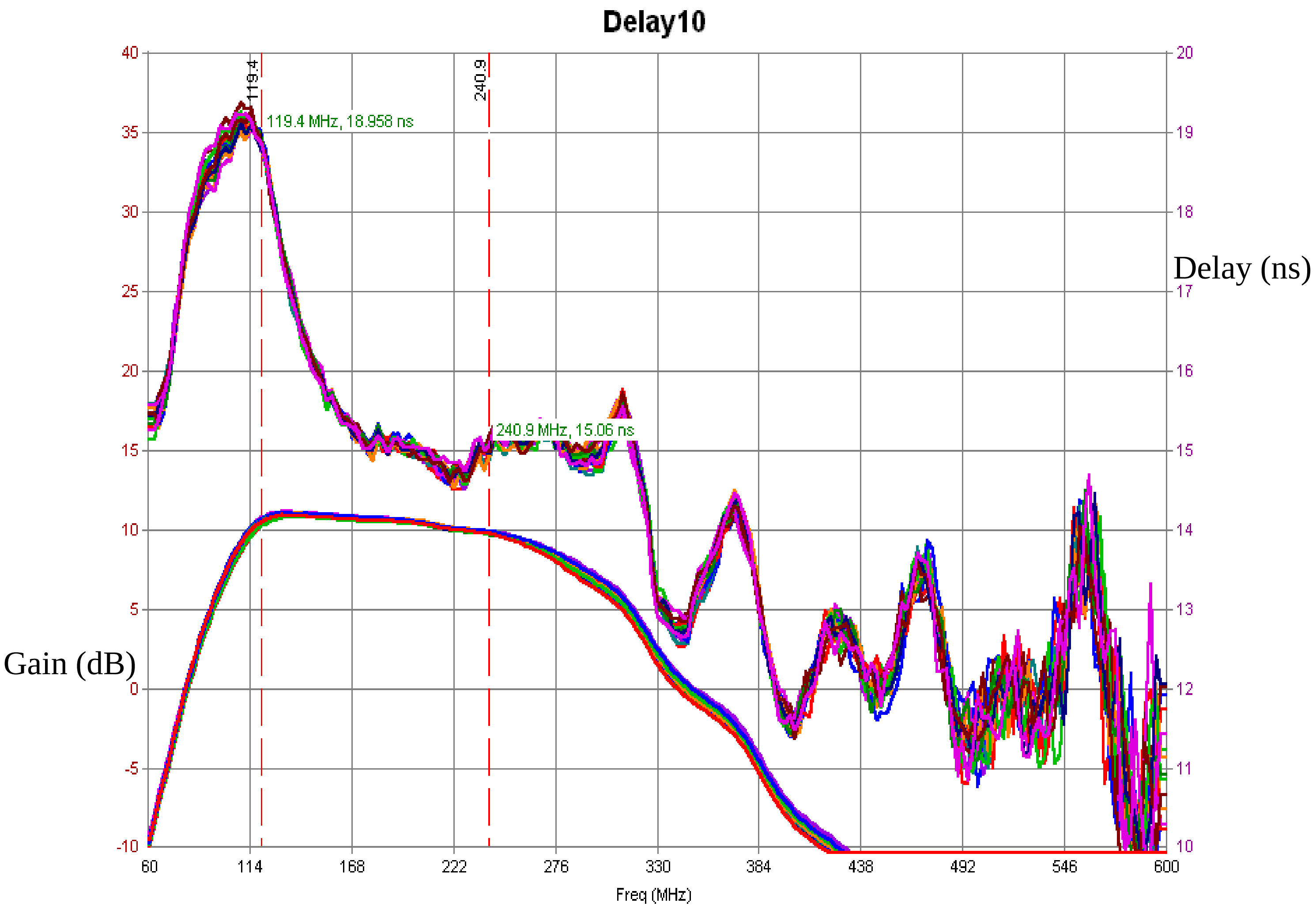
- 4-channel prototype board constructed using coplanar waveguide in 4-layer PCB with 10-ns max delay
- Isolation > 40 dB between channels and between switched lines within a channel
- Delay reproducible between channels to ~0.1 ns (1σ)
- Gain reproducible between channels to ~0.3 dB (1σ)
- Gain independent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



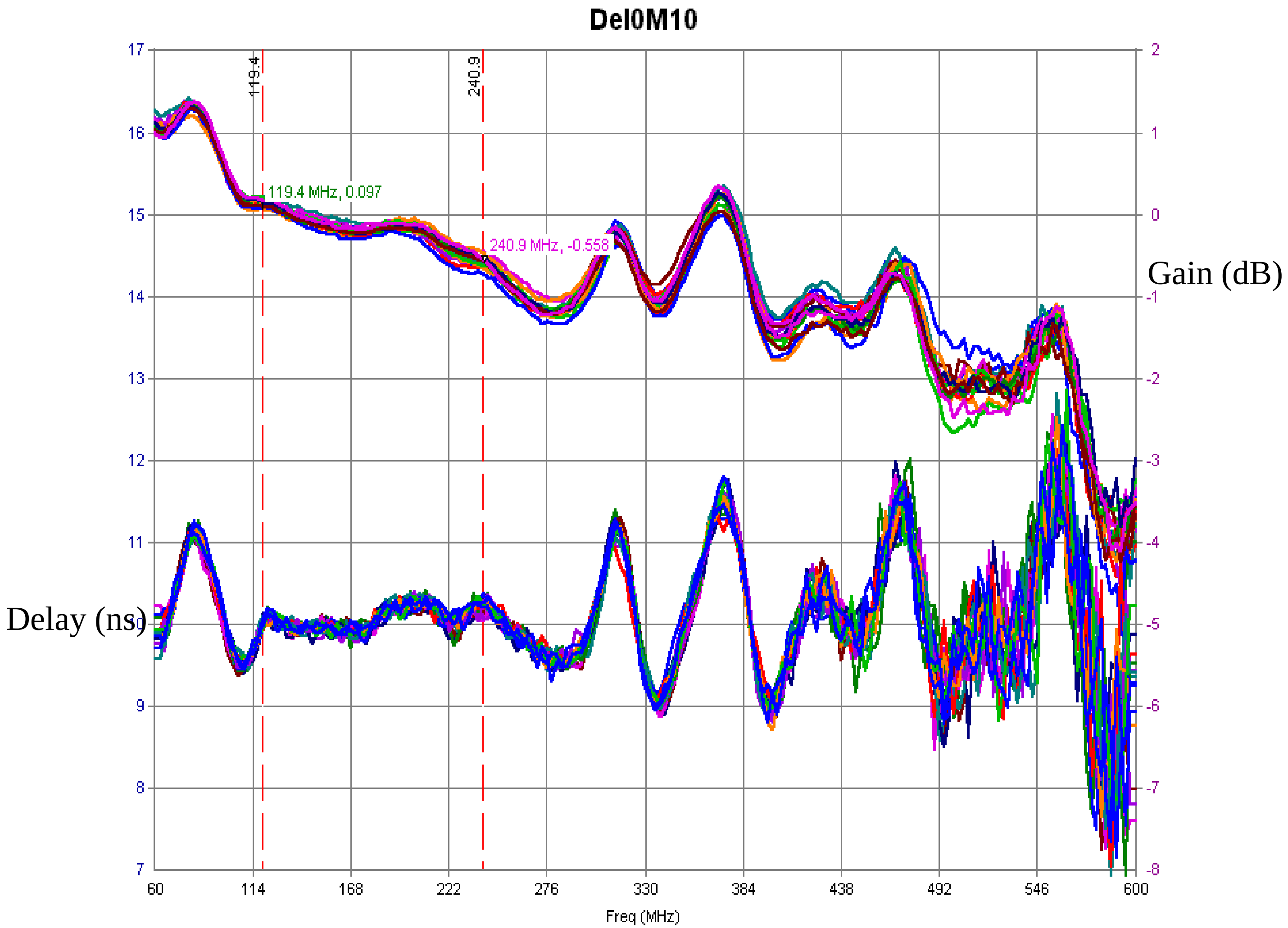
Prototype LOFAR HBA beamformer: measured gain and delay for minimum delay



Prototype LOFAR HBA beamformer: measured gain and delay for maximum delay



Prototype LOFAR HBA beamformer: measured gain and delay differences, max – min delay

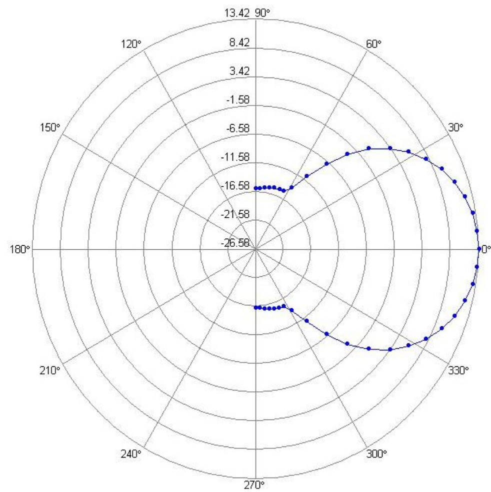


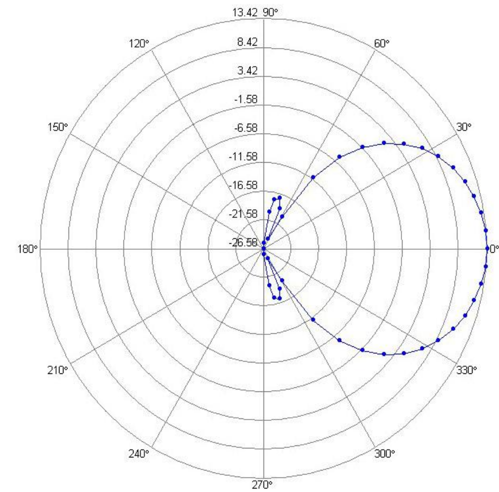
Simulated antenna tile patterns for beam steered to zenith

E plane

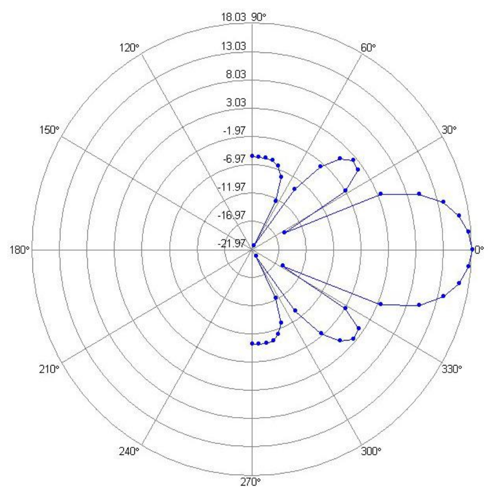
H plane

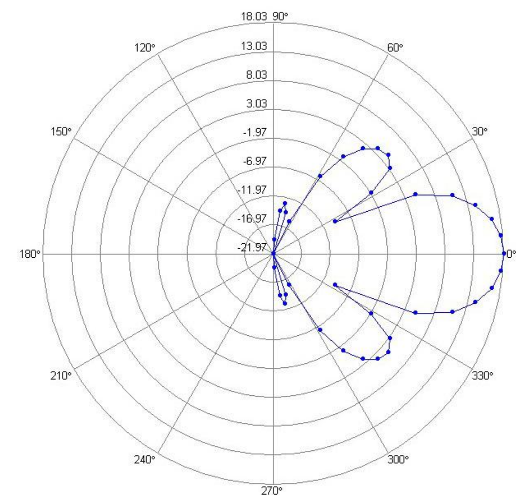
80 MHz





153 MHz



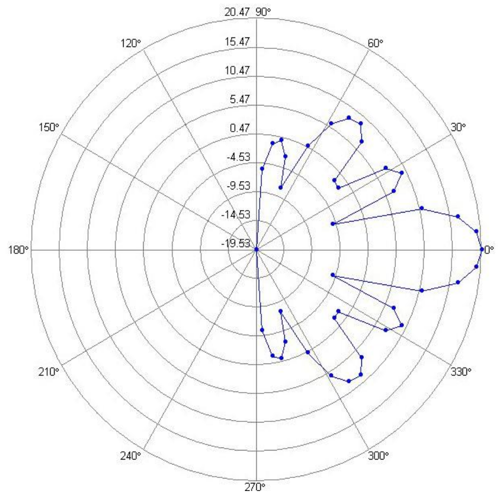


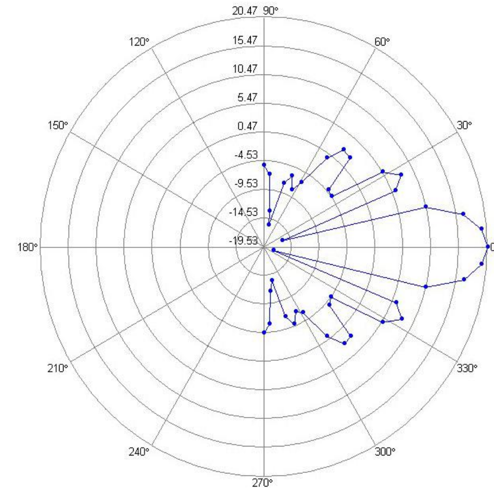
Simulated antenna tile patterns for beam steered to zenith (cont'd)

E plane

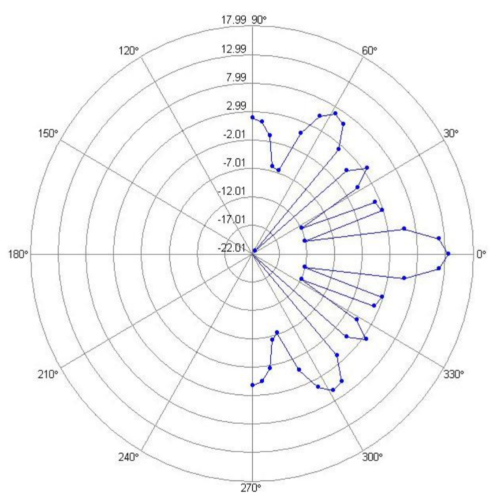
H plane

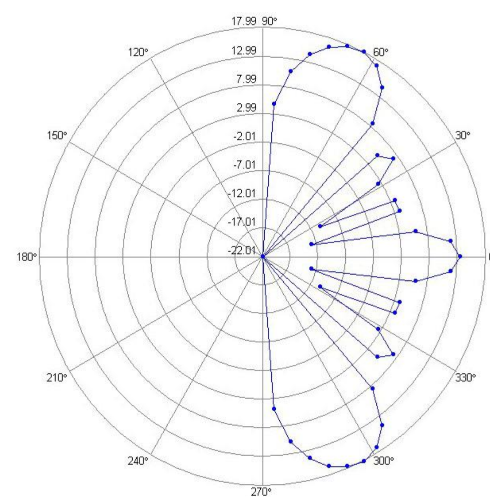
227 MHz



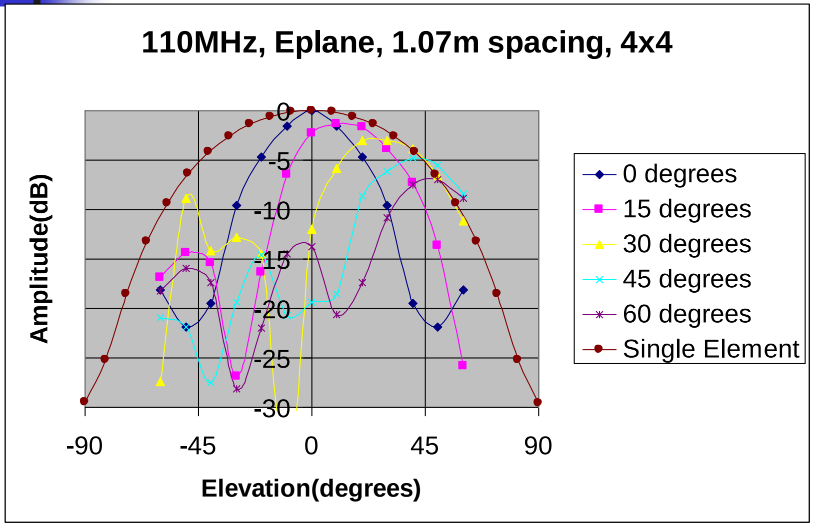


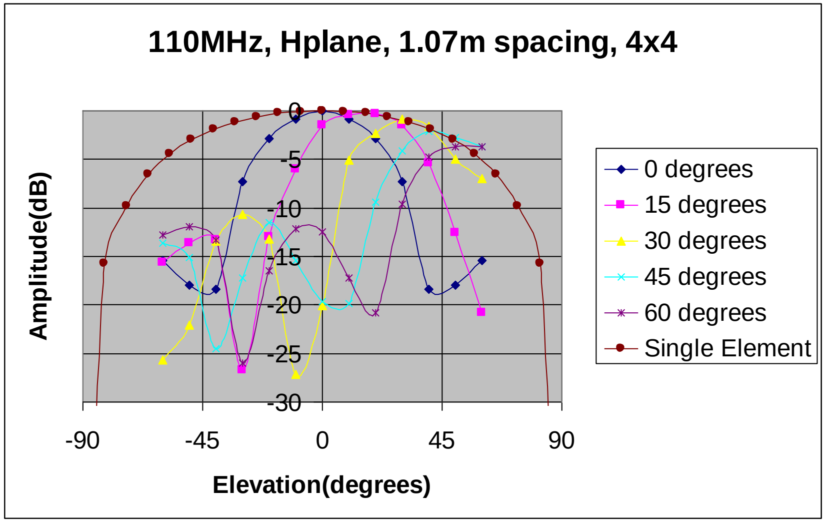
300 MHz

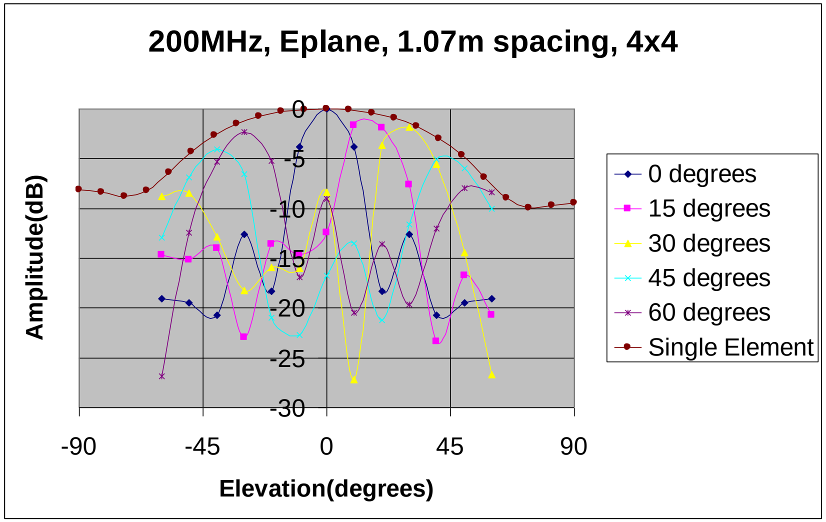


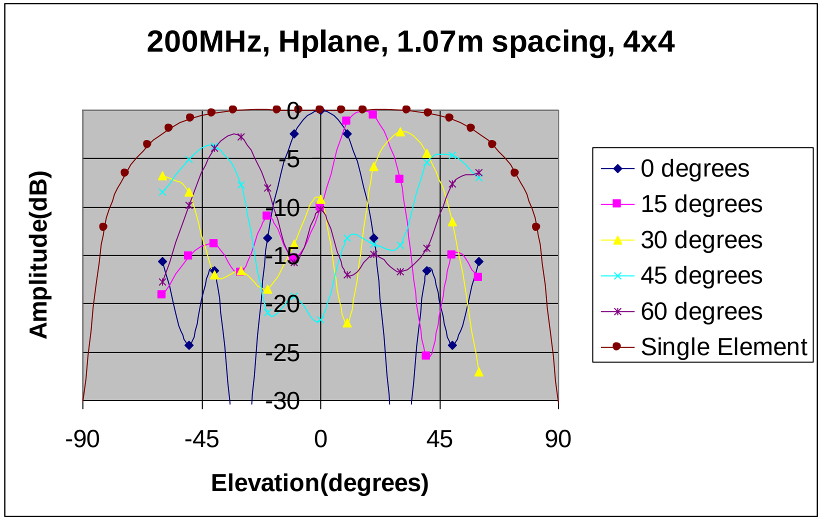


Measured antenna tile patterns for five steering directions









Looking ahead toward CDR….

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

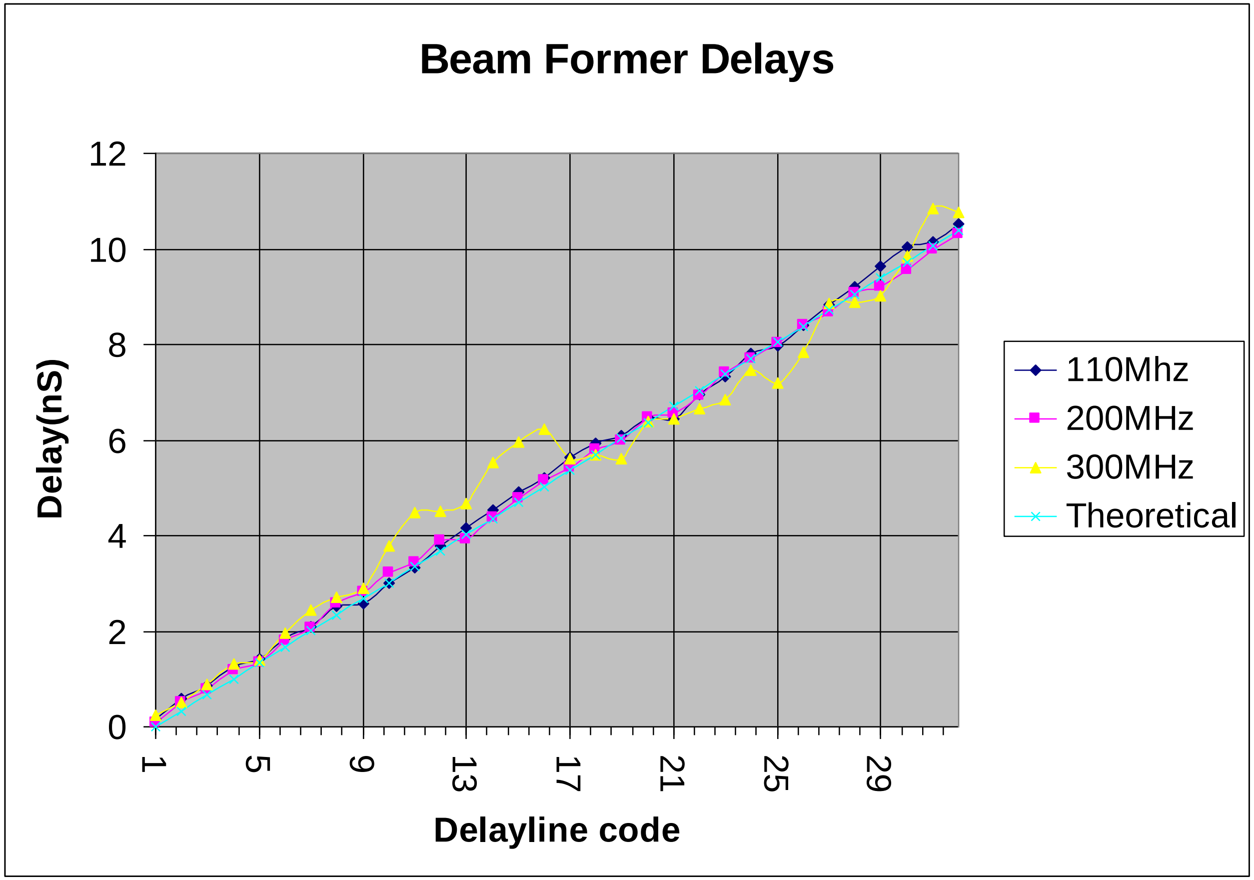
Item	*Quantity per tile*	*Total cost ($US)*
Dual-polarization antenna element	16	$500
LNA (using ATF-55143)	32	$300
LNA → beamformer cable	32	$50
Beamformer boards	2 delay line + 1 digital interface	$500
Beamformer chassis, power supply & final amps	1	$100
Groundscreen	1	$50
Shipping		$100
Assembly / installation		$300
Total		$1900

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

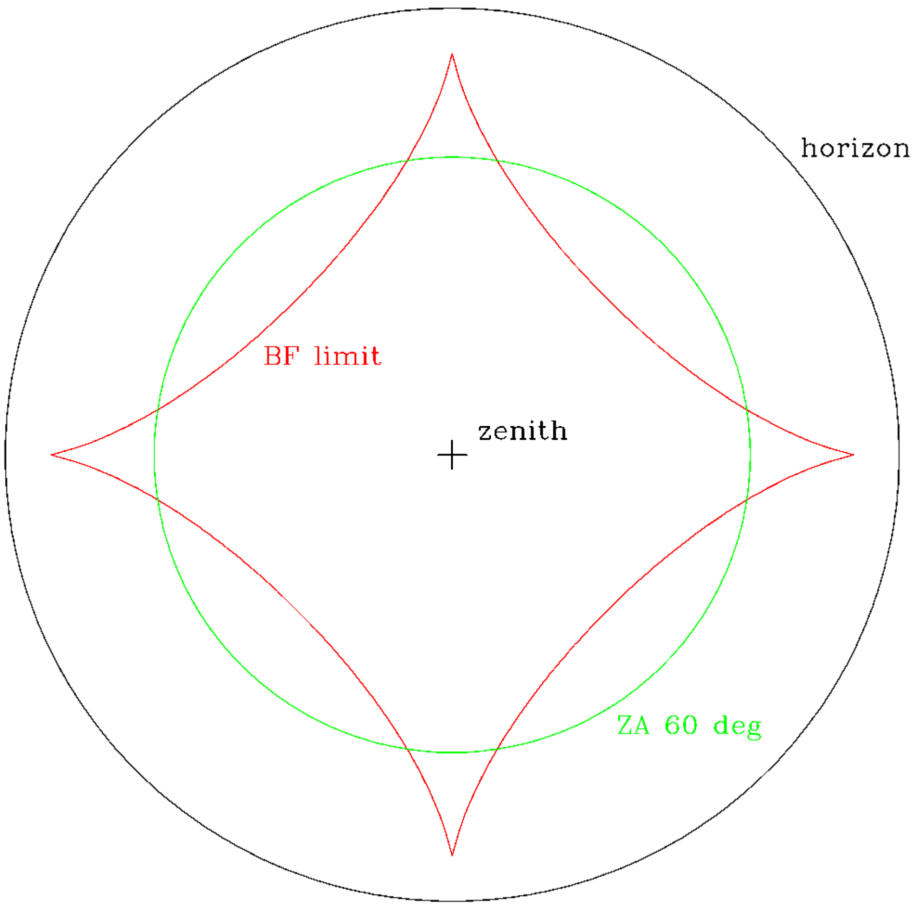
Beamformer: technical issues

- 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°/180° 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 ~2000 HEMTs over ~3 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.