Report on ECHO measurements of ORBCOMM dipoles in Green Bank

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Summary

The ECHO calibration drone, an experimental method for mapping the primary beam of widefield telescopes like PAPER/MWA and HERA, was recently tested by flying over the ORBCOMM beam mapping setup in Green Bank WV. This memo is a rapid report on these tests.

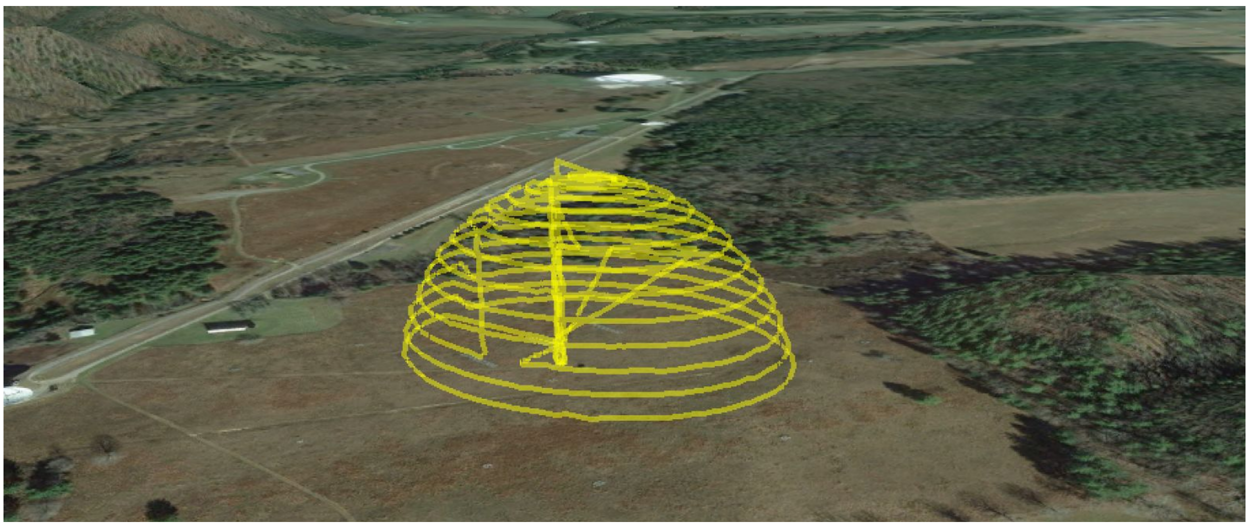
About ECHO, background and design

The goal of the Experimental Calibrator for HI Observatories (ECHO) is to enable precision cosmology with low frequency radio arrays by mapping the primary beam response using a drone-mounted transmitter. Accurate maps of the primary beam have been found to be crucial at multiple stages of analysis in Epoch of Reionization analysis, but have historically been difficult to obtain. Other methods either rely on external sources of radiation such as the ORBCOMM satellite constellation or extragalactic point sources or on lab testing in anechoic chambers. ECHO aims to provide a direct measurement with a system where all parameters are under the experimenter's control.

The ECHO source is a programmable oscillator which provides nearly 10mW of power at a frequency of our choosing from 137MHz to 4.4GHz. The source antenna is a bow-tie "broadband dipole" chosen for its smooth (but relatively inefficient) response vs frequency. The antenna is designed for calibration of wireless equipment in the field, so is relatively robust and has calibration information available. The drone we are currently using is an X8+ octoquad (four arms, 8 rotors) from 3D Robotics. The drone is flys automously following a pre-programmed flight path and records its GPS position and heading to an on-board sd card. It also transmits a telemetry signal to a laptop on the ground side. Typical flight times are about 15 minutes. The source antenna is slung beneath the craft at a distance of about 15 cm.

The External Calibrator for Hydrogen Observatories (ECHO) configuration at the time of the August 2015 testing. A broadband bowtie dipole is slung beneath an octoquad UAV (an X8+ from 3DR).

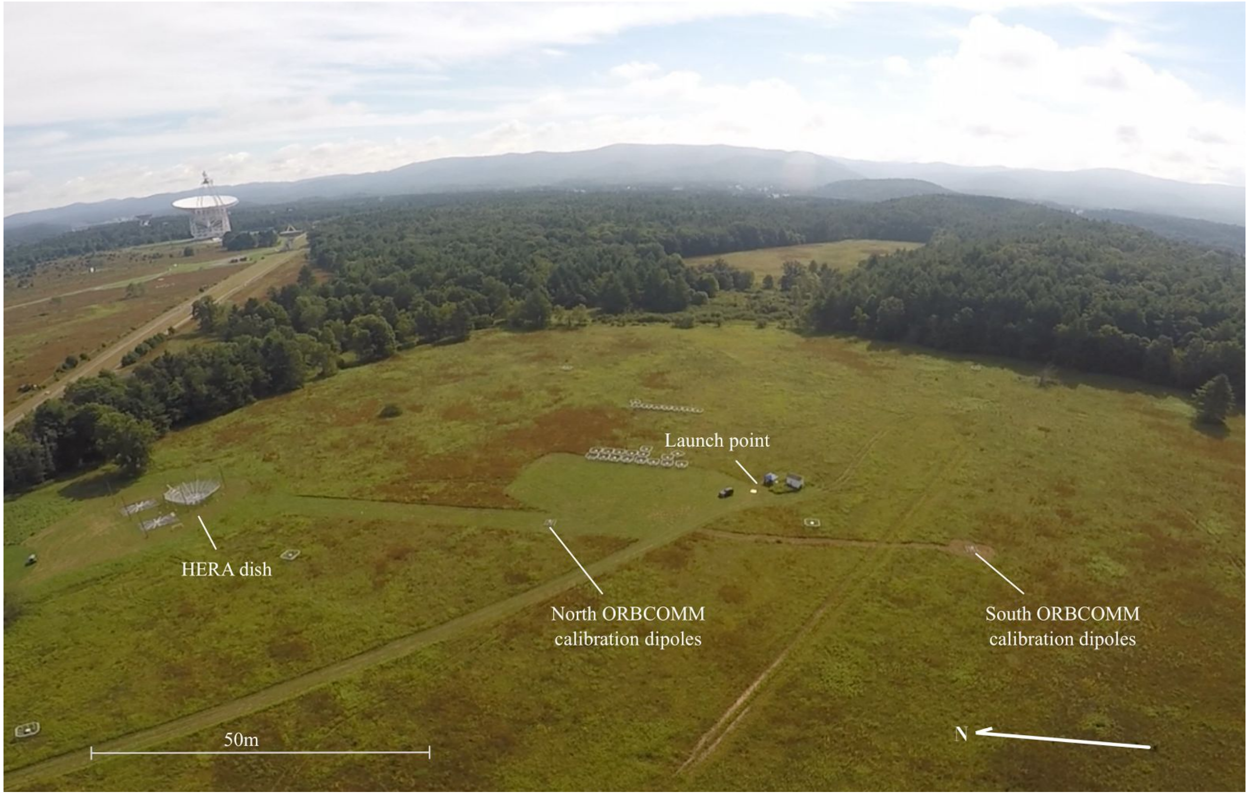
The flight pattern to map the beam follows the same HEALPIX pattern as the pixelization typically used by imaging analysis routines to store images and beam patterns. An nside 8 RING ordering of HEALPIX provides a single spiral-like path on sphere (here set to 100m radius) with a number of waypoints that is small enough to fit in the limited on-board memory of the autopilot and an angular distance between flight rings of 5 degrees. The orientation of the dipole is locked to the cardinal directions by programming a distant region of interest (ROI), each flight is completed twice, once with a NS transmit dipole orientation and again rotated by 90 degrees. In this way we map the complete polarization response of the antenna under test --as multiplied by the beam of the transmit dipole.



The beam mapping flight pattern uses the HEALpix pixelization which divides the sky into equal area pixels and orders them in a ring pattern. The total flying time of 60 minutes was accomplished in four flights of 15 minutes.

About the orbcomm setup

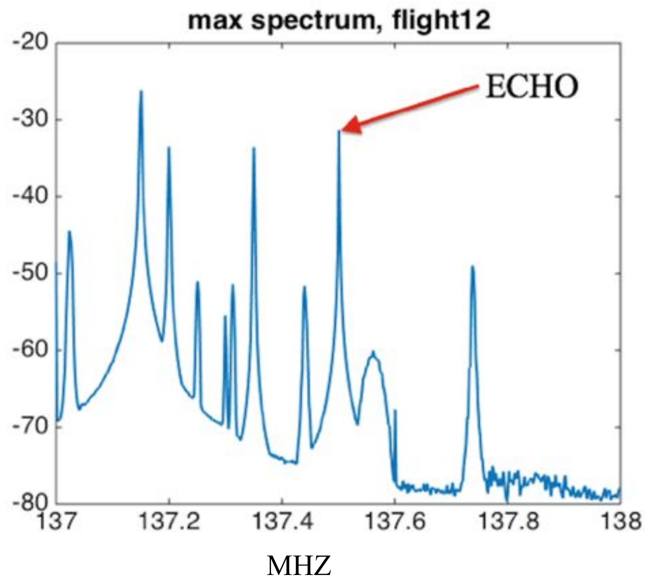
On this trip the goal was to map antennas which were part of the ORBCOMM mapping system described by Neben et al (2015) which uses the digital downlink transmissions of the ORBCOMM satellite constellation to map beam response. The ORBCOMM system is currently in operation at the NRAO Green Bank site preparatory to mapping the beam of the HERA dishes. In that procedure the antenna under test is recorded along with a tuned dipole situated nearby, the ratio between the two being insensitive to variations in power from the satellite transmitter. Uncertainty in this method depends somewhat on the location of the dipoles relative to their surroundings. This error is characterized by first performing a null test, where the antenna under test is temporarily replaced with a second calibration dipole, the ratio measurement now establishing the difference between two nominally identical antennas. This is the configuration used during the ECHO flights.



An aerial view of the Green Bank test site taken on day 3 of testing. North and South calibration dipoles and the HERA dish (currently under construction) are separated by 50m. The Green Bank Telescope is visible in the near distance. All operations were conducted from the indicated launch point, all personnel remained in this area during mapping flights.

The goal of the ECHO measurement is to make maps of both dipoles (denoted by position as North (N) and South (S), not to be confused with their respective linear polarizations NS and EW) with ECHO transmitting in an empty region of the ORBCOMM band. With the transmitter situated at 100m directly above the North dipole, the transmitter amplitude was adjusted (both in the programmed power output and then with attenuators) until the received power was similar to that from an orbcomm satellite at zenith. The spectrum output from the two dipoles was also examined for evidence of spectral broadening due to clipping, and more attenuation was added until the leakage into adjacent 5kHz ORBCOMM channels was <5%.

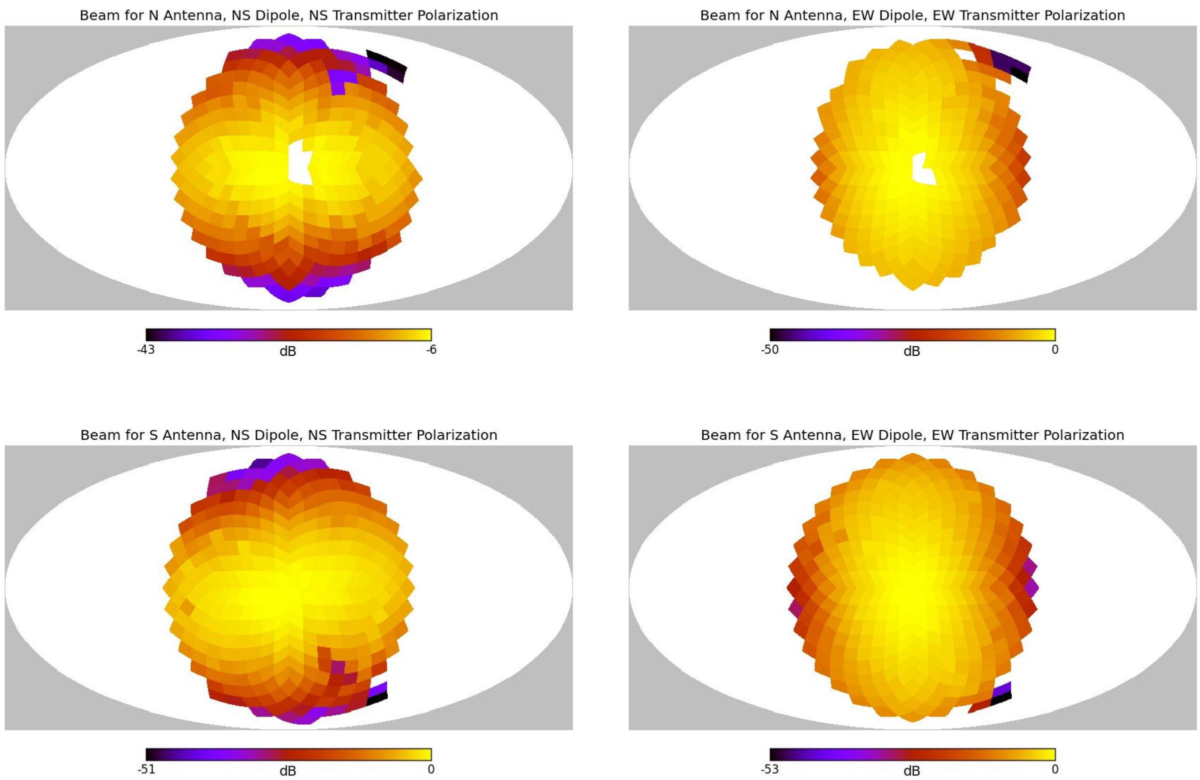
Transmitter power (with attenuation)	-14dBm
Frequency	137.5MHz
Apparent bandwidth	<5kHz



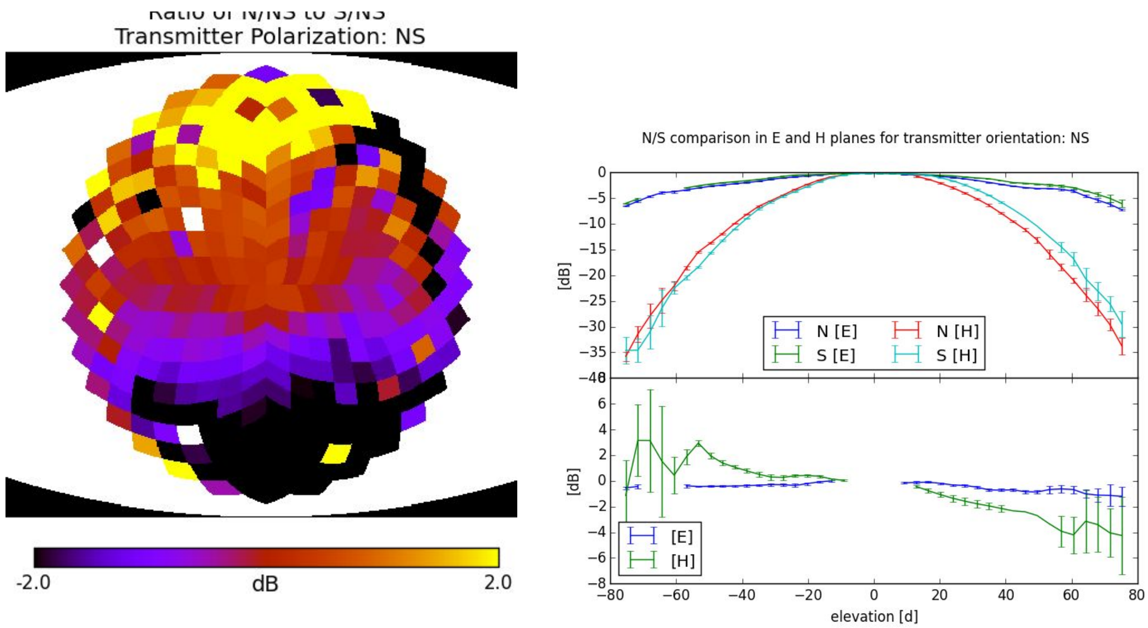
The goal of the ECHO measurement is to make maps by transmitting a (relatively) weak continuous wave signal in an empty region of the ORBCOMM band. This allows us to use the existing ORBCOMM receiver system and to make a direct comparison with the beam maps made using the satellite signals.

Results

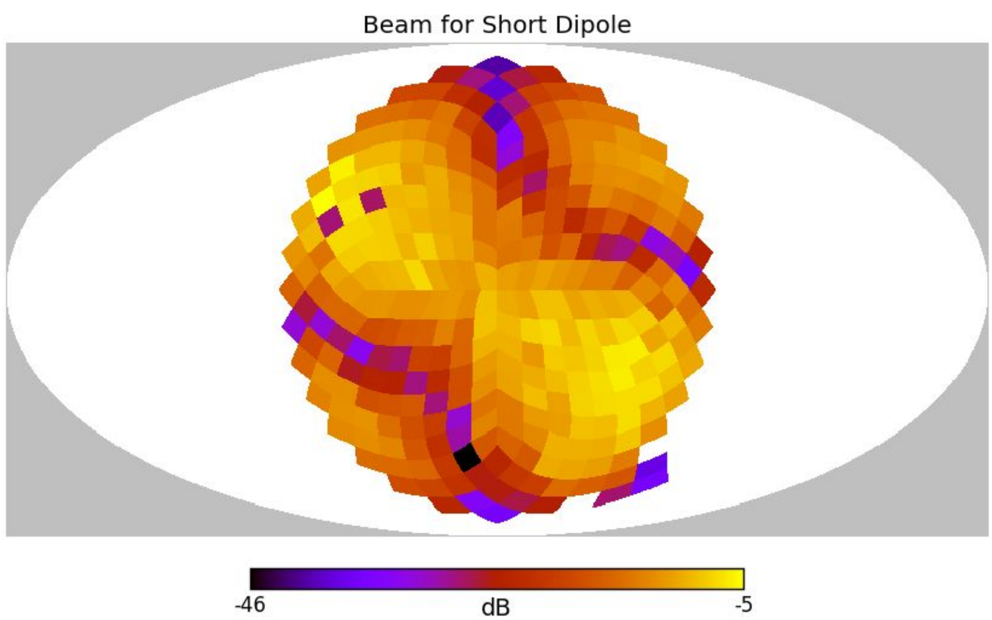
Mapping runs were completed for both polarizations on both north and south dipoles for a total of four runs.



A first look at the beam maps from each of the polarizations of each of the calibration dipoles. Next analysis steps include a more careful flagging of data from beginning and end of the flights.



Ratio of between beam maps of nominally identical dipoles. The overall tilt systematic is the primary subject of current investigation.



Both transmit and receive antennas are kept in the same plane. Therefore we get geometric effects which couple NS to EW, though not quite with the expected east-west symmetry.

Other experiments focused on the question of establishing links between the absolute measurement technique and the ratio technique of the ORBCOMM analysis. For this purpose we performed several long bisection runs parallel and perpendicular to the axis of the line inscribed between the two sets of dipoles. The perpendicular flight is particularly interesting as the transmitter is equidistant from the two receivers where the received power ratio will nominally be unity. The parallel bisection is mainly interesting at the end points where, though at different distances the drone visible to each receiver station at similar elevation angles. A third experiment sought to measure the primary beam of the transmitting dipole. The drone was locked in position and rotated through 360 rotations to make a cut along a constant bore-sight angle. This was done at multiple altitudes to get a range of cuts.

We'll continue to examine these data and will report back later with our findings.

Sincerely,
Team ECHO

Team ECHO during field testing at the HERA/PAPER site in Green Bank,WV Left to right: Ben Stinnett, Danny Jacobs, Abraham Neben, Lauren Turner, Jacob Burba