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Astro 2010 Activity

Pushing the Limits of the EVLA: An Enhancement Program for the Next Decade



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Summary

The NRAO has established a strategic plan (Lo et al., Astro 2010 position paper, *The Impact of the National Radio Astronomy Observatory*) for scientific discovery and technical development in the next decade which leads naturally to a long range vision for radio astronomy. This is one of five papers outlining for the Program Prioritization Panel a series of activities to implement this vision.

On time and on budget for completion at the end of FY2012, the Expanded Very Large Array Project (EVLA) will provide the astronomical community an order of magnitude increase in sensitivity above the original VLA, contiguous frequency coverage between 1 and 50 GHz, as well as incomparable flexibility in the spectral performance of the new WIDAR correlator. With these capabilities, the EVLA will be a major new facility at the forefront of astronomical research for the next decade. To leverage the US astronomical community's ongoing and long-standing investment in this unique instrument, we propose a set of modest cost, low risk enhancements to the EVLA that will explore the spatial and spectral extremes of the EVLA and significantly enhance the scientific power of the array:

(i) *E-configuration*: Twenty new pads close to the center of the characteristic EVLA Y-shaped infrastructure will allow for an ultra-compact "E" array configuration that will offer enhanced speed and surface brightness sensitivity, reduced sidelobe response, greatly improved image fidelity, as well as superior mosaicking. Scientific applications include large-angle, low-surface brightness surveys and mosaic observations of large sources, imaging of the SZ effect in galaxy clusters, H_I and non-thermal imaging of nearby galaxies.

(ii) *Pie Town Link (PTL)*: The resolution of the EVLA can be improved by a factor of two by upgrading the nearby Pie Town antenna to EVLA standards and directly connecting it to the EVLA correlator. The increased resolution will enable many critical astronomical programs and will, for example, allow users to image gaps in protoplanetary disks caused by forming planets, to distinguish between starburst and AGN contributions in cores of galaxies at all redshifts, and to improve astrometric accuracies for models of Galactic structure and dynamics by adding thermal emitters, like stellar photospheres and planetary nebulae to the objects for which parallax and proper motion measurements can be obtained.

(iii) *Low Frequency System (LFS)*: We propose to construct a new, ~50-1000 MHz low frequency receiver system for the EVLA. The upgrade will especially benefit from the EVLA's long baseline configurations, offering enormously improved scientific access to cosmic reionization, radio relics and halos, search for extrasolar planets, and observations of high-redshift sources, among other applications.

(iv) *Water Vapor Radiometers (WVRs)*: Adding a suite of compact WVRs to the EVLA will improve the overall phase calibration at frequencies above ~15 GHz by correcting for rapid phase errors produced by tropospheric water vapor fluctuations. This upgrade will permit observing during non-ideal weather conditions and thus extend significantly the observing time available for high frequency projects, especially for weak sources.

Science Goals

Ultracompact E-configuration

The scientific drivers for the ultra-compact E-configuration are straightforward: surface brightness sensitivity and image fidelity. The ongoing EVLA project combines state-of-the-art receivers with the widest possible observing bandwidths to achieve an enormous improvement in raw sensitivity. That sensitivity is, however, distributed over a wide range of spatial scales, allowing excellent imaging but missing the most extended, low surface brightness emission which in many cases accounts for the bulk of the emitted flux. By concentrating all EVLA antennas into the smallest practical area on the ground, the E-configuration applies the power of the EVLA to image this extended flux with the best possible surface brightness sensitivity over the entire ~ 1 -50 GHz EVLA frequency range. We expect a 1σ continuum surface brightness sensitivity of 50-100 μK in a 1 h integration at any frequency. At the same time, this concentration of antennas produces a much more well-defined synthesized beam (point spread function) on large scales, leading to corresponding improvements in image quality (both in correctness and dynamic range). The E-configuration will bridge the gap between the ~ 3 times higher resolution EVLA D-configuration and the ~ 3 times lower resolution of the Green Bank Telescope (GBT). A combination of GBT with EVLA E-configuration observations will thus create the best performance in the world for imaging faint, large-scale radio structures. This powerful enhancement will enable a large variety of new science:

▷ *Galactic and Local H_I*: The distribution of H_I, the fundamental building block of the Universe, is typically very diffuse. Interferometric surveys of Galactic H_I emission thus miss a substantial fraction of the entire flux. Only observations in compact array configurations in combination with single dish data can fully map the diffuse gas (for E-configuration observations of the molecular gas in Galactic star forming regions, see Astro2010 Science White Papers [SWP] by Bally et al., Mundy et al., Lis et al., Loinard et al., Feigelson et al.). Further out, Galaxy interactions in the form of tidal interactions or ram pressure stripping are a major process for distributing atomic gas between galaxies. Again, this gas is rather tenuous and widespread, but only the filamentary high column density regions are typically imaged by interferometers (see SWP by Lockman & Ott). The EVLA E-configuration will provide superior sensitivity at extended scales, and will permit the construction of wide-field, deep, high fidelity images of such systems.

▷ *Cosmic Web*: Deep E-configuration observations will push the EVLA H_I column density sensitivity down to values of $< 10^{16} \text{ cm}^{-2}$ at which the connections of galaxies to the cosmic web become visible. This will provide a basic test of Cold Dark Matter models and allow direct observations of cold gas accretion, e.g. in the form of condensing high velocity clouds from diffuse halo gas (see, e.g., SWP by Putman et al.). Compared to most single dish telescopes, the spectral baselines of an interferometer are more stable (standing waves and other unwanted effects on the single elements correlate out). Thus, EVLA E-configuration observations are ideal for observing the very wide, faint spectral lines expected from the cosmic web.

▷ *Radio Continuum and Magnetic Fields:* Surface brightness sensitivity is also germane for observations of faint thermal and non-thermal radio continuum emission. E-configuration observations will directly probe the structure and polarization of radio relics in galaxy clusters, ideally in combination with the EVLA LFS proposed in this paper (see also SWP by Rudnick et al.). In addition, large-scale galactic outflows of material from nucleated starbursts can be traced to large distances and the magnetic field, which may be the product of the outflowing gas or the facilitator of the outflow, can be studied in great detail for various Hubble types.

▷ *Radio Lobes:* The Mpc size jets of radio galaxies are typically organized in the form of bright inner and low surface brightness outer lobes. The structures within the outer lobes are very sensitive to the interaction of the jets with the surrounding medium and can trace the physical conditions in the ejected plasma. In turn, the lobes provide matter and energy feedback to the intragroup or cluster medium. Low surface brightness lobes are also expected from radio galaxies that have recently shut off their central engine and are now fading away. The E-configuration, particularly when combined with matched resolution LFS observations, can probe these objects across cosmic timescales and improve on previous searches by an order of magnitude.

▷ *SZ effect and cosmology:* E-configuration is ideally suited to image the upscattering of CMB photons by hot electrons in galaxy clusters (SZ effect; see SWPs by Myers et al.; Golwala et al.). Observations at ~ 30 GHz will provide the sensitivity to observe the full SZ effect over an entire cluster while still resolving its inner structure (a resolution of ~ 50 kpc at a redshift of ~ 0.8 can be achieved). This will result in a direct measure of the electron density distribution at any redshift.

The combination of sensitivity and resolution required for these studies is unique to the EVLA; no other telescope, current or planned, can make these images.

Pie Town Link

The location of the VLBA antenna in Pie Town was deliberately chosen to double the baseline lengths of the most extended configuration of the VLA (A-configuration, see Fig. 2). To take full advantage of the corresponding 2 times increase in spatial resolution, a conversion of the Pie Town antenna to EVLA standards in terms of receiver bands and bandwidths as well as electronics and software is required. The antenna will be connected to the EVLA WIDAR correlator by a state-of-the-art digital fiber link (note that WIDAR was designed to take additional inputs from non-EVLA stations) which will replace the older, narrow-band analog connection. The conversion of the Pie Town VLBA antenna to EVLA wide bandwidth standards represents a technically straightforward, scientifically compelling, and cost-effective upgrade of the EVLA's capabilities.

The PTL can be seen as a natural complement to the E-configuration: whereas E-configuration will enable the imaging of large scale emission with high surface brightness sensitivity, the PTL will allow the EVLA to observe sources at resolutions of up to $0.02''$. The new science enabled by the PTL will include:

▷ *Planet Formation:* The PTL will double the resolution of protoplanetary disks observed in the nearest regions of solar-type star formation (e.g., at a frequency of 45 GHz and $D \sim 140$ pc the physical resolution becomes ~ 4 AU). This will enable direct imaging

of the thermal dust emission from large dust particles and planetesimals at Jovian radii in disks surrounding solar-mass stars, and will provide the opportunity to directly image gaps and, potentially, protoplanets in these disks (see SWP by Wootten et al.).

▷ *AGN-Starburst Connection*: One of the most pressing questions about high redshift galaxies is the relationship of AGNs and starburst regions (see, e.g., SWP by Carilli et al., Appleton et al.). Flux measurements alone cannot reliably distinguish between the two phenomena and direct imaging of the size and shape of the central emission is needed. As PTL will operate in the full 1-50 GHz EVLA frequency range, the observing frequency can be adapted to a value where the emission starts to become resolved (resolution at 1.4, 5, and 30 GHz, will be $\sim 0.7''$, $0.2''$ and $0.04''$, or ~ 4.5 , 1.3 , and 0.3 kpc at $z \sim 5$, assuming WMAP cosmology) but still remains bright enough for reliable detection (generally, with the VLBA, starburst contributions are resolved out and are not visible). This will provide a measurement of the star formation history of the Universe, as well as explore the details of the AGN-starburst connection vs. redshift.

▷ *High Redshift Thermal Emission*: In addition, galaxies in the early Universe have their thermal emission redshifted to EVLA frequencies. At $z \sim 5$, thermal emission will be measured by EVLA+PTL at a physical resolution of ~ 150 pc, about half the size of the Central Molecular Zone in our own Galaxy.

▷ *Gravitational Lensing*: The PTL is also ideal to determine the total mass and sub-structure of galaxy clusters via strong gravitational lensing (SWP by Koopmans et al.). Radio observations are ideal as they are not affected by extinction. Radio flux measurements of different lensed images are therefore much more reliable than optical images and mass distribution models are more accurate. The PTL resolution of up to $0.02''$ will be ideal for this purpose.

▷ *Astrometry*: Finally, the PTL's sensitivity and resolution can contribute significantly to astrometric observations. The VLBA lacks the sensitivity to observe faint thermal emission. This limits astrometric VLBA surveys of the Galaxy's 3-dimensional spatial and kinematic structure to special classes of sources with non-thermal emission like masers (SWP by Reid et al.). PTL observations are sensitive enough to reliably detect thermal sources like stellar photospheres, planetary nebulae, or AGB stars at high spatial resolution. Determinations of the parallax and proper motions of these sources add invaluable data points to the grid on which the dynamical models rely on (see SWP by Henry et al.).

Low Frequency System

The older, path-finding "legacy" VLA low frequency (< 1 GHz) receivers are narrow-band and, unfortunately, interfere with the newly installed wide-band EVLA receivers. To remedy this situation and re-establish EVLA access to this unique frequency window, we propose to construct a suite of new wide-band receivers that cover a frequency range of ~ 50 -1000 MHz. The new receiver system will be superior to the old system in bandwidth, system temperature (by a factor of ~ 3), versatility, and stability and will allow users to access the following science themes:

▷ *Transients and Extrasolar Planets*: One of the most exciting themes of upcoming, dedicated low frequency arrays are large scale, all-sky surveys of transients. The EVLA

LFS can pioneer these studies taking advantage of the stability of the EVLA and radio frequency interference (RFI) isolation of WIDAR (SWP by Lazio et al. [a]). The SWP by Lazio et al. [b] describes the possibility of detecting extrasolar planets via their magnetospheric emission. The LFS can push the limits towards solid detection of this effect and has the potential to contribute significantly to planet searches that are performed at other wavelengths.

▷ *Steep-Spectrum Sources*: LFS observations will be indispensable to trace the steepest spectrum electron populations in the Universe. Such observations are central to constraining galaxy and cluster size, energy content, and evolution as well as intracluster medium studies (SWPs by Arnaud; Markevich; Myers; Rudnick).

▷ *Supernovae*: The EVLA LFS will be ideal to probe SNR-molecular cloud interactions via thermal absorption and trace evidence for secondary electron production from cosmic ray interaction with dense material. The LFS will also contribute to multiband, radio to gamma ray studies of particle acceleration in SNRs (SWP by Soderberg et al.)

▷ *Atomic Gas and Magnetic Fields Across Cosmic Time*: Spectral lines at low frequencies are typically those of radio recombination such as carbon lines that trace cold atomic gas, molecular lines suitable to probe the evolution of fundamental physical constant (SWP by Kanekar et al.), or the redshifted 21 cm line of H_I. The 216-470 MHz window with low RFI will allow us to observe H_I absorption in the $2.0 < z < 5.6$ redshift range, and observations in the 110-174 MHz window will provide access to $7.2 < z < 12.9$. H_I emission lines from galaxies at those redshifts are too faint for detailed study. Hydrogen absorption against bright background quasars, however, will be a prime target for the proposed receiver system. This enables observations of H_I Zeeman splitting which is a unique opportunity to probe the magnetic field in the early Universe (see also SWP by Dowell et al. for Zeeman measurements in the local Universe). The H_I absorption line probability is known to increase rapidly with redshift, until we ultimately reach the Epoch of Reionization (EoR) at a redshift probably lying in the 110-174 MHz window.

▷ *Cosmic Strömgren Spheres*: The same capabilities are also ideally suited to searches for the rare, largest-scale ionized bubbles, cosmic Strömgren spheres, associated with bright quasars and/or clustered galaxy formation (see SWP by Furlanetto et al. [a,b]). The search is facilitated by the large LFS field of view at the longest wavelengths, corresponding to large volumes than can be sampled. Studies of the highest redshift radio galaxies themselves are also important as they are signposts of the Dark Matter concentrations in the early Universe (SWP by Miley et al.).

All of the above will be technically challenging observations that are in many cases vulnerable to RFI. Their success will depend greatly on the spectral line flexibility and RFI mitigating capabilities of the EVLA's WIDAR correlator which is currently being installed.

Water Vapor Radiometry

The high frequency end of the EVLA will be covered by the installation of new and refurbished receiver systems up to frequencies of ~ 50 GHz. Atmospheric water vapor, however, is notorious for negatively influencing radio interferometry at frequencies of ~ 15 GHz and higher. Water vapor increases sky brightness, increases atmospheric

opacity, and introduces phase noise driven by turbulent fluctuations in the tropospheric water vapor content across an array. The first two issues can be overcome by a careful selection of an observatory site and the EVLA site on the Plains of San Augustin in New Mexico at $\sim 2,200$ m elevation is one of the best available locations in the continental U.S. The third effect leads to atmospheric phase fluctuations that increasingly decorrelate the astronomical signal with increased antenna separation; careful, differential measurements of the sky brightness in front of the individual array elements can be used to determine and eventually correct the phase variations. This is the basis of the water vapor radiometer (WVR) system we propose for the EVLA.

The phase fluctuations can be particularly bad on baselines longer than ~ 1 km and at times of the year when the tropospheric water vapor content is high (summer, daytime). They scale linearly with frequency, impacting the highest frequencies the most. Currently the only way to calibrate the phase fluctuations is to slew the antennas as fast as possible between the target source and a nearby calibrator with a short cycle time (1-2 mins, so-called “fast switching”). But this only works under very stable conditions and incurs a significant observing time penalty. WVRs can potentially increase the time over which the phase is coherent by an order of magnitude, eliminate the need for fast switching, increase observing efficiency, and minimize scheduling constraints on high frequency projects. This is especially important for the EVLA, for which half the receivers operate at frequencies of 15 GHz and above, providing the highest available spatial resolution of any current cm-wave, connected-element interferometer. WVRs would therefore permit the full utilization of the extreme resolving capabilities of the EVLA’s most extended configurations; in particular, PTL observations will benefit enormously from the WVR system.

The science for which a WVR system on the EVLA provides increased access encompasses imaging of all thermal emission processes throughout the Universe. In our own Galaxy, imaging of protoplanetary disks around nearby young stars (SWP by Wootten et al.), imaging of ionized thermal jets and stellar winds, even imaging of the photospheres of supergiant stars, will be possible at the highest resolution and in weather conditions not currently usable at high frequencies. Furthermore, high-precision astrometry of thermal and non-thermal processes (e.g., maser emission) will be enabled by the WVR system. Indeed, with new access to continuous frequency coverage with the EVLA, imaging surveys for local and redshifted rotational transitions of CO, HCN, and other molecules are expected to produce very high demand for high frequencies (SWP by Carilli et al.; Yun et al.; Appleton et al.; Meyer et al.; Johnson et al.). Any option to increase the available time at these frequencies will be of crucial importance for the success of these experiments and to bridge the gap between cm-wave EVLA and mm/sub-mm-wave ALMA science drivers.

Technical Overview

Ultracompact E-configuration

Building the E-configuration for the EVLA involves the construction of 20 new antenna pads at the EVLA site. Sixteen of the pads will form the “pure” E-configuration, whereas the other four stations will enable a configuration slightly stretched to the north; using the latter will produce better image fidelity with less shadowing for southern sources, similar to the current EVLA “hybrid” configurations with stretched north-south baselines. The new antenna pads will be connected to the rest of the array with railroad structure (station and railroad layout as in Fig. 1), optical fibers for signal and communication transfer, and cables for electrical power.

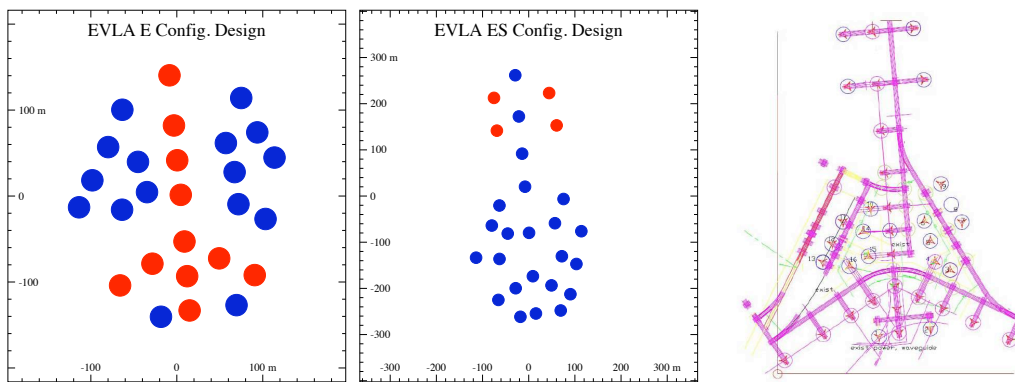


Figure 1: The left panel shows the proposed locations of the antenna stations for the E-configuration. The red dots indicate existing D-configuration stations that will be utilized, and the blue dots mark the locations of the new antenna pads. The dot sizes represent the actual 25 m diameters of the antennas. All stations are within 125 m of the center. The center panel shows the hybrid E-configuration with the extended north arm which would allow better imaging at declinations south of -20° and north of 75° . In this panel, the four red dots indicate the four additional stations, and the blue dots show both the existing D-configuration stations and the new stations for the standard E-configuration. The right image depicts the layout of the railway tracks that will be needed to access the stations.

Pie Town Link

The PTL comprises an upgrade of the present VLBA antenna located in Pie Town to an EVLA-compatible system and will connect the antenna to the EVLA core located about 52 km to the east (see Fig. 2). In detail, the PTL includes 1) the installation of eight cryogenic EVLA receivers that cover the EVLA frequency range of 1-50 GHz, including new feed horns to match the VLBA antenna optics; 2) a complete EVLA LO/IF system; 3) the optical-fiber based Ethernet monitor and control system; 4) a multichannel long-haul fiber network between Pie Town and the EVLA, including at least one repeater station; 5) a set of Pie Town station cards in the EVLA WIDAR correlator; and 6) an

update of relevant monitor and control software. The Pie Town antenna will be able to support both EVLA and VLBA observations as required by user demand.

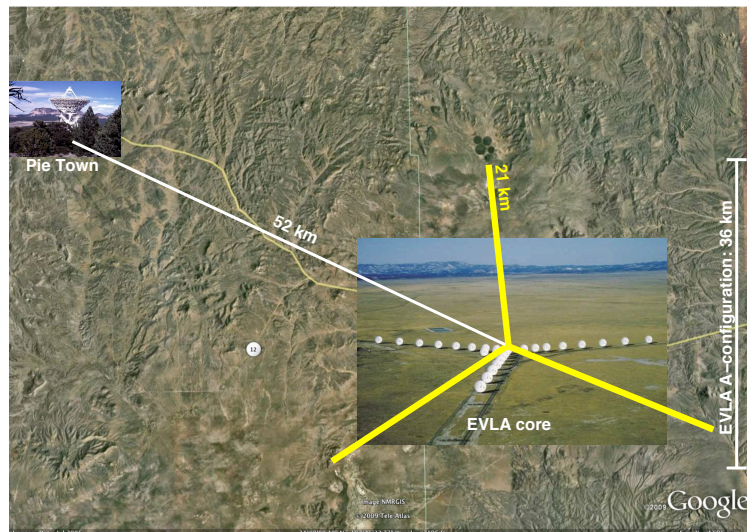


Figure 2: Birds-eye perspective of the Pie Town link. The distance from Pie Town to the EVLA center is 52 km which is less than twice as long as the longest A-configuration baseline length (36 km). This location of the Pie Town antenna with respect to the EVLA site is ideal to double the spatial resolution and substantially improve the uv-coverage of the EVLA for northern sources. The classic arms of the EVLA Y shape are marked in yellow. (Terrain image taken from Google Earth.)

Low Frequency System

The EVLA LFS is based on a new, wide-band receiver that is currently in the design phase (see Fig. 3). In addition, a new set of feeds will be installed to meet the 50-1000 MHz bandwidth specifications of this instrument. Due to optical and mechanical restrictions of the EVLA antennas the feed design is particularly challenging. The project may be laid out in three phases 1) The design and construction of prototype low frequency receivers; they will be tested with the current low frequency feeds. 2) Populating all the EVLA antennas (+ Pie Town) with the newly-developed receivers. 3) Wide-band, deployable feed design and construction for the entire frequency range; this will likely require an ensemble of three different feed structures, some of them deployable to minimize the impact on higher frequency EVLA observations.

EVLA Low Frequency Improvement Project
Conceptual Diagram
(One Polarization Shown)

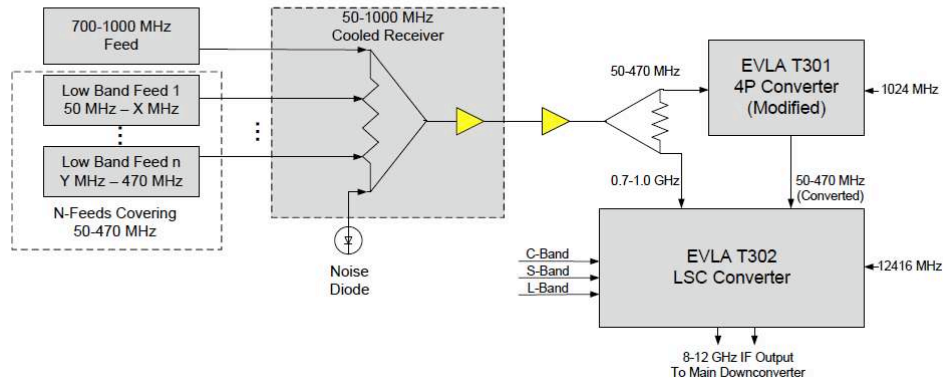
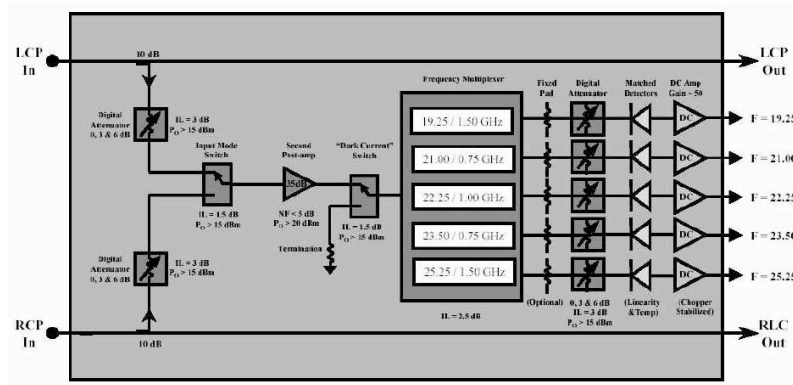


Figure 3: Conceptual block diagram for a low frequency EVLA receiver system. Note that the feeds require additional design efforts to accommodate the EVLA antenna characteristics over the entire low frequency range, which spans more than one order of magnitude in frequency.

Water Vapor Radiometry

The WVR project at NRAO was begun a few years ago¹. The current design is based on highly temperature stabilized MMIC (monolithic microwave integrated circuit) devices, with five channels covering the tropospheric water vapor line at 22 GHz. The system piggy-backs on the existing EVLA 22 GHz receivers. The EVLA high frequency receivers are all located close to each other on the feed ring to ensure maximum overlap of the adjacent beams in the near-field. Fig. 4 shows the block diagram of our design, along with test results for an earlier 3-channel version deployed on two VLA antennas, which demonstrated a decrease in phase noise by a factor of ~ 4 through application of WVR corrections. The new, 5-channel design is expected to provide excellent measurements of fluctuations in both the water line and the adjacent continuum. This is important in order to subtract any changes in atmospheric brightness temperature due to liquid water from the water vapor line itself. Differences in the fluctuations in the water vapor emission at two telescopes can then be correlated with phase fluctuations on the same baseline to produce a calibration correction for the astronomical signal. This procedure substantially increases the observing efficiency at high frequencies. By correcting for non-ideal weather conditions, the WVR system will also substantially increase the amount of observing time available for experiments that require access to the highest frequencies.

¹see EVLA memoranda #73 and #74 on <http://www.aoc.nrao.edu/evla/memolist.shtml>



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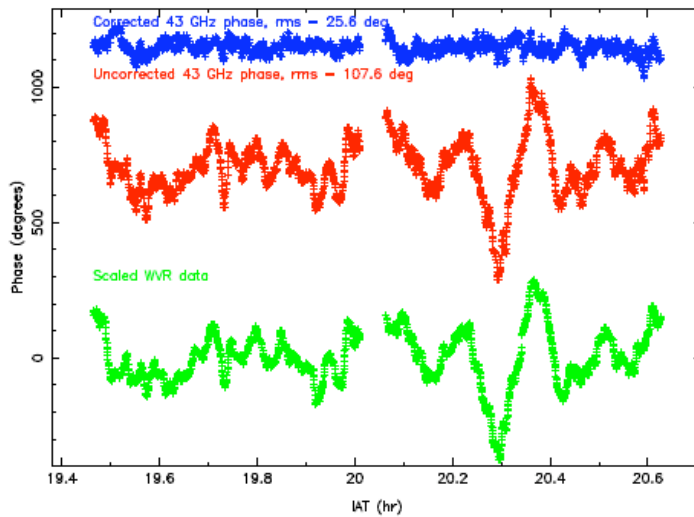


Figure 4: *Top*: Block diagram of our prototype 5-channel WVR design for the EVLA. *Bottom*: Test results from a previous, 3-channel WVR system. The data were taken on a clear day, on a 6 km baseline and at 43 GHz. The uncorrected phase is shown in *red*, the scaled WVR output in *green* and the phases corrected by the WVR in *blue*. Note that the phase scatter in this case was reduced dramatically from an rms of $\sim 108^\circ$ to $\sim 26^\circ$.

Technology Drivers

Ultracompact E-configuration

All of the required technology is well known to NRAO and replicates array infrastructure with a 30-year history of success. The project carries essentially zero technical risk.

Pie Town Link

The PTL is almost exclusively based on EVLA technologies and consequently has little technical risk. However, the VLBA Pie Town antenna and EVLA antennas do not share a common design, and an additional effort to redesign the receiver so as to match the VLBA feed system will be required. These activities are identical to those required for all EVLA and GBT receivers and are an area of long-standing NRAO expertise with low technical risk. Because the Pie Town antenna is far away from the core of the EVLA, some attenuation of the signal in the connecting fiber is expected and a repeater station will be required. This is off-the-shelf technology which we plan to purchase.

Low Frequency System

The receiver technology required for this effort is well-known and most parts are commercially available. Consequently, technical risk is low. The wide-band feeds will require additional design efforts, which will be carried out at Virginia Tech. This development is potentially beneficial to future, low frequency telescopes and may contribute to the developments needed to realize the Square Kilometer Array (SKA).

Water Vapor Radiometry

As noted previously, our proposed WVR receiver system is based on an advanced, existing design and prototype. Research will be required to make optimal use of the WVR data. The ultimate improvements in calibration through the use of WVRs is currently unknown, however tests to date show promising results.

Activity Organization, Partnerships, and Current Status

Ultracompact E-configuration

About 80% of the E-configuration construction work will be carried out by contract labor under NRAO staff supervision. Planning of the exact station locations, their design and the required track, power and fiber connections is essentially complete, and construction can start at any time, depending only on the availability of funds.

Pie Town Link

Most aspects of this work will be carried out by NRAO staff. The feed redesigns will be done at Green Bank, where the EVLA feeds were designed. The already proven EVLA receiver designs and antenna upgrades will be constructed in New Mexico, with key frontend technologies (notably, the low-noise first stage amplifiers) being provided by the NRAO Central Development Laboratory. The fiber connection builds on the narrow band system previously used to demonstrate the feasibility of a real-time Pie Town link to the VLA, and is expected to be straightforward. The PTL activity can commence once funds are obtained.

Low Frequency System

The LFS development will be carried out in partnership between NRAO, the U.S. Naval Research Laboratory (NRL), and Virginia Tech. NRL will provide technical and cost support to the activity. The wideband feed design work will be done at Virginia Tech and will involve postdoctoral and graduate student contributions.

Water Vapor Radiometry

Whereas NRAO designed and produced the prototype system originally tested, the final design and construction of the WVRs may be carried out in partnership with other domestic or international partners, ideally institutions that also operate synthesis array telescopes, and university groups with strong interests in interferometry and atmospheric physics.

Activity Schedule

Ultracompact E-configuration

If funding becomes available in FY2011, the construction of the E-configuration can start immediately, and be finished within a time frame of ~6 months and well within 2012. The project would then be synchronized with the completion of EVLA construction.

Pie Town Link

The PTL has been planned and costed and the project can start immediately upon the availability of funds. Ideally it would be coordinated with the completion of the EVLA construction project at the end of 2012.

Low Frequency System

The first major stage of the LFS will be the design, construction, and deployment of the new receivers, using the current VLA feeds. Supported by NRL, this work has been initiated and a prototype will be ready in 2010. The wide-band feeds will require additional design efforts; the technical tools for the design studies are well developed and readily available. The LFS can be initiated in the very near future, depending on the availability of funds.

Water Vapor Radiometry

The initial design study of the WVR system progressed well but the project was put on hold while the EVLA construction project took priority. If funds were to become available in FY2011 the design and testing phase of this project could resume, with the goal of implementing the WVR system on all EVLA antennas plus the Pie Town antenna by 2015.