Haystack Observatory Analysis Center

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Abstract

Analysis activities at Haystack Observatory in 2009 were closely related to the technology development progress that is reported separately. Some of these efforts were:

- analysis of the expected efficiency of MV3
- analysis of the Eleven feed in a Dewar for optimum use on the Patriot 12-m antenna
- upgrade of the program *fourfit* to handle the broadband delay
- generation of Matlab scripts to duplicate much of the functionality of the post-correlation program *fourfit* for rapid modification and development of new modeling
- investigation of the impact of the phase variation due to changing differential linear polarization on the phase delay

1. Introduction

It is often difficult to separate analysis and hardware development. Here we report numerical calculations and software development related both to the technology development and to the observation program of the IVS. In this period the developments are entirely driven by the VLBI2010 program and the advances associated with the implementation of the broadband delay (BBD). The broadband delay is obtained by measuring the phase across four bands that will eventually span approximately 10 GHz, using the curvature to estimate the charged particle contribution. This is in contrast to the current determination of delay as the group delay across about 1 GHz at X-band, using S-band to provide the ionosphere correction.

The hardware development which has prompted the analysis effort reported here is the project that has installed proof-of-concept broadband systems on the 5-m MV3 antenna at GGAO, Greenbelt, Maryland, and on the 18-m antenna at Haystack Observatory, Westford, Massachusetts.

2. Analysis of the MV3 Efficiency

Antenna chamber measurements of the Lindgren feed, which is mounted on the 5-m MV3 antenna for the proof-of-concept broadband system, were combined with direct physical measurements of the sub-reflector and primary reflector shape of the MV3 antenna to better understand the efficiency and gain characteristics after the measured efficiency was found to be very low. Additionally, it did not seem possible to determine an optimum focus setting.

The problem was found to be a mis-match of the paraboloidal shape of the primary reflector and the shape of the sub-reflector, which is not hyperboloidal. One possible way to improve the efficiency is to make a new sub-reflector of the proper shape, but this was judged unnecessary since the new 12-m antenna was anticipated to be available in mid- to late 2009.

This study has led to understanding the low efficiency of the antenna that has been experienced with standard S/X observations over the entire history of the antenna's usage.

3. Analysis of the Optimum Dewar Design for the Patriot 12-m Antenna

A newly designed feed from Chalmers University, designated the Eleven feed, is expected to be used for VLBI2010. However, it is important to optimize the size of the Dewar that will house the Eleven feed on the 12-m antenna. To do this, the physical dimensions of the Eleven feed were used in combination with a proposed design of a Dewar/cryostat and with the specifications of the 12-m to determine the size of the Dewar that would minimize the blockage of the sub-reflector and maximize the efficiency of the antenna. Figure 1 displays the dependence of the Eleven antenna's feed efficiency on the cryostat radius and the cryostat wall length protruding above the top face of the feed.

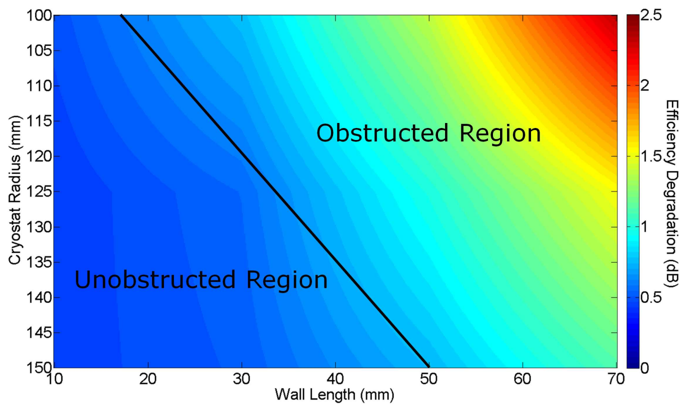

Figure 1. Feed efficiency dependence on cryostat size. The obstructed region is that in which the cylinder radius and length are such that the opening angle of the feed is obstructed by the cylinder wall in the geometric optics sense. The efficiency degradation increases from bottom left to top right.

4. Estimation of Broadband Delay Using *Fourfit* and Matlab Scripts

The program *fourfit*, which evolved from *frnge*, continues to be the program for obtaining the observables from the Mark IV correlator output. Up to now it has dealt only with a single band of data, such as S or X, and the calculation of the ionosphere corrected delay has been made at the following stage of analysis. To obtain the broadband delay, all four bands must be fit simultaneously in order to obtain the maximum signal-to-noise ratio. Furthermore, in some cases a source may not be detected in some band because of the low SNR in that band. To remedy this, *fourfit* has been enhanced to simultaneously fit multiple bands for amplitude, phase, delay, and rate. For the first time the contribution of the ionosphere to the phase can also be introduced in *fourfit* to accommodate the quadratic phase term introduced by charged particles along the signal path. Further improvements will allow the simultaneous estimation of the ionosphere difference contribution to the delay. Ultimately all polarizations will be combined in the estimation of the observables.

A MATLAB implementation of *fourfit*, which is written in C, has been developed specifically for rapid prototyping of VLBI2010 broadband fringe fitting algorithms. This software does not possess the full functionality of *fourfit* but does incorporate the identical fringe-search engine. The

MATLAB fringe fitting software has enabled the development of a new phase calibration correction algorithm that has been shown to align fringe phases across 2 GHz (4 contiguous 512 MHz bands) of analog bandwidth. Figure 2a shows the raw fringe phases obtained on the Westford to GGAO baseline while observing source 4C39.25, and Figure 2b shows the phase calibrated fringe phases. This result is a significant step towards realizing the goals of VLBI2010. It is expected that this algorithm will also allow fringe fitting of non-contiguous 512 MHz bands, and future broadband development observations will be conducted to test this expectation.

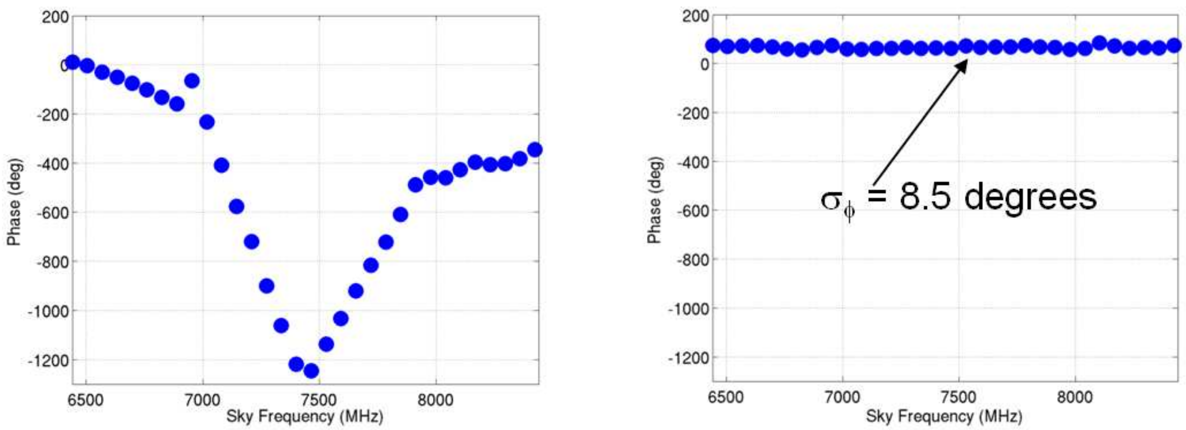

Figure 2. Cross correlation phase on Westford-MV3 baseline for a) raw fringe phases and b) phasecal-corrected fringe phases.

5. Polarization

The feeds being developed for the VLBI2010 broadband delay system intrinsically produce linear polarization. As the antennas rotate to observe a common source from different parts of the world, the relative parallactic angles of the antennas will vary. In order to realize the maximum sensitivity it will be necessary to cross-correlate all possible polarization products.

To investigate the effect, observations were made of the source 4C39.25, which passes south of Westford and north of MV3. With this geometry the two antennas rotate in opposite directions as the source crosses the sky, and the relative parallactic angles change by 180°. The cross-correlation amplitudes for the 512 MHz band above 3.5 GHz are shown in Figure 3 for one of the parallel-hand and cross-hand polarization cross-correlations. (Due to intrinsic labeling in the post-correlation software, the vertical and horizontal polarizations are assigned to the circular polarization labels R and L.) The amplitudes of the 10 minute scans follow the pattern expected for the change in relative parallactic angle, although the magnitude of the cross-hands does not come up to that of the parallel hands as would be expected if the responses of both antennas were the same in both polarizations.

The two polarizations in each antenna are independent, so in principle two independent estimates of the delay are obtained for each scan. Furthermore the delay difference between the two polarizations should differ by a constant value after phase calibration. An active area of research is how to obtain the best estimate of the delay observable or observables from the linear polarizations.

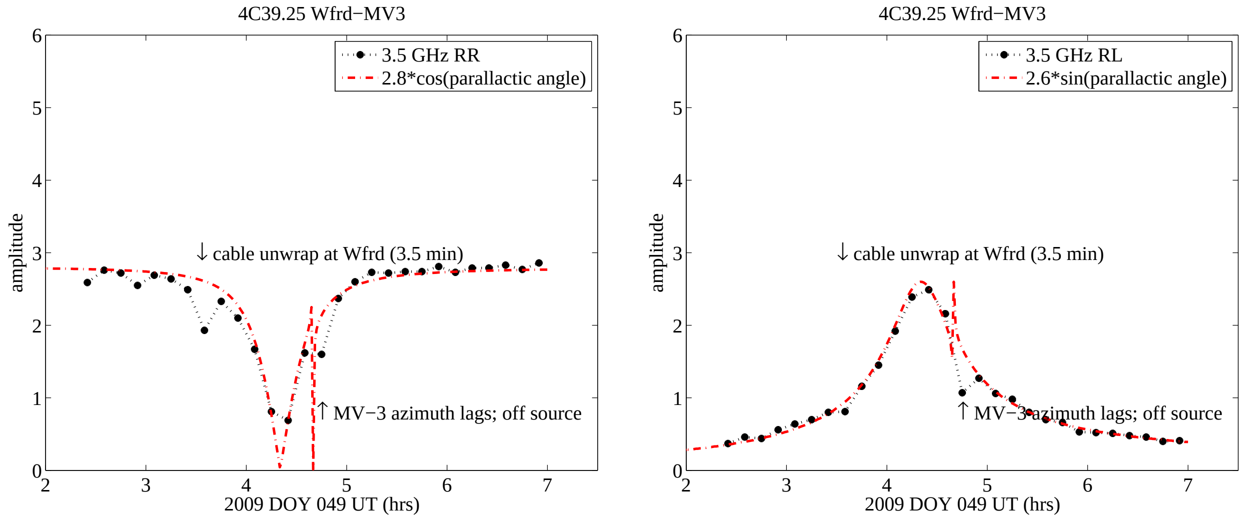

Figure 3. Amplitudes for the parallel-hand (RR) and cross-hand (RL) linear polarization correlations for the 3.5 GHz band.

An alternate approach that would avoid the problem of reduced cross-correlation amplitude for differential parallactic angles around 90° would be to produce circular polarization just following the feed (in the Dewar). This approach is being considered also, but calibration of the cross-polarization in each antenna is a concern.

6. Outlook

Efforts will continue to apply the analysis tools for optimizing the VLBI2010 observing system hardware and to develop algorithms for estimating the new observables to be obtained from the broadband equipment. Foremost will be how to make use of the multi-polarization observations in an optimal production mode.

Among the first observations with the new 12-m antenna waiting to be assembled at GGAO will be the sampling of sources with both simple and complex structure in order to assess the impact of source structure phase on the broadband delay. Previously at Haystack models were developed of the phase change with frequency and baseline of several sources by using the S/X structures and by making assumptions about the spectral characteristics of the components. More detailed modeling will be necessary to compare with observations when actual data become available.