HERA Memo #95
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Motion of HERA Antenna Feeds

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1 Introduction

This memo describes our study monitoring the long-term motion of the HERA antenna feeds over a two-month period. We measured the displacement of the feeds from their ideal position over the center of the dish from the end of September - November 2020. These measurements, coupled with simulations studying the effects of feed movement on the antenna beam and calibration, will help us understand how irregularities in the instrument affect the data and what steps are necessary to mitigate these effects.

2 Methods

We monitored the feed positions for all antennas with raised feeds in nodes 1 and 4 (21 antennas in total) for two months immediately after the feeds were repositioned, beginning on Sept 22, 2020. Fig. 1 shows the locations of the antennas within the array. Measurements of the x, y, and z displacements were taken approximately once per week. We define +y to correspond with north, and therefore +x corresponds with west. +z measures vertical height. The ideal xy position of the feed is directly over the center of the dish. We measured x and y displacements relative to this point. The z height of the feed has a fiducial value of 4.438m above the hub of the dish, and we consider z displacements relative to this height. HERA Memo #75 covers the initial feed positioning approach in more detail.

Once per week, we asked the site crew to measure the z height of the feed using a laser distance measure, and to provide photos like that shown in fig. 2 for the x and y displacement measurement. In order to show the xy displacement of the feed for the photo, the site crew uses 3 laser plumb bobs mounted onto a plywood jig, which is centered over the hub of the dish. Fig. 2 contains an image of this jig and explains this further.

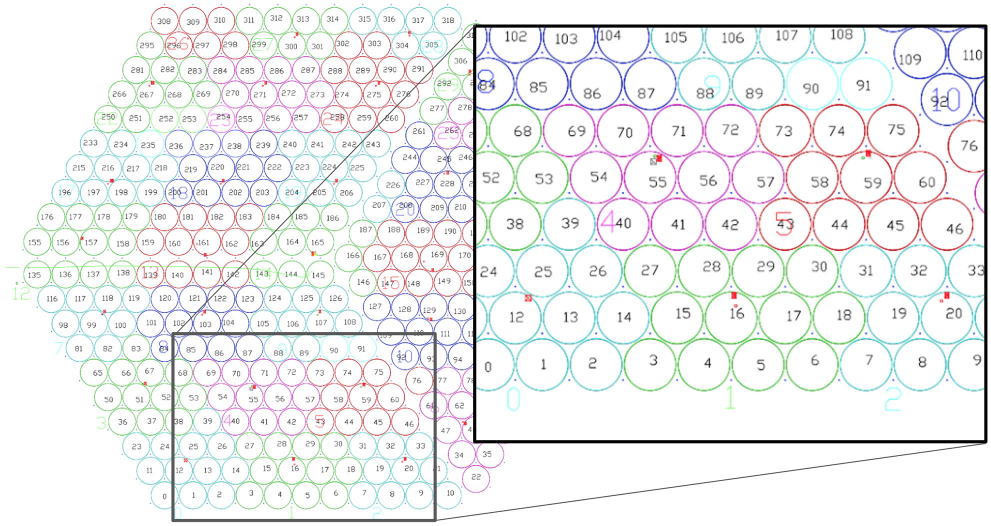

Figure 1: *Nodes 1 (green) and 4 (pink) within the HERA configuration. We monitored the positions of all antennas in node 4, and all antennas in node 1 except antennas 6 and 27. These two antennas were not included because their feeds had not yet been raised.*

Figure 2: *Left: An example of the photos used to determine the x and y feed displacements for a single antenna. Right: The plywood jig centered over the hub of the antenna's dish. The laser points seen on the targets in the left photo are produced by laser plumb-bobs attached to the jig. If the feed is perfectly centered in x and y, the laser points should appear in the centers of the targets. We can identify north (+y) by the metal arm which is flanked by two white ropes on either side.*

In order to measure total displacement in x and y, we used the application Omnigraffle to draw two squares: one connecting the centers of the four targets, indicating the current location of the feed, and a second square of the same size connecting the red laser points, indicating where the feed would be if it were perfectly centered. The distance between the centers of these two squares indicates the total displacement of the feed from the center of the dish. The magnitude of this displacement in cm is found by comparing this distance to one of the targets, which we know is 12.5cm in diameter. This magnitude is then decomposed into x and y components and recorded. Fig. 3 demonstrates this process in more detail.

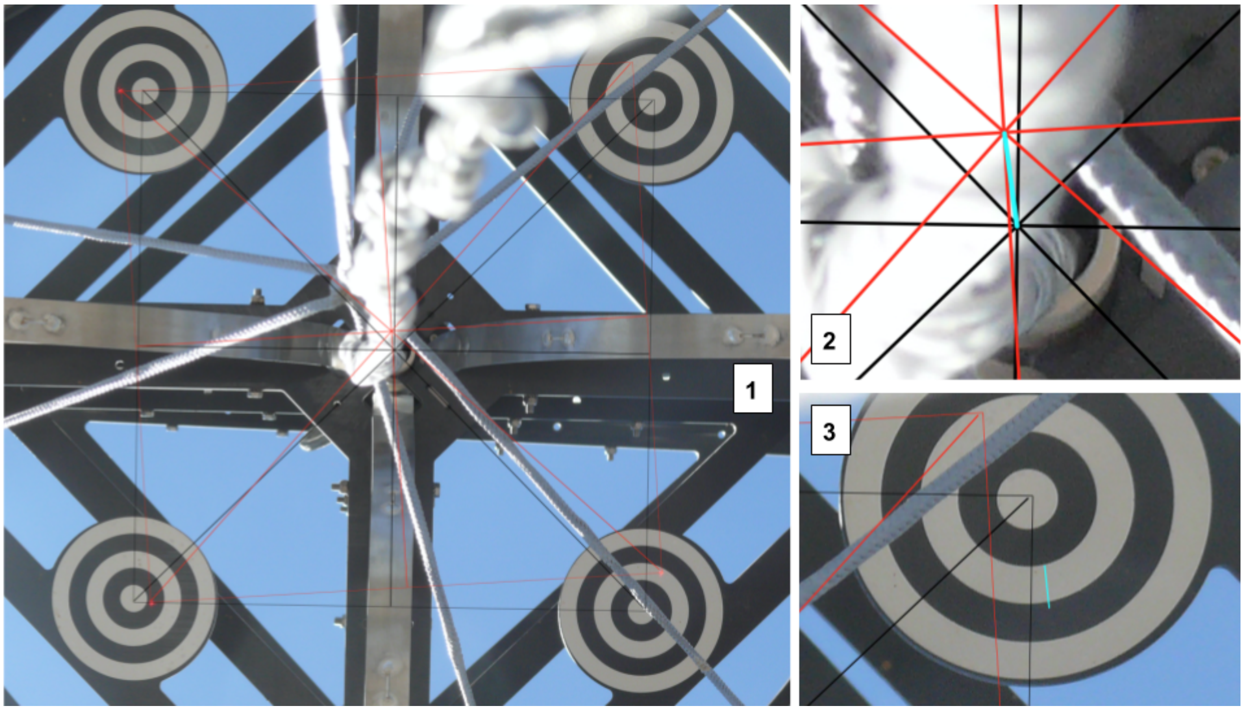

Figure 3: *Method for measuring the feed displacement from center. Image 1 shows the two squares defining where the feed would be if it were perfectly centered (red, defined by laser points) and the actual location of the feed (black, defined by the target centers). The cyan line in image 2 measures the total displacement of the feed from center. In image 3, the cyan line is compared against the target in order to determine the magnitude of the displacement to the nearest mm.*

3 Results

3.1 Data

The distribution of displacements over the course of our study had an RMS of 1.2cm in the x direction and 1.8cm in the y direction. Only 2 antennas moved more than 3cm in either the x or y direction. The distribution of z displacements had an RMS of 0.8cm from the fiducial height of 4.438m above the hub. After repositioning, we observed that the feeds drifted to a new position in x and y within in the first two weeks, and remained stable at the new position within approximately ± 1 cm in x and y. Fig. 4 shows the week-by-week movement of each feed, and fig. 5 shows histograms of the movement of the feeds over the two month observing period and the movement of feeds relative to their week 2 position.

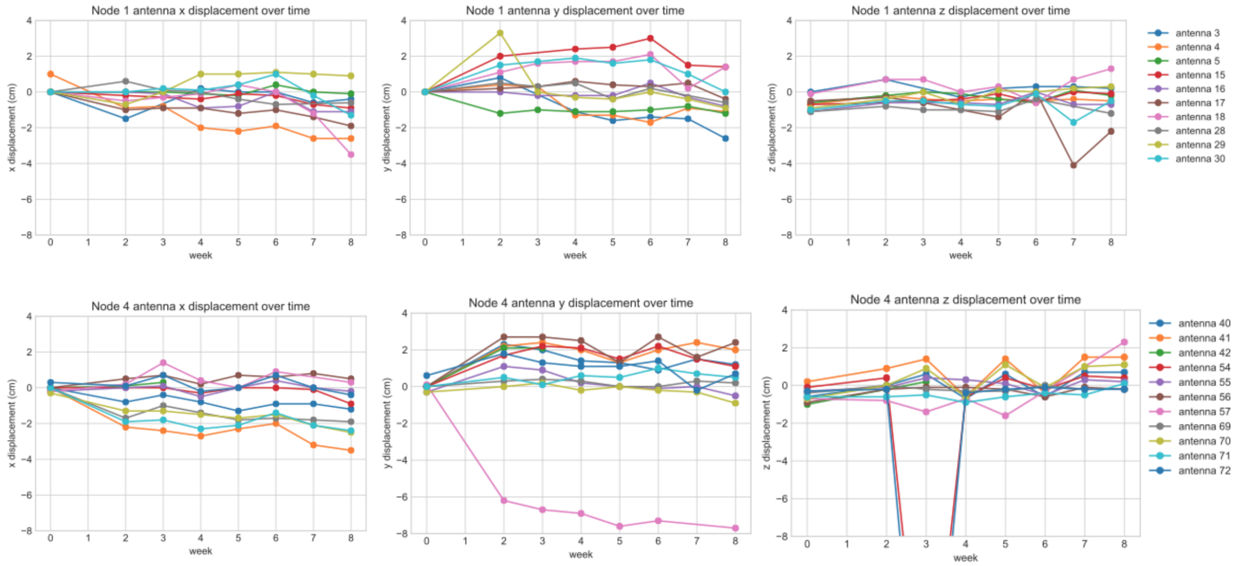

Figure 4: *The displacement of each feed over the course of the 2 months during which we measured feed displacements. The outliers in the node 4 z heights during week 3 represent a displacement of 19 and 23 cm. We suspect these values are caused by some type of recording error.*

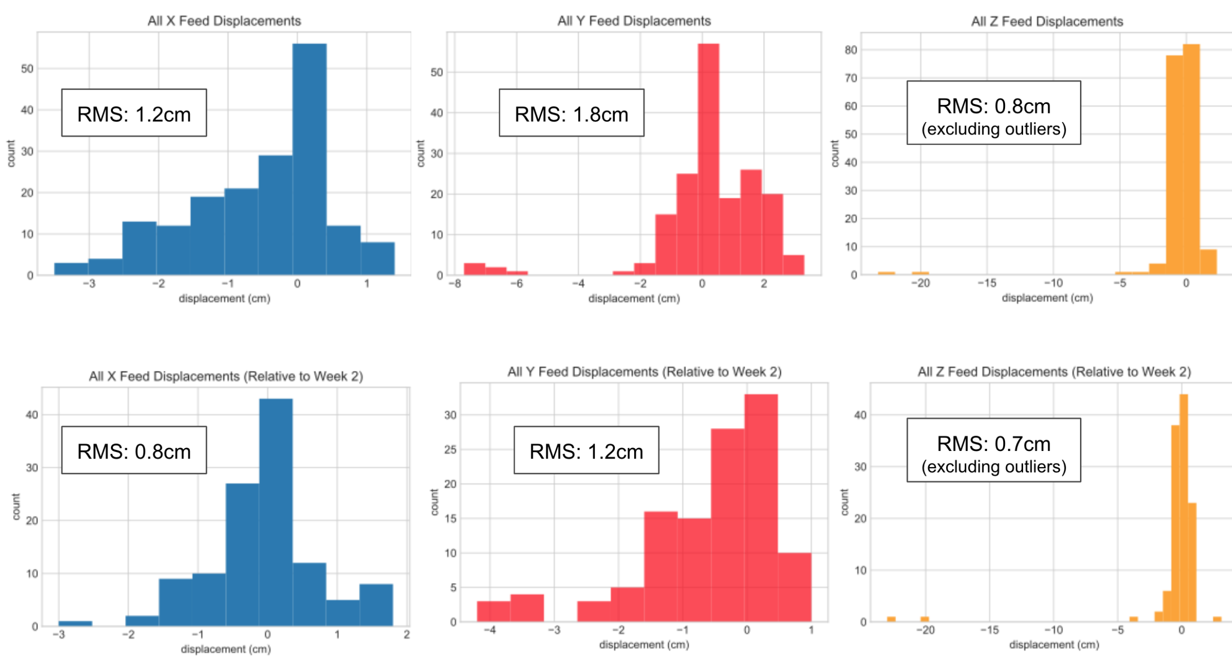

Figure 5: *Top row: histograms of all measurements of feed displacements from their ideal position. Bottom row: histograms of feed displacements from their week 2 position, for all measurements done during and after week 3.*

The position of the feeds may be affected by the configuration and activity of the telephone poles that they are tied to. Poles on the interior of the array support the three feeds forming an equilateral triangle around the pole, whereas poles on the edge of the array support only two feeds. We are concerned that this causes a bend in the exterior poles that increases over time, which would cause the feeds to move more. Though the loads on the poles carrying feeds on the interior are balanced, adjustments made to one feed causes significant movement in the other two feeds attached to the same telephone pole. Out study did not have to consider this scenario, as no feeds in neighboring nodes were raised or adjusted during that time. However, our study did include 3 edge antennas (antennas 3, 4, and 5 in node 1) so we are able to investigate whether the feeds of edge antennas moved more than the feeds of antennas on the interior of the array. Fig. 6 investigates edge antenna behavior by plotting the RMS per antenna in the xy plane and in the z direction. We conclude that the edge antennas do not appear to have a higher RMS than the other the antennas we studied.

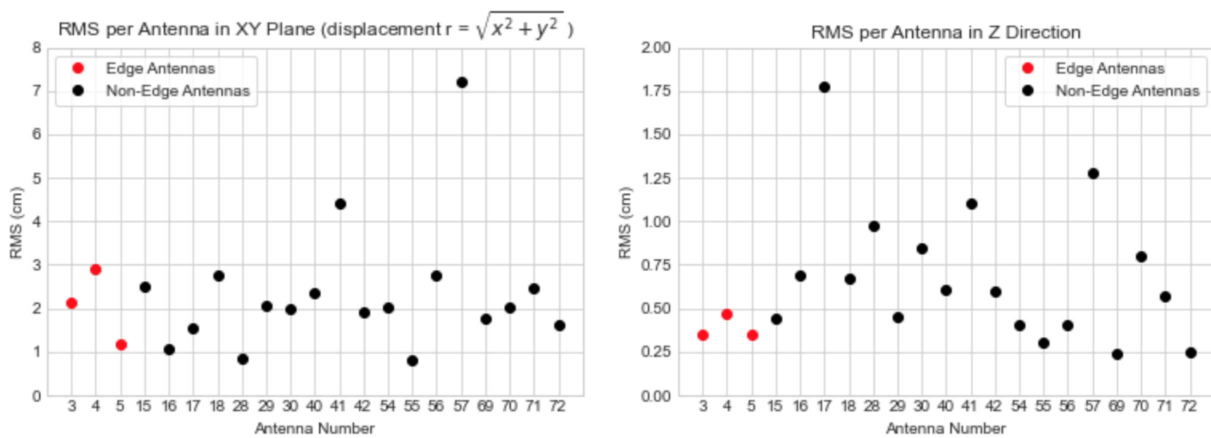

Figure 6: *Comparing the RMS of edge and non-edge antennas for displacements in the xy-plane and in the z-direction. The total displacement in the XY plane is defined by* $r = \sqrt{x^2 + y^2}$*. The z-direction calculation excludes the two outliers that are discussed in fig. 4. We note that in both plots, the edge antennas do not appear to be drawn from a separate distribution from the other antennas. We conclude that our data do not demonstrate a higher variation in feed displacement for edge antennas.*

3.2 Uncertainties

We identify three main sources of uncertainties in our method for measuring the x and y displacements of the feeds: 1.) uncertainties in the centering of the jig on the hub, 2.) uncertainties in the alignment of the plumb-bobs on the jig, and 3.) uncertainties arising from taking the photographs themselves, such as week-to-week inconsistencies in camera angle, skew, etc. Because the z heights are measured using a laser distance measure, we expect the uncertainty in the z measurements to be smaller than the uncertainties in x and y.

As stated in section 2, in order to calculate the xy displacement, we should be able to draw identical squares between the centers of the targets and the laser points emitted by

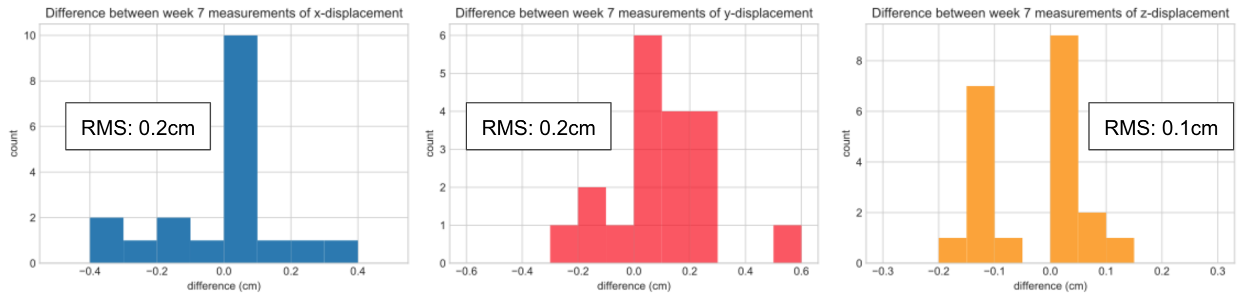

Figure 7: *Histograms displaying the difference in displacement measured in the first and second set of independent measurements performed on the same day during week 7.*

the plumb-bobs. If the jig is off-center, the laser points will still form a square, albeit one that yields an incorrect displacement measurement. This scenario is also possible if all three plumb-bobs are misaligned in the same direction, however this is unlikely. We assume that if the laser points appear similarly aligned, they are correctly aligned. One misaligned plumb-bob makes it impossible to draw a square between the three laser points. Taking the photo of the feed at an angle causes a similar issue, and the effects may be confounded with the effects of plumb-bob misalignment. The best way for controlling this effect is to record the error of the square the three laser dots make.

In order to quantify the repeatability of our measurement method, we asked the site crew to perform two independent measurements of the displacements for all antennas in nodes 1 and 4 on the same day. Fig. 7 summarizes the results of this experiment, and suggests that our z measurements are accurate within ± 0.1cm and our x and y measurements are each accurate within ± 0.2cm.

4 Discussion

The results of our study will provide future simulations with values that more accurately reflect the actual behavior of the array. In particular, our results will be used to guide feed displacement values in electromagnetic simulations of the antenna beam (S. Dynes et al, in preparation). We expect feed displacements to affect the primary beam, which in turn affects the calibration. We therefore wish to perform an analysis similar to that done N. Orosz et al, 2018 in order to study the effect of feed displacements on the redundant calibration. A HERA Memo in preparation by H. Kim et al. will study these effects further. We are also interested in comparing our data against chi-squared per antenna values from existing calibration files, to see if we can identify the effects of feed motion on the quality of the calibration and check for agreement with simulated predictions.

We hypothesize that immediately after centering, there are small inequalities in the tensions of each rope holding the feed in place. This causes feed to settle into a new equilibrium position, and explains why the feeds appear to drift into a more stable position within the first two weeks in our data. The outcomes of the studies described in the paragraph above, in particular the redundant calibrations studies, will help determine how often the feeds must be repositioned and what additional measures, if any, are necessary to mitigate this behavior in order to preserve the instrument sensitivity necessary for EoR detection.

5 Acknowledgements

We would like to thank the site crew for taking weekly measurements on our behalf. This study could not have been completed without their work.