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HERA

MEMO 069

To: HERA Collaboration

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Copy to: South African Radio Astronomy Observatory (SARAO)

Subject: Node 9 Passband Diagnostics, Removal of Notch Feature, and Feed Cabling Instructions

I. Executive Summary

Between 10-14 June 2019, we conducted a HERA site visit, the primary purpose of which was to diagnose passbands in node 9 which were deemed to be faulty. This document describes our method of diagnosing faulty passbands, and the individual improvements made by all major steps in the diagnostic process. After diagnosis, the 50-60MHz notch feature was no longer present in the autocorrelation spectra of any polarization of any node 9 feed; the same improvements are now being made to all feeds connected to node 0. Our node 9 diagnosis produced a useful test of node control module (NCM) integrity, which is also described.

II. Data Collection

Examination of autocorrelation spectra (SNAP amplitude in dB scale versus frequency) was our principle tool for determining the health of any given antenna polarization. This data can be collected in real time or may be monitored throughout the day as part of a system health database called hera.today (soon to be heranow.reionization.org), which shall be described in more detail later in this memo. For real time data collection, we used scripts designed by the HERA collaboration which access data directly from the four SNAP f-engines inside a node.

II.1 Real-Time Data Collection

For any on-site network connection which offers DCHP addresses (e.g. the container, KAPB laptop room, etc.) you may access the SNAP head node, 'hera-snap-head', via ssh hera@154.114.13.12. This machine is designed to access all SNAPs in the field, and uses the hostname scheme 'heraNode[X]Snap[0,2]', where X is the node number. At time of writing, only nodes 0 and 9 are wired and connected to the network. These hostnames should be pingable (e.g. 'ping heraNode0Snap1'); if they are not, the node may not be receiving power. The power state of each node may be found on hera.today, and is updated approximately once per minute under namesake status keys, such as 'status:node:9'. To switch on all relevant equipment in a node (i.e. the front end modules (FEMs), post-amplification modules (PAMs), and SNAP boards) via the hera-snap-head machine, run 'hera_node_turn_on.py –f –p –s <X>', where '<X>' is the node number you wish to turn on.

Once a node is turned on, you must program and initialize the SNAPs before collecting data from them. Do this by running (on hera-snap-head) 'hera_snap_feng_init.py –i –s –p –e', where 'feng' stands for f-engine. We call these SNAPs 'f-engines' because they channelize the analogue signal into digital bins of fixed frequency bandwidth. To collect data, run commands such as 'python hera_get_corr.py heraNode9Snap3 –t 10 –n 2 –c 5 5. In this example, 2 (-n) consecutive ten-second-long (-t) integrations will be grabbed from the 5th input of the 3rd SNAP in node 9 and correlated together (-c 5 5). Using the database at http://hera.today/snaphookup.html, one can see that this 5th input (heraNode0Snap3:5) corresponds to the E pol of Antenna 125. Using the hera_get_corr script, data is stored in .npz format with a filename ‘snap_correlation_<JD>.npz’, where <JD> is the Julian time of the first spectra that was recorded. Auto correlation data is stored in the ‘data’ key of this data object, which itself is a three dimensional array of shape (-n, 1024, 0), where –n corresponds to the namesake argument used in hera_get_corr (the number of spectra to accumulate) and the third dimension always has size 0 (the data is effectively two-dimensional). ***NOTE,*** due to a bug in the hera_get_corr script at the time of writing this memo, the 0^{th} spectra in the data key should never be used, it is not representative of the data coming from the SNAP. For example, never use the data stored at [‘data’][0,:,0] . Begin your analysis starting with the next spectra: [‘data’][1,:,0].

II.2 Viewing Autocorrelation Data via the hera.today System Health Database

The same database which stores the antenna/node/SNAP mappings (e.g. heraNode9Snap3:5) also plots recent autocorrelation data for every antenna it has access to. Figure 1 shows an example output of hera.today/powers.html, which updates the data from all available passbands approximately once per minute, and displays the timestamp (and corresponding JD) of the most recent plots.

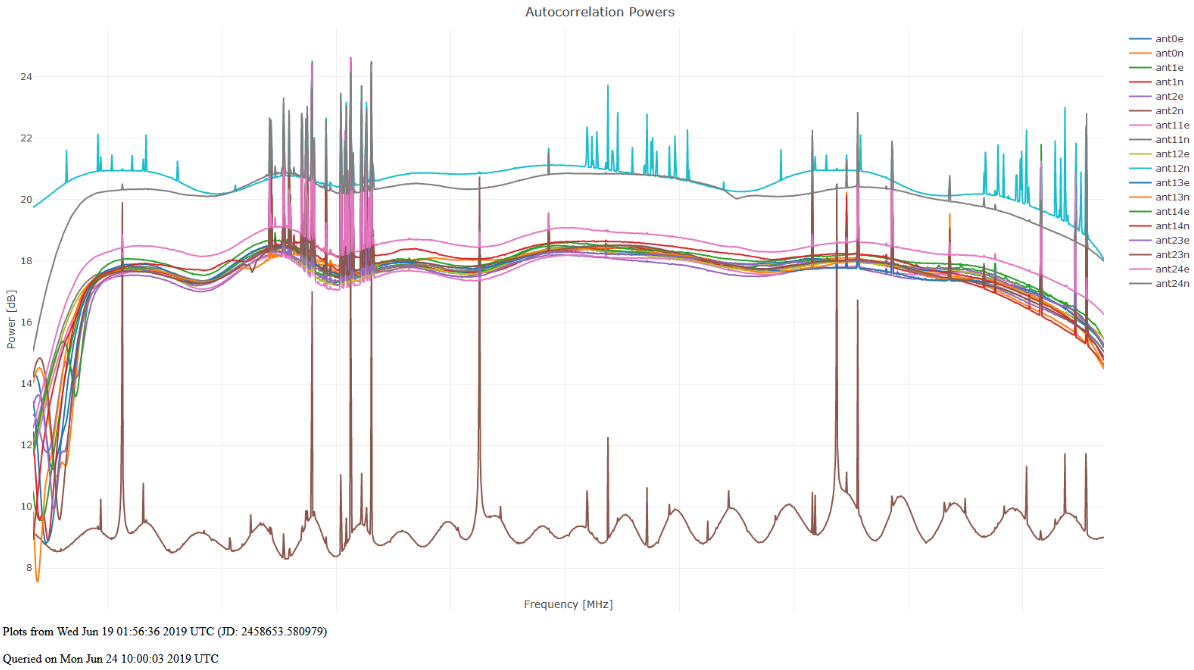


Figure 1. Example autocorrelation data from hera.today. These plots update approximately once per minute; the timestamp (and corresponding JD) of the data recording automatically updates on the webpage (see bottom left of figure).

III. Passband Diagnostic Method

There were multiple ways by which autocorrelation passbands could be deemed problematic. Three primary ways include the presence of the ‘notch’ feature between 50-60 MHz, having a passband which is considerably low in amplitude across the 50-250MHz band, and having ‘ripples’ anywhere in the autocorrelation spectrum which make the passband considerably less flat. Figure 2 demonstrates a combination of problematic features in the N and E polarizations of Antenna 125, prior to debugging.

Three refinements to the feed and its connections to the node were made to improve faulty passbands. First, all springs were removed between the Vivaldi feed and its support ropes. Results from a previous site trip and subsequent beam simulations, and data analysis in the HERA Commissioning channel on Slack suggested that spring removal would completely remove, or significantly reduce, the 50-60 MHz notch effect. Second, the SMA, CAT7 and fibre cables extending from the Vivaldi feed to the hub of each dish were systematically checked for damage, wound with plastic ribbon so that the shields of the SMA and CAT7 cables made continuous electric contract, and taped in regions where the cables were at risk of making electrical contact with the fins of the Vivaldi feed. A detailed overview of this cabling process may be found in Appendix A. Third, both the FEM and PAM side of each single-polarization optical fibre were cleaned (four places to clean – two ends of two fibres).

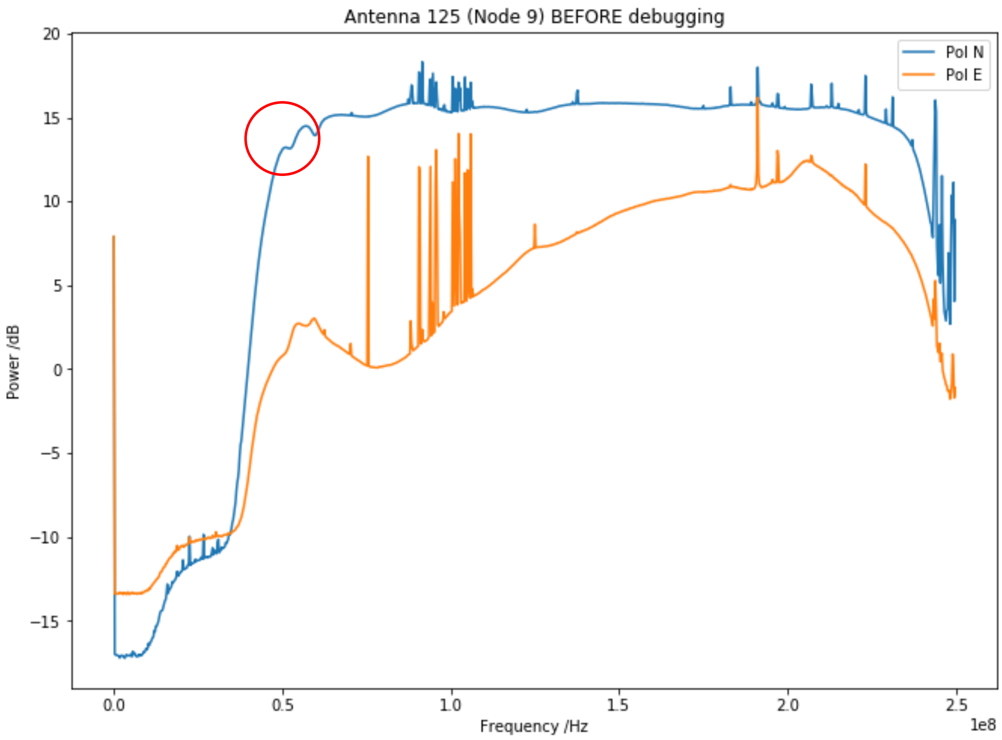


Figure 2. The autocorrelations of the N/S and E/W polarizations of Antenna 125 recorded by the third SNAP of node 9 before any debugging; both passbands were deemed to be problematic. The N pol, while having a fairly flat passband, contains the 50-60 MHz notch feature (red circle, caused by an inductor-like current loop passing through the springs which fastened the Vivaldi feed to its support ropes). The E pol has a curved, low-amplitude passband. This figure represents the state of the antenna when we started our site trip.

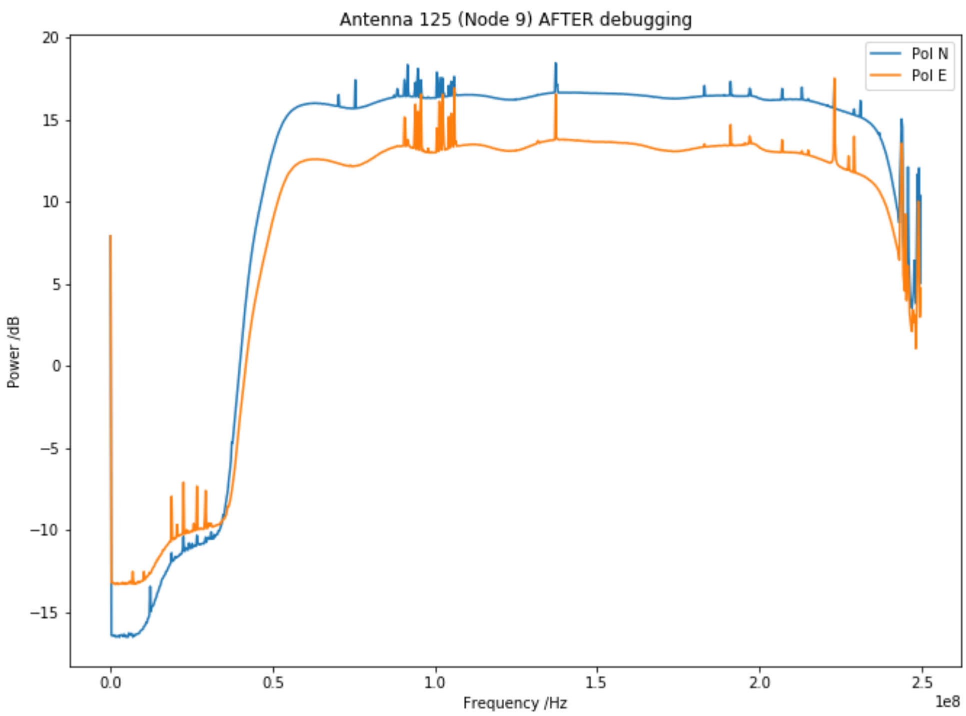


Figure 3. The autocorrelations of the N/S and E/W polarizations of Antenna 125 recorded by the third SNAP of node 9 after all debugging. Differences in passband between this figure and Figure 2 result from springs being removed, cables being installed per Appendix A, the feed being re-lifted and brought down once more, the FEM-PAM fibre connections cleaned, and the feed being re-lifted again.

Figure 3 documents the passband change of the N/S polarization of Antenna 125 after our diagnostic. The passband of Figure 2 was recorded before we made any of the three improvements described above. Figure 3 depicts the passband after the feed was lowered, springs were removed, cables were installed per Appendix A, the feed re-lifted and brought down once more, all four fibre connections described above being cleaned, and then having the feed re-lifted again. Data recorded after the second refinement (springs removed, etc.) and before the third refinement (cleaned fibres) has been lost. Feed repositioning error may have occurred between each of the two datasets, as re-positioning was performed using a laser range finder to identify the vertical ('Z') height of the feed above the hub; X/Y error in the feed centre with respect to the hub was minimized by eye. Should the feed not be in the same (X, Y, Z) position with respect to the central hub, it is possible that the impedance of the feed output could change, causing noticeable differences in passband structure between Figures 2 and 3. A future memo will thoroughly document the effects of positioning errors on the antenna beam shape, and describe a method to reliably reposition feeds and minimize their position change due to environmental effects (such as wind, rain, and temperature changes) throughout the course of an observation.

Figures 4 and 5 represent the last recorded state of all polarizations of all node 9 antennae after passband diagnosis. The passbands of the E/W polarizations of antennae 106 are 124 look considerably different than the rest, and at a much lower amplitude, suggesting they either have a faulty FEM or PAM analogue chain. Note the notch feature in the N/S polarization of Antenna 125, which appears in Figure 2, is no longer present – validating our motivation for removing the springs from all feeds. The notch feature does not show up in any polarization of any antenna after debugging.

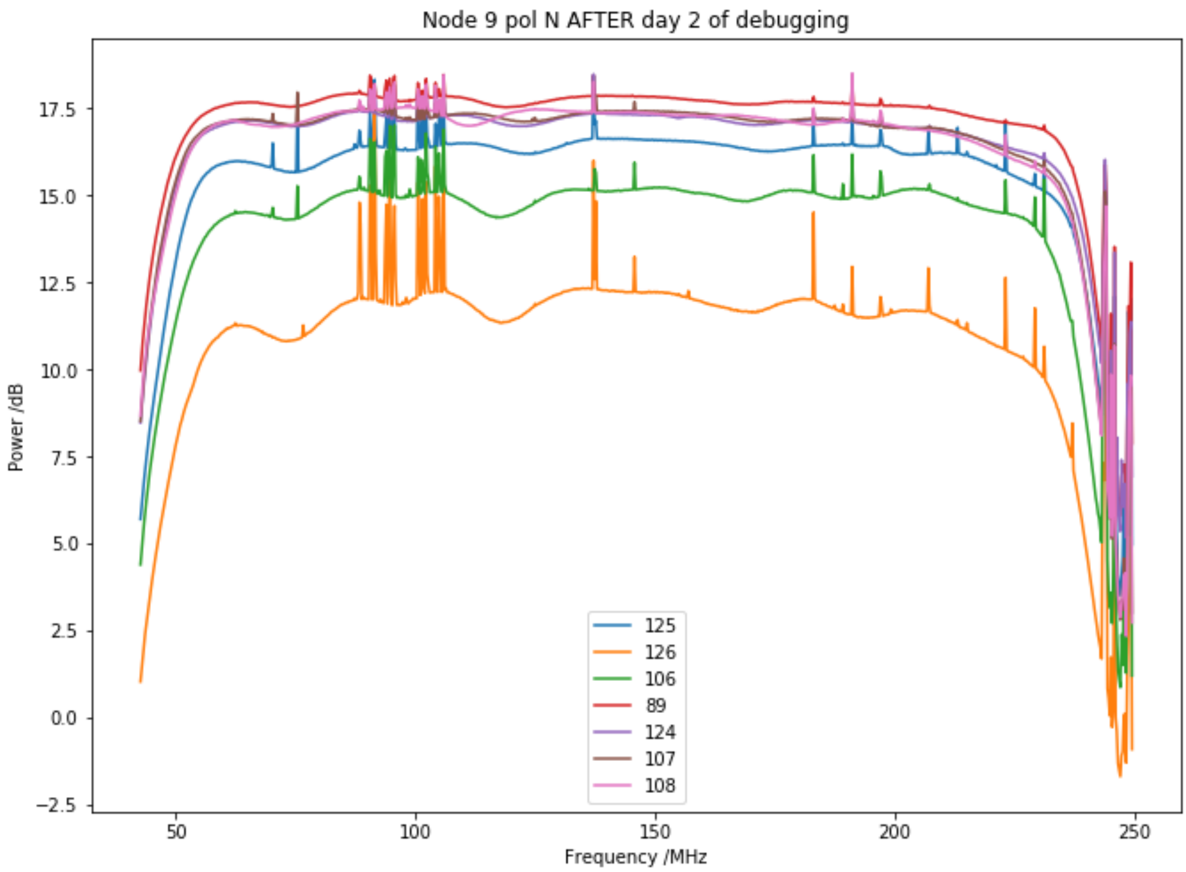


Figure 4. The autocorrelations of the N/S polarization of all antennae of node 9, after all debugging. No polarizations exhibit the notch feature and all have passbands with an acceptably high amplitude.

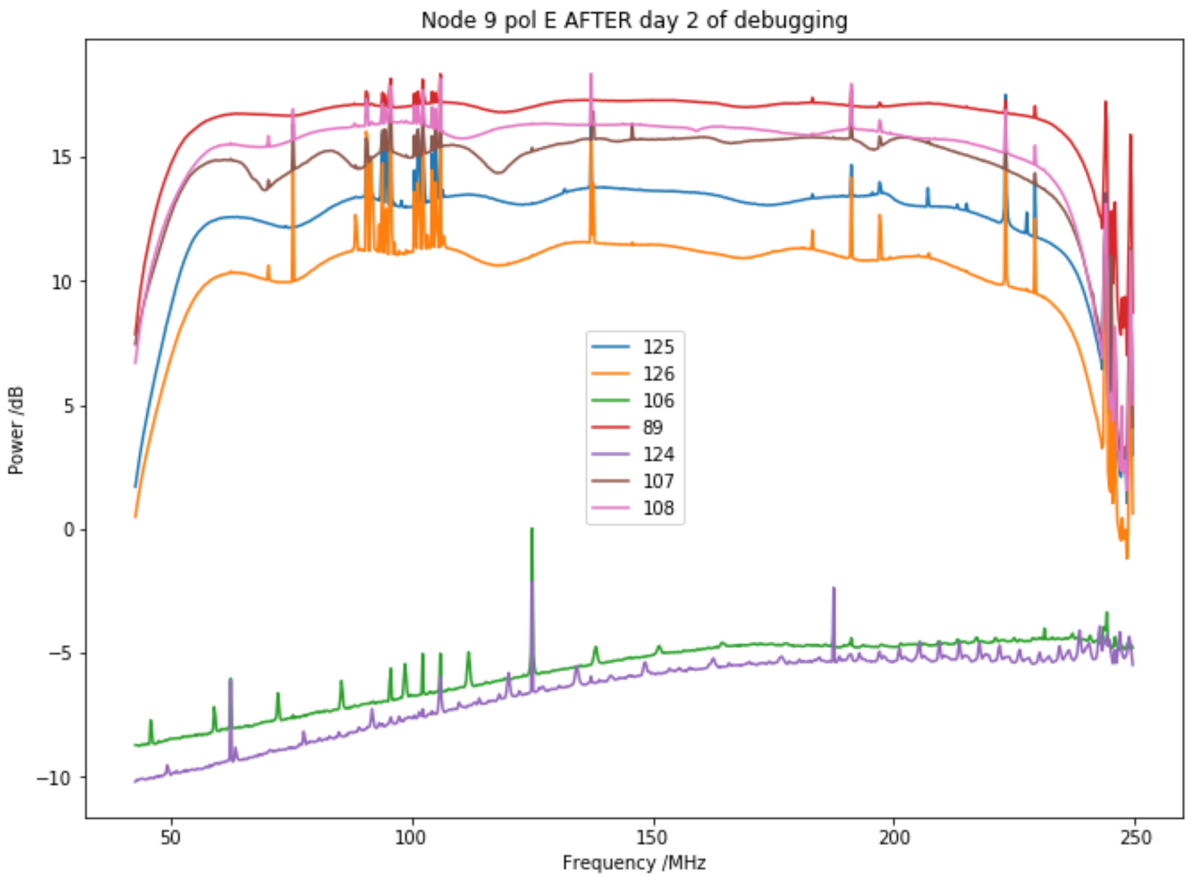


Figure 5. The autocorrelations of the E/W polarization of all antennae of node 9, after all debugging. No polarizations exhibit the notch feature. All polarizations have passbands with an acceptably high amplitude, except for antenna 106 and 124, which likely have a faulty FEM or PAM.

IV. Node Control Module Diagnostic

We experienced multiple power losses of node 9 while making passband improvements, and have concluded these were the result of a faulty node control module (NCM). While initializing node 9 via hera_snap_feng_init.py –i –s –p –e and recording (between feed modifications) autocorrelation data via the hera_get_corr script, we often received terminal output errors about the SNAP boards being offline. Meanwhile, we could access data from node 0 without issue and confirmed that node 9 itself was powered, as one of the stand-alone node cooling fans was on. To re-establish communications with the SNAPs in node 9, we hard-reset the three power switches in the top left of the node container, and then re-executed the hera_node_turn_on and hera_snap_feng_init script sequence. This did not solve our communication issue.

Using the hera.today node status page, we not only observed that the power statuses of the node 9 SNAP were off (boolean '0', red font colour), but the FEM and PAM power statuses of node 9 were off as well. All power statuses to node 0 were on (boolean '1', green). Considering that node 9 itself was receiving power but that we could not communicate with its contents, we concluded there was either a faulty NCM or a damaged fibre connection between the NCM and container. To discriminate between these two options, we cleaned and tested every fibre and patch cable connection between the NCM and white rabbit switch in the container, which serves as the physical I/O for executing node scripts (e.g. hera_node_turn_on) via ssh and the node itself. To test the buried fibre connection between node 9 and the container, we used a patch cable to connect two of these fibres (blue and orange in Figure 6) together and route the serial communications from node 0 (not node 9) through these cables, for node 0 was known to have a functioning NCM. All patch cables and fibres, including the buried ones just described, carried signal properly. Thus, we conclude some component of the node control module itself was broken, not a fibre.

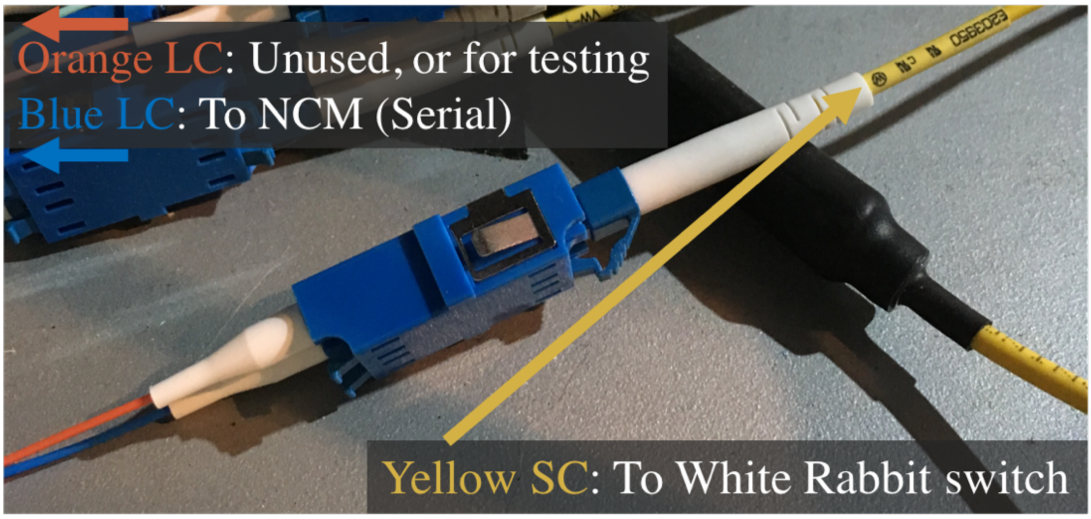


Figure 6. LC (blue and orange) and SC (yellow) fibres used to communicate between the White Rabbit switch (in the HERA on-site container) and the node 9 NCM. Typically, only the blue fibre connects to the NCM, via a patch cable into the X'd out input of Figure 7, and the orange fibre is not used. However, the orange and blue SC fibers may be connected via a patch cable to test the underground fibre cables between the node 9 NCM and the container.

We did not open the NCM in order to identify faulty components, such as a transceiver. We did, however, test whether communicating with the SC fibre input of the NCM (the arrow-marked input of Figure 7) as opposed to the conventional LC input (crossed-out input in Figure 7) solved our communication issue. It did not, suggesting either transceiver could still be broken and/or that there is another issue with the NCM.

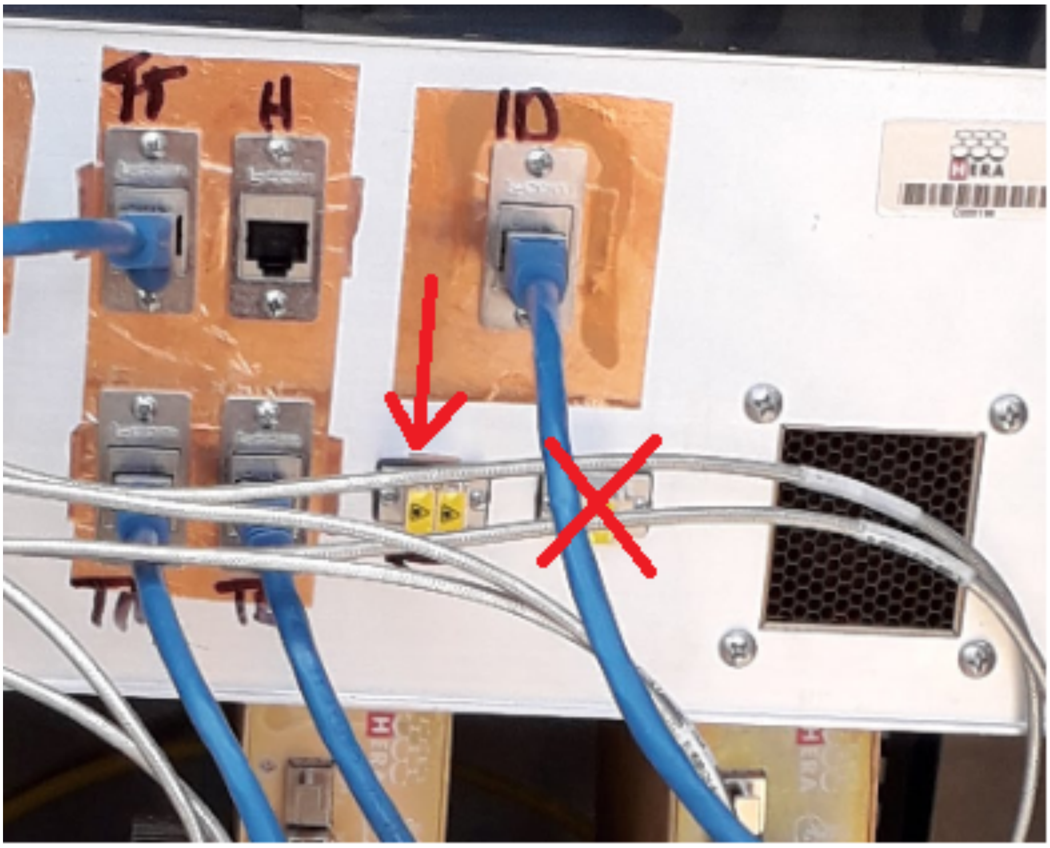


Figure 7. Node 9 Control Module fibre inputs. The LC transceiver ('X') is typically connected to the container fibre, which goes to the White Rabbit switch, via a short patch cable. We tried connecting the container fibre to the SC transceiver instead, hoping this would solve the node 9 NCM communications issues, but it did not.

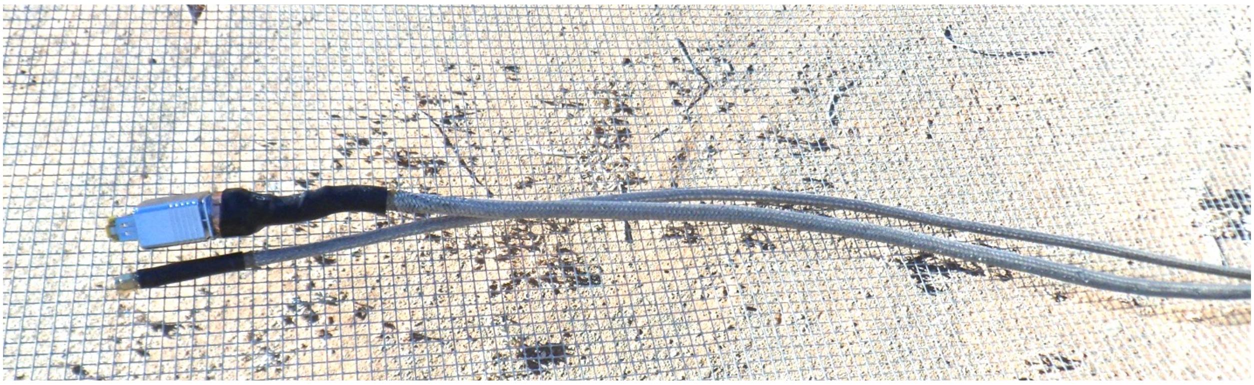
Appendix A - FEM Cable Installation

This appendix described how to install the cables through the feed and attach to the FEM. There are two primary watch points:

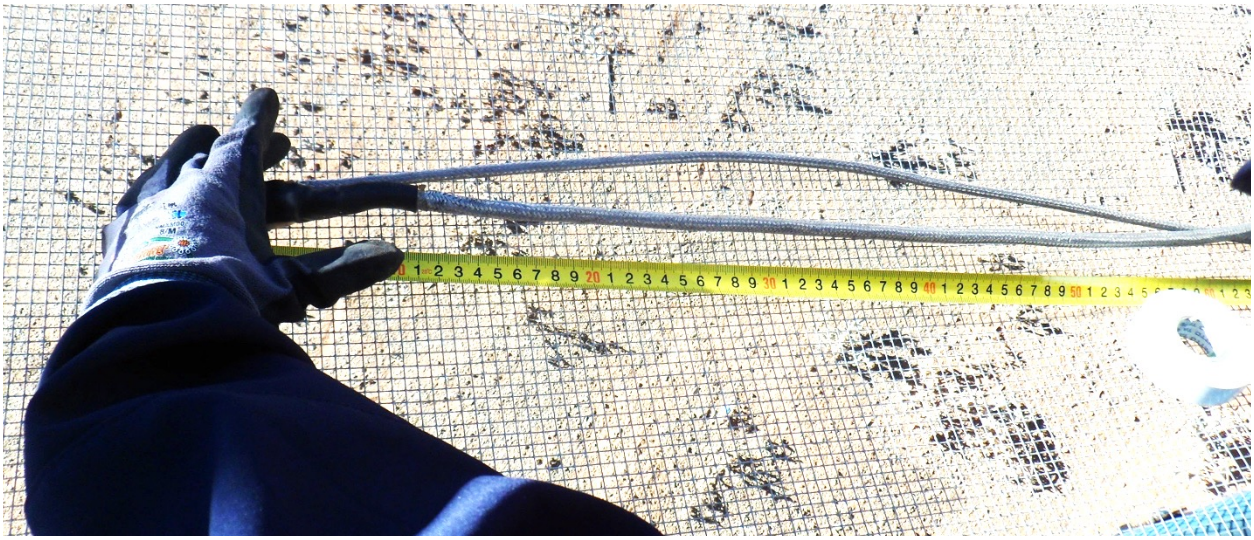
1) Make sure that the exposed cable shields (the exposed wire braids) cannot touch the feed blades. Use tape to insulate these.
2) Make sure that the exposed cable shields (the exposed wire braids) are wrapped together with the plastic wrap from the hub to the tape.

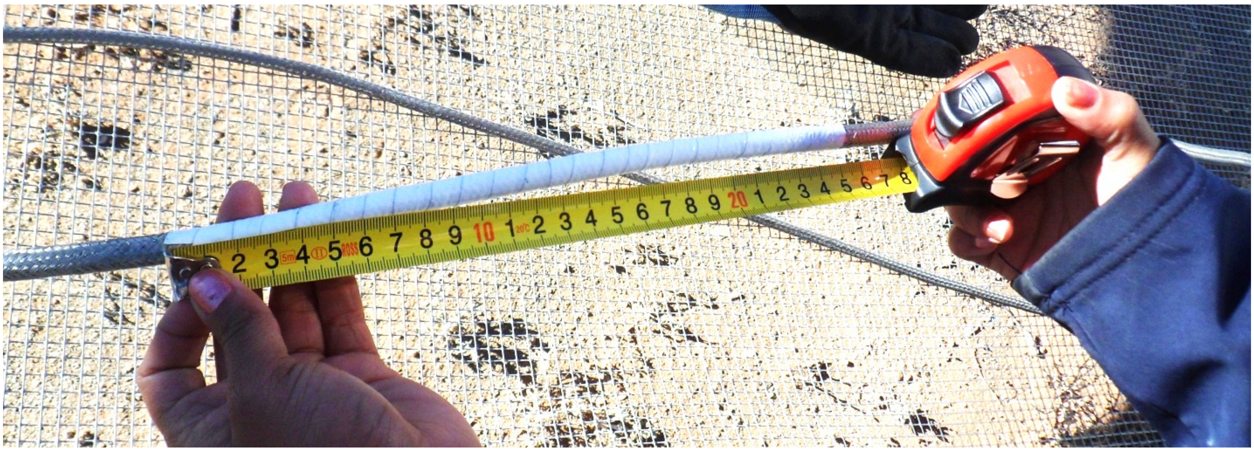
Start: All cables (fibre, SMA, and CAT 7) have been fed into the dish, are laid straight with all connectors (the ends of cables) next to one another. Conduit has been removed from feed centre.

- Lay the SMA and CAT 7cables next to each other on the antenna:



- Starting at 38 cm from the end of the SMA and CAT7 cables, insulate each cable with electrical tape for 25 cm, ending at 58 cm from the ends of the cables. Make sure the electrical tape overlaps, but not more than two tape thicknesses:



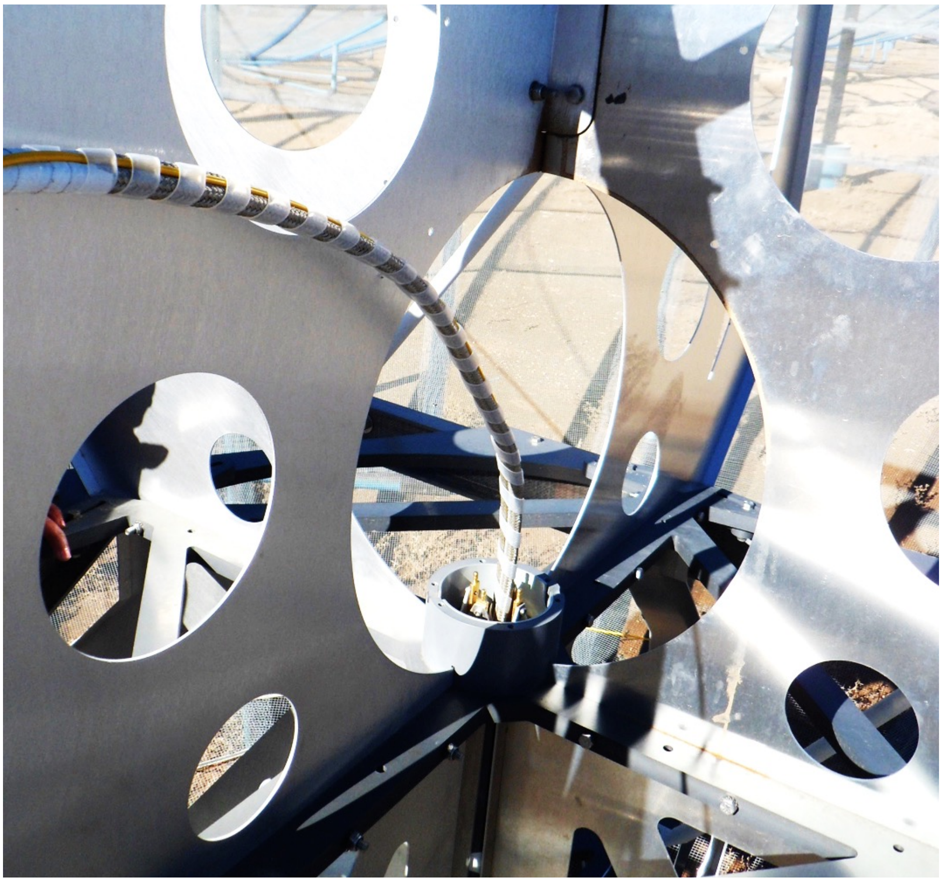


- Insert the SMA and CAT7 cables and the optical fibres through the centre of the feed, without the plastic conduit (tube).
- Place both halves of the plastic conduit (tube) around the cables and fibres, tape together, and push the tube up the middle of the conduit:

- The fibres and cables should lay out from the top of the tube:

- Fasten the tube in place:

- Carefully pull the fibres and cables from the tube. Cut ~1.5 meters of the plastic braid. Apply the plastic braid to bind all cables (SMA, fibre, and CAT7) together, starting at the end of the plastic tape and continuing towards the hub. Be careful not to sandwich the fibre between the SMA and CAT7 cables since the 2 braided cables should be in electrical contact and the fibre is very fragile:



- Once this initial wrapping is complete push the wrapped cables back into the tube until ~2.5 cm of taped SMA and CAT 7 cable is outside the plastic collar at the centre of the feed. The CAT7 cable should go out the West side of the plastic collar, and the fibre and SMA cable should go out the East side. Make sure the fibres are *underneath* the SMA cable. When the coax and the fibre pass through the hole in the collar, the fibre should be at the bottom and it should be able to move:

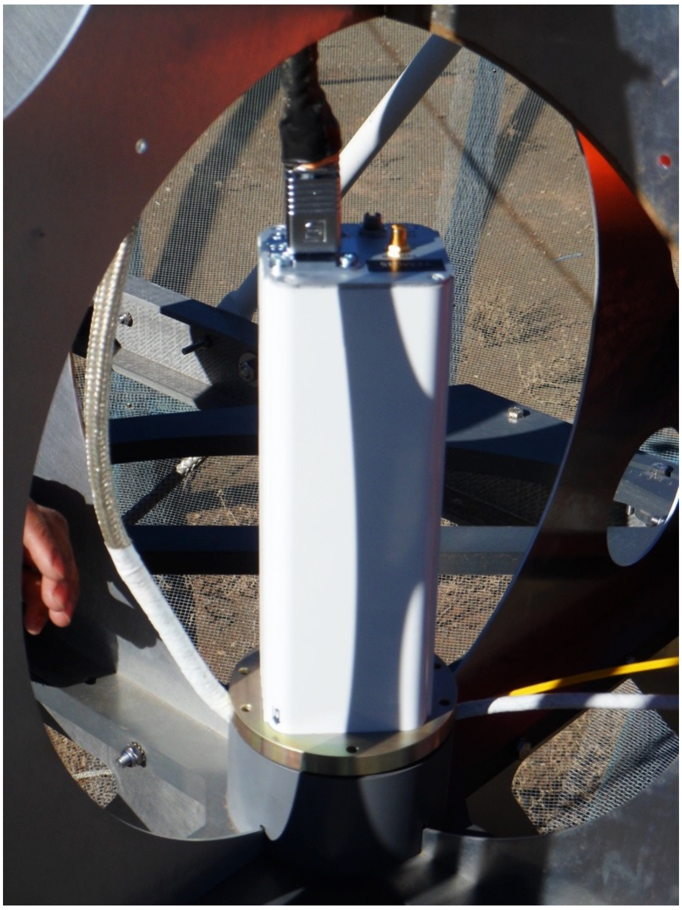
Note that the taped section of the cables extends from the plastic tube to outside the collar so that there is no possibility of the metal shield (metal braid) touching the feed blades.

- Visually assure that the taped portion of the CAT 7 and SMA cables extends into the plastic tube, and cannot touch the blades:

- Grab a FEM, record its serial number. Connect the CAT7 to the top of the FEM:

- Check again that the taped portion of the CAT 7 and SMA cables extend into the plastic tube, and cannot touch the blades:

- Connect FEM to feed pins and screw the FEM into the plastic collar. Make sure there are approx. 2-3 cm of tape showing on each cable outside the collar and FEM.



- Connect the SMA cable to the FEM. Use an SMA torque wrench to make final turns.
- Clean the fibres and connect them to the FEM. Make sure the polarizations are correct! (b/2 to North, a/1 to East).
- Use cable ties to place the CAT7 and SMA + fibre cables into contact with the side of the FEM unit. Apply a rain cover over the top of the cables and FEM:

- Cut another ~1.5 meter length of plastic braid and use it to wrap the cables and optical fibres together. Use as many pieces of plastic braid to wrap the cables until they reach the insulated portion in the hub.