

# Beamforming the Station

Beamforming is the process by which the station electronics collect the antenna signals and delays the signals to allow them to be coherently summed to point at a certain point in the sky.

Depending on your bit-mode, you can control between 244 and 976 of these beams, each of which can take on a unique frequency and pointing direction.

Typically, all beams are pointed in the same direction, with the same antenna-set, and only differ in the selected frequencies. While other pages will discuss why/how we can deviate from that choice, this page will focus on observing a single mode, in bit-mode 8 (to use most of the available bandwidth in a given mode).

## General Beamforming

In order to create a beam, you will need to execute a `beamctl` command. This command will require a spatial configuration, a spectral configuration and an antenna configuration. Roughly, a single `beamctl` command will look like either of the following stencils. The antenna sets, bands and subband components of these commands have been described elsewhere in this chapter.

```
user1@lcu$ # Observe with the LBAs
user1@lcu$ beamctl []-antennaset=LBA_OUTER \
[ ]-rcus=$rcus \
    --band=$bandLBA \
    --beamlets=$beamletsLBA \
    --subbands=$subbandsLBA \
    --digdir=$pointing
user1@lcu$
user1@lcu$ # Observe with the HBAs
user1@lcu$ beamctl []-antennaset=HBA_JOINED \
[ ]-rcus=$rcus \
    --band=$bandHBA \
    --beamlets=$beamletsHBA \
    --subbands=$subbandsHBA \
    --anadir=$pointing \
    --digdir=$pointing
```

## Numeric Lists in LOFAR commands

The inputs to LOFAR commands can contain numeric lists. These lists use both semi-colon indexing to describe a range of inclusive values (e.g., 0:2 represents 0,1,2) and command separated values or lists to refer to multiple separate groups (e.g., 0,1:6,9). Spaces cannot be included in these groups.

When attempting to exclude values, be sure you aren't accidentally including them at the start/end of a range.

## RCUs

RCUs represent the LBA antenna or HBA tiles you intend to use for your observations. As of writing, I-LOFAR currently has 1 malfunctioning LBA and 2 malfunctioning HBAs. Reaching out to observers will give you the current definitive list of the antenna you should be using for your observations.

When flagging a given antenna or tile, it is recommended to always flag both polarisation to prevent biases from excess intensity in one polarisation than another when beamforming (e.g., you could introduce a +2% bias to Stokes V by only flagging one polarisation).

## Beamlets

The allocated beamlets can be anywhere on the range allowed by your chosen software level (e.g., to allocate 200 beamlets in 16-bit mode, I can allocate them at 0:199 or 20:219). The selected beamlets will be used in set ascending order when producing BST data, or will be allocated as-given when transferring the data with CEP packets to your recording node (e.g., in 16-bit mode beamlets 0 - 60 will be transported on port 0, 61 - 121 will be transferred on port 1, etc.).

Your count of beamlets in each given beamctl command must match the amount of subbands used in each command. Beams will fail to be allocated if you attempt to use the same beamlets between multiple simultaneous beamctl commands, or if there are insufficient beamlets available (e.g., allocating more than 244 in 16-bit mode).

As an example, any of the following beamlet/subband pairings are allowed.

```
# Non-simultaneous beams
--beamlets=0:19 --subbands=0:19
--beamlets=0:19 --subbands=20:39
--beamlets=20:39 --subbands=0:19

# Simultaneous beams
--beamlets=0:19 --subbands=0:19 // --beamlets=20:39 --subbands=0:19
--beamlets=0:19 --subbands=0:19 // --beamlets=20:39 --subbands=20:39
```

## Pointing (anadir/digidir)

Pointing is typically specific in right ascension and declination in the J2000 (ITRS) coordinate space, but any casacore-supported coordinate system is accepted by the station (

<https://casacore.github.io/casacore-notes/233.html#x1-23000A.2.3> ), such as SUN, MOON or JUPITER.

Depending on the coordinate basis, the input value differs. By default, for J2000, the first value ranges from 0 to  $2\pi$  in radians, covering 24 hours of right ascension, while the second range from  $-\pi/2$  to  $\pi/2$  in radians, covering 180 degrees of declination (overall, `0.0 0.28311571157112000`). For other coordinate systems, the inputs should be radians relative to a given source, but typically you can keep the values as `0.0 0.0 0.0`.

## LBAs

The LBAs allow for beams to be configured in any direction from 0MHz to 100MHz. Unlike the HBAs, they do not have any limitations that limit the spatial locality of the chosen beams on the sky.

Unlike HBAs, LBAs only require the `pointing` component of the `beam` command, as they do not have analogue beamformers that need to be pointed prior to digital beamforming.

## HBAs

Unlike the LBAs, the HBAs have an analogue beamformer to combine each of the 16 antenna in each tile into a coherent beam prior to any digitisation and electron beamforming. As a result, the HBAs require an extra configuration parameter, `--anadir`, and the chosen beams must be kept close to each other to prevent signal loss due to falloff in the analogue beam.

It is best to think of beaming for HBAs as a two step process. Firstly, the analogue beamformer limits our field of view to that of a single tile ( $\sim 15^\circ$ ), and then the digital beamformer further limits the field of view to that of the selected tiles in the array ( $\sim 0.5$ - $2^\circ$  for the entire array). If the digital beam is not in the main lobe of the analogue beam, there will be a significant degradation in signal quality.

The HBAs currently do not have any extra RFI filtering modes (potentially will be present in LOFAR2.0 to reduce the effects of DAB radio), though have three observing modes: HBA<sub>Lo</sub> (mode 5, band '110\_190'), HBA<sub>Hi</sub> (mode 7, band '210\_250')

## General Comments

It is recommended to leave a 30-60 second gap between starting a beam and recording the data, especially for the first observation of a run and for sequential HBA observations. This gives sufficient time for the antenna to power on and beamforming electronics to be fully initialised. Recording directly after a beam is allocated will often result in empty packets being sent to the recording node, followed by a few seconds of noisy output as the beam settles on the correct point

in the sky.

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