

Station Signal Processing Pipeline

1. Antennas

LOFAR station is a wide-band radio receiver, which operates at the frequency range from 10 MHz to 240 MHz. The full reception band is divided into low band (10 MHz – 90 MHz) and high band (110 MHz – 240 MHz). The frequencies in between low band and high band are not used due to RFI from FM radio transmitters.

The station signal processing has been originally designed assuming that three different antenna arrays would be used. These arrays would have been the low-band-low (LBL) antenna array, the low-band-high (LBH) antenna array, and the high-band antenna (HBA) array. However, the present standard stations do not have the LBL antennas, and the LBH antenna array is thus referred to as the low-band antenna (LBA) array.

Antennas used in LOFAR stations are briefly introduced in following two sections. Notice that the antenna array configurations are configurations of full antenna arrays. It is always possible to manually select only a subset of a full antenna array to be used e.g. in beamforming. Positions of individual antenna elements and antenna array definitions of a station are stored in station configuration files.

image.png

2. Receiver Control Units (RCUs)

The analogue signals from LBA elements and HBA tiles are transferred in coaxial cables to a LOFAR station cabinet, where each of the cables is connected to a receiver unit. A RCU performs input selection, followed by amplification and filtering of the analogue input signal. The conditioned analog signal is sampled with a 12-bit A/D converter. The A/D converter produces real signal samples at either 200 MHz or 160 MHz sampling frequency. Combinations of filter passband and sample clock frequency are selected so that the selected frequency band always aliases around zero frequency, without frequency aliasing inside the passband. With one of the available combinations the signal spectrum will be inverted, but it can be inverted back in

subsequent processing steps.

The receiver units are numbered starting from zero. X-polarisation cables are connected to even-numbered RCUs and Y-polarisation cables are connected to odd-numbered ones. The only deviation from this rule is the LBA outer field, whose X-polarisation cables are connected to odd-numbered RCUs and Y-polarisation cables to the even-numbered ones. A receiver unit has three inputs: LBL, LBH, and HBA. The LBL and LBH connectors have an 8 V bias voltage. The HBA X-polarisation connectors have the 48 V bias voltage for power supply. The HBA Y-polarisation connectors have a 3.3 V bias voltage only when communicating with the HBA tiles.

A core station or a remote station with 96 LBA elements and 48 HBA tiles has 96 RCUs. The LBA inner array is connected to the LBH inputs and the LBA outer array to the LBL inputs. Despite the naming convention in RCUs, both LBA inner and LBA outer use the same kind of antenna elements. The HBA tiles are connected to the HBA inputs.

Due to their larger number of HBA tiles, international stations have 192 RCUs. The 96 LBA elements of an international station are connected to the LBH inputs of the RCUs, and the 96 HBA tiles are connected to the HBA inputs. In a basic installation of an international station the LBL inputs are left empty, thus facilitating later installation of an additional antenna array.

| RCU mode | antenna set | accessible frequencies [MHz] | sampling frequency [MHz] |
|-----------------|--------------------|-------------------------------------|---------------------------------|
| 3 | low band | 10-90 | 200 |
| 4 | low band | 30-90 | 200 |
| 5 | high band | 110-190 | 200 |
| 6 | high band | 170-230 | 160 |
| 7 | high band | 210-270 | 200 |

The subbands bandwidth is given by sampling frequency/1024 (1st polyphase filter). The maximum total bandwidth is given by the product of subbands bandwidth and the number of subbands (244 for 16 bit mode, and twice that number for 8 bit mode), resulting in :

| sampling frequency [MHz] | bit mode | subbands bandwidth [kHz] | number of subbands | maximum total bandwidth [MHz] |
|---------------------------------|-----------------|---------------------------------|---------------------------|--------------------------------------|
| 200 | 16 | 195.3125 | 244 | 47.6 |
| 160 | 16 | 156.250 | 244 | 38.1 |
| 200 | 8 | 195.3125 | 2*244 | 95.3 |
| 160 | 8 | 156.250 | 2*244 | 76.3 |

3. Remote Station Processing Boards (RSPs)

After frequency band selection and A/D conversion in the RCUs, the received signals are transferred to remote station processing boards. The RSP boards perform all digital signal processing that is done at the station, and send data to central processor (CEP).

The discrete signal samples arriving from a RCU to a RSP board are first buffered in a FIFO buffer. In order to compensate for differences in signal delays in the coaxial cables, buffer length can be adjusted independently for each individual RCU. The buffer is followed by a polyphase filter, which divides the wide band input signal into so-called subbands.

A polyphase filter is a novel FFT-based implementation of a bandpass filter bank, which divides the real input signal into 1024 complex subband signals. Because the real input contains two identical (mirrored) copies of the signal spectrum – one at positive and the other at negative frequencies – the lowest 512 subbands are complex conjugates of the 512 highest ones. The whole receiver passband is thus covered by the 512 lowest subbands, which are used in further processing. Depending on sample clock frequency, subband width is either $200 \text{ MHz}/1024 = 195.3125 \text{ kHz}$, or $160 \text{ MHz}/1024 = 156.250 \text{ kHz}$.

After the polyphase filter the signal bandwidth is small enough to facilitate phased-array beamforming, which produces beamformed subband signals called beamlets. Although 512 subbands are produced in the polyphase filter, only 244 beamlets can be formed by the station signal processing. Subbands used in beamforming are selected immediately after the polyphase filter. The beamforming is performed in a ring, where a process handling signal from one RCU receives a partial beamforming result, adds the contribution from its own RCU, and passes the result forward to the process handling signal from the next RCU. In order to facilitate the beamforming, the RSP boards of a LOFAR station are connected together as a ring. After a full cycle in the ring, the beamformed sample is complete and ready to be transmitted to central processing.

The beamforming ring is divided into four separate lanes, each of which has its start and end point in a different RSP board. Beamformed data are output from those RSP boards that are endpoints of the beamforming lanes. In core stations the beamforming lanes can be split into two halves, allowing independent beamforming with the HBA0 and HBA1 arrays. Because 244 beamlets can be formed with both arrays, the splitting allows core stations to form 488 beamlets simultaneously, but each of them with only 24 HBA tiles. Four additional output RSP boards are defined in the split mode, i.e. data are being output from eight RSP boards simultaneously.

In addition to the beamforming, the RSP boards can calculate so-called subband statistics, beamlet statistics, and array covariances (crosslet statistics). Likewise the beamlets, the co-variances are also formed in the ring of RSP boards, and their calculation is divided into four lanes. All these crosslet lanes start from and end to the same RSP board, which also outputs the data. The crosslet output board is usually different from the beamlet output boards. The RSP boards can also send either raw A/D converter samples or subband data to ring buffers in transient buffer boards.

An RSP board has four antenna processors (AP). Each AP processes two orthogonal polarisations from its connected antenna. Each RSP board thus has 8 digital inputs for the signals from the RCUs, which defines the number of RSP boards in a station: core stations and remote stations have 12 RSP boards, whereas international stations have 24 RSP boards.

4. Transient Buffer Boards (TBBs)

Transient buffer boards are not part of the main signal processing chain, but their function is to store a short period of raw voltage data in a ring buffer. Writing to the buffer can be stopped when a triggering event is detected or a stop command is sent, after which the data can be read from the buffer.

TBBs are physically connected to the RSP boards, which provide the raw data that is buffered to the boards. As can be seen from the figure above, the TBBs can record two kinds of data. These are buffered in either: "transient" mode, where real signal samples are copied to TBBs immediately after the FIFO buffers in RSP boards, or in "subbands" mode, where complex subband data produced by the polyphase filter are copied to the TBBs. TBB memory is divided into pages, which are large enough for 1024 12-bit data samples in "transient" mode. Because the subband data is in 16-bit format, only 487 of the 512 subbands can be recorded in "subbands" mode. The storage capacity of the TBBs for spectral and transient data is laid out in the [TBB Design Description document](#)

One TBB is capable of recording data from 16 RCUs, and each TBB is thus connected to two RSP boards. Core stations and remote stations thus have 6 TBBs, whereas international stations have 12 TBBs.

Data from I-LOFAR's TBBs can be obtained and stored on a cluster in the Rosse Observatory. Data is transferred from the TBBs to the cluster at 3.3Gbps and is currently written at 300 MB/s. The cluster consists of 6 nodes; 4 computing nodes, 1 head node and 1 node acting as a storage server for TBB data. The head node controls the operations of the cluster while the computing nodes are used to listen for and write incoming TBB data. During a TBB observation the cluster must be instructed to listen for TBB data in order to convert it into a usable hdf5 file format.

5. Local Control Unit (LCU)

Local Control Unit (LCU) is a computer running the Redhat Linux OS. All station control happens via the LCU, which runs a number of control processes that communicate with the different processing boards of the station. LCU also receives station clock signals from GPS and a rubidium standard. Users can log on to the LCU via a ssh connection, and control the whole station from the command line. Single-station control is covered in more detail in [Section 3](#), and relevant commands are listed in the command reference.

6. Further Reading

Further information about any of the topics discussed above can be found in the [LOFAR Station Data Cookbook](#).

Revision #3

Created 21 May 2024 11:47:44 by Owen

Updated 21 May 2024 12:01:15 by Owen