# LOFAR: a Digital Aperture Array Radio Telescope

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## Abstract

Construction of the Low Frequency Array (LOFAR) is nearly complete. It consists of 48 stations, mostly concentrated within the Netherlands, and spreading into Europe. Each station has 48 or 96 dipole antennas and antenna tiles, optimized for 30-240 MHz. LOFAR uses a combination of true time delay and phased-array techniques. Digital beam-forming gives the system agility and allows rapid repointing and the potential for multiple simultaneous observations. Digital buffering allows a posteriori imaging of transient events. LOFAR has automated processing pipelines interacting with its long-term archive. In all its aspects LOFAR is an important pathfinder for the SKA.

## 1. Summary

The LOFAR radio telescope [1] is the first telescope of its size which is based on phased array principles. This gives astronomers a flexible instrument which can electronically steer multiple independent beams on the sky. In total 48 stations [2] are distributed over a large area to achieve an angular resolution of arcsec accuracy with acceptable UV coverage. All data from the stations come together in the central systems where the data of the stations can be correlated [3] for the imaging modes or (in)coherently added for the beamforming modes. Also other modes are present which serve the cosmic ray and transient detection communities.

The frequency range of LOFAR is optimized from 30-240 MHz. This range is covered by two antenna sensors. The low frequency range from 30-80 MHz is covered by the Low Band Antennas and the higher frequency range from 120-240 MHz by the High Band Antenna tiles. Each HBA tile consists of 16 small antenna elements to gain a constant sensitivity over the full frequency range. The signals from the 16 elements of the HBA tile go in to a first stage analogue (time delay) beamformer.

In LOFAR three types of stations are defined:

- Core stations (< 3 km from the centre): consist of two HBA fields of each 24 tiles and 96 LBAs
- Remote stations (further away from the core in the Netherlands): consist of 48 HBA tiles and 96 LBAs
- International stations (in Germany, France, Sweden and the UK): consist of 96 HBA tiles and 96 LBAs

The data is sent via 10 Gbps fiber infrastructure to the central systems housed in the University of Groningen's Computer Centre. After online correlation and/or beamforming the data is stored temporarily and later further processed in an offline cluster. There the data is reduced, calibrated and imaged for the imaging mode by processing pipelines. The reduced data is shipped to the archive sites.

Within LOFAR trigger algorithms will constantly scan the data for cosmic rays or transient events. Once an event is detected the individual dipole data can be retrieved back for one second for the full bandwidth, since the individual dipole data are recorded by buffer boards.

## 7. References

[1] Marco de Vos, Andre W. Gunst, Ronald Nijboer, "The LOFAR Telescope: System Architecture and Signal Processing", *Proceedings of the IEEE*, Vol. 97, No. 8, 1431-1437, August 2009

[2] A.W. Gunst and M.J. Bentum, "Signal Processing Aspects of the Low Frequency Array", *IEEE International Conference on Signal Processing and Communications*, 600-603, 24-27 November 2007, Dubai, United Arab Emirates.

[3] John W. Romein, P. Chris Broekema, Jan David Mol, Rob V. van Nieuwpoort, "The LOFAR Correlator: Implementation and Performance Analysis", *ACM Symposium on Principles and Practice of Parallel Programming (PPoPP'10)*, 169-178, January 2010.

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