Author: Michiel van Haarlem, Hans Kollen (editors)	Date of issue: 2007-04-01 Kind of issue: limited	Scope: wp/LOFAR/SES Doc.id: LOFAR-ASTRON-SRS-001	
	Status: Final – for System CDR Revision nr: 4.1	SRS-001-iss41	

Low Frequency Array

LOFAR

System Requirement Specification

This document represents the LOFAR System Requirement Specification (LOFAR SRS). It contains the top-level requirements to which LOFAR has to be designed and where LOFAR is defined as a Wide Area Sensor Network for astronomy, geophysics and precision agriculture in the Netherlands.
This document refers predominantly to the Astronomical Application.

In its current status (4.1) this document is no longer a pure requirements document. Since its first issue, it has been heavily influenced by the actual implementation of the system.

Distribution list: UPDATE

Group:
Review committee E. van den Heuvel (chair, University of Amsterdam) A. Berg (SARA) W. Brouw (University of Groningen) R. Schilizzi (SKA-ISPO/U. Leiden) C.H. Slump (University of Twente) A.B. Smolders (NXP Semiconductors) E. Stolp LOFAR Project Mark Bentum Ger de Bruyn André Gunst Michiel van Haarlem Hanno Holties Auke Latour Ronald Nijboer Ruud Overeem Jan Reitsma John Romein Gijs Schoonderbeek Michael Wise Albert-Jan Boonstra Stefan Wijnholds

Document history:

Revision	Date	Section	Page(s)	Modification
DR-01	2001-10-24	All		First Release
DR-02	2001-12-07	All		Update after review of chapters 1 and 2 by Astron, see SDE MoM of 19/01/01. Various inputs for chapter Operations received and included.
DR-03	2001-12-21	All		SAS paragraph included in chapter 2.3. Further updates of chapter Operations.
DR-04	2002-02-19	All		Operations is now chapter 4 and Functions & performance is chapter 3. Operations chapter updated.
Issue 1	2002-03-06	All		Operations chapter 4 completed with Astron review comments. Preliminary update of chapter 3. Release for ISRR (2002-03-11)
Issue 1.2	2002-09-05	All		Major review of the document in preparation for the SRR. Chapters 1 and updated and more detail added Chapter 3 contents brought in line with the science taxonomy of the SCB, functional requirements incorporated that were included in chapter 4. Chapter 4 functional requirements moved to chapter 3. Chapter 5 through 8 new requirements added.
Issue 1.3/1.7	2002-09-24	All		Intermediate review issues
Issue 2.0	2002-09-25	All		SRR issue, final comments and updates included in various chapters. Due to the many changes, no change bars are present in the document.
Issue 2.1	2002-10-03	3.08.1	26, 27	Subsection 3.08.1 (Top-level requirements) of section 3.08.1 (Monitoring and Control function) added, which was omitted in the previous issue.
Issue 3.0	2003-12-17	3	21-29	DCR 001 implemented Editorial changes
Issue 4.0	2005-04-01	All	All	Complete revision to include DCR-002, 003, 004, 005 and the DMT proposed changes. Top level requirements for the Non-Astronomical Applications are included.
Issue 4.1	2007-04-01	All	All	Minor Update for System CDR

Table of contents

7.08 Logistics

8 Verification requirements

1 Introduction

1.1 Purpose of this document

This document represents the LOFAR System Requirement Specification. It contains the top-level requirements to which LOFAR has to be designed and where LOFAR is defined as a Wide Area Sensor Network for astronomy, geophysics and precision agriculture in the Netherlands.

This document defines the verifiable requirements and constraints applicable to the LOFAR System and can thus be used to check the compliance of LOFAR with the Science User Requirements.

This document is the top-level source of the corresponding industrial specifications: Subsystem Requirement Specifications will be derived from this document.

1.2 Motivation and Definition

The initial goal of LOFAR was directed towards the astronomical application that is to say to open a new window on sky in the electromagnetic spectrum from ~10–240 MHz (corresponding to wavelengths of 1.2–30 m) with unprecedented sensitivity and resolution. This portion of the spectrum has been poorly explored compared to the higher frequencies, mainly due to the complicated structure of the ionosphere and several technical limitations. This has resulted in radio maps with resolutions on the scale of arc minutes and consequently serious confusion effects, which have limited the imaging sensitivity to the Jansky level.

In the early seventies a large suite a radio telescopes was completed covering the radio spectrum from 10 MHz to 30 GHz. In the past three decades many of these telescopes got receiver upgrades, which improved their sensitivity by a factor ten. For existing decametric radio telescopes such upgrades were of no use, since they were sky noise limited right from the beginning. The only way to increase sensitivity in this wavelength regime is by a drastic increase in collecting area. With modern receiver technology this can be accomplished by using compact, low cost receptor elements. To realise the full potential sensitivity of such an instrument, baselines of at least 300 km have to be spanned in order to avoid confusion due to limited resolving power. With the advent of advanced signal processing methods, effective cancellation of man-made interference has become feasible, allowing the use of larger instantaneous bandwidths. Recent years have seen many advances in wide-field self-calibration imaging procedures, as well as in high performance computing systems. It has been demonstrated that the NRL-NRAO 74 MHz VLA receiving system can now explore this spectral window almost down to the instrumental sensitivity limits at the milli-Jansky level. Such developments have paved the way for the exploration of this spectral region with the unprecedented imaging power of LOFAR. Technological advances also offer efficient ways for time-series processing, enable a variety of new detection algorithms for the exploration of the transient and bursting universe.

The realization of a low frequency radio telescope that will fulfill the desires expressed above is a costly affair for which funding is not readily available.
The LOFAR funding granted by the Dutch government is tied to the realization of LOFAR as a Wide Area Sensor Network for astronomy, geophysics and precision agriculture in the Netherlands. Since funding is limited, LOFAR will be realized in several phases. The Phase 1 Baseline is sufficient in scope and performance to satisfy the needs and requirements of both the funding government and the Dutch scientific community represented in the LOFAR Consortium. For the astronomical application, it does not realize the full performance, lacking especially in resolution and overall sensitivity. Several design choices have been made that allow significant cost reductions both in procurement and development. Future extensions will be mainly the addition of Remote Stations at larger baselines. For the geophysical application the Phase 1 configuration gives sufficient coverage of the Northern provinces. In future, the addition of Remote Stations in the area of Limburg and Noord-Brabant would be highly interesting, which is in line with the long-baselines required for the astronomical application. For the agriculture application the coverage in Drenthe offers sufficient research opportunities. There is clearly a synergy between the future wishes of three communities, so the inter-disciplinary character of LOFAR will be maintained also in future phases.

The LOFAR Phase 1 Baseline consists geographically of a Compact Core area and 45 Remote Stations. Each Remote Station will be equipped with 96 High Band (4x4) antenna arrays, 96 Low Band antennas, 13 three-axis vibration sensors (geophones), one to three microbarometers (for infrasound detection) and several auxiliary systems e.g. for weather monitoring and GPS time/position measurements. In the Core area, with ~2 km diameter, there will be 32 stations. For the astronomy application, there will be a total of 3072 4x4 High Band and 3072 Low Band antennas in the Core area. The number and configuration of geophones and microbarometers in the Core area is yet to be defined. Selected stations will be equipped with additional sensors for the agriculture application. The maximum baseline between stations in the Phase 1 Configuration is roughly 100km.

For the astronomy application, the Low Band antenna will be optimised for the 30-80 MHz range. The High Band antenna will be optimised for the 120-240 MHz range. The FM band is suppressed in the antenna LNAs and in the receiver for both antennas to minimize intermodulation products from FM transmitters.

Remote stations will be connected by 10 GbE technology to the Central Processing systems. The sensor data will be dominated by the astronomical antennas (2 Gb/s, being the equivalent of a single dual-polarized beam over 32MHz, so 1x32MHz or 8x4MHz etc). The input section of the Central Processor is dimensioned such that 32 Core Stations and 50 Remote Stations can be accommodated simultaneously. The processing capacity is matched to the proposed scenario for EoR observations. For the astronomy application, Full Tied Array beamforming will be supported. Transient detection will be supported (probably using large collections of low-bandwidth beams). Buffering of the full sampled bandwidth and limited triggering (primarily UHECR detection) will be available at station level.

1.3 Background design information

To keep this document concise and readable, several top-level design concepts are presumed. In particular the basic architecture (an aperture synthesis array consisting of phased array stations) is referred to throughout. Part of the functional breakdown is implied to allow for a clearer wording of requirements.

To appreciate the information contained in this document, some concepts and numbers from the LOFAR conceptual design are given below. A detailed description and definition is given in the top-level Architectural Design Document (LOFAR-ASTRON-ADD-006).

The Phase 1 Baseline has the following key features, presented here in connection to subsystems:

- Remote Stations (sensor-fields) equipped with ~100 High Band antennas, ~100 Low Band antennas, 13 three-axis vibration sensors (geophones), one to three microbarometers (for infrasound detection) and several auxiliary systems e.g. for weather monitoring and GPS time/position measurements.
  - Low Band Antenna element, optimised for the 30-80 MHz range, with a sharp cut-off filter above 80MHz. The suppression below 30MHz will be matched to the environment. The antenna LNA will only suppress these frequencies to the extent needed to maintain linearity over the full band. The receiver will have a separate filter for observations below 30MHz that matches the signals to the available dynamic range in the ADC to allow night-time observing for 80% of the night-time. An alternative design would be not to suppress the band further in the receiver and accept a further reduced duty cycle (possibly down to 10%). The Low Band antenna elements can be used down to 30 degrees elevation.
  - High Band antenna that can be used between 120-240 MHz. The FM band is suppressed in the antenna amplifier for both antennas to minimize intermodulation products from FM transmitters.
  - Broad-band integrated receiver and digital processing system. The receiver uses direct conversion of either an 80 or 100 MHz band. Each receiver is connected to a Low Band and a High Band antenna; only one of these can be selected at a time. The digitized signal will be buffered for ~1 sec for Cosmic Ray detection. In the first digital processing step 256 kHz subbands are formed. Only a subset of these bands is further processed. The maximum total bandwidth selected for further processing will be 32 MHz. Each Remote Station delivers a single dual polarization beam at 32 MHz, or 8 dual polarization beams at 4 MHz or any combination in between. The resulting output data rate

is 2 Gb/s. The secondary filtering stage (to 1 kHz channels) is done in the Central Processing system. Sub-bands can also be buffered, allowing Transient Detection.
- Three-axis vibration sensor (geophone), placed 10m below the surface to get below the ground-water level. The geophones are passive elements connected through 2x3 signal lines.
- Sample-unit for geophones, using an 0.5 ms samplerate at 24 bit. Data are transported as 32 bit words, so the 13 geophones at a Remote Station generate a 2.4 Mb/s datastream.
- KNMI microbarometer in 0.5 m diameter tubes, placed just below the surface, with six tubes
- Agriculture sensor systems will be installed near selected fields, details yet to be defined.

- In the Compact Core, with ~2km diameter, a total of ~3200 High Band and ~3200 Low Band antennas are placed in 32 stations; the number and configuration of geophones and microbarometers is yet to be defined.

- The maximum baseline will be ~100 km. Stations are oriented such that future extensions across Europe add significantly to the spatial sampling for the astronomy applications. Extensions to Limburg also add significantly to the scientific value of the geophysical application. Longer baseline European extensions are being explored. Stations near Bonn (Effelsberg) and Munich (Germany) are to be completed in 2007.

- The approximate locations of the inner ~32 stations have been fixed, the remaining locations will be selected in a later phase to allow for cost optimisations (especially driven by available network infrastructure).

- The input section of the Central Processor is dimensioned such that 32 Core stations and 50 Remote Stations can be accommodated simultaneously at their full bandwidth. The processing capacity is matched to the proposed scenario for EoR observations. The exact processing demands for the geophysical and agriculture applications are to be worked out in detail.

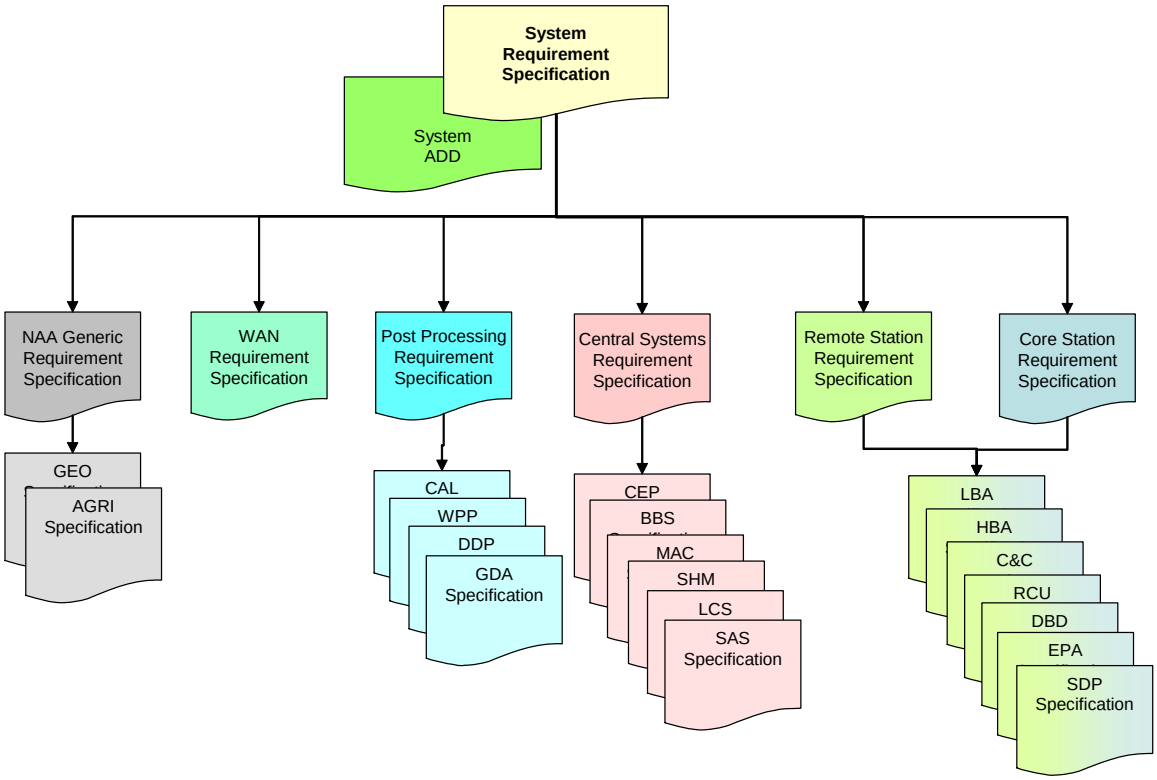
- For the astronomy application the following main observing modes will be supported:
  - Synthesis imaging.
  - Transient detection (probably using correlation of large numbers of low-bandwidth beams).
  - Tied Array beamforming.
  - Antenna-based buffering of 1 sec at full-digitised bandwidth and limited detection/triggering (in particular for UHECR events) at station level.

1.4 Scope and context

This document contains the LOFAR System (top) level requirements, which includes all instrument related equipment (hardware and software), all communication and -infrastructure items, all support equipment and facilities needed to support the LOFAR functions defined herein. LOFAR will be delivered in two major increments, leading to an Initial and an Ultimate Operations Capability, as defined in RD.2. Requirements are given both for the IOC and UOC.

The place of the LOFAR System Requirements Specification in the hierarchy of specifying documents is depicted in Figure 1-1. The main driving input requirements for this document originate from the Science User Requirements Document, which contains high-level scientific requirements derived from the Scientific Applications (user cases) Document.

Figure 1-1 LOFAR specification tree



1.5 Glossary

Definition of terms and acronyms used in this document, are provided in a separate document: LOFAR Terms, definitions and abbreviations, LOFAR-ASTRON-RPT-002 (RD.2).

1.6 Contents

This document is organized in the following chapters:

Introduction
Provides introductory information and a background for the requirements contained in this specification. It includes a definition of the Applicable Documents which are called out in the main body of this document to the extent specified. It also lists the Reference Documents, which are to be used in preference to alternative sources unless there is sufficient and good reason to deviate.

LOFAR Top Level Requirements
Summarizes the objectives of the project and provides general requirements. The requirements in this section are general of nature and will not be indicated with a requirement number and will not be formally verified, due to this general nature. These requirements provide the necessary framework for the specific requirements in the following chapters.

Functional Performance Requirements
This chapter defines the quantified functions and parameters related to performance of the LOFAR telescope system such that system operations requirements are achieved.

Operational Requirements
This section defines the operational requirements applicable to the LOFAR system.

Design Constraints

Environmental constraints
This section defines the environment which applies to the LOFAR equipment

Quality factors
This section defines requirements for Product Assurance and RAMS.

Engineering Design constraints
This section defines, for LOFAR equipment and supporting equipment the required engineering design constraints.

Operations Design Constraints
This section defines the constraints on the design arising out of operations

Interface Requirements
This chapter defines the specific requirements applicable to the LOFAR system arising from other (external) interfacing systems; it further defines high level internal LOFAR interface requirements.

Supporting Requirements
This chapter defines requirements related to simulation, maintenance and training equipment.

Verification Requirements
This chapter defines the requirements how to achieve verification of the requirements placed on the LOFAR system.

1.7 Applicable and reference documents

1.7.1 Applicable documents

The LOFAR specification and design shall comply fully to the list of applicable documents, to the extent stated herein. In case of conflict this SRS shall have precedence.

No.	Document Number	Issue	Title
AD.1	http://www.lofar.org/PDF/LOFAR_Scientific_Applications_1.0.pdf	1.0	International Science Applications Document (pdf)
AD.2	http://www.lofar.org/PDF/NL-CASE-1.0.pdf	1.0	NL science case for LOFAR

1.7.2 Reference documents

The following list of reference documents are for general guidance only and need not to be applied. However they shall be given preference over other documents covering similar topics. The latest issue shall be used.

No.	Document Number	Issue	Title
RD.1	LOFAR-ASTRON-ADD-006	4.1	LOFAR Architectural Design Document
RD.2	LOFAR-ASTRON-RPT-002	2.0	LOFAR Glossary of Terms and Abbreviations
RD.3	LOFAR-ASTRON-ADD-015	1.0	LOFAR Calibration Framework

2 Deleted

In the current version (4.1) of this document, this chapter has been deleted. To ensure that the overall numbering remains consistent, it has been left empty.

LO-3 Functional and performance requirements

NOTE: The requirements specified in this chapter are based on the Science User Requirements Document (spreadsheet) as discussed in the SCB meeting of 2002/08/25. The sections follow the performance categories used in the Science URD, with some empty categories left out or covered by high level specifications. It should be noted that the selection and grouping of categories is somewhat arbitrary, as is the location of some specific requirements. The reader is encouraged to concentrate on the content of the requirements rather than on the scheme used to decompose the system into performance categories.

LO-3.01 Spectral Characteristics

This section refers to the part of the spectrum observed with LOFAR. It has an impact on the antenna and receiver specifications, but also on the dimensions of all digital processing.

LO-3.01.1 Operating Frequency

Deleted

-01 LOFAR shall be able to measure electromagnetic radiation in a frequency range from 10 MHz to 240 MHz, with sensitivity requirements as function of frequency as specified in 3.04.1.

-02 LOFAR receptors should be optimized for the frequency ranges: 30-80 & 120-240 MHz. Observations should also be possible (best effort) in the 10-30 MHz range. Some ability to operate in the 80-88 MHz range is welcome (but not essential). Operation between 240 and 300 MHz is desirable (to be examined).
Extensions beyond the optimized frequency range should not jeopardize observations in 30-80 and 120-240 MHz bands.

LO-3.01.2 Instantaneous Bandwidth

In the current (phase-I) LOFAR design, each digital signal path is either connected to a low band antenna element or to a high band antenna element. To get a wider instantaneous frequency coverage, receptor groups (“substations”) can be formed within each Station. Each of these groups of antennas can observe at a different frequency band (simultaneously). This limited subarraying capability allows simultaneous observations in multiple frequency bands separated by more than 32 MHz (but note that the number of digital signal paths is kept fixed).

-01 LOFAR shall have a maximum instantaneous bandwidth of 32 MHz per polarization for digital signal path. It shall be possible to position this band anywhere within the operating frequency band. The 32 MHz need not be contiguous and can be selected from the available digitized bandwidth.
It shall not be possible to select different digitized bands for the two polarizations of a single antenna element.

-02 It shall be possible to define up to four groups of antenna elements for each Remote Station, where all antenna elements in a group shall have the same frequency range (however, no more than 32 MHz per station can be transported and processed; also the frequency range may differ between the groups).

-03 It shall be possible to define up to four groups of antenna elements for each Virtual Core station, where all antenna elements in a group shall have the same frequency range (however, no more than 32 MHz per station can be transported and processed; also the frequency range may differ between the groups).

LO-3.01.2.1 Maximum Observable Bandwidth

All beams can use channels selected at will from the available digitized frequency range within each sub-array. (Each beam corresponds to at least ~195/156 kHz, so in 32 MHz there can be up to 164/205 beams!)

Definition: The 32 MHz band (consisting of 1 or split up in more bands, either by selection or integration) generated by a remote station will be referred to as "Output Bands" in this and the following chapters.

-01 LOFAR shall have a maximum bandwidth available for further science processing of 32 MHz.

The limit is one of data rate (~2 Gbit/s), not of bandwidth! This needs reformulating – it is not clear and depends on the mode. Also different for core and remote stations.

-02 The actual total available bandwidth may be lower, down to ~195/156 kHz, so there can be up to 32 MHz/(195/156) kHz = 164/205 beams in some observational modes.

-03 LOFAR Phase 1 shall provide modes where 32 MHz is available for one independent dual polarized beam for each station.
(also here ~2 Gbit/s not 32 MHz).

This needs reformulating – it is not clear and depends on the mode. Also different for core and remote stations.

-04 It shall be possible to process the information from the Virtual Core antennas for the full selected 32 MHz band.

LO-3.01.2.2 Number, width and placement of output bands

-01 It shall be possible to select sub-bands for further processing at will from the 100/80 MHz digitized bandwidth.

-02 Deleted

-03 It shall be possible to select the effective width of each of the output bands independently (either by selection or integration) up to 32 MHz, where the sum of the width of all bands shall not exceed 32 MHz.

(Why limit it to 8? This needs reformulating – it is not clear and depends on the mode. Also different for core and remote stations.)

-04 It shall be possible to position each of the one to eight output bands independently within the 32 MHz instantaneous bandwidth, but not necessarily with overlap between these bands.

(This needs reformulating – it is not clear and depends on the mode. Also different for core and remote stations.)

-05 The phase relations between the subbands and channels within a beam shall be known to such a level (TBD - filter coefficients, beamformer weights) that wider bands and corresponding time series can be reconstructed from subbands and/or channels.

LO-3.01.3 Spectral Resolution

-01 LOFAR shall offer a spectral resolution of at least 1 kHz (preferably less) in each polarization for science processing when the full 32 MHz is being used.

-02 LOFAR shall allow for spectral averaging both between beamforming and correlation and post-correlation.

-03 Signal fidelity and noise characteristics shall be assessed (criteria TBD) before spectral averaging.

(RFI 3.01.5.1 refer to that section?)

-04 LOFAR shall be able to trade spectral resolution for total bandwidth down to sub-band level and taking spectral averaging into account.

-05 The signal processing performed on each subband (producing the 1 kHz resolution elements) shall leave the relative phases of subbands and spectral channels intact or predictable.

LO-3.01.4 Spectral Dynamical Range

-01 LOFAR shall have a spectral dynamic range in final data-products that is not limited by continuously present RFI sources with a strength of up to 40 dB on top of the whitened integrated sky noise power in at least 32 MHz bandwith (continuous presence being defined as present for at least 80% of the time; this requirement implies that the signals of such sources are not clipped at any station).

(Action: 40 dB above needs to be discussed! (It comes from Boonstra's RFI strategy document))

-02 It shall be possible to reduce the spectral dynamic range after RFI mitigation or at the user's request. For phased array operation either bit truncation has to be avoided, or sufficient information must be available to reconstruct the ratio of noise standard deviation to quantization threshold.

(Comment: Little RFI mitigation at station level expected – scrap this requirement.)

(Questions: What is the effect on RFI mitigation techniques, including future developments. Also – do we get the available bandwidth back for science?)

LO-3.01.5 Frequency Agility

The DMT understands that switching in frequency and in beam (i.e. position on the sky) both have the same constraints.
We have discussed these matters with A.Gunst and are not happy with the proposed changes.

Description of desired situation:

Situation Before: Beam 1 (BW=B_1 MHz, Ra_1, Dec_1, Freq=f_1)
switch to
Situation After: Beam 1' (BW=B_* MHz, Ra_*, Dec_*, Freq=f_*).

1. Pre-programmed series of frequency and/or beam changes should be possible with short time interval (preferably less than a second – typically 0.1s):
Ra_1,Dec_1,f_1 and Ra_*,Dec_*,f_* are known ahead of time (minutes to hours before!). Beams 2, etc unchanged – so assume that B_1=B_*.

2. Response to trigger. Should be possible within the time available in the Transient Buffer (typically 1-3 seconds). Ra_*, Dec_* are unknown, but f_* lies in the same digitized frequency range as f_1 (no changes in A/D sample rate).
If necessary, resources may be withheld from situation before the switch e.g. B_* in bandwidth may be unused and may be "switched in" after the trigger has been received. Preferably though one of the existing beams B_1…B_N should be used to form the "new" beam.

3. New Observation. Here the whole range of beams/bandwidth are redistributed. The new Ra_1…N, Dec_1…N, f_1…N are in principle different from the old values. Switched like this

should be achievable on a timescale of 30-60 seconds.

-01 Changing the location of the frequency band of any of the output bands shall be possible in less than 1 second in case of scheduled switching sequences.

1 second=ok. See 3.01.5 above - Scenario 1

-02 Changing the location of the frequency band or any of the output bands shall be possible in less than 3 seconds in case of scheduled trigger response. The requirements needs to be met only in case the time between 2 successive triggers will be at least 1 minute.

See 3.01.5 above - Scenario 2

What is “a scheduled trigger response”.
3 seconds=not ok; 1 second=ok; where does 1 minute “statement” come from.
(1 second is the time covered by the buffer – so effective latency of 0 sec is achievable).
These changes do not require correlator reconfiguration.

-03 Changing the location of the frequency band or any of the output bands should be possible in less than 10 sec in case of changes due to manual interaction or schedule changes. The requirement needs to be met only in case the time between 2 successive manual interaction or scheduled changes will be at least 1 minute.

See 3.01.5 above - Scenario 3

Here correlator reconfiguration is possible. We would be interested in exploring whether “spare correlator capacity” can be set aside to cope with external triggers on a 1 sec timescale.

Otherwise:10 seconds=ok; where does 1 minute “statement” come from.

We will define observation modes, and would like to further discuss the “correlator flexibility” when those are available (including expected switching scenarios)

-04 The time specified to change the location of the frequency band or any of the subbands shall include the switching time between antenna elements and any delays introduced by the control functions.

LO-3.01.5.1 RFI avoidance and mitigation

Question: can we do RFI mitigation at remote station level. Answer: Yes limited.

-01 Deleted

-02 It shall be possible to constrain RFI mitigation functions such that time-series can be reconstructed after calibration of ionospheric phase fluctuations with TBD accuracy required for pulsar timing applications.

Action: Numbers to be provided by B. Stappers

-03 The applied RFI mitigation techniques shall be designed or configured to minimize the removal of periodic or aperiodic celestial signals.

Action: Numbers to be provided by B. Stappers

LO-3.01.5.2 Simultaneous use of more than one receiver

-01 LOFAR shall have sufficient digital signal paths to process either all low frequency or all high frequency antenna signals, but not both of them simultaneously.

-02 Simultaneous use of low frequency and high frequency antenna elements shall be possible by using groups of antenna elements (as defined in 3.01.2-2), some with only low frequency, others with only high frequency antenna elements.

Note: It will not be possible to simultaneously use an LBA and HBA antenna element that are connected to the same receiver path.

LO-3.01.6 Signal Path

Note TBW (SCB)

-01 The LOFAR signal path shall be linear within +/- TBD % for voltage and +/- TBD % for power i.e. non-linear devices such as Automatic Gain Controllers should not be present in the signal path.

Action: Numbers to be provided by ..

-02 Filtering of the subbands shall be such that the strength of an aliased interferer in the stopband (outside the transition band) shall be at least smaller than the astronomical source 'Cassiopeia A'. The neighbouring subband will be considered as transition band.

-03 Leakage between IF/baseband signals mixed down from different sky frequencies and transported to the central processor shall be less than TBD %.

Action: Numbers to be provided by ..

LO-3.02 Spatial Frequency Coverage

This section defines the required u,v coverage of LOFAR and has its major impact on the geometrical configuration of the stations within the array. Relevant issues are discussed in memo LOFAR-ASTRON-MEM-030, and are to be further investigated by simulations. The requirements in this section may be subject to changes in response to advances in understanding of calibration and imaging issues (and their cost impact).

LO-3.02.1 Angular Resolution

Note: DMT can come up with better statements. In principle the maximum achievable resolution is set by the maximum baseline, however to get acceptable images requires adequate filling of the uv-plane - and is therefore set by more detailed configuration issues. DMT discussion to follow.

-01 Deleted

-02 Deleted

-03 Deleted

LO-3.02.2 Short Spacings

-01 LOFAR shall provide interferometer data with a baseline of at most a few (TBD) wavelengths.

Action: Numbers to be provided by ..
Comment: Some short baselines may be formed from sub-stations in the Core.
Comment: Also look out for (core) beamformer complications

-02 The scale-free character of the areal distribution of LOFAR shall begin at a radius of no smaller than 250 meters. This ensures that the central core itself is significantly centrally condensed, and that a portion of the array exists with good sensitivity to very large scale structures.

Action: TBD with DMT

LO-3.02.3 Density and Uniformity of (u,v) Coverage

Action: TBD with DMT

In this subsection, the term "full coverage" refers to sufficient sampling of uv cells to meet the sidelobe level and sensitivity requirement stipulated in item -05. As such, it constitutes a requirement on a combination of completeness and uniformity. Such coverage must be achievable for at least 50% of the celestial sphere.

Comment: Outcome may be to refer to document with configuration guidelines

-01 Deleted

-02 Deleted

-03 Deleted

-04 Deleted

-05 Deleted

LO-3.02.4 Snapshot Capability

Action: TBD with DMT

-01 Deleted

LO-3.03 Sky Coverage

This section defines the required fraction of the sky to be visible instantaneously and during the year. The instantaneous sky coverage has impact on the antenna design and the multi-beaming capabilities. The accessible declination range is related to the antenna/station configuration and in particular to the latitude of the site. The requirements stated here are somewhat inconclusive, reflecting the variations in science requirements in this area.

LO-3.03.1 Celestial Sphere

-01 LOFAR shall be able to observe with good sensitivity for point sources (>50% from the sensitivity in the direction of the zenith) down to elevations of 30 degrees.

-02 The LOFAR LF antenna shall have an instantaneous FOV of > 1 steradian around any given position on the sky (with the restriction of 3.03.1-01).

Note: Requirement only for low band antenna. The high band antenna is optimized for sensitivity. Its instantaneous FOV follows from the element spacing.

LO-3.03.1.3 Overlap with Other Telescopes

-01 Deleted

LO-3.03.2 Galactic Plane

-01 Deleted

LO-3.04 Sensitivity and Surface Brightness

This section defines the required sensitivity of LOFAR. It has impact on the total number of antenna elements, their distribution over stations and their efficiency. Apart from the Science requirements, the top-level calibration requirements are an important source for this section. An attempt has been made to identify the driving requirements and deriving expected sensitivities from them. The sensitivity calculations used in this section (including the assumed sky noise characteristics) are given in LOFAR-ASTRON-MEM-053.

LO-3.04.1 Sensitivity

Deleted

-01 LOFAR shall be designed such that the sky noise dominates the antenna noise over 30 - 80 MHz and 120 - 240 MHz.

-02 LOFAR shall be calibratable for at least 50% (TBC) of time at all optimized frequencies.

-03 LOFAR's sensitivity shall be based on achieving the response of a fixed number of matched dual-polarization dipoles:
* 7700 LBA
* 7700 4 x 4 HBA tiles

Refer to table TBD

-04 The tied array beam former mode (see 3.09.1-03) shall consist of at least all core stations and as many further stations in the rings surrounding the core as possible.

LO-3.04.2 Surface Brightness

-01 Deleted

-02 Deleted

LO-3.05 Imaging Characteristics

This section contains requirements related to the instantaneous field of view, and the way it is sampled with station beams. This has impact on the antenna design, the station configuration and the specifications of beamforming subsystems.

LO-3.05.1 Instantaneous Field of View

-01 It shall be possible to image the entire Field of View of the primary antenna elements.

LO-3.05.2 Multibeaming

Multibeaming is a key property of the LOFAR architecture, needed to increase the operational efficiency and flexibility, to facilitate calibration and to allow all-sky monitoring applications. In the requirements below a "beam" refers to the general concept of an observed direction on the sky. Combined with the bandwidth and spectral resolution requirements, this implies a specification in terms of collections of quasi-monochromatic beams.

-01 LOFAR shall provide at least 164/205 independent beams per station.

-02 The available bandwidth per beam shall be at least 195/156 kHz

-03 Deleted

-04 It shall be possible to position each LOFAR beam (as described above) with sufficient flexibility such that any position above the horizon can be included in the main lobe of the beam (this allows the use of discrete spots in az & el that the beam can be centered on, as is currently proposed for the HF compound antenna).

-05 It shall be possible to track celestial objects on the sky during imaging and tied array observations (both sidereal tracking and tracking of objects in the solar system).

LO-3.05.3 Dynamic Range

-01 LOFAR shall be able to provide a dynamic range of at least 10^5 : 1 for continuum imaging (thermal noise imaging to classical (microJy) confusion limits).

-02 LOFAR shall allow integration of measurement data over extended periods of time:
a. TBD months over a frequency range from TBD MHz to TBD MHz
b. TBD months over a frequency range from TBD MHz to TBD MHz
c. TBD

LO-3.05.4 Sidelobe Level and Pattern

-01 Station sidelobes shall be sufficiently low or smooth to allow for a full calibration (to be worked out in more specific requirements).

LO-3.05.5 Subarraying

No specific requirements (some will follow from calibration requirements).

LO-3.05.6 Pointing accuracy

No specific requirements at system level, however: calibration requirements will have an impact on the subsystem requirements (e.g. stability and quantization of RF beamformer for the high frequency antenna element)

LO-3.05.7 Beam-Switching Agility

These elements have already been mentioned in 3.01.5. Same comments apply.

-01 Changing the direction of the beam shall be possible in less than 1 second in case of scheduled switching sequences.

-02 Changing the direction of the beam shall be possible in less than 3 seconds in case of scheduled trigger response. The requirement needs to be only met in case the time between successive triggers will be at least 1 minute.

-03 Changing the direction of the beam shall be possible in less than 10 sec in case of changes due to manual interaction or changes in schedule. The requirement needs to be only met in case the time between 2 successive manual interaction or changes in schedule will be at least 1 minute

-04 Observation data (specify: both uv-data and tied array beams) acquired during a change of beam direction shall be flagged.

LO-3.06 Temporal Characteristics

This section contains requirements related to time-sampling and time-series processing. Given the LOFAR architecture, time resolution should be related to a specific observational mode. Generally speaking the need to remove ionospheric phase fluctuations (also in full phased-array operations) will set limits on timing accuracy.

LO-3.06.1 Sampling

-01 LOFAR shall provide Post-correlation (uv-data): 1 msec for 1 kHz channels (for normal imaging integration to ~1 sec will be standard procedure).

It will not be possible to get the raw data (1 ms, 1kHz) out of BG – this will set the output possibilities; can reduce the number of output baselines though!

Question: Maximum sub band resolution (195/156 kHz). Can we average >1 sub-band before correlation? Time resolution always 1/bandwidth.

-02 In tied array mode, the phase relationships between the 1 kHz channels shall be preserved to a sufficient degree to allow reconstruction of wider bands (up to the full 32 MHz for the VC) and enabling timeseries to be provided with time resolution corresponding to the inverse of these wider bands.

LO-3.06.2 Latency

No specific requirements

All essential requirements can be found in beam and frequency switching See 3.01.5 - 1

LO-3.07 Polarization Characteristics

-01 Polarization properties (alignment, gain, etc…) of dipoles should be sufficient to yield (sub)station beams with coherence loss of less than 2% (100 dipoles).

Comment: We assume that individual dipoles within a station are not perfectly aligned, but that calibration of station dipole characteristics are sufficient and stable enough to meet the above requirement for all times.

-02 The polarization properties of the station beams should be stable enough to allow their calibration to better than 0.5% with external calibration measurements no more than once per 10 minutes.

(This is based on achieving 10-4 relative polarization accuracy from 77 stations and 5 hours of data.)

-03 LOFAR shall provide visibility data in all four Stokes parameters.

LO-3.08 Monitoring and Control function

LO-3.08.1 Top-level requirements

The upper limit for the number of observations is not related to the maximum number of beams. There can be many more independent observations. An extreme example would be if all stations were to execute a different observation (no synthesis imaging, may be even no beamforming at the stations but independent timeseries processing)

-01 LOFAR shall provide a single distributed monitoring and control function.

-02 The monitoring and control function shall ensure that all parts of the system work together coherently.

-03 The monitoring and control function shall exclude control dependencies that are not necessary from a functional point of view; in particular remote stations should be capable of autonomous operation for periods of at least an hour.

-04 The monitoring and control function shall ensure that failures in hardware, software or signal transport are detected.

-05 The monitoring and control function shall take autonomous action to compensate for failures where possible.

-06 The monitoring and control function shall give users transparent and hierarchical access to the instruments functions and parameters.

-07 The monitoring and control function shall provide layers of security and access control.

-08 The monitoring and control function shall be designed to operate the instrument fully remotely, with options to grant full access to part of the instrument (incl. central processor) to sufficiently qualified users.

-09 The monitoring and control function shall provide a subfunction that will calculate and report performance monitoring data to users.

-10 All LOFAR subsystems shall provide monitoring data to the monitoring and control function (for performance monitoring and closed-loop control functions)

-11 The monitoring and control function shall provide for a long-term logging subfunction with workflow support for the Operational Team and with sufficient information to relate system events to artefacts in the data.

-12 It shall be possible to monitor and control the execution of multiple observations in parallel.

-13 In case of failure of the principal monitoring and control network, those functions required to analyze the network failure and recover from the failure, shall continue to work using an alternative communication path.

-14 It shall be possible to change the value of parameters during the acquisition provided these parameters do not have impact on the required acquisition or processing resources (e.g. changing beamdirections shall be possible, changing the number of beams shall not be possible).

-15 The monitoring and control function shall provide statistical information (on what timescales and in how many directions) on the RFI environment, weather conditions and ionospheric behavior to other system functions (in particular to the specification and scheduling function).

-16 It shall be possible to abort an observation if monitor parameters exceed user specified limits (including RFI mitigation performance indication parameters).

-17 It shall be possible to control RFI mitigation processes in which multiple stations have to cooperate or in which stations and the central site have to cooperate.

-18 The monitoring and control function shall provide the communication, storage and processing resources required for the station level RFI mitigation processes.

-19 The monitoring and control function shall provide sufficient information on the digitization thresholds and offsets for all systems (TBD) to enable reconstruction of the noise characteristics.

-20 On the fly calibration information shall be available to the monitoring and control function.

LO-3.08.2 Control requirements

Requirements regarding control of the instrument (configuration of beamforming, correlation etc)

-01 LOFAR shall have a control system that actively controls all system settings in the instrument.

-02 The control system shall be capable of autonomously calculating system settings in response to changes in instrument status, environment or measurement results.

-03 It shall be possible to activate the calculated system settings either automatically (autonomous control) or after explicit confirmation by the operator (manual control).

-04 It shall be possible to specify when settings should be activated automatically and when they need to be confirmed by the operator.

-05 It shall be possible to synchronize all timing reference equipment of stations cooperating for an observation.

-06 It shall be possible to control the flow of measurement data in the data transport network.

-07 The control system shall manage the allocation of system resources (acquisition, processing, storage e.g. to avoid conflicts between simultaneous observations).

-08 It shall be possible to receive and accept updated schedules before the end-time of the currently active schedule has expired.

-09 The control system shall provide a hierarchical view on the physical system.

-10 The control system shall provide a hierarchical view on designated logical control concepts, like observational modes, beams, subbands.

LO-3.08.3 Monitoring requirements

Requirements regarding monitoring the status of the instrument (configuration and health)

-01 It shall be possible to consolidate monitoring information to produce high-level monitoring information from low-level monitoring information.

-02 Subsystems shall report completion of actions to MAC

-03 It shall be possible for all user roles to produce summarized historical monitoring information.

-04 The measurement data flow shall be augmented with the result of control decisions that have influenced the data flow at the position in the data stream where the control decision comes into effect.

-05 It shall be possible to consolidate monitoring information both on the physical instrument status and on designated logical concepts like observation, correlator.

LO-3.09 Data Acquisition Characteristics

This section describes the functions in the acquisition and initial processing path. This includes the definition of observation modes (synthesis imaging, tied array, pulsar detection) and of intermediate and final dataproducts. Also the functional and performance requirements for RFI mitigation, the data transport network and some derived performance parameters for data handling are listed here.

LO-3.09.1 Observational Modes

This section identifies the top-level observational modes.

-01 LOFAR shall provide a synthesis imaging mode where station beams are correlated to form visibilities, including real-time correction of ionospheric and instrumental effects to allow for integration bins as long as 1s and as wide as 200kHz.

-02 In synthesis imaging mode it shall be possible to form visibilities between all corresponding monochromatic beams (same frequency, same direction) from all stations (Remote Stations and stations in the Virtual Core). This means that the central processing function should be able to handle the full data stream from the Remote Stations in synthesis imaging mode.

-03 LOFAR shall provide a full phased array mode where the signals from all stations within 50 km of the core are phased up, after real-time correction of ionospheric and instrumental effects, and transformed back into time series for pulsar processing.

-04 LOFAR shall provide a Virtual Core synthesis imaging mode where visibilities are formed from all stations in the Virtual Core, where the product of the number of beams and the data rate per beam is at least 256 Gbit/s.
Which combinations of the number of beams and the data rate per beam are possible remains TBD.

Comment: two requirements i.e. one on total data rate and another on configuration of core correlations

-05 LOFAR shall provide a Event Processing mode where buffered data can be processed after internal or external triggers.

-06 LOFAR shall provide ionospheric and instrumental real-time calibration functions in all observational modes.

-07 It shall be possible for the scientist to access the results of each post processing cycle (TBD).

-08 It shall be possible to re-process data retrieved from archive.

-09 LOFAR shall offer a mode in which indivdual dipole complex gains can be calibrated. The effective duration of such a calibration cycle should not exceed 5% of the available observing time.

LO-3.09.2 Data Products

-01 LOFAR shall produce final dataproducts based on automated and interactive processing of acquired data.

-02 Final dataproducts shall include parameterized sky models (including the Global Sky Model), residual and restored images (including combined wide field images), event lists and statistics, de-dispersed pulsar data.

-03 LOFAR shall produce intermediate dataproducts, including integrated visibilities, pulsar voltage timeseries, ionospheric data and RFI statistics.

-04 Intermediate dataproducts shall be made available directly to users primarily through a preview function; they will be available for export to the extent that the normal export mechanisms allow.

-05 Archived and exported data products shall be fully selfcontained: Including meta data describing or identifying the original specification and the details (specify) of the acquisition, RFI mitigation, calibration and imaging process. This also includes the instrumental configuration, software versions and auxiliary data. (time stamps and central configuration management archive)

-06 Product metadata shall identify ownership and distribution rights.

-07 LOFAR shall produce, update and maintain a Global Sky Model according to the description provided in TBD.

-08 It shall be possible to refine the Global Sky Model in a controlled way using results from observations.

-09 Deleted

LO-3.09.3 RFI Management

-01 LOFAR shall detect and suppress any RFI signals in real-time and with high resolution (ms, kHz) to the level that is needed for proper calibration in imaging applications. This implies that RFI sources should be either completely removed (by e.g. blanking spectral channels) or that their location and strength should be known sufficiently to account for them in selfcalibration.

-02 LOFAR shall have spatial RFI mitigation functions at station level.

-03 All RFI mitigation functions can be switched off at any time (active or for whole% observation/session) during an observation.

LO-3.09.3.1 Self-generated RFI environment

The standards referred to below essentially specify that the effect of self-generated RFI shall be negligible compared to external RFI sources; for subsystems close to the antenna the EMC requirements are very strict and specific, for other areas like the Central Processor industrial EMC standards are applicable.

-01 All LOFAR hardware, including test equipment, shall be compliant with the LOFAR EMC standard AD. TBD.

LO-3.09.4 Data Transport function

This section specifies top level data transport requirements, covering both the main data flow and the transport of control and monitoring information.

-01 LOFAR shall provide for transport of measurement data, monitoring data and control data.

-02 LOFAR shall provide for transport of data from all Remote Stations to the Central Processor.

-03 LOFAR shall provide for transport of data from the Virtual Core (substations) to the Central Processing facilities.

-04 LOFAR shall be capable of transporting data autonomously (this implies that the data transport network shall be able to operate independently of other subsystems).

-05 The data transport network shall incorporate its own autonomous network management and control system.

-06 The data transport shall be protected against any environmental influences as specified in section 5.01.

-07 The data transport network shall incorporate the ability to detect and identify failing network equipment (hardware and software).

-08 The data transport shall be protected against (mechanical) damages caused by inadvertent human or animal activities.

-09 The data transport network shall be protected against unauthorized use.

-10 The data transport shall not be interrupted or corrupted during maintenance activities, related to the data transport.

-11 LOFAR shall be able to transport all monitor and control data between the LOFAR subsystems that it connects.

-12 LOFAR shall provide for a redundant (back-up) network to transport all control data and consolidated monitor data between the LOFAR central processor (CEP) and the remote and virtual core stations.

-13 The monitoring and control data shall be transported via single full duplex network.

-14 The data transport network connecting the LOFAR stations to the central processing facility shall be deployed according to the regulations applicable to general datanetworks.

-15 It shall be possible to reuse the LOFAR data transport network for other purposes after the lifetime of LOFAR.

-16 The data transport network shall preserve the time ordering of each input data flow (this implies that all output data from a station keeps the correct relative time order).

LO-3.09.5 Detailed data handling requirements

This section contains several high level requirements regarding the data flow and temporary storage in the instrument.

-01 LOFAR shall provide sufficient processing and storage functions to handle the data flow from the Remote Stations and the Virtual Core and to transform it in the specified data products.

-02 LOFAR shall provide storage capacity to keep intermediate data products of normal synthesis observations (1 sec and 1 kHz resolution, 32 MHz processed bandwidth and 77 stations) available for a limited period of time (at least 7 days = approx. 1 PetaByte).

-03 LOFAR shall be able to buffer data from Remote Station in order to correct for the arrival time difference due to the geographical positions of the Remote Stations and the Virtual Core substations, and to any delays introduced by data processing and transport equipment.

-04 LOFAR shall provide for random read access to (intermediate) data products stored for intermediate periods.

-05 LOFAR shall provide for processing capacity for analysis of the data during processing.

-06 LOFAR shall be capable of concurrent read and write access to (intermediate) data products stored for intermediate periods.

-07 LOFAR shall provide for processing capacity for data (flow) processing tasks.

-08 LOFAR shall contain processing capacity for the generation of final data products.

-09 LOFAR shall contain storage capacity for temporal storage of final data products.

-10 LOFAR shall be able to export final data products.

-11 LOFAR shall be able to export final data products via remote access.

-12 LOFAR shall provide for a resource model (as input for the monitoring and control process) including on-line information on:
- storage capacity
- input bandwidth

- data routing bandwidth
- processing capacity
- analysis capacity

-13 LOFAR shall provide processing capacity for monitoring and control processes.

-14 LOFAR shall provide for access to (intermediate) data products.

-15 LOFAR shall make the (intermediate) data products available for inspection by the user (scientist).

-16 LOFAR shall provide processing capacity for data access and visualization tasks.

-17 Deleted

-18 It shall be possible to perform pulsar observation analysis applications.

-19 It shall be possible to analyze processed data after completion of the observation.

-20 It shall be possible to process incoming data streams in real-time.

-21 It shall be possible to start analysis of processed data during the observation.

-22 LOFAR shall be able to synchronize incoming data streams.

-23 It shall be possible to perform the processing tasks as listed in the previous requirements simultaneously.

-24 LOFAR shall have an on-line storage of system models.

Note: global sky model, instrument model (for calibration), RFI model.

LO-3.10 Calibration and Post-Acquisition Processing

This section contains the top level Calibration requirements.

-01 LOFAR shall be capable to perform the on-line or off-line calibration and processing required to generate data products as specified in section 3.9.2.

-02 LOFAR shall be able to reduce the volume of the (raw) observation data by means of calibration such that it is compatible with the available processing capacity.

-03 For imaging applications the LOFAR calibration function shall be capable of correcting phase fluctuations to the accuracy of < 0.1 rad based on available bright calibration sources (Cat. I, as defined in RD. 3).

-04 LOFAR shall be designed to estimate the instrumental responses in the direction of the Cat I sources continuously in all observing modes.

-05 LOFAR shall be capable of performing on-line selfcalibration in order to extend the integration time of acquired data to get sufficient SNR per visibility for further processing (this integration time is specified in 3.9.1-01 as 1 sec).

-06 LOFAR shall be designed to characterize the ionosphere for each beam direction in each remote station, both in synthesis imaging and in full phased array mode.

-07 Inspection of intermediate calibration results shall be available to the investigator or science center for whom the observations were performed.

-08 Each LOFAR station shall be able to acquire at least the following environmental data at 10 sec (TBC) intervals:
a) Air temperature at several places in the antenna field and inside the housing of station electronics, with 1 K accuracy
b) Relative humidity inside and outside the housing of station electronics, with 10 % accuracy
c) Wind velocity and direction, with 1m/s and 5 deg accuracy
d) Lightning information, using general purpose lightning detectors

e) Rain and snow conditions, including wetness of the ground

LO-3.11 Archiving and Dissemination

LO-3.11.1 Archiving

-01 LOFAR shall provide both short-term and long-term storage of intermediate and final dataproducts.

-02 Intermediate dataproducts that can be further processed based on user input shall be kept available on short-term storage for a period of one week (TBD: the selection of dataproducts to which this requirement applies needs to be defined more precisely).

-03 Only final dataproducts shall be kept on long-term storage.

-04 LOFAR shall provide a quick-look function to allow users to assess the quality of intermediate dataproducts over general communication networks.

-05 LOFAR shall provide a catalog of all data products.

-06 The data product catalogue shall contain information on the quality and usability of the observation's results.

-07 Deleted

-08 Deleted

-09 The archive shall keep data for the lifetime (TBC) of the instrument.

-10 The archive shall be set up such that the chance of data loss is less than TBD

LO-3.11.2 Export

-01 It shall be possible to deliver final data products to scientists on digital storage media.

-02 It shall be possible to deliver final data products to scientists over computer networks.

-03 It shall be possible to retrieve observation data from the archive by searching on parameters in the product metadata.

LO-3.11.3 Data grid and Virtual Observatory

This section describes how LOFAR relates to the Grid and Virtual Observatory projects.

-01 It shall be possible to access LOFAR data-products through middleware developed within the international Grid community (typically the Globus toolkit).

-02 It shall be possible to merge designated LOFAR dataproducts (TBD, in particular the Global Sky Model) in distributed databases.

-03 The data product catalog shall be accessible using Virtual Observatory middleware.

LO-3.12 Specification and Scheduling function

Responses to triggers are not always fully pre-defined. In particular the position on the sky is often a crucial part of the trigger information that is received (i.e. for a really important event one

cannot prepare a beam in the direction of the trigger)

-01 LOFAR shall provide a specification function allowing users to initiate observation requests, to detail such requests and to check the status of these requests.

-02 The specification function shall be responsible for the translation of astronomical specification into instrumental settings and configurations (e.g. from a required sky coverage to a collection of beams with certain properties).

-03 The specification function shall provide optimized entry functions for the observational modes listed in 3.09.1.

-04 LOFAR shall provide a scheduling function allowing staff at Scientific Exploration Centers and members of the Operational Team to create an integrated instrument schedule based on specified observation requests and maintenance requirements.

-05 The scheduling function shall provide assistance in the scheduling process by suggesting computer generated schedules, allowing user interaction.

-06 The scheduling function shall be capable to dynamically change the schedule in case active observations are aborted by the monitoring and control function and in case external triggers with sufficient priority (e.g. gamma ray bursts) demand a change in the schedule.

LO-3.12.1 Observation Specification

Requirements regarding the specification of an observation (general and reference cases) are stated in this section. The process starts with an observation request generated by a scientist user. The detailed procedure will be defined in the LOFAR Operations Plan.

-01 LOFAR shall be able to receive observation requests submitted by scientists.

-02 It shall be possible to request post processing of archived data products

-03 It shall be possible to request archiving and export of data products

-04 LOFAR shall be able to evaluate observation requests received from scientists on their technical feasibility.

-05 All requests that require significant LOFAR resources (both for acquisition and for processing of archived data) shall be subject to approval by a scientific review board [TBD].

-06 The approved observation request shall be available TBD days/hrs prior to the observation execution time.

-07 It shall be possible to derive an observation schedule from the information contained in an approved observation request.

-08 The observation request shall be specified such that no human interaction is required during execution of the observation.

-09 LOFAR shall maintain a record containing all specified observations with all observational requirements.

-10 LOFAR shall include the administrative process of handling observation requests, including approval, rejection and status reporting.

-11 It shall be possible for scientists to provide supporting and specifying information with their request.

-12 It shall be possible to specify parameter values in terms that are generally accepted in the user community (note: must be specified in more detail). This includes common units, time and date information and co-ordinate systems.

-13 It shall be possible to specify maintenance activities to be included in the LOFAR observation schedule.

-14 It shall be possible to specify preventive maintenance activities at regular intervals including health checks.

-15 It shall be possible to specify corrective maintenance activities (repairs).

-16 It shall be possible to specify observations ('triggered observations') that depend on an internal or external trigger.

-17 It shall be possible to specify a fixed period in time for an observation (e.g. for synchronization with other telescopes).

-18 It shall be possible to specify criteria that determine when an observation should stop.

-19 It shall be possible to specify, as one observation, measurements of a sequence of observation targets.

-20 LOFAR shall be able to check and consequently to notify the user that a requested observation has been performed at an earlier point in time.

-21 LOFAR shall provide a database containing reference information of scientific users and observation proposal reviewers.

LO-3.12.2 Observation Scheduling

Requirements regarding the specification of an observation schedule and timeline (general and reference cases) are stated in this section. The schedule will consist of approved observations, corrective and preventive maintenance activities.

-01 It shall be possible to create a consistent schedule of multiple simultaneous observations and maintenance activities.

-02 It shall be possible to create a consistent schedule of only observations or only maintenance activities.

-03 The LOFAR schedule shall only contain approved observations and approved maintenance activities.

-04 LOFAR shall be controlled on basis of the generated schedule.

-05 It shall be possible to create a schedule report that shows the available remaining capacity of the instrument over a period of at least 6 months (in order to support the approval process).

-06 All generated schedules shall be compliant with the constraints of observations and maintenance.

-07 The scheduling process shall take preferences of observations and maintenance into account.

-08 All generated schedules shall be compliant with the availability of resources.

-09 It shall be possible for the operator to modify any schedule.

-10 It shall be possible to generate an operational schedule (i.e. a schedule that is to be transferred to the monitoring and control function for execution) for a period of at least 2 weeks.

-11 It shall be possible to inform a scientist automatically about when his/her observation is scheduled.

-12 It shall be possible to reschedule observations that have been interrupted.

-13 It shall be possible to schedule a remaining part of an observation if it has been interrupted, but only if it is suitable to split an observation.

-14 It shall be possible to reschedule observations that have not been completed

-15 It shall be possible to schedule observations that will be started through a pre-defined event (trigger). The occurrence of such an event should lead to the activation of a well defined alternative schedule (a so-called "priority" or "stand-by" schedule).

-16 It shall be possible to schedule re-processing of archived data.

-17 It shall be possible to schedule post processing jobs on request.

-18 It shall be possible to schedule archiving and export of data products.

-19 The scheduling function shall generate consistent (lower level) schedules for both data flow processing and dataset processing on the central processing system.

LO-3.13 Non-Astronomical Applications General requirements

This section contains specific requirements for the geophysical and agricultural applications that will be embedded in the LOFAR system and remote stations. These applications will be referred to as Non-Astronomical Applications (NAA) in this and the following sections.

-01 The NAA shall not compromise the functionality of the astronomical application.

-02 The location of the NAA sensors and associated equipment on each LOFAR site shall be agreed with LOFAR.

-04 The authorization to access any LOFAR site shall be agreed between LOFAR management and the NAA responsible key-person.

-05 The configuration of the equipment to be installed on each site (outside, in the soil or inside the equipment shelter) shall be described in detail and provided to the LOFAR project management for approval.

-06 The sensor installation on site shall be performed in line with the LOFAR schedule. (Usually before the installation of the LOFAR antennas).

Note: Antennas and cable ducts may be damaged by heavy equipment that will be used to prepare the site and to install sensors and equipment shelter etcetera.

-07 All NAA equipment, except sensors and associated cabling, shall be accommodated in the on-site LOFAR equipment shelter.

Note: To allow control of any radiation that may disturb the astronomical application.

LO-3.13.1 Platform related requirements

This section provides requirements to NAA dedicated software running on LOFAR platforms either on Remote Station sites or as part of the Central Systems software.

-01 NAA dedicated SW, which will run on LOFAR common platforms, shall not compromise any other application running on the same platform.

-02 NAA SW shall be designed as self-supporting modules with well described interfaces that may be using common drivers and resources as agreed with LOFAR.

-03 The priority of running NAA SW shall be agreed with LOFAR, but shall never be higher than the astronomical application SW.

-04 All NAA equipment and SW shall be provided with a user manual.

-05 The NAA SW shall be dedicated for the purpose of: I
* preprocessing of sensor data
* compression and packaging of sensor data
* managing the interface to LCU and WA

LO-3.13.2 NAA Sensor Data Transfer and Storage

All NAA data that has been temporarily stored in the LOFAR facilities will be safe up to the agreed maximum storage time, also in case of power failures.

-01 The NAA data shall be transferred via the WAN to the Central Systems storage area. The volume and data rate shall be mutually agreed between NAA and LOFAR.

-02 LOFAR shall grant access rights to the NAA data storage area.

-03 The size of the NAA data storage area shall be mutually agreed between NAA and LOFAR.

-04 The NAA shall retrieve the stored data within 48 hours (TBC) after which it will be overwritten by fresh NAA data.

Note: The temporary storage will preserve NAA data as long as 48 hours (TBC), except in cases of force majeure e.g. fire or other catastrophes, where this period cannot be guaranteed.

LO-3.13.3 NAA specific functions

-01 The NAA equipment design including fit and form factor shall conform to the LOFAR design conventions and constraints as stipulated in section 5 of this specification.

-02 In case sensors can not be replaced without major disturbance of the site (by heavy equipment etc) sufficient redundant sensors shall be taken in to account conform the estimated reliability factor.

LO-4 Operational Requirements

LO-4.01 General

This section states general operational requirements. These are currently justified on the general requirements in Chapter 2.

-01 The LOFAR operational model shall take into account the following user roles (as defined in RD. TBD):
- Operator (member of the Operational Team)
- Engineer (member of the Operational Team)
- Staff (staff scientist, member of a Scientific Exploration Center)
- Scientist (member of the broader user community)
- Visitor

-02 LOFAR shall be aimed to be operated all-around-the clock (7 days per week 24 hours per day). This is stipulated by a number of requirements in this specification.

-03 LOFAR shall have a single, well-defined operational control center offering full control over all functions.

-04 LOFAR shall have multiple Scientific Exploration Centers offering full control over end-user functions of the instrument specified in TBD.

-05 LOFAR shall allow individual users access to designated functions (in TBD) through public communication infrastructure, in particular for the specification of measurements, the monitoring

of progress of observations and the inspection of measured/processed data.

-06 It shall be possible for the operator to control and monitor the LOFAR instrument for the operator role capabilities from the operational center.

-07 It shall be possible for the Engineer to control and monitor the LOFAR instrument for the engineer role capabilities from the operational center.

-08 It shall be possible for the Operator to control and monitor the LOFAR instrument for the operator role capabilities from all the LOFAR station sites.

-09 It shall be possible for the Engineer to control and monitor the LOFAR instrument for the engineer role capabilities from all the LOFAR station sites.

-10 It shall be possible for all users (Operator, Engineer, Staff and Scientist) to control and monitor the LOFAR instrument for their specific role capabilities from anywhere on the internet.

-11 It shall be possible to specify on a per user basis which facilities and resources may be accessed by the user.

-12 The system shall provide security to prevent unauthorized physical access to facilities and resources.

LO-4.02 Routine operations

This section gives system level requirements for the routine operations of LOFAR.

-01 For routine operations LOFAR shall be operated based on committed schedules, including both science and maintenance tasks.

-02 Schedules shall be established based on pre-specified science measurements and maintenance requirements.

-03 LOFAR shall register all specified, active, completed and failed measurements.

-04 LOFAR shall maintain a register with required maintenance, filled either manually by operators and engineers or automatically by the monitoring and control function.

-05 Routine operations shall only require user or operator intervention when system functions fail. (LOFAR shall be able to operate unattended during routine operations.)

-06 The amount of operator or user-interaction required during failures shall be kept low (balancing the cost of a larger operational team against the cost of a more complex monitoring and control function).

-07 Reconfiguration of LOFAR from one observational mode to another shall not take longer than 1 minute provided all software applications are present at their designated location.

-08 LOFAR shall provide a uniform hierarchical view of hardware and software components in the instrument for monitoring and control purposes.

-09 LOFAR shall provide for an extendible collection of abstract monitoring views of the instrument.

-10 It shall be possible for the operator to configure and initialize all LOFAR instrument resources.

-11 Routine operations shall include the specification and handling of observations that have predefined start conditions (e.g. an external trigger) rather than a predefined start time.

LO-4.03 Non-routine operations

This section gives system level requirements for non-routine operations of LOFAR

-01 It shall be possible to abort running observations.

-02 When an observation is aborted, any data from that observation that has been sent to the central processing facility shall not be lost.

-03 It shall be possible to abort an observation without affecting other observations, including those that are running simultaneously with the observation to be aborted.

-04 The malfunctioning of antennas or stations shall not affect routine operations unless the effect on the acquired data exceeds previously specified criteria.

-05 It shall be possible to instruct the LOFAR monitoring and control function to shift to a defined override schedule (typically to follow-up on transient events).

-06 It shall be possible to initiate system tests from the operator interface.

-07 It shall be possible to report asynchronous monitoring events (alerts) for example to alert the operator that a hardware or software failure has occurred.

LO-4.04 Start-up and shutdown

This section gives system level requirements for LOFAR start-up and shutdown, including check-out at initialization.

-01 It shall be possible to control all LOFAR functions from the operational center, without requiring physical access to the remote stations including start-up and shut down.

-02 The start-up of LOFAR functions shall follow a pre-defined sequence taking not longer than:
* 10 minutes for a hot start (= restart)
* 24 hours for a cold start

-03 It shall be possible to start-up or shutdown individual stations without disturbance [TBC] of routine operations.

-04 The shutdown of LOFAR shall follow a pre-defined sequence taking not longer than TBD minutes.

-05 It shall be possible to shutdown and start-up a station locally i.e. at the station location.

-06 Initialization of shut-down and start-up sequences shall be restricted to operators and engineers.

-07 Any dependencies in the start-up and shutdown sequences shall be automatically verified (so they do not depend on operator intervention).

-08 The shutdown of pre-defined parts of the LOFAR system shall have no [TBC] impact on LOFAR operations.

-09 LOFAR shall be designed to enable an operational readiness check, including redundancies, prior to commencement of any LOFAR operations (initial check-out).

-10 The operational readiness check shall not take longer to complete than 5 minutes.

LO-4.05 Non-Astronomical Applications specific operational requirements

-01 Start-up and shutdown shall be possible without operator assistance. I

Note: Assuming the main power to the NAA is switched to ON.

-02 NAA start-up and shutdown shall not depend on the status of other LOFAR equipment (except main power).

-03 NAA data acquisition and processing shall start autonomously after start-up (or after a remote command from LOFAR operations via MAC)

-04 The NAA equipment shall be able to return to MAC the result of health checks in case these are started under MAC control. (TBC)

-05 The results of the health check will not be interpreted by MAC, but this shall be the responsibility of the NAA operator unless agreed otherwise. (TBC)

-06 Operational performance of the NAA shall be the responsibility of the NAA supplier within the constraints set by this document.

-07 Operations or control intended to be performed with NAA data or equipment shall be requested via the LOFAR operations control centre.

-08 It shall be possible for LOFAR operators to shutdown NAA equipment (locally or remote) in case of emergency without previous contact to the NAA supplier. LOFAR operations shall inform the NAA responsible or key-person in case of such events.

-09 Operator intervention shall be restricted to maintenance only.

-10 Maintenance of NAA equipment shall be planned and agreed in line with the LOFAR maintenance schedule.

LO-4.06 Deleted

sections 4.06 through 4.10 deleted, most requirements moved to section 3

LO-4.11 Failure management

LO-4.11.1 General

General requirements regarding failure management

-01 No single failure in LOFAR shall lead to personnel safety hazards.

-02 Deleted

-03 Failures in one of the LOFAR subsystems shall not lead to failures in other subsystems.

-04 No single operator command shall cause catastrophic, serious, or major consequences. (Refer to RD.2 "Glossary" for meaning of Failure severity)

-05 No voltage-transients or "cut-off" of electrical power shall lead to catastrophic or serious consequences. (Refer to RD.2 "Glossary" for meaning of Failure severity)

-06 The absence of operator commands shall not cause catastrophic or serious consequences. (Refer to RD.2 "Glossary" for meaning of Failure severity)

-07 Single-point-failures in the design shall be listed.

-08 Each-single-point failure in the design shall be justified, and assessed against alternative design(s) where this single-point-failure would not occur.

-09 The correct functioning of each single-point-failure in the design shall be monitored by a watch-dog function.

-10 LOFAR shall be constructed in such a way that safety hazards are avoided.

-11 Failing equipment shall not provide data. (observ. Data, monitoring data?) Failing equipment shall indicate the problem if power is on, and the control function shall take appropriate measures.

LO-4.11.2 Detection and reporting

Requirements regarding failure detecting equipment and how failures are to be reported including level of detection

-01 Each subsystem shall have the capability to examine the correct execution of its functions, without any support from other subsystems.

-02 Each subsystem shall have the capability to examine the correct execution of its performance; functions of other subsystems may be used in these.

-03 Each subsystem shall have the capability to respond with a subsystem status report, to an operator request for determination of its correct functioning.

-04 The status report of the functioning of a subsystem shall be available in 5 seconds.

-05 The status report of a subsystem shall reflect the functioning of the subsystem at or after the operator request has been submitted to the system.

-06 The status report shall display the status of a function, together with the system time the status was determined.

-07 It shall be possible to recognize the following failure types:
a) negligible
b) minor
c) major
d) serious
e) catastrophic

LO-4.11.3 Diagnosis and recovery

Requirements regarding distinguishing of failures how failures are to be recovered

-01 Each station shall have the capability to answer to an operator interrogation, in case of detected failures at the station, what antenna chain fails, what the failure is, and in what piece of equipment the failure takes place.

-02 Each station shall have the capability to switch-off each individual antenna chain connected to it.

-03 The system shall have the capability to be operated by an operator in an autonomous mode, and in a manual control mode.

-04 In the autonomous mode, all malfunctioning equipment and/or stations shall be switched off autonomously, and a message with all details of this action shall be brought to the attention of the operator, and recorded in the systems log-file.

-05 In the manual control mode, the operator shall have the capability to switch on or off all equipment and/or stations as he wishes to do.

-06 Operator actions shall be recorded in the systems log-file, in such a way that a complete picture of all correct functioning and/or all malfunctioning equipment, together with their operational and/or switch off statuses, can be achieved.

-07 It shall be possible to take recovery actions without consequences for other parts of LOFAR; the system shall minimize impact of recovery actions.

-08 LOFAR shall be able to recover autonomously in case of failures that are classified as minor or negligible.

-09 The LOFAR design shall ensure that disabled units do not corrupt the remaining system.

LO-4.12 Deleted

Requirements of 4.12 moved to section 3.

LO-4.13 Delet

LO-4.14 Lifetime

Operational lifetime requirements, including spare parts and supporting equipment

-01 Deleted

-02 LOFAR shall be designed for a continuous operational period of 3 month. (after this time maintenance will be necessary e.g. exchange/cleaning of filters, airco)

-03 LOFAR shall be designed for a minimum life time of 10 years, including initial installation, testing and commissioning period.

-04 The average availability of LOFAR during the operational period shall be better than 90%. Availability is defined here as being available for scheduled observations in at least one of the supported operational modes.

-05 Large scale maintenance and/or an upgrade shall give the possibility to reach a life time of 20 years.

-06 The NAA shall be designed for a continuous operational period of 10 years; in particular the geo sensors, which can not be replaced without major disturbance of the site

-07 The NAA shall be designed with an average failure rate less then 1% per year over its operational lifetime.

LO-4.15 Maintenance

Requirements regarding maintenance concept, corrective and preventive

-01 LOFAR shall be designed to fully fail less than two times per year, the number determined as average over its operational period of 10 years.

Note: Full failure is defined here as not being able to operate in any observational mode for more than two hours due to malfunctioning of one or more subsystems. The requirement applies to the period after initial commissioning of the system or any upgraded components.

-02 The maximum period of repair once a failure of LOFAR has been established, shall be 1 [TBC] week.

-03 All users with scheduled measurements during the failure period shall be informed of the non-availability of the system

-04 All users of LOFAR shall be notified of all regular future maintenance periods

-05 All subsystems shall not loose more than 4 hours of acquired or processed measurement data (not yet permanently stored) as a result of an outage in the external power supply.

-06 All subsystems shall have the capability to restart autonomously and without failures, after an outage in the external power supply.

-07 All subsystems shall be available within 300 seconds after restart

-08 All software/firmware in LOFAR shall allow its re-installation by an engineer.

-09 It shall be possible to replace all software/firmware configuration items in LOFAR through software-upgrades, initiated by an engineer.

-10 Each software configuration items shall provide its full identification on operator request.

-11 The software identification shall be available to the operator within 10 seconds after the request was made.

-12 Each subsystem shall list its hardware items that shall be replaceable.

-13 All hardware items that have been identified as replaceable shall be "hot replaceable".

-14 All subsystems shall include functions that allow maintenance of hardware and software.

-15 Maintenance of NAA equipment shall be possible without affecting the operation of the astronomical application.

LO-4.16 Training and support

-01 A functional simulator (referred to as LOFARSim) shall be provided as a training facility for operators and other users of LOFAR, and to provide a test platform for changed functions and software components.

-02 A performance simulator (referred to as LOSIM) shall be provided to generate representative data with user-specified disturbances applied to it, to support the development of new post-correlation algorithms and the evaluation of configuration changes.

-03 The LOFAR function for specification of observations shall be self-explanatory to the extent that scientists with experience in the use of synthesis radio telescopes do not need further assistance in the specification of routine observations.

LO-4.17 Disposal phase

Requirements regarding used materials, ecological aspects, programmatic reserve.

-01 Sufficient funding shall be reserved in the project for any disposal actions defined in TBD.

-02 The conditions for removal of LOFAR station infrastructure shall be defined in TBD.

-03 The LOFAR design shall be fully compliant to all environmental rules applicable to the LOFAR sites.

-04 LOFAR shall be designed to have no lasting adverse environmental effects on the facility and station site locations.

-05 Disposal of the NAA equipment, at the end of its life or at the end of the LOFAR project whichever comes first, shall be the responsibility of the NAA supplier.

LO-5 Design constraints

This chapter specifies the design constraining requirements such as determined by the environment the instrument will be placed in or relating to mechanical and electrical guidelines, product assurance, safety hazards, government regulations etc.

Some requirements provided in this chapter which appear to be only applicable at subsystem level may be moved to the "supporting specifications" as these are established.

LO-5.01 Environmental Requirements

LO-5.01.01 General

General environmental requirements

-01 Deleted

-02 LOFAR shall be designed or protected against any deterioration leading to failure to meet the requirements specified herein caused by climatic and environmental conditions during its complete lifetime (both operating and non-operating).

-03 The design of LOFAR shall be appropriate for operation in the natural environment for the geographical location of facilities and stations i.e. North-East Netherlands (and part of North-West Germany).

-04 LOFAR equipment shall be designed for the induced transportation environment appropriate to the mode of transport being used (road, air, sea, etc.) between place of manufacturing and final installation on a LOFAR site.

-05 deleted

LO-5.01.02 Site and infrastructure requirements

General requirements for station sites, building locations, connecting roads

-01 Buildings or parts of buildings containing central processing equipment and operator areas shall have a climatic conditioning system which can control the temperature within the range of 18 ºC to 23 ºC and the humidity within the range of 50 % to 70 % independent of weather conditions.

-02 Buildings specifically constructed for LOFAR shall fulfil local and governmental requirements of the country where they are located.

-03 LOFAR stations shall fulfil local and governmental requirements of the country where they are located.

-04 LOFAR stations and facilities shall be accessible via road for installation and maintenance of equipment.

-05 LOFAR equipment located in stations or outside the central processing and operating facilities shall be adequately protected against intrusion by unauthorized persons or by “larger” wandering animals (fences, ditches, audible signals etc)

-06 LOFAR central processing and operating facilities shall be provided with remotely video and audio monitoring equipment.

-07 LOFAR stations shall be provided with remotely operated video and audio monitoring equipment.

-08 LOFAR station shall be provided with a fixed telephone line to call with the operators in the central processing room.

LO-5.01.04 Contamination and precipitation

-01 LOFAR equipment located in stations or outside the central processing and operating facilities shall be able to operate without degradation of the performance during any type of precipitation (To be precized).

-02 LOFAR equipment located in stations or outside the central processing and operating facilities shall be adequately protected against performance degradation caused by contaminating particles (dust, sand etc), polluted air or any precipitation, including acid rain.

-03 LOFAR receptors/groundplanes equipment shall be easy to clean without the need of disassembly.

-04 Buildings or parts of buildings containing central processing equipment and operator areas shall have a climatic conditioning system that is capable of maintaining a TBD particle level per cubic feet (removing particles from the incoming outside air and circulated air).

LO-5.01.05 Climatic requirements

-01 LOFAR equipment located in stations or outside the central processing and operating facilities shall be able to withstand moisture and humidity levels up to 100 % RH.

-02 LOFAR equipment located in stations or outside the central processing and operating facilities shall be able to withstand an outside air temperature within the range of -35 ºC to 45 ºC.

-03 LOFAR equipment located in stations or outside the central processing and operating facilities shall be able to operate inside specification if the outside air temperature is within the range of -20 ºC to 35 ºC.

-04 LOFAR equipment located in stations within 20 km (TBC) from sea or large salt water surfaces shall be able to withstand precipitation and air containing (dissolved) salt particles.

-05 LOFAR equipment located in stations or outside the central processing and operating facilities shall be able to withstand wind velocities up to 150 km/hr.

LO-5.01.06 Ground area properties

Antenna sites ground area requirements, ground plane, improvements, independence

-01 The station site shall provide means to position receptors and associated station equipment in a stable reliable manner.

-02 The station site ground surface shall be flat within .... TBD m.

-03 In the area within TBD km around the station site any obstruction (trees, houses etc) higher than …TBD shall not be present.

-04 The soil, on which the stations are planned, shall not contain high voltage cables, gas pipes or any large metal objects buried less than 50 cm under the surface.

LO-5.01.07 Radio Frequency Interference

Protection and measures against interfering signals from outside the instrument

-01 LOFAR shall not be damaged by RFI signals less than TBD V/m.

-02 LOFAR shall not be susceptible for RFI signals, in-band or out-band, other than via the receptors.

LO-5.01.08 Electro Magnetic Compatibility

During each phase of the LOFAR life, from equipment integration until its end of life, the instrument shall neither cause disturbance to other systems, nor suffer loss of performance due to other systems or to the RFI environment.

The ability of LOFAR to perform its mission with the required performances shall be

demonstrated by tests, analysis, inspection, verification of records or demonstration according to the system verification requirements.

-01 The design of LOFAR subsystems shall meet the requirements specified in the supporting standard: Electrical & EMC standards (The following requirements indicate towards the content of this standard)

-02 The EMC safety margin, which is defined as the ratio between susceptibility threshold and the interference at any point within the system, shall be greater than 12 dB (TBC)

-03 All "Off the Shelf" equipment applied within LOFAR shall posses as a minimum the CE marking, including electrical and electronic supporting and infrastructural equipment.

-04 Cable harness requirements (to be elaborated)

-05 A hybrid grounding concept as shown in figures TBD shall be used for EMC purposes. Ground loops involving DC, and low frequency AC, currents shall be avoided inside the system. Intentional currents through structure are not permitted. (to be elaborated)

-06 Maximum effort shall be put into designing signal interfaces to withstand noisy environments and to minimize the generation of excessive noise.

-07 Emission requirements and tests (to be elaborated)

-08 Susceptibility requirements and tests (to be elaborated)

LO-5.01.09 Lightning

-01 LOFAR shall be able to withstand the electromagnetic field impact defined in TBD during operation without any damage or characteristics degradation because of a lightning discharge.

-02 LOFAR shall be able to survive the electromagnetic field impact defined in TBD without any damage or characteristics degradation because of a lightning discharge.

-03 LOFAR dedicated buildings and equipment located on sites shall be protected to minimize the effects of a direct lightning strike using certified methods.

-04 Observation data taken during a lightning strike shall be flagged.

LO-5.01.10 Grounding

Requirements regarding grounding of equipment, personnel safety and instrument performance (electrical grounding concept), use of design standards

-01 Electrical safety ground shall be designed according to the regulations imposed by the local government (or LOFAR Electrical & EMC design standard).

-02 Equipment electrical grounding shall be designed according to the regulations imposed by the LOFAR Electrical & EMC design standard (To be elaborated)

LO-5.01.11 Corrosion

-01 LOFAR equipment and buildings shall be protected against corrosion.

-02 LOFAR electronics and connectors in areas with a higher air flow (for cooling) or outdoor environment shall be additionally protected against corrosion.

LO-5.01.12 Earth Shocks

-01 LOFAR equipment and buildings shall be protected against earth shocks with a magnitude up to 3.8 on the scale of Righter.

LO-5.02 Engineering Design Constraints

LO-5.02.01 General

LO-5.02.02 Size, volume and area

Requirements regarding size of station equipment, stations, buildings etc.

-01 LOFAR equipment applied (located inside in station shelters or buildings) shall be of standard size and volume as specified in the Design & Construction standard AD. TBD.

LO-5.02.03 Shape

Requirements regarding shape of station equipment, stations, buildings etc.

LO-5.02.04 Materials and Processes

Use of adequate and (ecological) allowed materials, deviations to be approved by the project, including management of applied materials.

-01 Each subsystem supplier shall establish, collect, review and deliver the Materials, Parts and Processes lists including all the Materials, Parts and Processes intended for use in the LOFAR equipment by his suppliers and himself. They shall reflect the current design at the time of issue. The objectives are the following:
a) to make sure that all requirements of the program are met,
b) to verify the Materials, Parts and Processes activity of equipment suppliers,
c) to control and monitor the status of Materials, Parts and Processes in accordance with program milestones.

-02 The estimated availability of the Parts and products obtained from Materials and Processes used shall be compatible with the final system's life cycle (tests, storage, mission).

-03 All materials used in the LOFAR design shall be fully compliant to all environmental rules applicable to the LOFAR sites.

-04 Materials used in the LOFAR design shall not have any lasting effect on the site locations.

-05 Materials used for the parts subject to the outdoors environment shall be maintenance free. (TBC)

LO-5.02.05 Marking

Configuration control (not: modes) of instrument equipment, supporting to maintenance etc.

-01 Each part material or product shall be identified with a unique and permanent part or type number.

-02 Method of marking shall be compatible with the nature of the item and its use.

-03 Identification numbers shall be marked on documentation and, where possible, on respective items.

LO-5.02.06 Software

-01 All Software development for LOFAR shall conform to the standard (TBD)

-02 All procured (Commercial) Off The Shelf software shall conform as a minimum to the standard (TBD), including the procurement process itself.

-03 Each subsystem shall specify a Metrics Program for LOFAR dedicated software developments that includes:
a) code inspections
b) Collection and trend analysis of NCR's/SPR's raised by time
c) Collection and trend analysis of NCR's/SPR's closed by time
d) MTBF analysis by means of statistical processing of relevant data
e) MTTR by analysis by means of statistical processing of relevant data
f) Data from life cycle reviews

LO-5.02.07 Power and other utilities

Requirements regarding power sources etc to be used

-01 LOFAR facilities and stations shall be provided with a connection to the local public electrical mains, unless a more cost effective approach can be demonstrated.

-02 An alternative power supply shall provide power according to the standards as for public electrical mains.

-03 The following LOFAR equipment or subsystem parts (TBD) shall be provided with means to operate during a mains power interruption of minimum TBD hours.

-04 LOFAR facilities shall be provided with a connection to the local utilities, unless a more cost effective approach can be demonstrated.

-05 A cost effective analysis for an alternative for power or other utilities shall include any maintenance, failure analysis and repair activities over the life time of LOFAR.

LO-5.02.08 Electrical

-01 The electrical design of LOFAR subsystems shall meet the requirements specified in the supporting standard: Electrical & EMC standards (the following statements indicate the subjects of this standard)

-02 Bonding, grounding and isolation requirements (to be elaborated)

-03 Cabling requirements (to be elaborated)

-04 Connector requirements (to be elaborated)

-05 Power architecture and quality including fault conditions (to be elaborated)

-06 Data bus architecture, harness and characteristics (to be elaborated)

-07 Failure handling requirements (to be elaborated)

-08 Video monitoring requirements (to be elaborated)

LO-5.02.09 Design and construction requirements

-01 The design of LOFAR subsystems shall meet the requirements specified in the supporting standard: Design & Construction standards AD. TBD (the following statements indicate the

subjects of this standard)

-02 Requirements related to construction of LOFAR facilities (buildings) (to be elaborated)

-03 Requirements related to construction of LOFAR facilities and equipment located on antenna station sites. (to be elaborated)

-04 Requirements related to construction of roads and access to LOFAR facilities (buildings) and stations. (to be elaborated)

LO-5.03 Quality Factors Requirements

Requirements related to the quality of the product.

LO-5.03.01 General

-01 LOFAR equipment and electronics shall be developed and produced with a 4 (four) sigma quality standard.

-02 The field return rate of equipment shall be less then 0.5% during installation and the first year full usage.

LO-5.03.02 ProductionProcesses (including Software)

-01 The production of LOFAR equipment shall include the following processes:
a) procurement, which shall cover:
- materials,
- components, and
- parts.
b) production/fabrication of components or software equivalents (modules),
c) assembly of components,
d) assembly of subsystems to form the final system, either within the production facilities or station sites and LOFAR facilities.

-02 The production engineering of LOFAR equipment shall ensure that the system, and all its component parts, can be produced in the way intended and shall be of acceptable quality, reliability and reproducibility.

-03 Quality assurance requirements for production defined in TBD shall apply.

-04 Standard procedures shall be used to produce LOFAR components.

-05 These procedures shall form part of the overall product assurance requirements and shall conform to all applicable specifications

LO-5.03.03 Deleted

LO-5.03.04 Workmanship

Good workmanship expected for mechanical, electrical and software production. It refers to the physical characteristics relating to the level of quality introduced by the manufacturing and assembly activities.

-01 General workmanship standards shall be applied as specified in the Product Assurance Plan (TBD) both for Software and Hardware production.

-02 LOFAR dedicated workmanship standards shall be specified in project dedicated documents and shall:

a) cover all phases of production, assembly and integration, testing, handling, and
b) include clear requirements for acceptance/rejection criteria.

LO-5.03.05 System Safety

Safety critical functions, propagation paths, design margins

-01 The LOFAR design shall possess design margins to cover all uncertainties in environment, analysis and properties of the materials and processes used.

LO-5.03.06 Security

-01 The LOFAR design shall have provisions to prevent unauthorized access to facilities and resources. (see 4.1-11)

-02 It shall be possible to specify on a per user basis which LOFAR facilities and resources (both hardware and software) may be accessed by the user.(see 4.1-10)

LO-5.03.07 Deleted

LO-5.03.08 Resource and Utilization requirements

Utilization of (hardware) resources, budgets and design margins.

-01 Resource estimates (budgets) shall be established for each type of capacity:
a) processor capacity,
b) memory capacity,
c) input/output device capacity,
d) auxiliary storage device capacity,
e) communications/network equipment capacity.

-02 The requirements shall be stated as percentages of the capacity type and shall include the conditions under which the resource utilization is to be measured.

-03 LOFAR software be designed shall be designed to use platforms as specified in LOFAR SW standard TBD.

-04 Resource data shall be made available (by each subsystem/equipment) if requested by MAC.

LO-5.03.09 Initial Calibration

Characterization or calibration of equipment or stations other than operational issues (parameterized measurement of electrical or geophysical characteristics)

-01 Each receiving chain shall be characterized before or during initial installation.

-02 Characterisation of a receiving chain shall encompass at least:
a) antenna pattern measurements
b) noise characteristics
c) gain - bandwidth characteristics
d) SCO stability characteristics

LO-5.03.10 Reliability

-01 The reliability of LOFAR equipment to meet its performance requirements over a period of 10 years shall be greater than 99.4 %.

LO-5.03.11 Maintainability

-01 The LOFAR design shall require a minimum of special tools and test equipment to perform assembly, integration and repair and maintenance activities.

-02 Deleted

-03 The maintenance program shall include a maintenance protocol and shall define measurable parameters for all pertinent operations, during all project phases, which shall include, but not be limited to the following:
a) mean-time-to-repair;
b) down-time;
c) limited-life;
d) fault detection or isolation capability;
e) spares requirements;
f) storage requirements (for spares)

-04 The results of the maintenance program evaluation shall influence the design and shall avoid costly, late alterations, or replacement of parts. The results of the maintenance program evaluation shall contribute to the criteria with which various concept designs are evaluated.

-05 Inaccessible hardware or structures shall require no maintenance during operation.

-06 Test and repair instructions shall be written for fault detection and maintenance of the LOFAR equipment.

-07 It should be possible to execute maintenance jobs with not more then 2 people per job.

LO-5.03.12 Flexibility and upgradability

-01 The LOFAR design (hardware and software) shall have a modular approach in accordance with the LOFAR software standard TBD.

-02 The LOFAR design (hardware and software) shall provide flexibility and expandability to support anticipated areas of growth or changes in technology or mission. (e.g. in the field of but not limited to: network bandwidth, storage space, processing power)

-03 All parts or sub-assemblies identified by an item number shall be designed to be functionally and dimensionally interchangeable with items which are identically numbered.

LO-5.03.13 Deleted

LO-5.03.14 Correctness

-01 The LOFAR design shall be verified according to approved verification plans.

LO-5.03.15 Efficiency

The re-use of software and hardware modules specifically developed for LOFAR shall be maximized.

-01 The use of "Off the Shelf" hardware and software shall have preference above development.

-02 Software developed for LOFAR shall be designed in a modular form such that re-use is possible and not limited to one subsystem or application.

-03 Hardware developed for LOFAR shall be designed such that re-use is possible and not limited to one subsystem or application.

-04 The use of existing standards for data formats shall have preference above development.

-05 The use of existing standards for data transmission protocols shall have preference above development.

LO-5.03.16 Integrity

-01 The LOFAR design shall include provisions for verification of the integrity of software and hardware during design, manufacture and once in operation.

-02 To ensure integrity of software, consideration shall be given to the requirement to inspect a module, or software subsystem during the following:
a) at various stages throughout production;
b) at various stages during integration;
c) after testing;
d) in-operation.

-03 To ensure integrity of hardware, consideration shall be given to the requirement to inspect a component, assembly or structure during the following:
a) at various stages throughout production;
b) at various stages during integration;
c) after testing;
d) in-operation.

LO-5.03.17 Usability

The ease with which a user can learn to operate, prepare inputs for, and interpret outputs of a system or component.

-01 LOFAR shall be designed to be operated by users, with the role of scientist, operator or visitors, having a superficial knowledge of the LOFAR design.

-02 The LOFAR design shall provide help and training facilities to assist novice users.

LO-5.03.18 Accessibility and Testability

Requirements regarding the design of equipment, access in case of maintenance, trouble shooting, test connectors etc

-01 The LOFAR design for both hardware and software shall provide self-test capabilities.

-02 All servicing and test points shall be accessible without disassembly of other equipment.

-03 All servicing and test points shall be clearly marked.

-04 Deleted

LO-5.03.19 Transportability and storage

Requirements regarding transport of equipment, vibration and shock environment of different transport possibilities

-01 LOFAR equipment with a mass of 25 kg to be assembled or installed on site or in facilities shall be equipped with hoisting or forklift interfaces.

-02 It shall be possible to disassemble LOFAR equipment for the reason of transportation or storage in its main parts.

-03 It shall be possible to transport LOFAR equipment via common means of transportation (truck, train, ship) not requiring any special transport licenses etc.

-04 It shall be possible to transport LOFAR equipment via common means of transportation (truck, train, ship) without any degradation of its function or performance.

-05 It shall be possible to store LOFAR equipment (spare parts) for 10 years without any degradation of its function or performance.

-06 The transportation and storage environment to be accounted for shall be taken as defined in AD.TBD standard.

LO-5.03.20 Life

In addition to operational requirements, see also section 4.14.

-01 Reusability of LOFAR equipment shall be ensured through design and by refurbishment and maintenance.

-02 LOFAR spare parts shall have a storage life consistent with availability and use during the full operational lifetime of the LOFAR equipment to which it applies.

-03 LOFAR support equipment shall be designed to maintain LOFAR for 13 years. I

LO-5.03.21 Portability

Requirements regarding the portability of software. An application is portable across a class of environments to the degree that the effort required to transport and adapt it to a new environment in the class is less than the effort of redevelopment.

-01 The design of LOFAR software shall provide the ability to be ported to different target environments (to be elaborated, which platforms).

-02 Adaptation of LOFAR software shall cost significantly less than the development of new software.

-03 Portability of LOFAR software shall be defined according to TBD portability standard.

LO-5.04 Operations Design Constraints

This section defines the constraints on the design arising out of operations

-01 LOFAR shall not require more than TBD persons to control its operation.

-02 TBD

LO-6 Interface Requirements

External Interfaces are defined as interactions or communications with the world outside LOFAR.

Internal interfaces are defined as interactions or communications between or internal in LOFAR subsystems.

LO-6.01 External Interfaces

LO-6.01.01 Power

-01 The power supplied to the LOFAR central facility shall have the following characteristics:
a) voltage 380 V +/- 10%
b) 3 phases
c) 50 Hz +/- 1 Hz
d) capacity of TBD kVA average, TBD peak

-02 The power supplied to LOFAR stations shall have the following characteristics:
a) voltage 380 V +/- 10%
b) 3 phases
c) 50 Hz +/- 1 Hz
d) capacity of 15 kVA average, TBD peak

-03 The power source to the central facility shall have back-up provisions (TBC)

LO-6.01.02 Communication

-01 Deleted

-02 The LOFAR central facility shall be provided with TBD telephone connections to the public network for speech, data exchange and video (TBD)

-03 The LOFAR central facility shall be provided with TBD high speed connections to the public network for speech, data exchange and video (TBD)

-04 The LOFAR central facility shall be provided with high speed dedicated connections to the TBD networks for speech, data exchange and video (TBD)

-05 The telephone and high speed connections shall have back-up provisions (redundancy) TBC.

-06 The telephone connection shall have the following characteristics and quality aspects: TBD

-07 The high speed connection shall have the following characteristics and quality aspects: TBD

-08 Interfaces shall be documented using TBD notation system or language

LO-6.01.03 Grid and Virtual Observatory interfaces

-01 LOFAR shall have interfaces to the international Grid facilities and to the Virtual Observatory in accordance to the requirements in 3.11.3.

-02 Deleted

LO-6.01.04 Data synchronization

-01 Each LOFAR station shall maintain an internal time standard with an accuracy of 15 nanosec.

-02 All LOFAR subsystems shall synchronize their internal time standards through the GPS network.

LO-6.01.04.1 GPS

LO-6.01.05 User Interfaces

-01 The LOFAR design shall be provided with the following user interfaces:
a) scientific user interface for observation specification and scheduling

b) scientific user data access visualization interface
c) scientific user data archive interface
d) visitor interface
e) scientific user off-line processing interface
f) observation referee/review board interface.

-02 The user interfaces shall be based on generic user interfaces.

-03 The scientific user interface shall be consistent across all the interactions with the instrument.

-04 The operator user interface shall be consistent across all the interactions with the instrument.

-05 English (US TBC) shall be used as the standard language for LOFAR.

-06 Developed software and "Off the Shelf" software shall be provided with user manuals.

-07 LOFAR user manuals shall be written in accordance with the guidelines specified in the LOFAR SW standards TBD.

-08 User interfaces shall be designed in accordance with the guidelines specified in LOFAR Human I/F standards TBD.

Note: Examples are "Web Contents Accessibility Guidelines 1.0" and "Section 508 of the Rehabilitation Act Amendments of 1998".

-09 The user interface shall be consistent and compliant with the conventions and guidelines of the host platform on which the user interface is presented.

-10 The terminology used in the user interfaces shall be compliant with the terms defined in the LOFAR Glossary (LOFAR terms, definitions and abbreviations, RD.2).

LO-6.02 Internal Interfaces

LO-6.02.01 Power

-01 Subsystem internal power supplies shall be specified according to LOFAR electrical & EMC standards.

-02 Subsystem internal power supply interfaces shall be as specified in the LOFAR ICD.

-03 LOFAR Equipment circuitry shall be protected against excessive currents by a current limiting device, and shall not itself produce excessive currents.

-04 LOFAR shall be protected against power transients and surges.

-05 LOFAR equipment circuitry shall be protected against the effects of inadvertent wrong polarity connections.(TBC)

LO-6.02.02 Communication

-01 LOFAR internal communications and data exchange shall be using the LOFAR dedicated data transport network.

-02 Each type of communication interface shall be designed as specified in the LOFAR ICD.

-03 The communication interface types shall be specified as one of the following:
a) command interface

b) monitor data interface
c) data exchange
d) synchronization interface.

-04 Each station shall have a communication interface of all types to the central facility.

-05 For remote stations the communication interface shall have TBD bps capacity and TBD characteristics.

-06 For Virtual core stations the communication interface shall have TBD bps capacity and TBD characteristics.

LO-6.02.03 Synchronization

-01 Deleted

-02 All stations shall time-tag received and processed data with the accuracy of their internal time standard (see 6.01.04-01).

LO-6.02.04 Deleted

LO-7 Support Requirements

LO-7.01 Support facilities

Simulator requirements

-01 The LOFAR simulation equipment shall be able to simulate data flow processing systems with dataflows as predicted for LOFAR.

-02 The LOFAR simulation equipment shall be able to "support" architectural studies for the LOFAR system design and development.

-03 The LOFAR simulation equipment shall be able to "support" design and development of LOFAR hardware and software.

-04 The simulation equipment shall predict the LOFAR behavior with the accuracy that is required for confident design of monitoring and control.

-05 The simulation equipment shall predict the LOFAR behavior with the accuracy that is required for confident design of observation specification and scheduling.

-06 The simulation equipment shall predict the LOFAR behavior with the accuracy that is required for confident design of self-calibration software.

-07 The simulation equipment shall be capable of taking hardware in the loop

-08 The LOFAR simulation equipment shall have the possibility to inject failures

LO-7.02 Maintenance

Maintenance equipment, EMC/RFI standards for tooling etc.

-01 Maintenance equipment designed especially for LOFAR shall meet the requirements specified in the Electrical & EMC standards

-02 All maintenance equipment that will be used on antenna sites during operations shall meet the requirements specified in the Electrical & EMC standards.

-03 All LOFAR subsystems shall specify what special test resources they require in the operational phase.

LO-7.03 Supply

-01 The following consumables shall be supplied: TBD

LO-7.04 Training Facility

This section contains the supporting requirements for LOFAR training facilities.

-01 TBD

LO-7.05 Personnel

This section shall specify any requirement, relevant to the system to personnel requirements., as applicable to the specific system under definition This section should contain (as applicable) requirements relevant to: manual operations, human-equipment interactions, constraints on personnel, areas needing concentrated human attention and that are sensitive to human errors and training as well as relevant to Human Factors Engineering Requirements

-01 TBD

LO-7.06 Training

-01 The design of LOFAR shall include on-line help for users.

-02 A training program for preventive and corrective maintenance shall be established.

LO-7.07 Publications

Requirements regarding scientific intellectual property rights

-01 LOFAR Science Data (final data products and results derived from these) shall be the available for publication without restrictions to the scientists originating the observation proposal. However, LOFAR and the LOFAR consortium shall be duly acknowledged in any publication where data and conclusions are presented.

-02 The extent to which and the duration for which LOFAR Science Data will be proprietary to the originating scientists shall be determined by the ARC.

LO-7.08 Logistics

Logistic requirements during built-up and operations, may include: system maintenance, software support, system transportation modes, supply-system requirements, impact on existing facilities, and impact on existing equipment.

-01 LOFAR parts, test equipment or supporting equipment with mass exceeding 25 kg shall be provided with provisions for handling and transportation.

-02 Preventive maintenance of LOFAR stations shall be performed in accordance with the maintenance program established for LOFAR.

-03 Maintenance equipment shall allow transportation between station sites.

-04 Deleted

LO-8 Verification requirements

-01 LOFAR shall be verified at levels selected from the following:
a) LOFAR System level
b) LOFAR Subsystem level
c) LOFAR equipment level (or software equivalent if applicable)

-02 The verification methods which shall be applied throughout the LOFAR program shall be selected from the following:
a) Test (T)
b) Analysis (A)
c) Inspection (INS)
d) Review of Design (ROD).

-03 Each numbered requirement in this LOFAR System Specification shall be verified by one or more verification methods.

-04 A verification plan shall be provided that reflects the approach presented in the Design, Development and Verification plan.

-05 System and subsystem level verification shall be performed as specified in the Verification Plan and Matrix.

-06 The system and subsystem close-out evidence shall be reported in a configuration controlled document, which shall be the input for the system or subsystem verification control document (VCD or SVCD).

-07 The requirement close-out information format shall be in the form of a technical note or report or outputs from development tools for each kind of verification method (test report, analysis or simulation report, inspection or review of design report).