LOFAR spectrum monitoring: dynamic range and spectral occupancy issues (part one)

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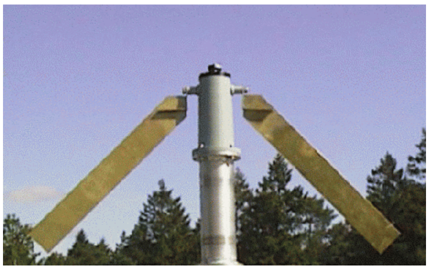
1. Introduction

Currently, (pre) studies are conducted for the Low Frequency Array Radio telescope, LOFAR, which is to be used in the frequency band 10-150 MHz (or thereabout). Some questions related to spectral occupancy and dynamic range, relevant for the LOFAR radio telescope, are addressed:

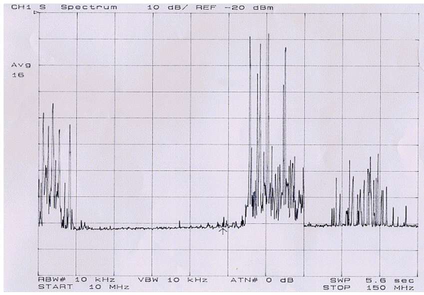
- Is the RFI situation suitable for locating the LOFAR telescope at a particular site?
- What is the spectral occupancy in time, frequency, polarization, direction, and power?
- What are the RFI power levels in relation to LNA linearity (IP2, IP3)?
- What are the RFI power levels in relation to the system noise; what is the number of ADC bits required?

2. LOFAR antenna, engineering model



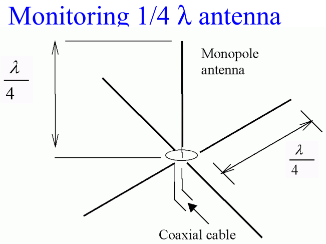
The picture above shows an engineering model active wideband LOFAR antenna which ASTRON development in collaboration with Rhode & Schwartz. At Astron, two of these antennas are currently tested. One of the two antennas is used for monitoring purposes.

3. Spectrum sweep, 10-150 MHz



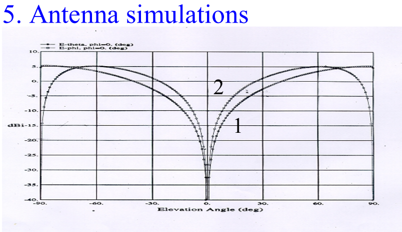
Using the engineering model LOFAR antenna, a first (uncalibrated!) spectrum plot was made. The AM transmitters below 15 MHz are visible, FM transmitters are present around 100 MHz, and around 150 MHz signals from the aeronautical bands are visible.

4. Monitoring 1/4 λ antenna



As not yet all calibration parameters of the LOFAR antenna were available, a ¼ lambda antenna was used for obtaining calibrated monitoring spectra. The LOFAR antenna was (partly) used in parallel for comparison. The ¼ lambda antenna has a bandwidth of 5 MHz. Tuning was done by varying the length of the antenna and the radials.

5. Antenna simulations



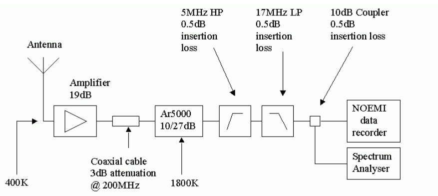
Antenna simulations show that at low elevations the conductivity of the soil is an important parameter. Curve 1 shows the gain of the ¼ lambda antenna above a perfectly conducting ground, curve 2 shows the simulated gain above soil. The simultions were compared with antenna measurements and with a folded dipole antenna (not discussed here).

6. Influence of antenna height

Freq (MHz)	Name	P (dB_m) on ground	P (dBm) on the 'Bouwhal'
88.0	Radio 2	-49	-26
90.8	Radio Drenthe	-65	-41
91.8	Radio 3	-39	-30
94.8	Radio 4	-47	-31
100.4	Sky radio in Irnsum	-48	-40
101.0	Radio 1	-50	-33

With the ¼ lambda antenna, measurements were done at the WSRT ground level and at the top of the construction hall at about 20 m. The difference in observed power is about 18 dB for signals from nearby (13 km) FM transmitters. This is (partly) caused by shielding of the forest. This test needs to be repeated at the open plains.

7. Spectrum monitoring, set-up



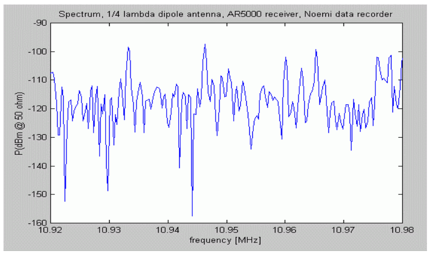
The antennas were connected, via an amplifier, to an AR5000 receiver. This receiver has a video (RF) output centered at 10.7 MHz. This output was connected, via bandpass filters, to a spectrum analyser and a datarecorder (sampler) from the NOEMI project (an STW-Tudelft-ASTRON project aimed at developing digital RFI mitigation techniques). Spectra were obtained by (offline) fourier transforming the time data series.

8. Sky noise temperature

Freq (MHz)	Sky-noise (K)
10	800000
20	90000
40	10000
80	1000
100	800
160	350

In the table above, the sky noise temperatures are listed for six frequencies in the LOFAR frequency range. An important demonstration of the usefulness of this part of the spectrum is whether at low frequencies the sky noise can be measured. The noise properties of the set-up used are such that the sky noise should be visible.

9. Observed sky noise



Using the ¼ lamda antenna, a 5 MHz bandwith, and a spectral resolution of 153 Hz, the sky noise at 10 MHz was calculated to be –117 dBm. In the figure above, a measurement is plotted which clearly shows that the spectrum between the CW signals indeed has a power of around –117 dBm.

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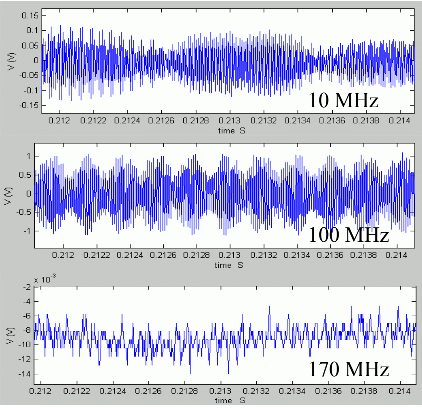
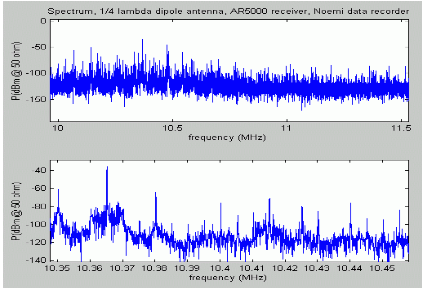
10. Observed time series



11. Dynamic range: number of required ADC bits

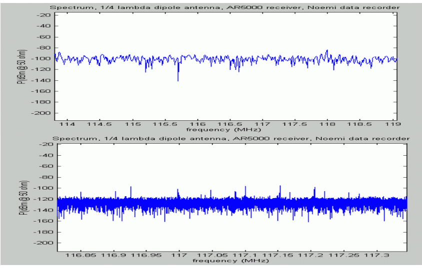
The figures to the left show the signal time series for the two strongest “RFI bands” (AM around 10 MHz, FM around 100 MHz), and for a band with low intensity RFI at 170 MHz. For the the 10 MHz observation, a 20 dB attenuator was used. At 170 MHz , the ADC quantization levels are clearly visible. The conducted experiments show that with the set-up used, both the weak and strong signal parts of the spectrum can be covered with a 12 bit ADC. The long-term monitoring station at the WSRT indicates that the spectral occupancy during the experiments were typical. This, however, needs to be verified, especially for the frequencies below 80 MHz.

12. Observing near strong RFI



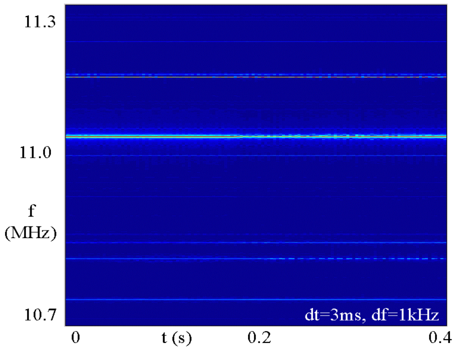
The figure above shows a 153 Hz reolution spectrum with a lot of strong RFI. After zooming in, however, on can see that the sky noise (calculated to be –117 dBm) is visible even though the RFI power is –40 dBm.

13. RFI mitigation



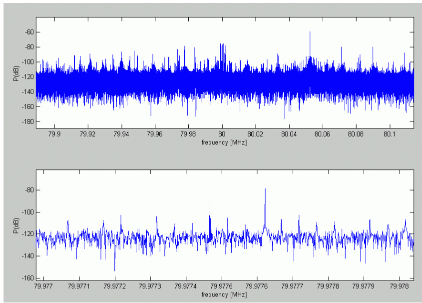
The upper, 10 kHz resolution, spectrum shows no interference. The lower, 20 Hz resolution, spectrum clearly shows a number of narrowband signals. These signals probably will not cause alinearities, but must (and can) be suppressed by (digital) mitigation techniques in order not to disturb the observed passband.

14. RFI characterization



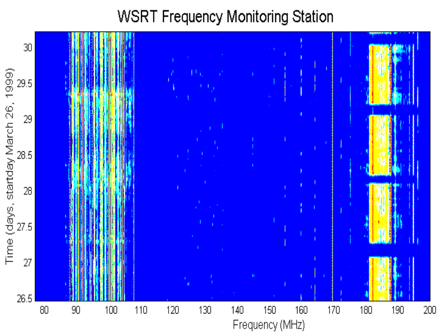
The figure above shows a spectrogram at 11 MHz. Most signals shown are widesense stationary at timescales of order second. A few are stationary on timescales of a few ms.

15. High spectral resolution



The figure above shows two 0.6 Hz resolution spectra. The lower figure is a zoomed version of the upper. One clearly sees Hz resolution spectral features (RFI). A Hz resolution LOFAR backend would be useful for coping with this kind of RFI.

16. Long term monitoring



The figure above shows a spectrogram of the band 80-200 MHz, as was observed with the WSRT monitoring station during a four-day measurement run. The FM transmitters around 100 MHz and a TV transmitter signal at 185 MHz are clearly visible. The TV signal was switched off during the night. Around 130 MHz, signals from the aeronautical bands are visible; at 160 MHz “marifoon” is present.

17. Conclusions

- The measurements indicate that 12 bit ADC dynamic range should be enough for a Lofar radio telescope which uses bands of order 5 MHz
- With the set-up used, the sky noise clearly is visible up to 80 MHz, also near strong RFI
- Observations should be possible near strong RFI
- At 100 MHz, about 18 dB less RFI power was observed at the WSRT ground level, as compared with a height of 20 m. Apparently and not surprisingly, the location of the antenna is an important factor.
- In apparently clean frequency ranges, there are many narrowband signals present which need to (and can be) mitigated by digital backends.
- Hz backend resolution is useful for suppressing the occuring Hz-bandwidth RFI signals

18. Conclusions (continued)

- By applying mitigation techniques, large parts of the Lofar frequency bands can be made suitable for astronomical observations

19. Next steps

- A gain / Tsys / RFI-power breakdown, based on the available material , is needed for the next two steps: system linearity analysis and estimaten of the required in-band RFI attenuation levels.
- Long term monitoring is necessary for obtaining day/night and seasonal variations in the spectrum occupancy.
- The for this research used set-up, is not suitable for long term monitoring, so long term monitoring facilities should be developed (e.g. extending the WSRT monitoring downto 10 MHz)
- The influence of height and antenna location on RFI power levels needs to be investigated further.

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