LOW FREQUENCY RECEIVERS FOR THE WSRT
A WINDOW OF OPPORTUNITY

J. van der Marel[(1)], E.E.M. Woestenburg[(2)], A.G. de Bruyn[(3)]

[(1)]ASTRON, P.O. Box 2, NL-7990 AA Dwingeloo, The Netherlands, E-mail: marel@astron.nl

[(2)]As (1) above, but E-mail: woestenburg@astron.nl

[(3)]As (1) above, but E-mail: ger@astron.nl

ABSTRACT

A new suite of receivers, the Low Frequency Front Ends (LFFEs) for the 115-180 MHz frequency range, has been installed and taken into operation at the fourteen telescopes of the Westerbork Synthesis Radio Telescope (WSRT), at the end of 2004. An LFFE consists of four folded dipole antennas (effectively two-element focal plane arrays for each polarization X and Y) and a two-channel receiver in every telescope, thus allowing full polarization observations. The output of the receivers is coupled into the IF-channels of the telescopes, without frequency conversion.

During the commissioning it appeared that there are several frequency sub bands, practically free of RFI and allowing good astronomical observations.

This paper describes the LFFE receiver design and properties. Both technical and operational details will be presented.

INTRODUCTION

The Westerbork Synthesis Radio Telescope (WSRT) consists of fourteen identical telescopes of which the dishes have a diameter of 25 m. Every telescope is equipped with a Multi Frequency Front End (MFFE) covering in total 8 frequency bands between 240 MHz and 9 GHz. To deal with the increasing interest in low-frequency radio astronomy, it was decided to extend the frequency range of the WSRT to lower frequencies with a band from 115 MHz up to 180 MHz. In 2004 new receivers, the so-called Low Frequency Front Ends (LFFEs), have been installed and taken into operation at all fourteen telescopes of the WSRT. Among the science drivers for this extension are imaging of the Galactic synchrotron background, both in total intensity as well as polarization, steep spectrum very high red shift radio galaxies, disks and haloes of normal nearby galaxies and searches for, and detailed studies of, very steep spectrum pulsars.

The WSRT is situated relatively close (20 km) to the TV tower of Smilde, which is continuously broadcasting at several frequencies. The FM radio emission and the emission at TV-channel 6 (182 -188 MHz) of this tower are so strong that they create a natural limit for the new low frequency receivers. By using dedicated filters with very high-Q elements for these interferers, it is possible to get a frequency band ranging from 115 MHz up to 180 MHz. This frequency range allows the coupling of the output of the receivers directly into the IF-channels of the telescopes, without frequency conversion.

The DZB backend of the WSRT can accept the full 65 MHz band of the LFFEs. Using recirculation within the DZB a high spectral resolution can be obtained, which is needed for efficient RFI filtering. It is also possible to select interference free parts using the bandwidth selection and tuning capabilities of the WSRT backend IF-system. During the commissioning it appeared that there are several frequency sub bands, practically free of RFI and allowing good astronomical observations. The installation of an active RFI mitigation system in the near future will further reduce the data loss due to RFI.

The LFFEs operate in a part of the high frequency band of LOFAR, the Low Frequency Array that will be located in the northern part of the Netherlands, coming on line from 2007. The availability of the LFFEs gives astronomers the possibility to gain experience with respect to the operation of a radio telescope in a harsh RFI-environment, in a frequency window shared with many other users. Moreover interferometric tests with a LOFAR high band pilot station in the vicinity of the WSRT can provide useful information about beam profile, side lobe levels and the polarimetric response as a function of zenith angle of a LOFAR station. This means that, besides already producing large sky maps in this frequency range, presenting astronomers a sensitive first look into the low frequency Universe, the LFFEs will also provide valuable experience for LOFAR.

SET-UP OF THE LFFE

Antenna Design

The antennas of the LFFE are folded dipole antennas, placed in a mini focal plane array of two elements for each polarization X and Y. Due to space limitations inside the focus box the antennas are mounted on movable structures outside the focus box. To make the folded dipoles less sensitive to weather influences (especially wind) tests were done with open antennas that roughly consist of the contours of a conventional fat folded dipole. It appeared that they were as effective as the conventional folded dipole antennas. Simulations showed that the optimal position of this mini focal plane array is 50 cm before the prime focus of the 25 m mirrors of the WSRT.
When observations are made with the LFFEs, the antennas are moved pneumatically into the position before the focus box. The photograph on the left of Fig. 1 shows the antennas in the observing position. To reduce weight as well as the influence of the movable structure on the antenna pattern it was decided to make this structure from a glass fiber composite material.
A requirement is that during observations with the other bands of the WSRT no influence on their performance due to the LFFE antennas is noticeable. That means that in the stowed position the LFFE antennas should not be visible by the antennas of the MFFE and that they are not blocking any incident radiation from the sky onto the mirror. This requirement resulted in a stowed position as shown in the photograph on the right of Fig. 1, where the antennas are just within the contours of the support structure of the focus box.

Fig. 1. The LFFE antennas at one of the telescopes of the WSRT array. The picture on the left shows the antennas in the observing position, on the right the antennas are visible in the stowed position.

Electronics Set-up

The design goal for the frequency range of the LFFE is 115-180 MHz, limited at the lower end by nearby FM radio broadcasts and at the higher end by the broadcasts of a nearby TV-station. In Fig. 2 a block diagram indicating the electronics set-up of the LFFE receiver is presented. The receiver chain consists of a combiner to combine the signals of the two folded dipoles for each polarization, followed by a directional coupler for the noise source coupling. To enable as much bandwidth as possible a dedicated filter with very high-Q elements has been designed to provide a high suppression of the FM-band and to suppress the strongest signals of the TV-broadcast just above 180 MHz. This filter is placed before the first LNA to avoid non-linearity in this LNA. After the first LNA 180° phase switches are placed. A band pass filter followed by a second amplifier completes the receiver chain resulting in a total gain of 58 dB. During the first tests it appeared that a very strong signal from a pager network at 169.75 MHz caused saturation in the second amplifier and it was decided to add a sharp notch filter before this second amplifier to suppress this signal with more than 35 dB. The frequency range of the LFFE allows coupling the receiver output directly into the IF-channels of the telescope. By means of a coax switch it is possible to select the IF output from the MFFE or the output from the LFFE.
The LFFE has been set up as an extension of the existing MFFE. This means that control of the LFFE (antenna movement and signaling) is conducted by the MFFE microprocessor, control lines for noise source switching and phase switching are shared and that power is provided by the power supply of the MFFE. The LFFE receiver is placed in a separate box in the focus box of a telescope and can be replaced independent of the MFFE. A multi-pole connector provides the connections between the MFFE and the LFFE.

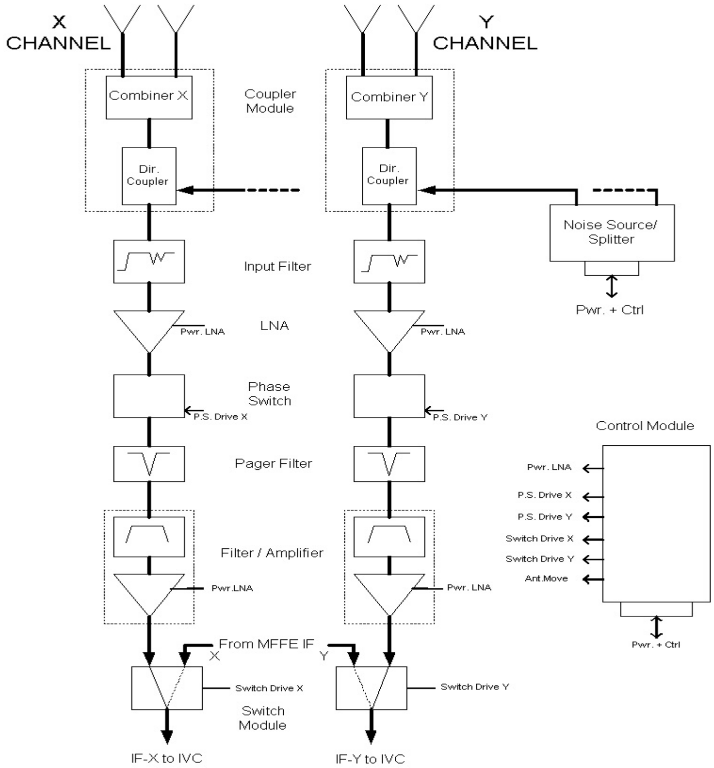

Fig. 2. Block diagram of the LFFE receiver.

PERFORMANCE OF THE LFFE

System Temperature, Efficiency and noise levels

The LFFE receivers have a receiver input noise temperature slightly below 300 K across the band, including the losses of the coupler module and the connecting cables to the dipoles. For the telescope system this results in a NEFD of 7000 – 10000 Jy. Unfortunately there is hardly any data available in this frequency range about absolute intensities of the sources in the sky. Antenna simulations indicate that the efficiency is between 28% and 36%. Using these values and the NEFD the system temperature is 350 – 500 K for the case that the efficiency is 28% and 450 – 600 K for the 36% case, at a frequency of 140 MHz. New measurements have been planned to improve the accuracy of these numbers.
Commissioning observations showed that after a 12 hour observation the noise in a map can be less than 5 mJy when using a 2.5 MHz wide band. This is close to the classical confusion level.

Beam Profile and Polarization Properties

For the lowest frequency (115 MHz) of the LFFE the half-power beam width (HPBW) of the primary beam is 6^{o}. At the highest frequency (180 MHz) the HPBW is reduced to 3.8^{o}. Measurements also show that the level of far side lobes is below -30 dB.
For on-axis sources no significant instrumental polarization is measurable. However, for off-axis sources at higher angles (which can be observed quite well due to the broad primary beam) instrumental polarization can be observed, most noticeable in Stokes Q.

RFI CLIMATE

The frequency band in which the LFFEs are operating is used for many different applications, from aeronautical navigation to TV broadcasts and from satellite communication to radio amateurs. To get an impression of the amount of RFI that can be expected in this band a plot from a 24 hour measurement with the WSRT RFI monitoring station is presented in Fig. 3. Most of the RFI in this band is intermittent and has a small bandwidth. Using short integration times, as many spectral channels as possible and a careful selection of the observed sub bands increases the amount of useful data. The RFI situation is considerably better in the hours between midnight and ~6 a.m.

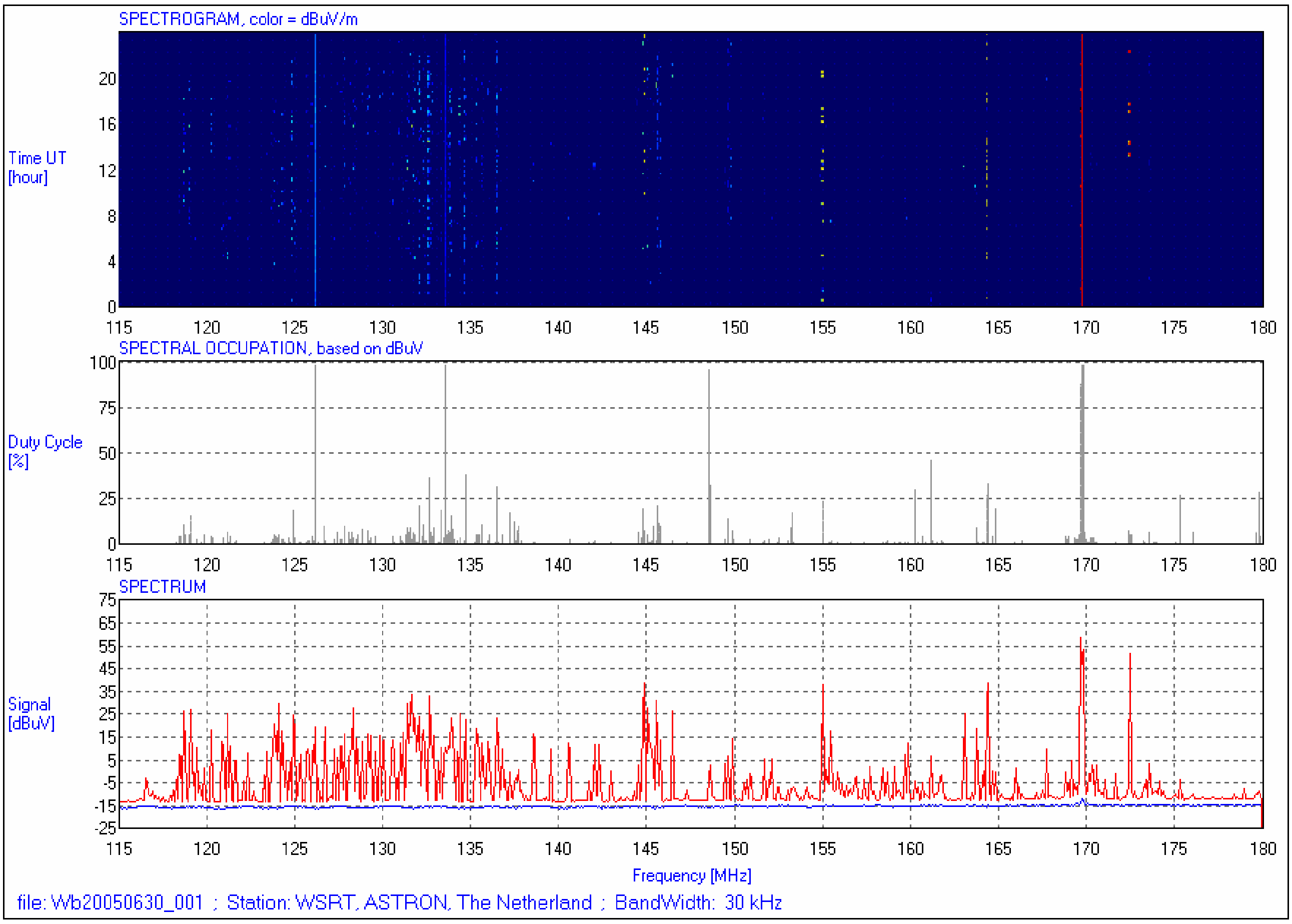

Fig. 3. Plot from a 24 hour measurement made with the RFI monitoring station of the WSRT, showing from bottom to top, the minimum and maximum signal strength, the duty cycle of the signals and the occurrence of the signal as a function of time.

CONCLUSION

Since the installation of the LFFEs has been finished at the end of 2004, several 12 hour synthesis observations have been performed. The huge data streams, due to short integration times and many spectral channels, are challenging the reductions software and computers. The first publications with astronomical results are under way (see for instance [1]). The LFFEs provide a tool for wide-field astronomical polarization imaging at very low frequencies, thus opening a new window on the Universe and at the same time giving valuable experience in preparation of LOFAR.

REFERENCES

[1] A.G. de Bruyn, "Low Frequency Polarimetry", these proceedings.

ACKNOWLEDGEMENT

The development, production and installation of the Low Frequency Front Ends at the Westerbork Synthesis Radio Telescope have been made possible with the financial support of the Netherlands Organisation for Scientific Research (NWO).