Low Frequency Astronomy – the challenge in a crowded RFI environment

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Abstract

Low frequency radio astronomy is a hot topic at the moment. Many large arrays of antennas are built to facilitate the astronomical research on low frequencies. Building an instrument for the frequency band below 30 MHz on Earth will run into some problems. One of the issues is the instable and sometimes even opaque ionosphere at low frequencies. Another issue is the man-made Radio Frequency Interference (RFI) at low frequencies. In this paper we will address the later one. An overview will be given of propagation models at lower frequencies; we will present measurements and will summarize the impact of RFI on radio astronomy at frequencies below 30 MHz.

1. Introduction

Research at low frequencies is one of the major topics at this moment in radio astronomy, and several Earth-based radio telescopes are constructed at this moment (e.g. the LOFAR project in the Netherlands [3,4], covering the 30-240 MHz range). Low frequency bands are considered as the last unexplored frequency bands. One of the major obstacles for observing at low frequencies is man-made RFI. The frequency bands are heavily in use by many communication systems. That results in strong signals all over the bands. The frequency range is, however, scientifically very interesting [8,9].

The signal levels of astronomical sources are very low, and usually the variation in observed power flux from a source is not significant. The main requirement is to determine the power flux as accurately as possible. The sampling error of an estimated mean value (for white noise characteristics) decreases as the square root of the number of observations. This implies that the measurement precision will scale with the square root of both the bandwidth, and the integration time of the measurement. This principle allows variations in received power to be detected that are many orders of magnitude below the noise floor of the receiver.

The signals from active spectrum users will be of major impact in the astronomical receiver systems. The observed signal strengths of active spectrum users and astronomical sources can easily be more than 100 dB [2]. In this paper the RFI situation for low frequency radio astronomy (frequencies below 20 MHz) will be addressed. In the next section the propagation properties will be presented. In section 3 we will present the measurements and a discussion in section 4. We end this paper with some conclusions.

2. Propagation

Radio propagation in the LF band (between 30 kHz and 300 kHz) and MF band (between 300 kHz to 3 MHz) is dominated by the ground wave. In ground wave communications, range is affected by a number of factors. The largest determining factor is the frequency: the lower the frequency the greater the range. After that, range will also depend on the power of the transmitter, the electrical characteristics (conductivity and dielectric constant) of the terrain over which the signal will travel, antenna efficiency and electrical noise at the receiver site. The range for surface waves is approximated by:

$$D(km) = \frac{200}{\sqrt{f(MHz)}} \tag{1}$$

At 1 MHz this approximation results already in a RFI horizon of 200 kilometers and it becomes worse and worse for lower frequencies. Another propagation mechanism is via sky waves. Sky waves are reflections from the

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ionosphere. While the wave is in the ionosphere, it is strongly bent, or refracted, ultimately back to the ground. From a long distance away this appears as a reflection. RFI from very long distances will be the result, up to hundreds of kilometers. Sky waves in this frequency band are usually only possible at night, when the concentration of ions is not too great since the ionosphere also tends to attenuate the signal.

The HF band (3 MHz to 30 MHz) operates almost exclusively with sky waves. The higher frequencies have less attenuation and less refraction in the ionosphere as compared to lower frequencies. At even higher frequencies (> 30 MHz) the waves completely penetrate the ionosphere and become space waves. The characteristics of the sky wave propagation depend on the conditions in the ionosphere which in turn are dependent on the activity of the sun.

3. Measurements

To assess the RFI situation at low frequencies we did spectral measurements at various places. These measurements were done as part of the LOFAR site selection campaign [1]. Measurements were taken in Germany, UK, Sweden, Poland, France, Portugal and in the Netherlands. The equipment used for the mobile measurements is fairly simple. A Rhode & Schwarz ESMB receiver is the data acquisition instrument, which connects to a notebook computer control and readout system. The input is connected to either the Rhode & Schwarz HE010 active antenna, the Schwarzbeck Vulp9118G passive antenna directly or the output of a LNA which connects to the Vulp9118G antenna. A Miteq 10-1000 MHz amplifier can be used, which has a noise figure ranging from 2.1 dB at 100 MHz to 1.14 dB at 610 MHz to 1.2 dB at 1 GHz. [1]

In Figures 1 and 2 a spectrum measured with the mobile measurement setup is shown. Figure 1 shows a spectrum from 5 to 45 MHz measured in Nancay, France. Figure 2 show a spectrum from 5 to 45 MHz measured in Tautenburg, Germany. From these measurements it is clear that the spectrum below 20 MHz is heavily in use. Very strong signals are received, up to signal strengths of -95 $dBWm^{-2}Hz^{-1}$ and more. We see very similar results between the two sites; a very occupied low frequency band with very strong signals. The distance between the two sites is approximately 800 kilometers.

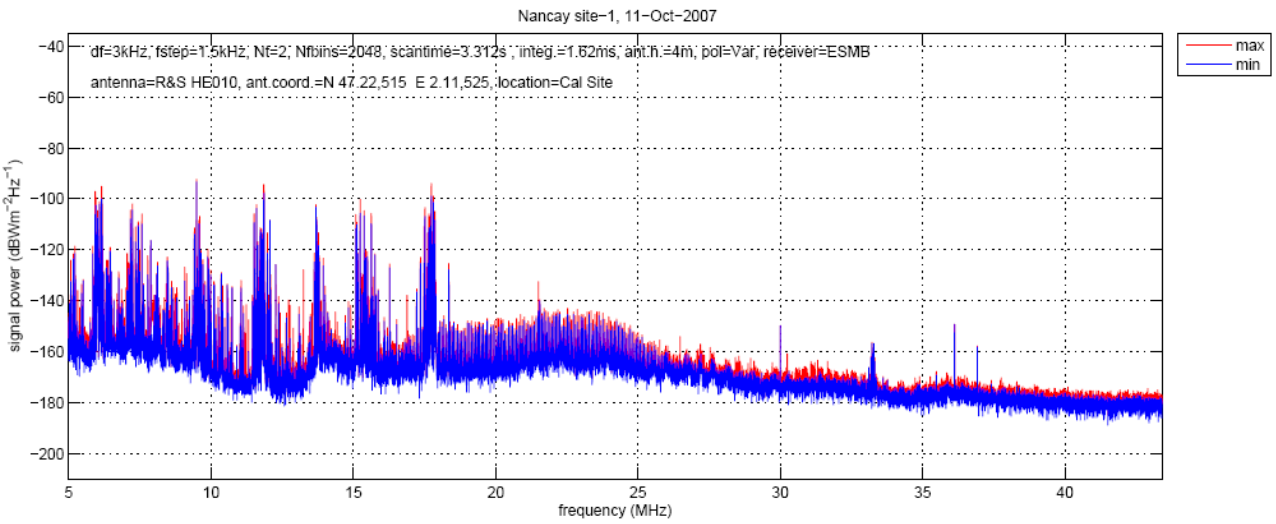

Figure 1. Spectrum from 5 to 45 MHz measured in Nancay, France.

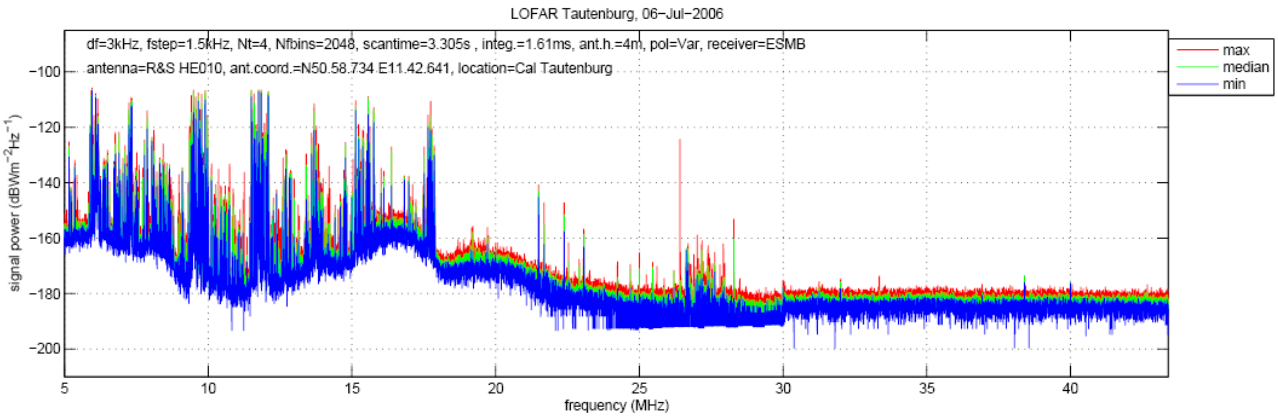

Figure 2. Spectrum from 5 to 45 MHz measured in Tautenburg, Germany..

4. Discussion

The levels observed in the measurement are very strong, more than -100 $dBWm^{-2}Hz^{-1}$. In [1] we discussed the impact of levels of RFI source on the astronomical measurements. For bands which are not allocated to radio astronomy, there may be strong observed transmitter powers present. These signals should not cause linearity problems for the receiver systems. Radio astronomical systems are designed such that a limited number of strong transmitters would not affect the linearity of the instrument. For the LOFAR system [3,4] this maximum allowed signal strength is set to 65 $dB\mu Vm^{-1}$ in a 3 kHz band. This corresponds to a maximum allowable flux of -115 $dBWm^{-2}Hz^{-1}$ in a 3 kHz band. For most of the LOFAR sites (located in Northern Europe) RFI is below this maximum allowable level. Of course this is only valid for the LOFAR frequency band, 30-270 MHz excluding the FM radio band.

Observing below 30 MHz, and especially below 20 MHz, is starting to become a problem. The levels of the RFI sources are very high as can be seen in the Figures 1 and 2. This will introduce possible problems in the receiver systems, through intermodulation products, leakage, or if the affected frequencies are not filtered out completely. In the measurements in the previous section we observe levels of -100 $dBWm^{-2}Hz^{-1}$ and sometimes even higher. Note that both locations (Nancay and Tautenburg) are radio astronomical sites and have relatively low RFI levels. However, due to the propagation properties at lower frequencies, signal levels will be high, even at very distance locations. The observed levels are very high: it is hard to make sensitive receivers with a very high dynamic range.

Another issue is the occupancy of the band. In [5,6] occupancy measurements have been done at frequencies between 30 and 3000 MHz. In the urban measurement, it is found that approximately 80% of the 30–60 MHz band is essentially free of signals to within about 7 dB of the environmental noise limit at 30 kHz spectral resolution. In [7] the authors show a similar, perhaps even better, occupancy in the 3 to 30 MHz band. Results are dependent on the bandwidth of the channels. With a 3 kHz resolution, they show a 95% of free channels in the band.

Based on the RFI levels below 20 MHz, it is almost impossible to do radio astronomical observations. As mentioned in the introduction, also the ionosphere is a problem in this frequency band. This makes that this frequency band is un-explored at this moment. To explore this frequency band, space-based instruments must be build. The only observation done at low frequencies is by the Radio Astronomy Explorer 2 in the seventies [8]. At this moment several research projects have been started to build such an instrument in space [9..15]. RFI is still an issue, even if the instrument is in space. The levels are very strong and might impact the receiver systems. Therefore it is very important to measure the RFI levels from Earth at several locations in space, eg. at the International Space Station, in low earth orbit satellite systems or higher in the atmosphere.

5. Conclusion

The low-frequency radio spectrum is occupied to a large fraction by terrestrial broadcasts, in particular longer-wave radio and television broadcasts and military and civil communications. This radio frequency interference is a severe problem for all kinds of ground-based radio telescopes. These signals block out cosmic signals directly at the

corresponding wavelengths, but they also lead to an increased noise level for observations at other frequencies through intermodulation products in the receiving system, through leakage, or if the affected frequencies are not filtered out completely.

At the longest wavelengths, low frequencies, these signals propagate through ground waves as well as sky waves reflected by the ionosphere. This is of course the reason why these wavelengths are used for world-wide radio broadcasts, but it also means that a terrestrial ULW radio telescope is sensitive not just to local interference, but also to interference from all parts of the world, irrespective of location. Therefore observing at low frequencies (below 20 MHz) is not realistic on Earth and such an instrument should be built in space. Even in space, Earth-based man-made RFI is present and should be taken into consideration in the design of the receiver systems.

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