THE EFFECT OF BLANKING OF TDMA INTERFERENCE ON RADIO-ASTRONOMICAL OBSERVATIONS: EXPERIMENTAL RESULTS

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ABSTRACT

The fast growth of the wireless communication industry poses severe limitations on radio astronomical observations. This is largely due to the fact that in radio astronomy, in contrast to communication systems, the signals of interest are many orders of magnitude below the receiver noise power levels. The structure of some communication signals opens the possibility to reduce the effect on radio-astronomical observations using advanced array processing techniques. One such structure is time slots, used in TDMA communication systems such as the Iridium system and the GSM system. In this paper we present the results of blanking of time-slotted interfering signals measured at the Westerbork Synthesis Radio Telescope.

Keywords: Interference rejection, signal detection, radio-astronomical receivers.

1. INTRODUCTION

The fast growth of the wireless communication industry poses severe limitations on radio astronomical observations. This is largely due to the fact that in radio astronomy, in contrast to communication systems, the signals of interest are many orders of magnitude below the instantaneous receiver noise power levels. These developments cause an increasing interest in detection and suppression of man-made signals in radio astronomy. The structure of some communication signals opens the possibility to reduce the effect on radio-astronomical observations using advanced array processing techniques. One such structure is time slots, used in TDMA communication systems such as the Iridium system and the GSM system.

Several methods have been proposed for single dish radio telescopes. A basic approach consists of a single channel power detector used for stopping the integration of the astronomical signal for the duration of the interference. Examples are Friedman's detection of change in the mean power, implemented in the RATAN 600 [2], and Weber's detector implemented in Nançay [7]. More advanced approaches assume the presence of an additional omnidirectional reference antenna which receives a clean copy of the interference. This allows to subtract the interference using LMS-type techniques [1].

The main drawback of such single channel detectors is that they cannot exploit spatial properties of the interference. In synthesis radio telescopes the desired astronomical signals as well as the interference are received by large sensor arrays. In this situation we can perform combined spectral-temporal and spatial processing to detect and remove only those narrow-band slices for periods and in directions in which the interference is present. This type of solution is very well suited to improve radio astronomical observations in the presence of time division multiple access (TDMA) communication systems such as GSM and Iridium. These systems divide each frequency band between several users, such that at each given moment the channel is given to a different user. Hence if the system is not completely loaded, the interference is time-slotted.

The goal of the NoEMI (Nulling of Electro-Magnetic Interference) project is to study the possible use of multichannel signal processing methods for the suppression of RFI.

In this paper we demonstrate how a simple spatio-spectral detection scheme enables the blanking of narrow-band interference. We will describe a system built for recording radio frequency interference (RFI) on-line. The effectiveness of the space-time detection and blanking process is also demonstrated by applying the algorithms to data measured at the Westerbork synthesis radio telescope (WSRT) using the on-line recording system.

For theoretical background the reader is referred to our previous work on the subject [6],[3] and the more extensive [4].

2. EXPERIMENTAL SETUP

The data recorder consists of an industrial PC with four PCI.212 sampling boards. Each board contains two ADCs, and the boards are synchronized so that in total eight telescope channels can be sampled simultaneously. The ADCs have a resolution of 12 bit with sampling rates of 20 MHz down to 0.313 MHz in steps of a factor of 2. After collecting a batch of data, it can be copied into system memory (384 MB), previewed and stored onto CDROM.

Fig. 1 shows an overview of the WSRT system to indicate the point where the NOEMI data recorder was connected. The WSRT is an East-West linear array of fourteen telescope dishes, mostly spaced at 144 m. Each dish is equipped with front-end receivers that can be tuned to several frequency bands. Both polarizations (X and Y) are received. The resulting 14×2 channels are amplified, filtered, down-converted to an intermediate frequency (IF) range around 100 MHz, and transported to the main building via coaxial cables. Here, the signals are fed to the equalizer unit which compensates for the frequency dependent attenuation in the ground cables. The equalizer unit has outputs for the broadband continuum system (DCB, 8 bands of 10 MHz) and for the spectral line system (DLB, 10 MHz). In the equalizer unit and in the DCB/DLB IF systems are mixers, amplifiers and filter units which take care of the baseband conversion and filtering. At baseband the signals

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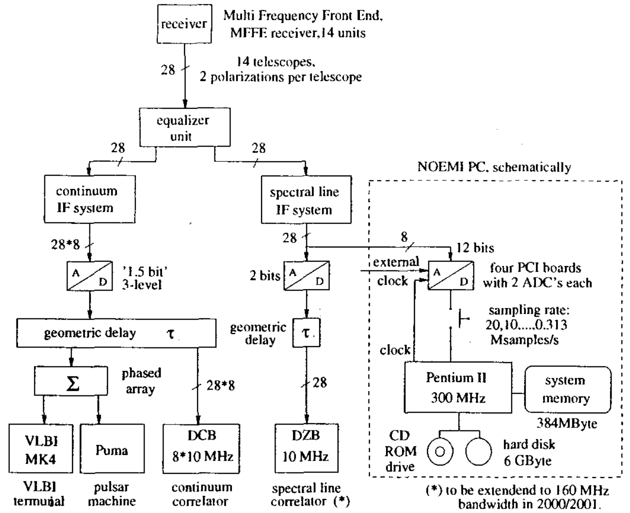

Figure 1: Overview of main WSRT systems with the NOEMI data recorders

are digitized to 2-bit resolution, a correction is applied for the geometric delay differences between the telescopes, and the signals are correlated (in pairs) in the DZB/DCB correlators. The NOEMI recorder is connected at the output of the DLB spectral line IF system. Of the 14 × 2 available telescope channels, a selection of eight are connected to the NOEMI ADC samplers.

The WSRT system contains also calibration noise sources, which are switched on for a 1.25s period every 10 seconds. For regular WSRT observations these noise sources are used for system noise and gain calibration purposes. In some of the observed NOEMI data sets these noise sources are clearly visible as a 5–15% power step.

3. MEASURED TDMA SIGNALS

An extensive set of interference measurements had been taken. Complete description of this data can be found in [5]. We shall give few examples of intermittent interferers that have been recorded.

In all observations the telescopes were tracking an astronomical source, to enable the investigation of the effect of interference suppression algorithms on both the interferers and on the astronomical signals. In most cases, 3C48 was used as reference, but we have also observations of pulsars (with and without interferers), and OH0130+621.

Graphs 2-4 demonstrates the time-frequency distribution of GSM uplink, downlink and Iridium signals respectively.

We can see that while the GSM up-link and Iridium are really intermittent, some of the channels in the GSM downlink are continuously active.

4. PROCESSING OF MEASURED DATA

We have tested our previously proposed blanking algorithm on some of the GSM data and demonstrated the effectiveness by adding the GSM observation to 'clean' 3C48 data, in a variety of scalings. As shown in this section, the results are quite good, as it is possible to recover a 3C48 absorption line which was completely masked by the GSM interference. This demonstrates the possibility of using blanking techniques for recovering the original sky signals in the presence of TDMA types of interference.

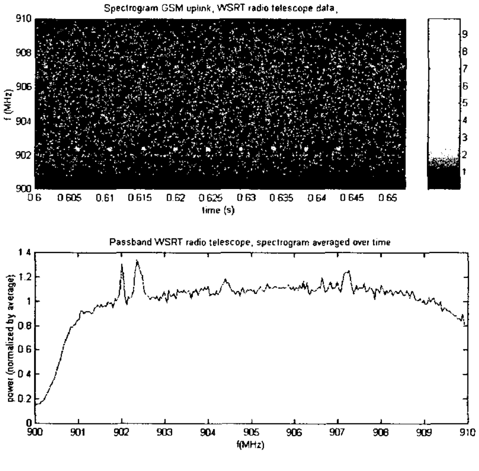

Figure 2: GSM uplink

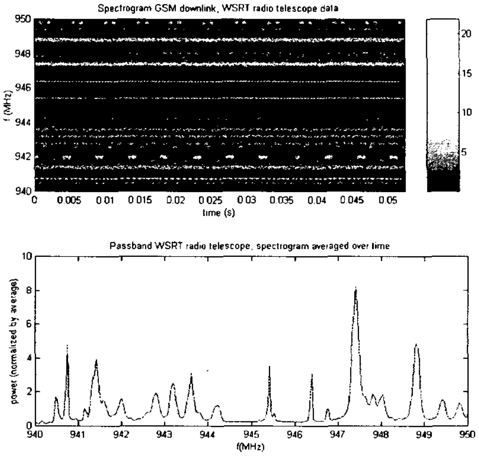

Figure 3: GSM downlink

4.1. Sub-band processing

As we have shown in previous research [6], we need to split the data into narrow-bands, in order to enable the use of narrow-band techniques. The basic idea is as follows. The data is split into many narrow sub-bands. Then for each of these sub-bands a cross-spectral matrix is constructed. The interference is detected based on its spatial structure, using the eigenstructure of the cross spectral matrices. In case that no interference is detected the cross spectral matrix is integrated into the spectral estimation, otherwise it is ignored (i.e, blanked). The resulting correlation and detection scheme is depicted in figure 5, a detailed description of the algorithm can be found in [3]. To demonstrate the dependence of the eigenstructure on the number of sources we have chosen a single

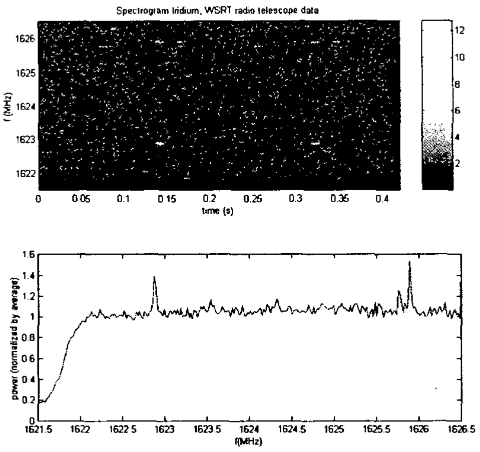

Figure 4: Iridium downlink

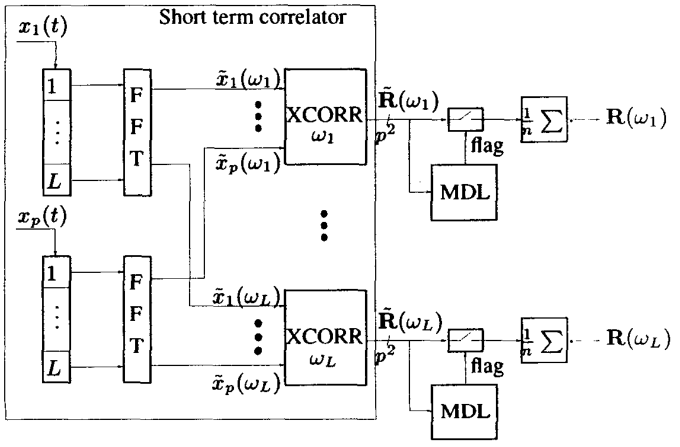

Figure 5: Computational structure of the blanking process

frequency channel of 52 KHz, in the GSM uplink, in which we had a continuous interference due to leakage from a local oscillator, and from time to time a weak GSM interference. and we computed the 0.5ms cross spectral matrices. Figure 6 presents the time evolution of the eigenstrcture of the matrices. One can clearly see the largest eigenvalue due to the CW interference, and the intermittent rank increase due to the GSM signal.

4.2. Clean 3C48 absorption data

To compare our frequency domain correlation process to the Westerbork correlator we have observed the galactic HI absorption of 3C48, a spectral line at 1420 MHz. Figure 7 shows the estimate of the power spectral density of the received signal based on the largest eigenvalue of the covariance matrix.

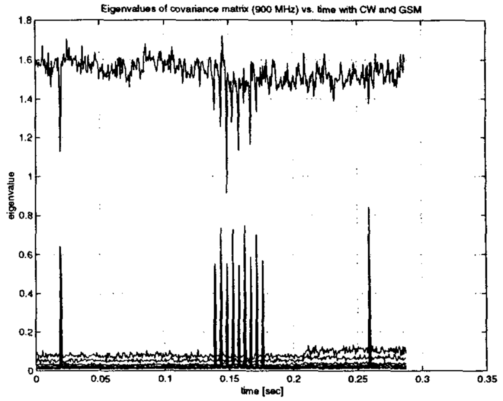

Figure 6: Time evolution of eigenstructure

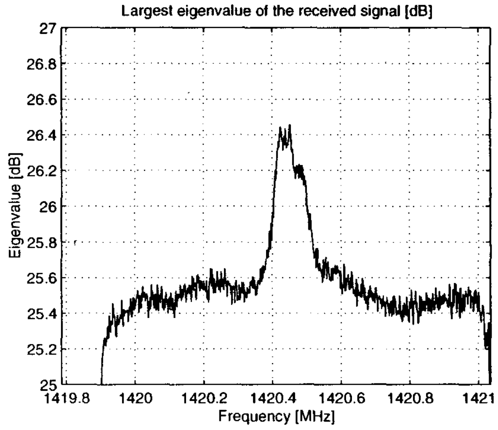

Figure 7: 3C48 power spectral density

The coherency (correlation coefficient) of signals x_i and x_j at the output of telescopes i and j is defined as

$$\rho_{ij}(\omega) = \frac{E(x_i(\omega)\bar{x}_j(\omega))}{\sqrt{E(|x_i(\omega)|^2)E(|x_j(\omega)|^2)}} = \frac{R_{ij}(\omega)}{\sqrt{R_{ii}(\omega)R_{jj}(\omega)}}$$

Since all telescopes are tracking the same source s, we have that $x_i = s + n_i$ where n_i is the noise at telescope i. With uncorrelated noise of power $E(|n_i|^2) = \sigma^2$, and a source power of σ_s^2, it follows that

$$\rho_{ij} = \frac{\sigma_s^2}{\sigma_s^2 + \sigma^2} \qquad (i \neq j)$$

Thus, the theoretical value of the coherency is constant over all nonzero baselines, and can be estimated based on the parameters of 3C48 and knowledge of the receiver noise. The frequency domain coherency of the recorded observation can also be computed and compared to the theoretically expected (asymptotic) value, and to the coherency measured with the DZB hardware.

Figure 9 shows the coherency function for all nonzero baselines. We verified that the absorption line is statistically significant. For comparison we include the same spectral line as processed by the WSRT DZB correlator in figure 8. The values of the coherency match those measured by the DZB.

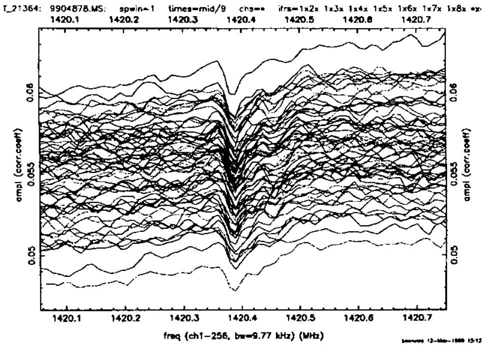

Figure 8: 3C48 coherency function as measured by the DZB

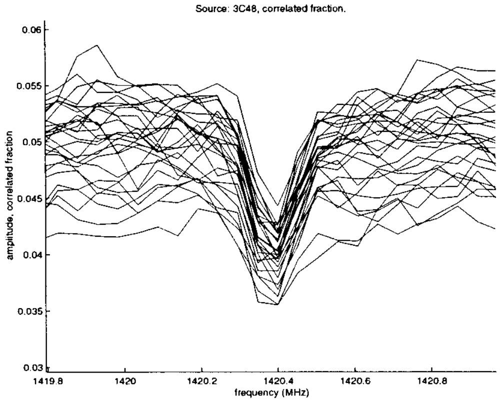

Figure 9: 3C48 coherency function (for all baselines)

4.3. 3C48 continuum emission with GSM interference

To demonstrate the capability of our sub-band blanking method as proposed in [6] and [3], we have superimposed on the 3C48 data another measurement file containing GSM interference, with the same bandwidth and varying the amplitude scaling of each file. Although a bit artificial, the good linearity of the WSRT system implies that had a GSM signal been transmitted with a carrier frequency 1420 MHz, then the measured data will be the superposition of the two signals, and system noise. This allows us to verify the blanking performance for various mixtures of signal-to-interference power, since the clean data is now available as a reference and also the theoretical coherency is well known.

The detection was based on the cross spectral correlation matrix of the resulting mixed observation data. However, instead of selecting a blanking threshold derived from a desired False-Alarm rate, we have simply thrown away the worst 30 percent of the data. We have computed the coherency of the clean, the contaminated and the blanked signals. Figure 10 shows the coherency functions for a particular mixture of signals and interference (0.1 for interference, 0.9 for clean 3C48) over all baselines. It is seen that the clean 3C48 spectrum shows the absorption line, which is completely masked when GSM interference is added. After blanking, the absorption line is almost perfectly recovered. For comparison we also included the results of blanking based on channel 2, without the sub-band decomposition, we can clearly see the failure of such single channel scheme, as the GSM signal was weak.

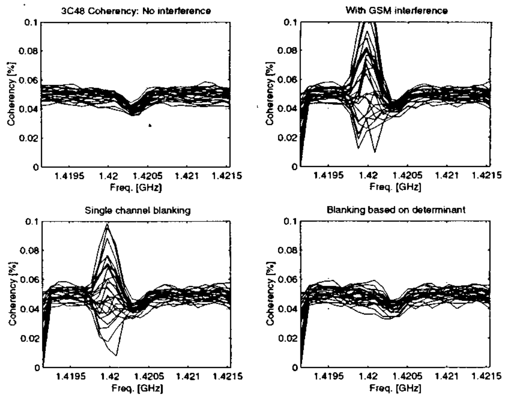

Figure 10: 3C48 mixed with GSM: averaged coherency functions of contaminated, clean and blanked data

5. CONCLUSIONS

This paper demonstrates the possible benefits of multichannel spatio-spectral blanking on measured data. The results are very pleasing although many technical issues are left open for further investigation.

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