Development of an Electromagnetic Interference Monitor from 1 GHz to 18 GHz

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Abstract After conducting an interference monitoring campaign using equipment from Wettzell [1], the IAR decided to develop a new transportable RFI measuring system covering the range from 1 GHz to 18 GHz. For this, new components like a new antenna with a proper calibration certificate and a spectrum analyzer were acquired in order to improve the frequency range of the observations and the sensitivity of the system.

Keywords RFI monitoring, VLBI sites, TIGO, IAR, transportable

1 Motivation

When evaluating a location for a radio telescope, either to make astronomical observations or for geodetic VLBI observations (such as at TIGO), from the point of view of electromagnetic interference (RFI) it is to be expected that the selected site is as quiet or free from interference as possible. To assess these characteristics at a particular site, a system for monitoring electromagnetic interference is needed that is compatible with the radio telescope to be used, and for studying and monitoring the same frequency bands as to be used by the observing system. This equipment should have high sensitivity and allow the detection of signals from very low power, which would greatly affect the observations made by the telescope.

The duration of the monitoring for RFI signals at a selected site is also important, as there are likely sporadic signals that may or may not repeat over a day or on different consecutive days. The measurement duration is conditional upon the time available for site selection. It is desirable to have as many measurements as possible, in order to obtain a database of the site for the evaluation of the progress with time, or in subsequent measurements since the operation of the radio telescope. This is of importance when making the effort (along with the appropriate agencies) to maintain the spectrum allocated for scientific use [2] free from interferences which may occur during operation of the telescope.

2 System Overview

The monitoring system of interference is divided into three stages. In this article we will focus on the stage of radio frequency and data processing:

- RF stage: includes the measuring antenna, RF amplifiers, low noise, system calibration using noise diode, and spectrum analyzer.
- Status of control and monitoring: includes the hardware to monitor the status of the RF amplifiers and control system calibration and monitoring of the input voltages.
- Stage of acquisition: the acquisition and control software for measurement is linked to the stage of monitoring and control, as well as the spectrum analyzer in order to make the RFI measurements.

The software was developed in the programming language “C” on a Linux platform, allowing portability to other platforms if necessary. For RFI measurements, the software uses data from a configuration file editable by the user with the different observation parameters

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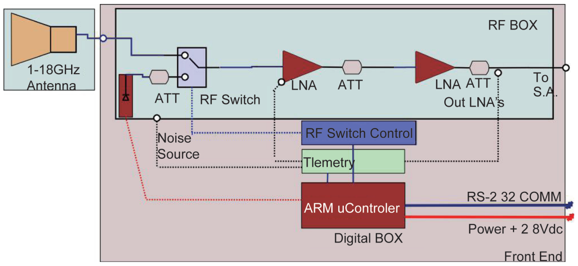

Fig. 1 RF Stage, block diagram.

such as start and end frequency, number of repetitions, resolution bandwidth or RBW, and pointing directions. The RF stage, or frontend, with its associated control is mounted on a custom antenna rotor, which allows observations on the horizontal plane orienting the antenna in different directions. The number of measuring points will be defined by the minimum bandwidth of the antenna, to the highest frequency. The polarization is changed mechanically, by rotating the axis of the antenna 90°. This system is in development at the time of writing this article. From the RF box, or frontend, an RF cable is routed to the spectrum analyzer. This cable should be short in order to minimize the signal attenuation; depending on the cable to be used the maximum length will be calculated.

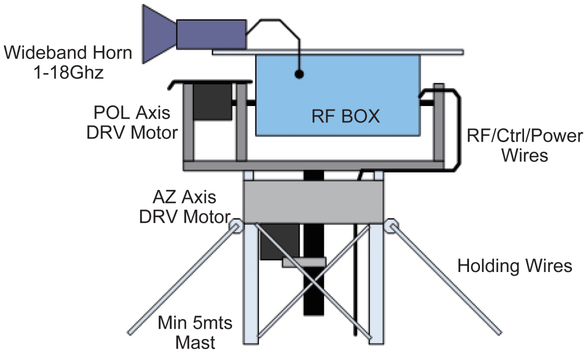

Fig. 2 Schematic view of the antenna rotor.

3 RF Stage Description

The RF stage is designed based on the following components, which were acquired for the present development.

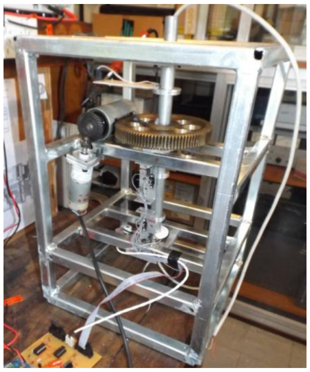

Fig. 3 Picture of the antenna rotor under development.

- RF Antenna: EST-Lindgren model 3117 with radome, operational frequencies 1 GHz to 18 GHz, HPW 85°@ 2 GHz — 40°@ 18 GHz (E-Plane), Gain 3–10 dBi.
- RF Switch: HP8761B, insertion loss: 0.8dB @ 18 GHz.
- Low noise amplifiers: Miteq model AFS42 NF 2.5 dB, operational frequencies 1 GHz to 18 GHz, Gain 39 dB.
- Noise Source: NoiseWave NW346D, ENR:23 dB.
- Spectrum Analyzer: Agilent N9344C, DANL −144 dBm.
- RF Down link cable: Heliax, Insertion Loss 12 dB/10 mtrs.

To evaluate the system properties the different parameters of each component are analyzed according to the Figure 1 block diagram, resulting in the total system gain and system temperature and thus knowledge about the sensitivity of the system.

- **System gain:**
  The system gain is given by the sum of the gain of each component. For this the minimum gain values of each component are evaluated.

$$G_{sys} = G_{rfSwitch} + G_{amp} + G_{att} + G_{amp} + G_{rfCable}$$

$$G_{sys} = (-0.8 + 39 - 6 + 39 - 12)\text{ dB} = 58.2\text{ dB}$$

- **Receiver temperature:**
  The system temperature is given by the following equation, with the temperature or noise figure from the first amplifier being the most critical. In the equation, the temperature from the spectrum analyzer (DANL) should be included as the last parameter to evaluate; but as this is very low, the aggre-

gate value of temperature is negligible, and thus is not included to simplify the equations.

$$T_{rx} = T_1 + \frac{T_2}{G_1} + \frac{T_2}{G_1} + \ldots + \frac{T_2}{G_1}$$

where:
T_{rx}: Receiver temperature
T_n: Each stage temperature
G_n: Each stage gain (linear)
For Passive or active componentes must be used

$$T_{passive} = (L-1) \cdot T_a$$

$T_{passive}$: Passive component temperature
L: Loss factor
T_a: Physical component temperature

$$T_{active} = (F-1) \cdot T_a$$

T_{active}: Passive component temperature
f: Noise Figure $F = 10^{(F[dB]/10)}$
T_a: Physic component temperature

$$T_a = 290°K$$

Evaluating the different component parameters gives:

$$T_{rx} = 330.28°K$$

- **Receiver sensitivity:**
  The receiver sensitivity is the parameter related to the minimum signal to be detected, thus allowing comparisons with other receiver systems.
  Taking into account parameters from the antenna and observed resolution band width, the sensitivity is calculated in the form of flux density units as follows:

$$S_o = \frac{k \cdot T_{sys}}{\rho \cdot A_e \cdot \sqrt{B \cdot t}} \, [\mathrm{Wm^{-2}Hz^{-1}}]$$

where:
T_{sys}: Receiver temperature plus antenna temperature
A_e: Antenna effective area
"k" Boltzmann's constant
"B" Resolution bandwidth
"t" Integration time
"ρ": 1/2 due to the linear polarization of the "H" or "V" antenna
Using the relationships between the parameters of the antenna A_e, G_i, and K_a and maintaining an impedance of Z=50 ohms, the sensitivity can be expressed as:

$$S_o = \frac{0.133}{\rho} \cdot \frac{k \cdot T_{sys} \cdot K_a^2}{\sqrt{B \cdot t}} [Wm^{-2}Hz^{-1}]$$

where:

$$K_a = 3.24 \cdot 10^{-8} f(Hz) \sqrt{\frac{1}{G_i}}$$

$f(Hz)$: Observed frequency
G_i: Isotropic antenna gain [dBi]
Thus leaving the sensitivity according to the observed frequency.
Using the following parameters as an example we get a sensitivity of:
F_o =1413.5Mhz
B = 10KHz
T_{Int} = 0.1mSeg
G_i=5dB
T_{ant} = 12K
ρ=1/2

$$K_a = 3.24 \cdot 10^{-8} f(1413.5 \cdot 10^6) \sqrt{\frac{1}{5}} = 20.29$$

$$S_o = \frac{0.133}{\rho} \cdot \frac{k \cdot (330.28 + 12) \cdot 20.29^2}{\sqrt{10 \cdot 10^3 \cdot 0.1 \cdot 10^{-3}}} = 5.17 \cdot 10^{-19} \mathrm{~Wm^{-2}Hz^{-1}}$$

$$S_{o[dB]} = -182.86 \mathrm{~dBWm^{-2}Hz^{-1}}$$

In order to obtain a better time resolution, multiple iterations of the same set of observations are made. This provides a larger number of samples allowing for a better evaluation of the presence of possible interfering signals.

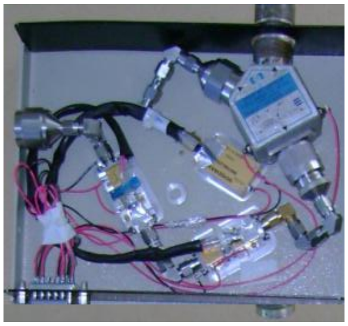

Fig. 4 Components of the RF stage.

- **System calibration:**
  The system calibration is performed using a noise diode with an “excess noise ratio” (ENR) of 23 dB; in addition, an attenuator is used in order to maintain a similar value for the expected system noise. At the end of each measurement cycle, two measurements are realized with the same settings as used before: the first with the noise diode off and the second with the noise diode on.
  With this measuring cycle, similar to a three-state Dicke type receiver, one can obtain a measure of the gain of the system and the temperature of the receiver, allowing the data to be calibrated and understand the functioning of the system.
  The temperature of the receiver is evaluated as follows:

$$ENR = 10^{\frac{ENR_{dB}}{10}}$$

$$T_o = T_{amb}$$

$$T_hot = T_o \cdot (ENR + 1)$$

$$Y = \frac{P_{on}[W]}{P_{off}[W]}$$

$$T_{rcv} = T_o \cdot (\frac{ENR}{Y-1} - 1)$$

$$G_{ercv} = \frac{P_{on}[W]}{k \cdot B[Hz] \cdot (T_{hot} + T_{rcv})} \ .$$

Figures 5 and 6 show the actual measurements and a system evaluation. It can be seen that the segment of 10 GHz to 14 GHz has a higher gain ripple level and the behavior translates into an increase in the system temperature. This is probably due to an adaptation mismatch of the amplifiers operating in that frequency.

It can also be seen that the temperature of the receiver is above 400 K when the calculation showed a system temperature of 330 K. This is due to a mismatch in the real components parameters or additional attenuation in the input transmission line, as well as the RF switch. In order to enhance the system parameters and reduce the input attenuation, higher quality RF cables and connectors should be used at the input stages.

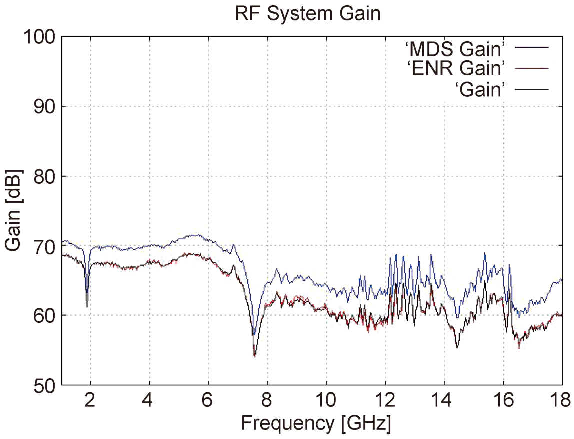

Fig. 5 System gain.

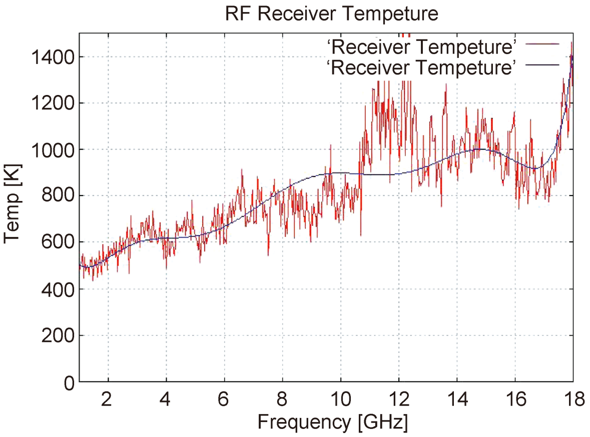

Fig. 6 System temperature.

4 Post-Processing of the Measurements

The raw data from the spectrum analyzer as well as from the control and monitoring modules are published online on a Web page for a visual check of system functionality. Go to http://www.iar-conicet.gov.ar/ggancio/rfi/rfi_stat.html for online RFI data.

After generating the measurement files, according to the previously set modes, the off-line processing is realized. In principle two analyses were performed: The first analysis takes all measurements made without distinguishing pointing direction or antenna polarization in order to obtain a global profile of the observed spectrum. With this set of measurements the maximum and minimum percentiles of 10 and 90 were obtained. These indicate the detected interference over a percentage depending on the number of samples, thus giving an idea of spectrum occupancy versus time observed. The second analysis evaluates each observed polarization and each measured direction separately, thus giving an idea of the RFI direction from which it came or some mode interference. This analysis is carried out the moment an RFI is identified in order to characterize and analyze its features in more detail. If the case allows it, with an RFI located in a frequency band allocated for passive use only, one may give notice to the national regulatory agency to intercede in the case. In both cases raw data is processed in the same manner; the difference lies in the number of files to process. Taking all the files in the first case and by filtering in polarization and direction in the second one. The raw data, in units of dBm given by the spectrum analyzer, are transformed into flux density units, related to the antenna input. With this the system parameters such as gain variations or antenna parameters are removed from the resulting plots. This unit also permits to evaluate according to the recommendations of the ITU [3] if the interference levels are detrimental or not for a radio astronomy station. The simplified equation for transforming units is as follows [4]:

$$S_{dB} = P_{SA[dBm]} - 10log_{10}B - G_{rcv[dB]} + K_A - 35.77$$

$$S_{dB} = [\mathrm{dBWm^{-2}Hz^{-1}}]$$

Figure 7 shows a sample image, which was obtained from 56 measured scans using a resolution of 30 kHz RBW in the range from 1 GHz to 18 GHz in the geographical location of the IAR (La Plata, Argentina). Figure 8 depicts a direction analysis for RFI incidence angles using data from [1].

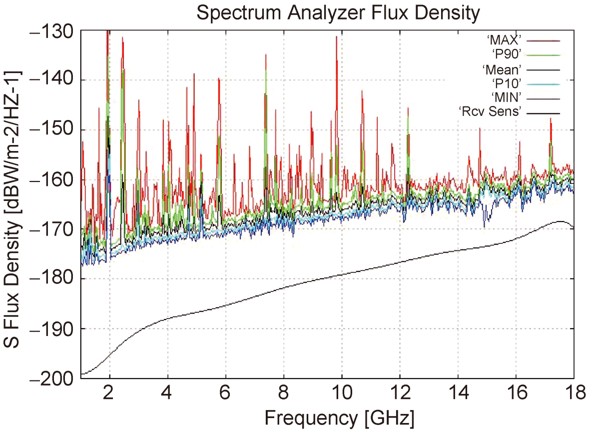

Fig. 7 Resulting spectrum.

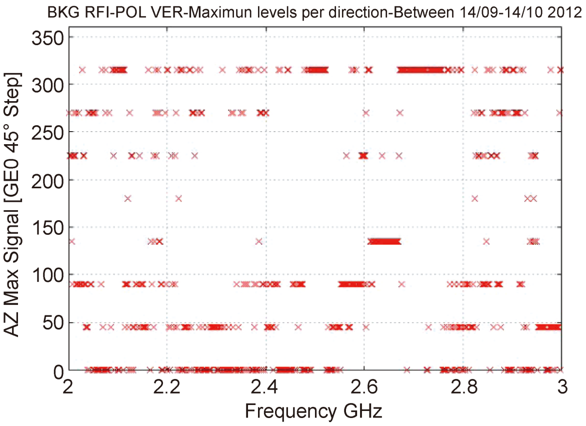

Fig. 8 Amount of RFI detected vs. direction.

5 Conclusions

A development of a new instrument for measuring electromagnetic interference "RFI" in order to perform a site characterization in order to evaluate potential sources of interference was presented. The development was designed to be portable, allowing their installation virtually anywhere. Once installed for evaluation in the IAR, it will generate a database for local RFI, operating continuously, allowing to assess their performance and to make improvements to the system.

References

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