

REPORT ITU-R RA.2126

Techniques for mitigation of radio frequency interference in radio astronomy

(Question ITU-R 237/7)

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1 Introduction

This Report aims to provide a concise technical summary of the current state-of-the-art in techniques for the mitigation of radio frequency interference (RFI) in radio astronomy. Specifically, this report considers techniques for the mitigation of man-made interference that originates from outside the instrument and is therefore beyond the control of the instrument operator. For the purposes of this report, the criterion for classification of a signal as RFI is simply that it is an unwanted but detectable portion of a desired observation that has the potential to either degrade or inhibit the successful conduct of the observation. Some interference is not easily detectable but can still degrade the observations. Its mitigation is much more difficult.

The aim of mitigation techniques is to permit observation at the levels of sensitivity specified in Recommendation ITU-R RA.769, with percentage of data loss within the limits specified in Recommendation ITU-R RA.1513. These Recommendations provide the conditions for efficient observing in radio astronomy, and provide the numerical basis for calculation of tolerable RFI conditions in sharing and compatibility studies. Mitigation methods other than simple excision of RFI-contaminated data are not widely used in radio astronomy, mainly because they are not easy to devise or perform and may require the development of extensive special software.

Until recently, the standard observing modes and signal processing techniques used in the course of making observations provided an inherent degree of interference mitigation that proved adequate to provide useful astronomical data in the presence of some interference.

For example, “fringe stopping” in aperture synthesis imaging has the tendency to decorrelate the RFI received at widely-separated antennas, which tends to suppress the RFI in the associated correlation products [Thompson, 1982]. In the case of some synthesis radio telescopes, such interference may result in a spurious bright source appearing in the maps at the celestial pole, making high declination observations difficult or impossible. Pulsars produce pulses of broadband noise, so a significant receiver bandwidth is needed to achieve a useful signal-to-noise ratio. The noise making up the pulses is subject to frequency-dependent dispersion as it propagates through the rarefied plasmas in the interstellar medium. When observing a pulsar with a radio telescope, the pulse is deliberately de-dispersed using a combination of hardware and software, to recover an accurate (non-dispersed) representation of the intrinsic pulse profile. This process tends to reduce RFI, because the process of de-dispersing the pulsar signal consequently disperses the RFI. Only limited mitigation is provided by these processes.

Data are always degraded when interference is present. Increasingly astronomers find that the strength and temporal/spectral density of RFI is such that observations are “saturated” by RFI and made useless. Perhaps the most vulnerable observations are those made with single-dish radio telescopes (continuum or spectroscopy), because the improvement in sensitivity to astronomical signals afforded by increasing integration time leads to a proportional increase in sensitivity to RFI signals. While certain observing modes offer some intrinsic robustness to low levels of RFI, the low

received signal strengths of cosmic radio emissions make radio astronomy highly vulnerable to interference.

The impact of RFI extends beyond simply preventing or degrading certain observations or types of observation. It also limits the overall productivity of the radio astronomy station, making desirable observations prohibitively difficult or expensive in terms of observing time requirements, processing complexity and operational overheads. An example is the increasing need for manual post-observation editing of data to remove RFI, as is sometimes practiced in aperture synthesis imaging [Lane *et al.*, 2005]. While quite effective, it is difficult to automate and therefore becomes extraordinarily tedious as the observation length and observed bandwidth increase. The presence of RFI sometimes translates into dramatically increased requirements for both labour and telescope time, which is as limiting to science as is RFI that irretrievably obliterates the emission being observed.

These issues have motivated research into techniques for mitigation of RFI that might be considered “automatic” or “real time” in the sense that any given technique is nominally an integral part of the instrument, and operates without human intervention. This is the context in which the techniques described in the following section are presented.

2 Techniques for mitigating RFI

The study of techniques for mitigating RFI contaminating the analog output of radio telescope receivers has been a topic of heightened interest in recent years, spurred on by technological advances that enable real-time signal processing approaches to RFI mitigation. A helpful introduction to this area is provided in summaries of recent conferences addressing the issue; see for example [Bell *et al.*, 2000 and Ellingson, 2005]. For the purposes of this Report, a concise taxonomy of mitigation techniques might be organized as follows:

1. *Excision*, in the sense of “cutting out” RFI. For example, RFI consisting of brief pulses might be mitigated by blanking the data when the pulse is present; this is *temporal* excision. Alternately, persistent RFI might be mitigated using array beam-forming techniques to orient pattern nulls in the directions from which the RFI is incident; this is *spatial* excision. A common property of all excision techniques is some loss of astronomy data, the possible distortion of the remaining data due to artefacts introduced by the excision process. Since blanking is essentially a loss in observing time, there is a concomitant increase in the observing time required to reach the required sensitivity or measurement accuracy.
2. *Cancellation*, in the sense of “subtracting” RFI from the telescope output. Cancellation is potentially superior to excision in the sense that the RFI is removed with no impact on the astronomy, nominally providing a “look through” capability that is nominally free of the artefacts associated with the simple “cutting out” of data. However, as discussed below, the tradeoff with respect to excision is usually that suppression is limited by the estimate of the interference received by the radio telescope.
3. *Anti-coincidence*, broadly meaning discrimination of RFI by exploiting the fact that widely-separated antennas should perceive astronomical signals identically, but RFI differently. In such instances the RFI makes a contribution to the background noise level at each antenna rather than to the correlated signals. This degrades the correlated signal received, which may require an increase in the observing time to achieve the signal to noise ratio needed.

Mitigation methods that are frequently or routinely used at observatories are mostly based on temporal excision, i.e. deletion of data that is believed to be contaminated by RFI. These are described in § 2.1. Spatial excision (§ 2.2) and methods involving cancellation (§ 2.3 and § 2.4) have been demonstrated using real or simulated astronomical data, but are in most cases are under further development or used only in special circumstances. The various forms of spatial excision

generally require considerable special software and increased computer power. Anti-coincidence techniques (§ 2.5) provide a very effective means of identifying data that are contaminated by RFI, but cannot strictly be classified as mitigation since they do not provide a means of removing interference other than temporal excision.

2.1 Temporal excision (blanking)

This is perhaps the oldest and best-known strategy for real-time mitigation of pulsed RFI. Interest in blanking seems to have emerged first in response to the problems encountered in observing in the 1 215-1 400 MHz band due to ground-based aviation radars. These radars typically transmit pulsed fixed-frequency or chirped sinusoidal waveforms with pulse lengths of 2-400 ms, 1-27 ms between transmitted pulses, and bandwidths on the order of 1 MHz. These pulses are often detectable through the sidelobe of radio telescopes hundreds of kilometres away. Although the transmission duty cycle is relatively low (typically less than 0.1%), accurate blanking is made difficult by the short period between pulses. A second factor which makes blanking of radar pulses difficult is that reflections from terrain features and aircraft generate additional copies of the pulse which arrive long after the “direct path” pulse (see, e.g. appendix of [Ellingson and Hampson, 2003]. It is common for these multi-path pulses to be strong enough to corrupt the astronomical observation and yet too weak to be detected reliably. Thus, a blanking interval triggered by a detected pulse must typically be many times longer than the detected pulse, in order to ensure that all of the multi-path copies of a detected pulse are also blanked. Blanking intervals having lengths up to 100’s of microseconds (i.e. 10-100 times the pulse duration) are typically required [Ellingson and Hampson, 2003].

A number of real-time techniques for temporal excision have been proposed and developed to various degrees. Friedman [1996], Weber *et al.* [1997], and Leshem *et al.* [2000], each describe methods for detecting impulsive interference and blanking the output accordingly. The National Astronomy and Ionosphere Center (NAIC) has developed a device for real-time mitigation of strong local radar pulses at the Arecibo Observatory (Puerto Rico). This device works by tracking the known pattern of the timing between pulses for this particular radar, and then blanking the output of the receiver in a time window around the expected pulse arrival times. More recent work in this area, including experimental results, is described in [Ellingson and Hampson, 2003; Fisher *et al.*, 2005 and Zheng *et al.*, 2005], with the latter two references addressing the similar problem of pulsed interference from aviation distance measuring equipment (DME).

The primary limitation of blanking is detection performance. This is because once an RFI pulse is detected, it can be completely removed by blanking. However, it is inevitable that some fraction of weak but potentially damaging pulses will not be detected. Over the time-scale of a single pulse, however, astronomical signals routinely have a signal-to-noise ratio (SNR) $\ll 1$; thus RFI must be reliably detected at these levels in order to be effectively suppressed in the integrated output. This is quite difficult, and the recent successes using blanking cited above are attributable to having detailed advanced knowledge of the RFI waveform, which can then be used to offset an inadequate SNR to some extent.

Further improvements in detection performance appear feasible using aspects of the RFI waveform that can be exploited without specific knowledge of the waveform, as, for example, cyclostationarity [Britteil and Weber, 2005] who applied it to the HIBLEO2 (Iridium) Satellite signals) and Kalman tracking [Dong *et al.*, 2005] who applied it to aviation radar). Another challenging problem is how to set detection thresholds and blanking window length so as to achieve an acceptable tradeoff between robust RFI mitigation (suggesting low thresholds and long windows) and limiting degradation of sensitivity and the introduction of blanking artefacts (suggesting high thresholds and short windows), which was studied by [Niamsuwan, Johnson and