

SIDHARTH MISRA, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA
PAOLO DE MATTHAEIS, Goddard Space Flight Center, National Aeronautics and Space Administration, Greenbelt, MD, USA

Passive Remote Sensing and Radio Frequency Interference (RFI): An Overview of Spectrum Allocations and RFI Management Algorithms

Introduction to “Technical Committees”

by John Kerekes, Vice President of Technical Activities

Each issue we feature one of our Technical Committees to share with the community their mission, objectives, and activities. Here we present a contribution from the Frequency Allocations in Remote Sensing (FARS) Technical Committee. As explained in the article, FARS represents the interests of our community in regards to use of the radio frequency spectrum. Please contact the Chair or Co-Chair (authors of the article) if you have an interest in participating in this Technical Committee.



membership of current frequency management issues, processes and influencing regulatory efforts by organizing a GRSS response. We coordinate GRSS technical recommendations and responses to regulatory organizations. We track current and future user spectrum requirements, investigate potential interference issues and promote the development of RFI detection and mitigation techniques.

As the usable spectrum gets increasingly crowded, the GRSS FARS community has taken a pro-active approach to deal with interfering sources. It is important not only to keep track of the constantly changing frequency allocations but also develop active interference detection and mitigation approaches to measure usable data in our spectrum of interest. The next section summarizes frequency allocation issues and interference observed by passive remote sensing instruments. Section 3 briefly describes the interference detection algorithms developed by the GRSS community, before summarizing recent and upcoming FARS activities in the last section.

1.0 INTRODUCTION

The Frequency Allocations in Remote Sensing (FARS) Technical Committee (TC) was formed in 2000 as a means for the IEEE Geoscience and Remote Sensing Society (GRSS) community to discuss spectrum management issues that affect the remote sensing field and to provide a unified interface to the regulatory world. Presently, FARS members include 84 engineers and scientists representing government, academic and industrial entities across 10 countries.

Spectrum management has become an important issue for many members of the GRSS. Increasingly over the past decade, members of GRSS engaged in passive and active microwave remote sensing have been coping with corrupt measurements due to radio frequency interference (RFI). Accordingly, the charge of the FARS TC is:

To interface between the GRSS membership and the frequency regulatory process, which includes educating the

2.0 OVERVIEW ON FREQUENCY ALLOCATION

At an international level, use of the radio frequency spectrum is regulated by the International Telecommunication Union (ITU). Changes to the Radio Regulations are adopted at the World Radiocommunication Conferences (WRC), held every three to four years. At every WRC, a worldwide table of allocations is agreed upon by the member administrations of the ITU, and is established among the different ITU regions.

Allocations are meant to accommodate one or more services within a shared frequency bands by coordinating their respective applications to minimize harmful reciprocal interference. Frequency allocations offer users an overview of the Radio Frequency environment and guidelines under which to operate in each particular band. Compliance with the ITU table is only required at an international level, while each

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country is free to modify the ITU table for services within its borders [1].

Each allocated service is generally granted either primary or secondary status. Secondary services shall not cause harmful interference to primary services. They also cannot claim protection from harmful interference caused by a primary service; however they can claim protection from harmful interference from sources of the same or other secondary services. Current Radio Regulations have allocated frequencies between 9 kHz and 275 GHz. It is important for GRSS FARS to represent the spectrum needs of its community at a spectrum management meeting such as WRC.

2.1 FREQUENCY ALLOCATIONS AND RADIO FREQUENCY INTERFERENCE IN PASSIVE REMOTE SENSING

Though frequency allocations exist for microwave remote sensing, RFI is still a significant issue. Table 1 shows a list of the most relevant frequency bands allocated to passive remote sensing EESS (Earth Exploration Satellite Service) [2],[3] with their main scientific uses and their spaceborne sensors which are currently—or are scheduled to begin—operating in that frequency band. The expected level of RFI and its sources are also indicated in Table 1. Except for the secondary 1.37–1.40 GHz allocation and the 6.425–7.25 GHz limited-protection band, all allocations are primary.

When the band is shared with other services, RFI degrades the quality of the remote sensing data. Passive sensors are especially vulnerable to RFI because of the very low levels of the detected signal that carries information. The last column in Table 1 reports level and likely sources of observed RFI. Even in protected and non-shared bands, RFI can still originate from sources emitting in adjacent bands. As noted in Table 1 and the figures below, even though many of the allocations are primary or protected, RFI still plagues the incoming brightness temperature (T_b) signals. Frequency allocations from 82 to 275 GHz were not reported, since the current RFI threat is low for those channels.

An example of the RFI threats stated in Table 1 is shown in Fig. 1 which indicates the RFI observed in three of the most used bands in passive microwave remote sensing (1.4 GHz, 6 GHz and 10 GHz). Due to different spectrum allocation rules in different ITU regions,

TABLE 1. RFI-THREATENED PASSIVE EESS FREQUENCY ALLOCATIONS.

BANDS (GHZ)	SCIENTIFIC OBSERVATIONS	SPACEBORNE INSTRUMENTS	RFI LEVEL AND SOURCES
1.37–1.40* 1.40–1.427	Soil moisture, sea surface Salinity, sea surface wind, vegetation index	SMOS, Aquarius, SMAP	High; out of band emissions mostly from air surveillance radars.
6.425–7.25**	Soil moisture, sea surface temperature, precipitation	AMSR-2, WindSat	Moderate (especially over the U.S.A.)
10.6–10.7	Precipitation, cloud liquid water, sea surface wind speed, sea surface temperature	TMI, AMSR-2, WindSat GPM GMI	Moderate (especially over Europe)
18.6–18.8	Precipitation, cloud liquid water, snow cover, sea surface wind speed, sea ice	JASON-2 AMR, AMSR-2, WindSat	Moderate; potentially from satellite TV service signals.
22.21–22.5 23.6–24	Atmospheric water vapor, Sea surface wind speed, sea ice, precipitation, snow cover	SSM/I, JASON-2 AMR, TMI, AMSR-2, GMI, AMSU-A	Moderate; vehicle anti-collision radars
31.3–31.8 36–37	Precipitation, cloud liquid water, snow cover, sea surface wind speed, sea ice	AMSU-A, SSM/I, TMI, AMSR-2 JASON-2 AMR, WindSat, SSM/IS, GPM GMI	Low; new sources observed off oil platforms near the Indian subcontinent
50.2–50.4 51.4–59.3	Atmospheric temperature profiling	TOVS (MSU), SSM/T, AMSU-A, SSM/IS	Moderate: potential for RFI due to spectrum-sharing rules at 55–57

*Secondary allocation

**Limited protection

the geographical distribution of RFI varies depending on the frequency. Data acquired over the United States of America show corruption in the 6 GHz region, whereas the United Kingdom and Italy are more affected at 10 GHz. Fig. 1 shows RFI hot spots observed by AMSR-E in December 2010 and Aquarius in December 2011, obtained by running a peak hold algorithm over approximately a month of data.

Fig. 1 is a snapshot of the current occurrence of RFI at the respective frequencies and does not represent the increase in RFI at various bands over time. There have been studies indicating a clear increasing RFI trend over the last decade. A study done by McKague et al. [4] gives an example of increasing occurrence of RFI at K-band from 2005 to 2010. Fig. 2 illustrates the temporal evolution of the spectral difference between the brightness temperature T_b of the AMSR-E 18.7 GHz and 23.8 GHz channels. A negative value of the T_b difference represents RFI in the 18.7 GHz channel. The bottom plot (for January 2009) shows an “arc” of RFI observed over the northern regions of United States. This broad arc is attributed by McKague et al. [4] to reflections off a Direct TV satellite signal, based on the relative position and incidence angles of the satellites.

Given the presence of interference at bands of interest to the remote sensing community and the vulnerability of passive microwave systems to man-made sources, over the past decade a significant amount of work has been done to develop RFI detection and mitigation algorithms.



FIGURE 1. Map showing RFI detected at three different frequencies: RFI at 1.4 GHz as observed by the Aquarius radiometers during December 2011, RFI at 6 and 10 GHz as observed by AMSR-E during December 2010.

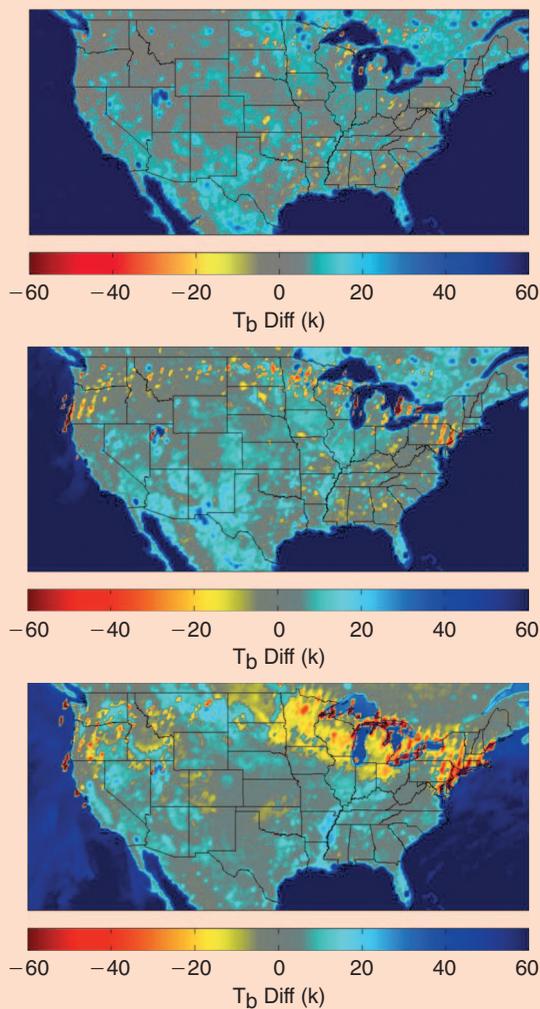


FIGURE 2. K-band RFI observed by AMSR-E for July 2005, July 2008 and July 2009. Values shown are the differences between brightness temperatures between 23.8 GHz and 18.7 GHz in V-polarization. RFI appears as negative differences < 10 K (courtesy of McKague et al. [4]).

3.0 RFI MITIGATION ALGORITHMS

RFI detection, mitigation, and in some cases estimation algorithms developed for passive remote sensing can be broadly classified in five categories.

- 1) **Spatial:** This class of algorithms detects the presence of RFI by comparing the pixel under test with its neighboring pixels. This approach is good for high-powered geographically isolated interference sources.
- 2) **Temporal:** These algorithms compare brightness temperature samples in the time domain. They work best for radar-type pulsed signals and are generally optimal when the integration period of the radiometer is matched to the offending interference pulse width [5]. The RFI source needs to be above the noise floor of the measured signal for a successful detection.
- 3) **Spectral:** For Continuous-Wave (CW) narrowband RFI sources a spectral algorithm gives optimal performance. The algorithm compares spectral bands with its neighboring bands for anomalously high signals.
- 4) **Statistical:** These algorithms are based on measuring higher order statistical properties of the signal to gauge its normality. They are non-trivial to implement, but have the capability to detect low-level interference depending on the type of interfering source.
- 5) **Polarimetric:** These algorithms take advantage of the polarimetric nature of some interfering source to distinguish it from the natural emission.

Fig. 3 gives an example of the different types of algorithms. As the diagram suggests, various algorithm classes can be combined to deal with different types of interfering sources. Though RFI detection algorithms have been built and developed for many missions over a wide spectrum, missions in the L-band have been the most active in pursuing RFI mitigation strategies. Between the current and upcoming space-borne missions, NASA's Aquarius mission, ESA's SMOS (Soil Moisture Ocean Salinity) mission and NASA's SMAP (Soil Moisture Active Passive) mission have implemented pre-launch and post-processing algorithms to deal with RFI. Even though all these three missions operate in the protected L-band, previous airborne missions have shown that RFI still occurs at this frequency (also seen in Fig. 1).

The Aquarius radiometers employ a purely temporal approach also known as "glitch" detector [6–8], closely related to the pulsed RFI detection method. The algorithm integration time was optimized to deal with early-warning radar sources with pulses of similar width [9].

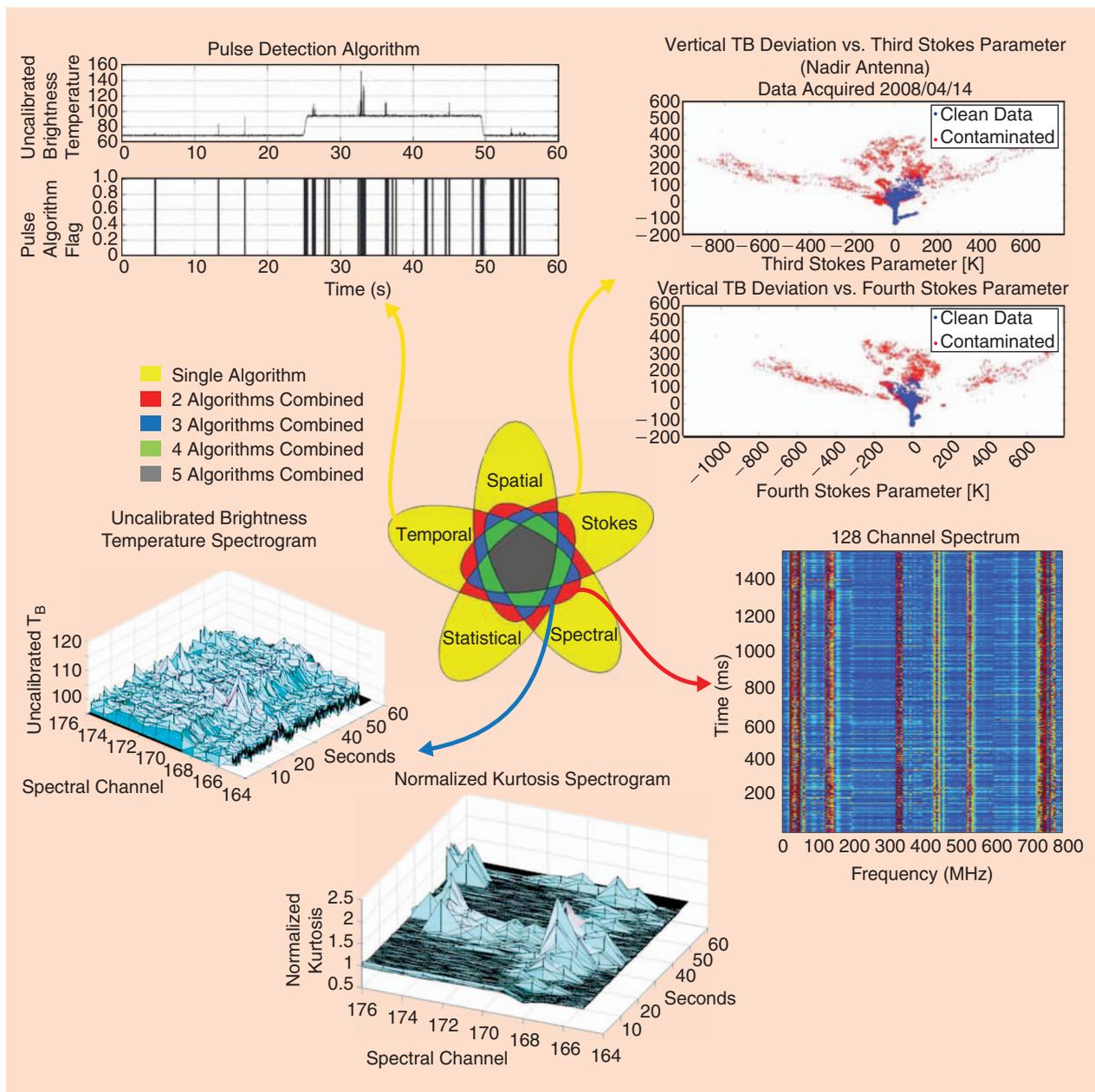


FIGURE 3. A five dimensional Venn diagram [16] illustrating the different classes of RFI detection and mitigation algorithms and their combinations. Two (red), three (blue), four (green) and five (grey) classes combinations are possible. The algorithms clockwise from top left are: Pulse Detection (Temporal) [8], 3rd/4th Stokes RFI Detection (Polarimetric, courtesy of Skou et al. [10]), Spectrogram for CW signals (Temporal + Spectral), Kurtosis (Temporal + Spectral + Statistical, courtesy of Ruf et al. [17]).

The algorithm is fairly easy to implement, but it is inherently biased and can only detect RFI above the noise floor of the radiometer, potentially missing RFI coming from continuous sources. Fig. 1 shows that it performs satisfactorily by picking up sources around the Europe, China and the Middle East.

The SMOS mission employs a unique interferometric technique for measuring brightness temperatures. This results in an RFI detection approach that is a combination of spatial, temporal (or angular) and polarimetric algorithms. The algorithm proposed by Skou et al. [10] looks

at the third and fourth Stokes parameters of the incoming signal and any deviation away from zero (as seen in Fig. 3 polarimetric). Another algorithm proposed by Misra et al. [11] takes advantage of the smooth geophysical variation of brightness temperature with respect to incidence angles, and detects deviations from a smooth fit. The SMOS mission has been very active in identifying the interference sources at L-band, geo-locating them and turning them off. This has led to more complicated algorithms that not only detect RFI sources but attempt to locate them as well [12].

Among the L-band space-borne missions, the upcoming SMAP mission has been the most aggressive in pursuing advanced detection and mitigation strategies for RFI affecting its passive sensor. The SMAP mission has designed a combination of temporal, spectral and statistical algorithms for RFI mitigation [13]. SMAP employs spectral sub-bands, and measures the higher order moments for each spectral/temporal grid to measure kurtosis. The algorithm is a very sensitive tool for low-powered signals, especially pulsed-type [14], though it suffers from central-limit conditions when subject to RFI from multiple types of sources. The algorithm is also resource intensive, as it significantly increases the data bandwidth of the radiometer downlinked for post-processing. Another penalty for implementing such an aggressive RFI detection/mitigation back-end is the cost of the system to the SMAP project [15].

There are many other detection algorithms aside from the ones mentioned above for dealing with RFI in passive microwave radiometry. Initial RFI algorithm development was of the spectral nature using analog sub-bands [18], these were later replaced by digital backends [19] to offer more flexibility and higher number of channels. Though these simple algorithms are fairly effective, they result in a high data bandwidth. Other innovative statistical techniques have also been developed such as negentropy [20], wavelets [21], Shapiro-Wilk [22], Anderson-Darling [23] to deal with interference.

Each algorithm implementation has its pros and cons. The future of RFI detection though is dealing with larger bandwidths with on-board mitigation. As the number of interfering sources increase over higher frequencies, the need for a wide bandwidth multi-channel statistical spectrogram also increases. Adding more spectral channels and higher order moments make downlinked data-rates unfeasible. Thus the current technology push is for the development of on-board mitigation of these large bandwidth products to manage data-rates.

4.0 CONFERENCES AND ANNUAL FARS COMMITTEE MEETING

Current and future RFI detection algorithm issues, increasing RFI trends, spectral corruption were presented recently at the GRSS-sponsored 13th Specialist Meeting on Microwave Radiometry and Remote Sensing of the Environment (MicroRad 2014). Topics ranged from a Ka-band radiometer design, RFI observed at 37 GHz, approaches to RFI detection in and mitigation for the upcoming Soil Moisture active Passive (SMAP) mission, development of on-board mitigation technologies and development of new algorithms for already operational sensors.

This year, the International Geoscience and Remote Sensing Symposium (IGARSS) held at Quebec City will include a full session with ten oral presentations named "Radio Frequency Interference Management and Spectrum Allocation for Remote Sensing". The focus of the session will be broader than previous years, encompassing

RFI detection and mitigation techniques, methodologies employed in related disciplines such as radio astronomy, and spectrum management issues.

The FARS Committee annual meeting will follow the "Radio Frequency Interference Management and Spectrum Allocation for Remote Sensing" session. Many important spectrum related issues will be discussed, including contributions to the upcoming WRC planned at the end of 2015. Among the agenda items for WRC-15 relevant to passive microwave remote sensing, there are allocations in the 10–17 GHz range to the fixed-satellite service, in the 20–26 GHz range to the mobile-satellite service and above 15.7 GHz to aeronautical mobile and radio navigation services that have the potential of creating RFI issues. Other topics of discussion at WRC-15 will include the fragmentation of the frequency allocations to remote sensing of the 71–106 GHz spectral regions. This is an important opportunity for the GRSS community to be able to provide a contribution to the regulatory process. Both member and non-members are cordially invited to join the meeting, contribute to the discussion, and get involved. The FARS Committee warmly welcomes new members. Anyone interested in joining the committee should contact one of its co-chairs, Sidharth Misra and Paolo de Mattheais.

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