RFI Problems and Solutions in Spaceborne Microwave Radiometers

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Abstract

The problem of RFI in spaceborne microwave radiometer data has been known since 1978 when it was first observed at 6.6 GHz with SMMR on SeaSat. Over the last several years, however, it has started to seriously impact remote sensing science products and is expected to continue to do so. This is primarily because the frequency requirements of remote sensing have begun to overlap active radio service allocations. For example, soil moisture is being sensed in the C-band, for which there is no passive service allocation. Thus, RFI detection and mitigation strategies are needed to ensure a radiometer will not be damaged by extreme RFI (survivability), can make measurements during RFI events (operability), and lastly will enable the removal of detectable RFI (excisability). Application to NASA's Aquarius radiometer and NASA's future SMAP radiometer, as well as potential application to the NPOESS MIS radiometer, will be discussed.

1.Introduction

Radio-frequency interference in microwave radiometers is not a recent phenomenon; however, it has only recently become an obstacle to meeting science requirements. Indeed, the SMMR on SeaSat [1] experienced RFI at 6.6 GHz in 1978 and then on Nimbus-7 through 1987 [2]. This RFI did not pose a serious threat to measurement of open-ocean SST's, the primary measurement of SMMR, and is reportedly much sparser than today's observations [3]. Since Nimbus-7, U.S. operational imaging radiometers, SSM/I and SSMIS on the DMSP satellite series have not observed the Earth below 18.7 GHz [4], and thus not experienced detectable RFI. Additionally, the sensors generally observed within the Earth Exploration Satellite Service (EESS) allocations for passive use. There is no allocation at C-band; therefore, the AMSR-E radiometer on EOS Aqua (launched in 2002) is plagued with RFI at 6.9 GHz over the US and elsewhere, making it extremely difficult to use for soil moisture remote sensing [5]. Additionally, the 10.7 GHz channel has evident RFI over Europe [6]. Measurements from the WindSat radiometer have confirmed this experience [3]. The next set of challenges includes L-band for soil moisture (SM) and sea surface salinity (SSS): the ESA's SMOS mission should launch this year (2008) [7] and NASA's Aquarius/SAC-D will be in orbit by 2010 [8]. Opportunities to address RFI through more advanced radiometer design exist with the NASA SMAP mission (an NRC Earth Science Decadal Survey mission recently announced for a 2012 launch) and the NPOESS microwave imager/sounder (MIS) [10].

2.The RFI Problem

Conventional spaceborne radiometers are simple in their signal processing – most merely comprise amplifiers, filters and detectors. The only intelligence, if you will, to the receiver is frequency selectivity and antenna gain pattern. Thus, any near- or in-band RFI from the Earth's surface is indistinguishable from natural thermal emission and produces erroneous excess brightness temperatures. If unknowingly used, this excess brightness temperature could then corrupt estimates of geophysical parameters and outputs of weather and climate models.

2.1 Victims and Sources

The RFI documented to date from spaceborne sensors is certainly due almost entirely to co-channel interference – that is interference from emitters transmitting within the radiometer passband. This occurs at C-band because there is no allocation to passive sensing and at X-band the majority of the allocation is shared with fixed communications. It would also be possible to receive out-of-band (OOB) interference from active services adjacent to EESS (passive) allocations. This is likely to occur in the L-band where air-search radars are allowed to operate right below 1400 MHz, adjacent to the EESS band. A study commissioned by the NASA Earth

Science Spectrum Management Office (SMO) showed that RFI could be expected even with perfect "brick-wall" filters on the radiometer receiver [11]. The following table summarizes past and potential RFI victims and sources. It is organized by increasing spectral frequency:

Frequency Band	Confirmed or Potential	Instruments	Nature of RFI
L-band	Potential	SMOS/MIRAS Aquarius/SAC-D SMAP	Likely to be OOB emissions from terrestrial radars
C-band	Confirmed Expected	SMMR on SeaSat and Nimbus 7 AMSR-E on EOS Aqua WindSat on Coriolis MIS on NPOESS	Majority is likely fixed service (FS) communcations. Mobile service (MS) and radiolocation possible. Proliferation of Part 15 USB devices expected.
X-band	Confirmed Potential	AMSR-E WindSat GMI on GPM core satellite MIS	Allocation shared with FS. WindSat uses extended band up into Direct Broadcast Service (DBS).
K-band 24 GHz	Potential	MIS and GMI ATMS on NPP (and NPOESS)	Allocation shared with Fixed Satellite Service (FSS) S-E links and FS. No confirmed cases. Shared with UWB vehicular radars. No RFI experienced.
Ka-Band	Potential	MIS and GMI	Allocation shared with FS and MS. No confirmed cases.
V-band	Potential	ATMS PATH from NRC Decadal Survey	Part-15 devices growth explosion expected. Allocation shared with inter-satellite service links visible from GEO.

The above is not offered with an alarmist attitude. Rather, note the only confirmed RFI has occurred at C-band where there is no allocation, at X-band where the allocation is shared with FS, and in an extended X-band where the allocation is to DBS. Although this has had a large impact on soil moisture remote sensing, the majority of operations continue interference free. However, caution must be taken because much of EESS is allocated on a shared basis. Technology improvements will make use of the higher microwave frequencies above 10 GHz more economical by FS and MS and thus probable.

2.2 Impact on Science

The use of L- and C-bands in radiometers is driven by scientific progress. Remotely sensed soil moisture and sea surface salinity data are largely missing from environmental models used for forecasting and prediction. Additionally, the technology needed to use large antennas to obtain acceptable spatial resolutions from orbit has been developed and has become practical for Earth science missions. This combination of science and technology has spawned a series of C- and L-band radiometer missions (as listed in the previous table).

A low frequencies (L and C-band), soil moisture (SM) fraction has a negative-signed dependence on brightness temperature of ~1 K/% with the exact value depending upon soil type, vegetation cover, surface roughness and other factors. Vegetation cover attenuates the signature increasingly with frequency. Thus, long wavelengths are needed. The SMAP radiometer is being designed to measure SM from space at L-band (1.4 GHz) with a radiometric error requirement of ~1.5 K. Including corrections for other factors, the retrieval error performance is predicted to be <4% volumetric. Thus, small levels of RFI of only a few Kelvins would cause the soil to appear dryer, which in turn be interpreted as lower past rain fall or higher evaporation. The problem is compounded at C-band and higher frequencies for vegetated areas because the SM signature is attenuated. These physics, coupled with the lack of EESS allocation in C-band, is a serious concern for soil moisture remote sensing to be done by MIS on NPOESS.

For SSS, the impact of RFI at L-band is 10-times more serious than for SM. The Aquarius mission requires 0.1-K error measurements to meet mission requirements. Thus, RFI of only a fractional Kelvin is of serious concern, although it is recognized the chances of receiving interference well away from shore is small. At present, these radiometers have design features to mitigate some RFI.

Of growing concern is the impact of RFI on numerical weather prediction (NWP) and direct data assimilation (DDA) models. These models are based on complex predictive filters. The filters work by comparing the outputs to remote sensing measurements – the differences called innovations are fed back to the model in an adaptive fashion. The better the model is a predicting, the smaller the innovations will be. Thus, even very low levels of RFI could drive a model off in an undesired direction. One study suggests that 0.2 K of RFI at 23.8 GHz would exceed ~38% of innovations for 10% of time [12]. Note, UWB vehicular radars utilize this frequency.

3. Solution – Design for RFI Mitigation

At NASA's Goddard Space Flight Center, we are using a three-aspect approach to design for RFI mitigation in microwave radiometers. The three aspects, represented by the acronym SOE, are: survivability, operability, and excisability. These three abilities are discussed below using the Aquarius radiometer as case study [11].

First and foremost, the hardware must **survive** any predictable RFI event without damage. To determine the maximum predicted RFI a static link analysis can be done between the sensor and known sources. Then appropriate measures to protect against the determined level can be taken. For example, the Aquarius radiometer incorporates diode limiters capable of 2 watts power. Additionally, frequency and operations coordination might be negotiated between spectrum managers to reduce the risk of a damaging RFI event.

The radiometer also needs to **operate** (meet measurement requirements) during RFI events (excepting, of course, co-channel interference). Thus, the radiometer passband filtering should be sufficient to reject OOB (from the radiometer's viewpoint) emissions before the detector. Good harmonic rejection is important at low RF frequencies. For example, the second harmonic to EESS (passive) at L-band lies in a radiolocation service allocation. Front-end amplifiers should also be protected from compression with sufficient filtering. In the event of co-channel interference, the radiometer should at least be able to recover from compression and saturation in a timely manner. Operability for Aquarius was implemented using multi-stage filtering with good harmonic suppression. The final band-definition filter has a 7-pole response to reject neighboring terrestrial radars.

Finally, radiometers can be designed to detect RFI and enable RFI-contaminated data to be **excised**. For example, a pulse-blanking scheme was devised in the 1980's to remove radar pulses [13]. A multi-channel sub-banding approach was demonstrated at C-band in 2002 [14]. These two approaches represent time and frequency diversity in the receiver. If RFI can be detected in time or frequency, it can be blanked before final integration. More advanced than threshold detectors is spectral kurtosis [15]. Using the kurtosis statistic, RFI can be differentiated from thermal emission. Experiments have shown using kurtosis RFI at about the NEDT level can be detected and removed.

4. Future Missions

Two future instruments present themselves as opportunities to further the implementation of RFI mitigation technologies in spaceflight hardware: NASA's SMAP, and NPOESS's MIS. SMAP requires an L-band radiometer to measure soil moisture and the possibility from OOB from terrestrial radars exists. A spectral kurtosis detector developed under a NASA Instrument Incubator Project (IIP) is applicable to SMAP requirements [15]. On NPOESS MIS, RFI is expected at C-band and X-band over land. A previous study for CMIS suggests a multiband approach at C-band is a low risk method of mitigation (CMIS). A low-risk kurtosis detector was also developed under the aforementioned IIP that augments the multi-band approach to improve detection capability [16]. At X-band, the possibility exists to use a separate 20-MHz reference band with kurtosis detection in the primary exclusive EESS allocation to quality check the full-band receiver operating over the entire shared allocation.

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