Radio frequency survey of the 21-cm wavelength (1.4 GHz) allocation for passive microwave observing

J.R. Piepmeier[1], M. Midon[2], A. Caroglanian[2]
[1]Microwave Instrument Technology Branch
[2]Communications and Microwave Systems Branch
NASA's Goddard Space Flight Center
Greenbelt, MD 20771
Email: jeff.piepmeier@nasa.gov

O.C. Ugweje
Department of Electrical and Computer Engineering
The University of Akron
Akron, OH 44325-3904
Email: ougweje@uakron.edu

***Abstract-* Because of the need to develop 1.4-GHz radiometers, a set of RF surveys was conducted in and around our laboratories. In this paper, a measurement campaign and analysis of radio frequency interference (RFI) in the 21-cm wavelength allocation for passive microwave observing, was undertaken. The experimental setup and measurement procedure are outlined and measured data are interpreted. Significant signals were discovered within and surrounding the allocated spectrum at 1.4 GHz. Some implications for remote sensing are discussed.**

I. INTRODUCTION

The capability to passively observe at relatively long wavelengths (>10 cm) in the microwave spectrum is important for remote sensing the Earth's surface. Measurements of soil moisture and sea surface salinity using microwave radiometers are most sensitive at long wavelengths. The consideration of these two measurements is quite timely because both are recent candidates for space-based observing[1]. International Telecommunications Union (ITU) regulations, however, only protect long wavelength observing within a primary allocation originally designated for the Radio Astronomy Service (RAS) from 1400-1427 MHz [1]. (There is a secondary allocation from 1370-1400 MHz [1, S5.339].) This portion of spectrum is an important allocation to radio astronomers because it contains hydrogen's 21-cm emission line. In fact, the regulations contain a footnote that reads "All emissions are prohibited in the following [band]: 1400-1427 MHz" [1, S5.340].

There is potential for transmissions from the fixed and mobile services surrounding the allocation to interfere with 1.4 GHz microwave radiometers by the presence of uncontrolled harmonics, inter-modulation products, or spurs. In addition, interference could occur during laboratory development and testing of radiometers when not all RFI-suppression hardware is in place. Because of these possibilities, and the need to develop 1.4-GHz radiometers, a set of RF surveys was conducted in and around our laboratories. Significant signals were discovered within and surrounding the allocated spectrum at 1.4 GHz. In this paper, the methods and the results of both outdoor and indoor RFI surveys are narrated.

[1]http://essp.gsfc.nasa.gov/

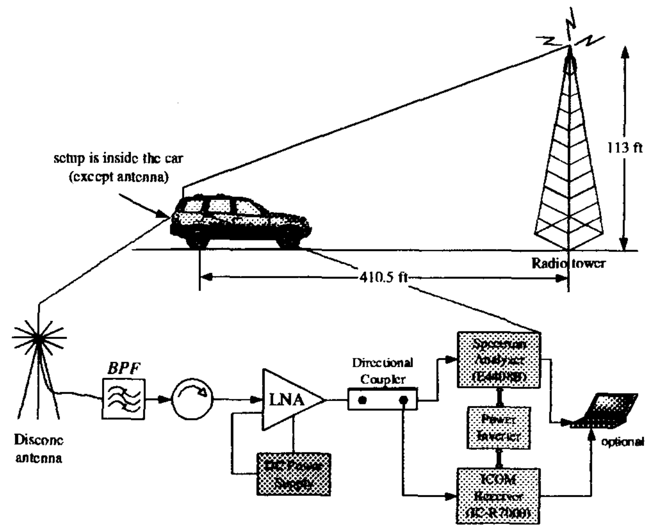

Fig. 1. Outdoor experimental setup diagram of receiving system used to measure RF spectrum. The indoor experiments used the same receiving system with a different antenna, but where located within a laboratory room.

II. OUTDOOR SURVEY

In the outdoor RFI survey, we were interested in performing a broad-spectrum survey inside and around the passive allocation band of 1400-1427 MHz. The tests essentially involve the measurement of the signal power at the frequency band of interest at a cellular radio tower. The outdoor primary test location was at a local site with several commercial voice, data, and paging carriers in operation on the roof of an office building. At the test site, measuring equipment was set up as illustrated in Fig.1. The receiving system was constructed from laboratory equipment, including an directional horn antenna, a tunable band-pass filter (BPF), several isolators, a low-noise amplifier (LNA), a directional coupler, a spectrum analyzer and a communications receiver. The LNA was used to extend the sensitivity of the spectrum analyzer. The LNA had 30 dB of gain and ~120 K noise temperature. The horn antenna allowed us to examine the directional properties of the received signals. The BPF was used to ensure that in-band inter-modulation products (IMP) where not generated within our own equipment by strong out-of-band signals. The isolators where used so that the LNA gain would not change with changing load impedance. The spectrum analyzer was the primary detector and the communications receiver was used to listen to the received signals. The survey team included an experienced amateur radio operator who could hypothesize a signal's type by listening to FM and/or AM demodulated audio. Note, we use the description of "in-band" for signals that fall within the 1400-1427 allocation and "out-of-band" for signals outside that band.

Before scanning the band of interest, the signal levels were measured with and without the LNA powered, and with and without the antenna connected. This process ensured our received signals where indeed being captured by the antenna and not being generated by our equipment. Starting with center frequency of 1.3881 GHz, the spectrum analyzer was setup with a frequency span of 200 KHz, resolution bandwidth of 1 KHz, and video bandwidth of 30 Hz. The spectrum was scanned using the communications receiver at an interval of 200 Hz. If signals here found, measurements were taken using the spectrum analyzer. A signal was determined "detected" if the operator could hear a demodulated tone on the receiver and see an elevated signal power on the spectrum analyzer. The survey revealed the presence of significant signals within and surrounding the allocated spectrum at 1.4 GHz. Of particular note is a signal found near the band edge at 1.399925 GHz. This signal had directional properties observed using the standard gain horn antenna. The signal would vanish if the horn pointed away from the building with the cellular antennas. It is possible that this signal is an intermodulation product of other legitimate signals, or itself could be legitimate as it exists within the 1350-1400 MHz allocation. The challenge to remote sensing is that the communications allocation reaches up to 1400 MHz. A radiometer should include a guard band inside of 1400 MHz so that signals at the edge of the spectrum do not contaminate the measurements.

III. Indoor Survey

The indoor survey was performed using the same receiver setup as the outdoor survey, except the directional antenna was replaced with a disc-cone antenna with omnidirectional azimuthal coverage. As before, the spectrum from 1390 to 1437 MHz was examined in detailed 200-Hz steps using the communications receiver. More than sixty individual signals where found within the frequency limits. Most of the signals were less than 3 dB above the noise floor of the spectrum analyzer,

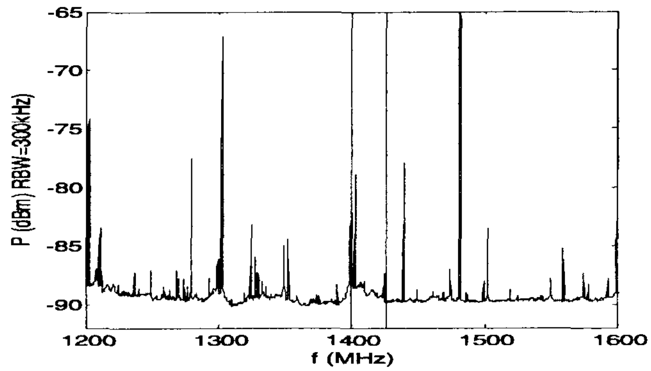

Fig. 2. Received spectrum from 1200 to 1600 MHz.

with several notable exceptions. At the band edge at 1400 MHz, two large signals at 1399.960 MHz and 1400.002 MHz were 25 dB and 23 dB above the noise floor. Additionally, the power density of the spectrum between these two signals was raised 5 dB above the surrounding noise floor. Within the band at 1403 MHz, there was a complex of signals with approximately 400-kHz bandwidth. The broadband power density was raised about 6 dB with several individual signals at 13, 15, and 17 dB above the noise. The raised noise floor of these signals is different from that observed during the outdoor tests.

Several attempts where made to track down the origin of these signals. Our original hypothesis was that they were being generated by computer equipment within the laboratory. We successively began shutting down equipment with no discernible results. The signals were persistent from day-to-day over a several week period. At this point, their origin is unknown by us.

Because the search for individual signals was time consuming and searching for their origins unproductive, a series of spectrum where acquired for further study. Fig.2 displays the received spectrum from 1200 to 1600 MHz. (Note, the BPF was removed from the system.) A flat noise floor punctuated by narrow band signals generally characterizes the spectrum. Surprisingly, the primary allocation 1400-1427 MHz does not appear as an empty notch of constant spectral density within the otherwise crowded spectrum. Rather, the power spectral density has a slope that begins higher at 1400 MHz and drops 2 dB towards 1427 MHz with several narrow band signals throughout. On the other hand, the surrounding spectrum is rather flat with the exception of the individual signals. In other words, it appears that the allocation is noisier than the out-of-band spectrum.

To examine the allocation in more detail, the spectrum received by the antenna was compared to that of a match termination. Fig.3 contains these curves. Note that received spectrum is notably higher than that of the match termination, including both individual signals and the continuum. The

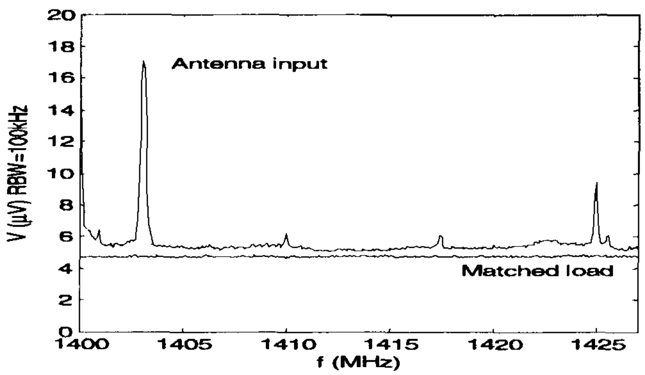

Fig. 3. Spectrum from 1400 to 1427 MHz. The calculated INR is 51%

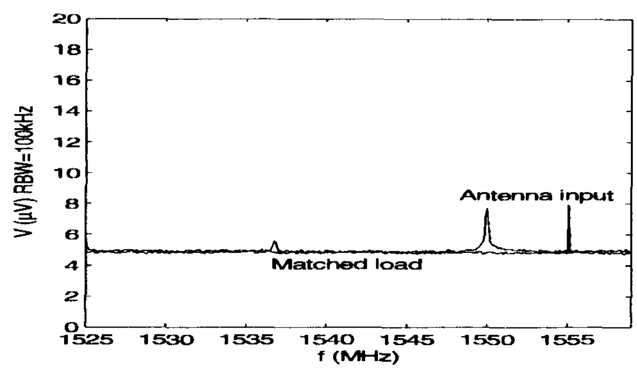

Fig. 4. Spectrum from 1525 to 1559 MHz. The calculated INR is 6%

computed interference-to-noise ratio (INR) is 51%. This calculation includes the receiver noise. This amount of increased noise cannot possibly be due to natural sources. The strongest natural source at this frequency is the Sun, whose brightness temperature can vary from 10^5-10^6 K. Only a few percent of the INR can be attributable to the Sun. It is possible that some of the difference is attributable to VSWR differences between the termination and antenna. However, three 20-dB isolators where used before the LNA to negate VSWR effects.

A "quieter" part of the spectrum was also measured for comparison. The band from 1525 MHz and 1559 MHz is almost exclusively allocated for space-to-Earth mobile and fixed services. There are some exceptions for the use of supplemental ground links for space-to-aeronautical service. Thus, the presence of ground-based emissions should be quite low. Fig.4 shows the received spectrum and that of a matched termination. Note the minimal increase in noise floor and the sparse presence of individual signals. The computed INR is 6.3%. In the flat portion from 1538-1548 MHz, the INR is 2.7%.

IV. Discussion

Measurements of the power spectrum in and around the primary allocation of 1400-1427 MHz were performed. Significant interference was observed within the band. Additionally, an unexplained increase in noise spectral density across the band was present. These characteristics were persistent on a daily basis over a several week period. One possibility is that a poorly performing RFI suppression filter was shaping the noise from a transmitting source. The strongest natural source, the Sun, was ruled out as the culprit. A quieter portion of the spectrum allocated for space-to-Earth fixed and mobile services from 1525 to 1559 MHz was also examined. Here the received spectrum was only raised 2.7% above a matched termination in portions without discernible signals (e.g., from 1438-1448 MHz). This amount could be attributed to solar radiation.

The peculiar signature present between 1400-1427 MHz is particularly disturbing from both a developmental and operational point of view. The presence of strong interference in the laboratory requires attention, beyond the meticulous amount normally paid in radiometer development, during the building and testing of L-band radiometers. Tests of radiometer stability in particular must be carefully planned so the results are not influenced by RFI. Operationally, science data cannot be gathered in regions with this type of RFI. It is particularly vexing that the surrounding spectrum looks relatively clean, despite the presence of individual signals. The fact that the raised and sloped power spectral density is isolated to the allocated band is puzzling.

For remote sensing applications, it may be useful to observe in additional bands. Specifically, one could consider the secondary allocation from 1370-1400 MHz and the space-to-Earth allocation within 1525-1559 MHz. A frequency-diversity RFI mitigation technique such as that proposed in [2] could be implemented. Particularly in the 1525-1559 MHz band, emissions from spacecraft transmitters would be spatially, spectrally, and temporally predictable. Most of the sources would be space-based radiating towards the Earth rather than ground-based radiating up towards the radiometer. Both direct-path and ground-reflected signals would have to be considered, but their geometry would be deterministic. Frequency diversity could be a useful RFI mitigation tool and provide additional bandwidth for increased radiometric sensitivity.

Acknowledgment

This work was partially supported by the ASEE NASA Summer Faculty Fellowship Program.

References

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[2] A.J. Gasiewski, M. Klein, A. Yevgrafov, and V. Leuskiy, "Interference mitigation in passive microwave radiometry," in *Proc. Int. Geosci. and Remote Sens. Symp. (IGARSS)*, Toronto, Canada, 2002, pp. 1682–1684.