Spectrum Management for the NPOESS Conical-scanning Microwave Imager/Sounder (CMIS)

David B. Kunkee
The Aerospace Corporation
PO Box 92957 M/S M4-927
Los Angeles, CA 90009-2957

Narinder S. Chauhan
NPOESS/IPO, The Aerospace Corp.
8455 Colesville Road, Suite 1450
Silver Spring, MD 20910

James J. Jewell, Capt. USAF
NPOESS/IPO
8455 Colesville Road, Suite 1450
Silver Spring, MD 20910

Abstract - **The Conical-scanning Microwave Imager/ Sounder currently under development by the National Polar-orbiting Operational Satellite System (NPOESS) Integrated Program Office (IPO) utilizes segments of microwave spectrum from ~6 GHz to above 190 GHz. During the development and optimization of the current CMIS baseline design, the Earth Exploration Satellite Service (EESS) (Passive) frequency allocations, and estimates of the expected RF environment played a substantial role in determining channelization. This will allow CMIS performance requirements to be met while minimizing the potential for Radio Frequency Interference (RFI) occurrences to CMIS.**

1. Introduction

Increasing utilization of the electromagnetic spectrum at frequencies where passive microwave remote sensing is performed has substantially increased the possibility and likelihood of interference to microwave observations of the Earth. Accordingly, it is increasingly important for sensors currently being designed to follow, as best as possible, the international allocations for the passive Earth Exploration Satellite Service (EESS). However, in many cases, these allocations are either inadequate, shared with other services, or in some cases, no allocation exists at all in spectral regions where microwave observation data are desired.

The Conical-scanning Microwave Imager/Sounder (CMIS) utilizes an extremely wide frequency range covering ~6 GHz (C-band) to greater than 190 GHz (G-band). Over this range there are several areas where EESS allocations are clearly inadequate, considering the performance that is required of the sensor. Indeed, airborne experimental observations at C-band where there is no protection from unwanted emissions in the form of an NTIA allocation, routinely encounter RFI of anthropogenic nature [1]. Even measurements within the band 10.6 – 10.7 GHz (X-band), where an EESS allocation exists, interference has been observed over populated areas [2]. At ~18 GHz (K-band) the EESS allocation is only 200 MHz. Bandwidth limitation and sharing of this segment with the fixed satellite service (see http://ntiacsd.ntia.doc.gov/uswp7c/), coupled with the desire for highly sensitive radiometric measurements in this band required that careful thought be given to the operating bandwidth of CMIS.

CMIS has substantial atmospheric sounding capability, with several channels exploiting the 50 – 60 GHz O_2 complex and the 183-GHz H_2O line. Realignment of the 50-GHz band from and changes to the EESS windows near 183 GHz from the last two World Administrative Radio Conferences (WARC) were considered by the CMIS designers as well.

Spectrum engineering and management has been achieved with CMIS as an integral part of the phase one (risk reduction) development. From August 1997 to February 2001, two NPOESS contractors, developed two entirely independent CMIS designs, including channelization, optimized according to a specific set of prioritized requirements. Primary among these requirements was the performance metrics of the required Environmental Data Records (EDRs) that are the end-product of the sensor. However, CMIS also had to meet cost, mass, power, data rate, volume and field of view requirements and, very important for spectrum usage considerations, data availability requirements. The requirements for the CMIS phase one development were contained within the Sensor Requirements Document (SRD) authored by the IPO. The SRD specifically required the CMIS channels to utilize EESS-allocated bands whenever possible, and use of bands outside of EESS allocations required justification by other program requirements and/or constraints.

As a result, the CMIS design was optimized against several constraints including spectrum allocations to achieve an overall "best value" baseline design to begin phase-two development. This paper will describe some of the spectrum engineering and management activities for CMIS during the risk reduction phase and the development of the current CMIS baseline design. Examples of CMIS technical performance metrics (EDR requirements) are shown and the role of system and program constraints on the CMIS spectrum usage described. The current channelization is shown and relevant design trades concerning the bandwidth and center frequency selections are discussed.

2. BACKGROUND

The primary driver of spectrum usage is the set of requirements placed on the sensor for remotely sensed data. Within the CMIS SRD each EDR was specified with several attributes, such as measurement accuracy, measurement precision, horizontal cell size, and others. As an example, two important CMIS EDRs are shown in Tables 1 and 2. For explanation of Threshold and Objective performance see the CMIS SRD (http://npoesslib.ipo.noaa.gov/S_cmis.htm).

TABLE 1.
SOIL MOISTURE REQURIEMENTS (SUMMARY).

Attribute	Threshold	Objective
Horizontal Cell Size	40 km	
Vertical Cell Size	0.1 cm	5 cm
Vertical Coverage	Surface to -0.1 cm	Surface to -80 cm
Measurement Range	0-100 cm/m	0-100 cm/m
Meas. Uncertainty (clear)	10 cm/m	*
Meas. Uncertainty (cloudy)	20 cm/m	*
Mapping Uncertainty	3 km	1 km
Swath Width	1700 km	1700 km

*Objective specified as 1 cm/m at the surface and greater of 5% or 0.013 cm/m (130 g/m^3) over the vertical column of 0-80 cm.

TABLE 2.
SEA SURFACE WINDS (DIRECTION) REQUIREMENTS (SUMMARY).

Attribute	Threshold	Objective
Horizontal Cell Size	20 km	1 km
Measurement Range	3-25 m/s	3-25 m/s
Measurement Accuracy	20 deg	10 deg
Measurement Precision	10 deg	10 deg
Mapping Uncertainty	5 km	1 km
Swath Width	1700 km	1700 km

The risk reduction contractors translated the 20 CMIS EDR requirements, considering several other system and program constraints specified by the SRD, into the current sensor baseline design. The selected CMIS design was developed through trade studies conducted by Boeing Satellite systems, Atmospheric and Environmental Research (AER) and Remote Sensing Systems (RSS).

The CMIS baseline design is a conical-scanning radiometer with a nominal reflector size of ~2.2 meters, data rate of ~500 kb/s, mass of ~275 kg requiring ~340 W of orbital average power. The CMIS is considerably larger than its heritage operational sensors which include the Special Sensor Microwave/Imager (SSM/I) and the Special Sensor Microwave Imager Sounder (SSMIS). By the time CMIS is launched it is anticipated that other conical-scanning radiometers on-orbit will include the Advanced Microwave Scanning Radiometer (AMSR) and the Navy's WindSat, both with over 1-meter apertures. The current channel set for CMIS includes 37 analog channels listed in Table 3. There is also a Fast Fourier Transform (FFT) performed on a 25 MHZ band segment centered at 60.434776 GHz (7+ O_2 line) that provides 40 additional channels. These are the CMIS FFT channels.

TABLE 3.
CMIS CHANNEL SET.

Channel Name	Polarization*	Center Frequency (GHz)	Band-width (MHz)
6V,H	VH	6.625	350
10V,H,L,R	VHLR	10.65	100
18V,H,P,M,L,R	VHPMLR	18.7	200
23V,H	VH	23.8	400
37V, H, P, M	VHPM	36.5	1000
60VA	V	50.3	134
60VB	V	52.240	1280
60VC	V	53.570	960
60VD	V	54.380	440
60VE	V	54.905	350
60VF	V	55.490	340
60VG	V	56.660	300
60VJ	V	59.380	280
60VK	V	59.940	440
60LL	L	60.3712	57.6
60LM	L	60.4080	16
60LU	L	60.4202	8.4
60LV	L	60.5088	44.8
60LFFT	L	60.434776	25
89V,H	VH	89.0	4000
166V	V	166±0.7875	1425
183A	V	183.31±0.7125	1275
183B	V	183.31±3.10	3500
183C	V	183.31±7.7	4500

*Polarizations: V=vertical, H=horizontal, P=linear +45°, M=linear -45°, R=Right Circular, L=Left Circular.

There are several characteristics of note from Table 3. To begin, the C-band center frequency is 6.625 GHz compared to 6.9 GHz for Advanced Microwave Scanning Radiometer (AMSR). The center frequency of the CMIS K-band channel is 18.7 GHz rather than 19.35 GHz as for the SSM/I or SSMIS. Further, the bandwidth is limited to 200 MHz conforming to the EESS allocation in that band.

3. KEY CHANNELIZATION TRADES

During the risk reduction phase every effort was taken to optimize the CMIS design in order to provide best value for a variety of customers. For CMIS, this optimization included the center frequency, bandwidth, and sensor measurement parameters adjusted according to the cost, mass, value to the EDR products and risk associated with sensor's ability perform the required measurements in each of the channels. The following provides a description of relevant trades for the CMIS channelization.

Several aspects about performing passive microwave measurements near 6 GHz were considered for CMIS. First, there is no EESS frequency allocation in the C-band region. Second, utilization of spectrum near 6 GHz by active services appears to be substantial. And, further, there are no C-band passive radiometers currently on orbit to obtain statistics of RFI occurrences from for design reference. However, there are two planned sensors, the AMSR to be flown on NASA Aqua in June 2002, and WindSat, with an expected launch date in early 2003. Finally, experimental airborne missions on several occasions have encountered RFI over selected areas when making C-band measurements [1].

The allocations near 6.8 GHz include the Fixed and Mobile Service (FS and MS) and Fixed Satellite Service (FSS) (Earth-to-Space), (see http://www.ntia.doc.gov/osmhome/alloctbl/alloctbl.html). Registered users of the spectrum near the 6.8 GHz region, include point-to-point terrestrial microwave communication links. In order to obtain a more clear picture of the RF environment and the issues associated with passive observations near 6.8 GHz, the IPO provided for two studies. First, a poll of registered users over the frequency range 6.2 – 7.0 GHz was provided to the CMIS risk-reduction contractors for their use in optimizing their sensor channelization and design of possible mitigation techniques. Second, a study was performed by the NOAA frequency management group and provided to the CMIS designers for reference. The study, took into account the general characteristics of registered users to provide an estimate of the probability of interference.

Currently, additional trades are still under consideration for CMIS in the C-band region and every effort is being made to understand potential effects of RFI and to make the CMIS measurements robust in this band.

Near 18 GHz, microwave observations are used to support several surface EDR data products, however, the Sea Surface Wind Direction EDR requirements generally drive the design to have the best-available sensitivity. Unfortunately, the EESS allocated bandwidth is limited to 200 MHz centered at 18.7 GHz. However, analyses indicated that it was possible to achieve adequate EDR performance, including Sea Surface Wind Direction attributes, without exceeding the 200 MHz measurement bandwidth. For CMIS this is partly due to support from an extensive set of channels contributing to estimates of surface and atmospheric parameters.

Within the 50 – 60 GHz band, CMIS avoids utilization of the band segment 50.4 – 51.4 GHz which is allocated to FS, MS and FSS (Earth-to-space). This segment of the band is relatively far removed from the center of the O_2 complex, and it is plausible that interference could result if this band segment was used. Near the center of the complex, CMIS channels between 59 – 64 GHz, including the FFT channels, lie within a band segment that is not allocated to EESS. However, the these channels utilize the same part of the center absorption region as the SSMIS sensor and the potential for RFI was appears to be very low.

At W-band, the CMIS channels are consistent with EESS allocations at 89 GHz. Although, currently it appears the likelihood of RFI is small, using EESS-allocated frequencies further minimizes this possibility while also providing recourse to address any harmful interference may occur from services operating in adjacent bands or at frequencies harmonically related.

For moisture sounding at 183 GHz, the CMIS baseline design requires large channel bandwidths to meet the atmospheric vertical moisture profile requirements. The bands extend beyond the allocated region, however, the chances of RFI in region appear small for the near future.

4. Summary

The CMIS channel selection was an integral part of the sensor optimization carried out over the risk reduction (phase one study) period. Channel selection was governed by the risk reduction contractor's procedure for scoring sensor performance against a prioritized requirements list contained within the sensor requirements document. One of the stated requirements was to utilize protected bands whenever possible and provide detailed justification where use of unallocated spectrum was recommended.

Currently, design trades are still under consideration to minimize the possibility of RFI to CMIS measurements in the 6-GHz region while at the same time investigating methods of improving measurement robustness. In several cases, the frequency utilization (bandwidth and center frequency) of CMIS is different than heritage sensors due in part to considerations of EESS allocations. Two examples are the CMIS 18.7-GHz and 89-GHz CMIS channels.

References

[1] Gasiewski, A. J., M. Klein, A. Yevgrafov, and V. Leuskiy, "Interference Mitigation in Passive Microwave Radiometry," accepted for presentation at the 2002 International Geoscience and Remote Sensing Symposium.

[2] Ashcroft, P., Remote Sensing Systems, Inc. Private Communciation.