CGMS-51-NOAA-WP-05
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Agenda Item 3.1
Discussed at WG-1

Subject	**Active Spectrum Management with Passive Bands**
In response to CGMS action/recommendation	
HLPP reference	2.2 Radio Frequency (RF) protection
Executive Summary	Spectrum is the lifeblood of Operational Meteorology – users need to be aware of proposals and plans for spectrum sharing that may impact meteorological and climatological data. It's clear that non-natural RF contamination will never go away and will most likely continue to increase. The EESS (passive) bands are at a very significant risk of increased noise levels from the conditions of today. We've calculated that low anthropogenic noise levels will be indistinguishable from natural radiation and that levels of anthropogenic noise will simply eliminate observation data for that geographical area. Predominantly, bands near and between 24 to 86 GHz are today's most significant risks for passive band degradation and corruption, however passive bands both below and above this range are also at or have been at risk. It is recommended that there be an emphasis on the development and implementation of RFI identification and sensor robustness measures. It's clear that if we do nothing, we will not know when or how much the meteorological mission has been degraded by RF contamination.
Action/Recommendation proposed	- Recommend consideration by member administrations of WRC-23 agenda items that may affect satellite remote passive sensing. - Recommend consideration of alignment with SFCG and WMO WRC-23 findings for passive bands.

	- Continue actions by TGRFI for development of mitigation techniques for use by CGMS members.

1 INTRODUCTION

In recent years the trend toward broadband applications in commercial, terrestrial, and satellite-based systems and networks, either fixed or mobile, has accelerated. The most imminent examples are IMT-2020/5G, the currently under development 6G, satellite mega-constellations, and ultrawideband (UWB). The necessary bandwidth to meet the data rates needed for such broadband applications requires these systems to use much higher frequencies. Unfortunately, these RF spectrum regions are also extensively used by passive microwave sensors, which rely on specific natural emissions produced by elements of the Earth's surface and its atmosphere that cannot be changed and are critical for meteorological observations.

Accommodating broadband systems in, or adjacent to, frequency bands used by passive sensors may also include compatibility issues and potentials for radio frequency interference (RFI) to passive sensors. Even though regulatory requirements are established at both national and international (ITU) levels to protect passive sensors, more services are squeezed into an already crowded spectrum, and problems arise when largely incompatible services find themselves allocated to adjacent radio frequency bands. General regulations and mitigation techniques applied uniformly across the spectrum are likely to be inefficient, potentially leading to a steadily increasing level of RFI over time. This kind of interference, which slowly grows with the level of deployment of such networks, is especially difficult to detect and monitor.

RFI in passive microwave remote sensing occurs when artificial (man-made) signals/noise (non-Gaussian) contaminate calibrated radiometric brightness temperature measurements of naturally occurring thermal radiation (Gaussian noise), thus introducing an error in the geophysical variable being observed which in the end leads to erroneous sensor performance and corrupted data. Most difficult in this context is RFI that is small enough to be realistic (not automatically rejected because the measured data are considered obviously wrong), but large enough to affect the data. This is often considered to be insidious contamination. Currently, passive band sensors are not equipped or designed to differentiate noise between natural and anthropogenic sources leading to an inability to detect insidious RFI.

The most important mechanism for mitigating RFI is to prevent RFI from happening before it starts. This is at the point where the frequencies of potential future RFI sources are determined, and regulatory conditions are established at national, regional, and international (ITU) levels. Only at that point can conditions/limits be established to protect passive bands from RFI. Once these large-scale systems are deployed, it will be very difficult, costly, and lengthy to modify the equipment causing RFI.

2 MICROWAVE REMOTE SENSING

Every physical body (water, soil, clouds, oxygen, trees, people – literally everything on earth) – spontaneously and continuously emits electromagnetic radiation. This energy (as thermal emissions) is measured by microwave sounders (radiometers) primarily located in a sun-synchronous polar orbit. The amount of energy a body emits is proportional to its temperature and tends to be very weak. For example, an object at a temperature of 100 Kelvin emits 0.1 pico-Watts (= 10^{-13} W) within 100 MHz and has a signal fluctuation on the order of 0.1-K → 0.1 femto-Watts (= 10^{-16} W). This energy requires an extreme sensitivity to being observed and makes it essential to maintain protected allocations at specific frequencies and to properly manage the use of the spectrum near the protected frequency allocations.

1.1 Future Use of Microwave Passive Sensing Bands

The following systems have been identified in the OSCAR database[1] as using remote passive band sensors:

Band *WRC-23 AI*	Satellite Programs	Meteorological Organizations
Below 18.5 GHz	CIMR, FY-3F to I, GOSAT-GW, Meteor-M N2-3 to 6, Meteor-MP N1/2	CMA, ESA, JAXA, RosHydroMet
18.6-18.8 GHz ***AI 1.16 & 1.17***	CIMR, CRISTAL, FY-3F to I, GOSAT-GW, Meteor-M N2-3 to 6, Meteor-MP N1/2, Metop-SG-B1 to 3, Sentinel-6B,	CMA, ESA, EUMETSAT, JAXA, RosHydroMet
18.8-20.2 GHz ***AI 1.16***	Currently in use, no future programs identified	
22.21-22.5 GHz ***AI 1.10***	Currently in use, no future programs identified	
23.6-24 GHz	CRISTAL, FY-3F to J, GOSAT-GW, JPSS-3/4, Meteor-M N2-3 to 6, Meteor-MP N1/2, Metop-SG-A1 to 3, Metop-SG-B1 to 3, Quicksounder, Sentinel-3C/D, Sentinel-6B, Soundersat (NEON)	CMA, ESA, EUMETSAT, JAXA, NOAA, RosHydroMet
31.3-31.8 GHz	FY-3F to J, JPSS-3/4, Meteor-M N2-3 to 6, Meteor-MP N1/2, Metop-SG-A1 to 3, Metop-SG-B1 to 3, Quicksounder, Soundersat (NEON)	CMA, EUMETSAT, NOAA, RosHydroMet
34 GHz	CRISTAL, Sentinel-6B,	ESA, EUMETSAT,
36-37 GHz ***AI 4 & 9.1 (D)***	CIMR, GOSAT-GW, Meteor-M N2-3 to 6, Meteor-MP N1/2, Sentinel-3C/D,	CMA, ESA, JAXA, RosHydroMet
42 & 48 GHz	Meteor-M N2-3 to 6	RosHydroMet
50.2-50.4 GHz ***AI 10***	AWS, FY-3F to J, JPSS-3/4, Metop-SG-A1 to 3, Metop-SG-B1 to 3, Quicksounder, Soundersat (NEON)	CMA, EUMETSAT, NOAA
51.56-51.96 GHz	AWS, FY-3F to J, JPSS-3/4, Meteor-MP N1/2, Metop-SG-A1 to 3, Metop-SG-B1 to 3, Quicksounder, Soundersat (NEON)	CMA, EUMETSAT, NOAA, RosHydroMet
52.6-59.3 GHz	AWS, FY-3F to J, JPSS-3/4, Meteor-M N2-3 to 6, Meteor-MP N1/2, Metop-SG-A1 to 3, Metop-SG-B1 to 3, Quicksounder, Soundersat (NEON)	CMA, EUMETSAT, NOAA, RosHydroMet
86-92 GHz **AI 10**	AWS, CRISTAL, FY-3F to J, GOSAT-GW, JPSS-3/4, Meteor-M N2-3 to 6, Meteor-MP N1/2, Metop-SG-A1 to 3, Metop-SG-B1 to 3, Sentinel-6B, TROPICS-4 to 7, Quicksounder, Soundersat (NEON)	CMA, ESA, EUMETSAT, JAXA, NASA, NOAA, RosHydroMet
114-118.75 GHz	FY-3F to J, Metop-SG-B1 to 3, TROPICS-4 to 7, Soundersat (NEON)	CMA, EUMETSAT, NASA, NOAA

[1] The OSCAR database is not necessarily an accurate source for future passive band spectrum use. Some inaccuracies have been noted. Quicksounder and Soundersat (NEON) are NOAA systems that are not yet in the OSCAR database.

148.5-151.5 GHz	Currently in use, no future programs identified	
155.5-158.5 GHz	Currently in use, no future programs identified	,
164-167 GHz	AWS, FY-3F to J, GOSAT-GW, JPSS-3/4, Metop-SG-A1 to 3, Metop-SG-B1 to 3, Quicksounder, Soundersat (NEON)	CMA, EUMETSAT, JAXA, NOAA,
174.8-182 GHz	AWS, FY-3F to J, JPSS-3/4, Meteor-M N2-3 to 6, Meteor-MP N1/2, Metop-SG-A1 to 3, Metop-SG-B1 to 3, Quicksounder, Soundersat (NEON)	CMA, EUMETSAT, NOAA, RosHydroMet
182-185 GHz	AWS, FY-3F to J, GOSAT-GW, JPSS-3/4, Meteor-M N2-3 to 6, Meteor-MP N1/2, Metop-SG-A1 to 3, Metop-SG-B1 to 3, TROPICS-4 to 7, Quicksounder, Soundersat (NEON)	CMA, EUMETSAT, JAXA, NASA, NOAA, RosHydroMet
185-190 GHz	AWS, FY-3F to J, JPSS-3/4, Meteor-M N2-3 to 6, Meteor-MP N1/2, Metop-SG-A1 to 3, Metop-SG-B1 to 3, TROPICS-4 to 7,	CMA, EUMETSAT, NASA, NOAA, RosHydroMet
228-230 GHz	Metop-SG-A1 to 3, Soundersat (NEON)	EUMETSAT, NOAA
231.5-252 GHz AI 1.14 & 10	Metop-SG-B1 to 3	EUMETSAT
Above 255 GHz	AWS, Metop-SG-B1 to 3	EUMETSAT

As can be seen, the use of the RF spectrum for passive band observations continues to increase, and technology improvements now permit access to much higher RF spectrum bands.

1.2 Remote Sensing in RF Passive Bands

Earth Exploration Satellite Service (passive) (EESS) bands continue to be recognized as being at high risk for anthropogenic sourced corruption. The FCC, in their Notice of Proposed Rule Making (NPRM) (21-186), recognized that current passive sensors are not able to differentiate between natural and man-made sources of signals.

As the use of adjacent and overlapping spectrum continues to increase, an impact on weather models and forecasting accuracy is expected, but the degree and nature of this impact are still unknown. The introduction and widespread implementation of 5G repeaters and the subsequent growth of Integrated Access & Backhaul (IAB) functions may further degrade or corrupt EESS (passive) band data observation activity.

Passive Band Sensors need an established set of standards to implement 'robustness' into their design. As mentioned earlier, passive band sensors cannot discern between natural and anthropogenic spectrum emissions, and this possess a real risk of data corruption to meteorological and climate data.

1.1.1 Why is this a problem for MW Sounders?

As designed, MW sounders only measure the total amount of radiative power as received by the antenna. A 230 Kelvin environmental observation signal that also has a 5 Kelvin anthropogenic sourced signal would be measured by the MW sounder as a measurement of 235 Kelvin. Similarly, a 235 Kelvin environmental observation signal that does not have any measurable anthropogenic sourced signals (0^{o} K) would also be measured as 235 Kelvin. The two scenarios are indistinguishable from each other to current MW sounders.

5G signals change due to varying factors (outside temperature, usage, power). To a MW sounder, these changes look like changes in signal power and thus variations in temperature.

1.1.2 RF Passive Band Situation ***as we see it.***

Non-natural RF contamination will only increase in intensity and in spectrum proliferation. This phenomenon has been observed in the spectrum management community for decades. Resolving this type of RF contamination is not easy and may not be affordably possible. The energy, by the time it's at the satellite, can't be 'removed' from the background – it's part of the background. Today, we believe we can only expect the presence of anthropogenic energy to be identified and mitigated with the aid of several methods. A broad and continuous effort is needed, in the regulatory arena (international and national), policy (responding to changes), and technical (adding things like new robustness to future systems.

1.3 Other Potential Sources of Contamination (beyond 5G)

5G is not the only expected source of passive band degradation. Commercial non-geostationary (NGSO) satellites are being deployed in large mega-constellations and require higher data rates and volume. The satellite uplinks (Earth to space) that are adjacent to the 50.2-50.4 GHz passive band have been identified as being a desired band for use by these mega-constellations.

We are also aware that there may be a variety of currently unknown sources of contamination that have yet to be identified as new technologies are developed and implemented. This has always been a risk, but the greater level of spectrum use today increases the chances that these technologies will try to edge up against protected passive bands. Therefore, growth in demand is expected, especially in the 57-64 GHz, in the various spectrum bands that are adjacent to passive allocated bands.

3 WHAT CAN WE DO?

Efforts are underway to develop methods and technologies that may reduce the risk of data corruption and loss. Some of the preliminary ideas being examined include flagging the data to mark that data that is suspect of corruption. This data can then be removed or de-weighted as decided by the meteorological community. Another approach is to map areas of observed or measured contamination – both in geography and time. Observations in those areas and times can then be 'flagged' for special handling.

Another step is to determine the impacts on the NWP. The environment is always changing and so measurements will also need to be ongoing as well as analysis of the data. An analysis is also important to determine at what point the NWP is affected, or that a particular passive band frequency is no longer usable.

Developing systems to use higher frequencies is possible, but these alternate frequencies will not have the same performance as the original bands with a subsequent loss in forecasting accuracy and climatology studies.

We will need to constantly assess and modify product development to make maximum use of data and we need to reach out to the community to expand on mitigation approaches. Technology advances may play a significant role in improving our ability to operate alongside these commercial systems and share the spectrum in a more effective and efficient manner.

4 ACTIONS AND/OR RECOMMENDATIONS FOR CONSIDERATION BY CGMS WORKING GROUP 1

- Recommend consideration by member administrations of WRC-23 agenda items that may affect satellite remote passive sensing.
- Recommend consideration of alignment with SFCG and WMO WRC-23 findings for passive bands.
- Continue actions by TGRFI for development of mitigation techniques for use by CGMS members.

5 CONCLUSION

Spectrum is the lifeblood of Operational Meteorology – users need to be aware of proposals and plans for spectrum sharing that may impact meteorological and climatological data. Based on many years of spectrum management experience, it's clear that non-natural RF contamination will never go away and will most likely continue to increase. We've seen each 'generation' of advanced wireless services, from '1G' to tomorrow's 6G, and each of these 'generations' have required a greater degree of access to the RF spectrum.

The EESS (passive) bands are at a very significant risk of increased noise levels from today's conditions. We've calculated that low anthropogenic noise levels will be indistinguishable from natural radiation and that high levels of anthropogenic noise will simply eliminate observation data for that geographical area. The implementation of 5G and following generations of broadband are expected to affect the EESS (passive) bands. We still don't have information on actual interference to a microwave sounder and it's not clear that it can easily be identified as such.

Predominantly bands near and between 24 to 86 GHz are today's most significant risks for passive band degradation and corruption, however passive bands both below and above this range are also at or have been at risk.

With the degradation of MW sounder data, there will be an impact to weather models and forecasting accuracy. It is recommended that there be an emphasis on the development and implementation of RFI identification and sensor robustness measures. It's clear that if we do nothing, we will not know when or how much the meteorological mission has been degraded by RF contamination.