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Prepared by USA
Agenda Item: I.1
To be discussed in WG I

Report on the Use of Frequency Bands Above 275 GHz

This document is the USA response to Action 29.16.

Report on the Use of Frequency Bands Above 275 GHz

1 Introduction

Recently, WRCs have improved Earth Exploitation Satellite Service (EESS) allocations in the bands 50 – 71 GHz and 71 - 275 GHz. A first attempt to put allocations above 275 GHz on the agenda of WRC 2003 failed. It was argued that active services are presently not able to identify bands for their operations and don't want to be restricted by allocations for EESS (passive) at a later time. A provisional item was put on the agenda for future WRCs. So far EESS bands are identified in FN S5.565 of the RR which was updated at WRC 2000. Studies are required to identify bands for future measurements of EESS passive. The studies have to identify bandwidth and protection requirements, and should give an indication on the possibility to share the band. It is necessary to indicate which type of measurement is planned in the future.

EUMETSAT informed CGMS that it is in process of preparing a study on this topic. The output is expected to be available early 2002. After completion of studies it will be necessary to promote the study results.

2. US Response and Recommendations

Action 29.16 CGMS Members to provide information on planned passive sensors using frequency bands above 275 GHz on future meteorological satellite systems.

The USA reviewed its plans for future meteorological satellite operations. A proposed passive sensor to be flown on the NPOESS will not contain any bands above 190 GHz. The USA does have plans for using frequency bands above 275 GHz prior to 2020. In the proposal below, the USA discussed plans for frequency use above 275 GHz. The USA will continue to review its plans for future, post 2020, passive sensors that may look at frequencies above 275 GHz.

COMMENTS TO THE NOAA REVISIONS TO

ITU-R Recommendations SA.515, SA.1028 and SA.1029

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These comments on frequency bands, bandwidths, and sensitivity levels pertain to Table 1 on page 26 of the document "Preliminary Draft Revision of Recommendation ITU-R SA.1029-1, Interference Criteria For Satellite Passive Remote Sensing" being proposed by the U.S. National Oceanic and Atmospheric Administration. In developing these positions the nadir sounding requirements for weather forecasting and climate studies were primarily considered.

Bands below 275 GHz:

1) The band 0.608-0.614 GHz (6 MHz) is potentially useful for soil moisture and salinity sensing from aircraft, and a stronger allocation is urged.

1.5) The band from 1400-1427 MHz is valuable for soil moisture and salinity remote sensing, and several space projects are being considered by ESA and NASA. The primary EESS allocation should be vigorously defended.

2) The appropriate band to reference around 2.7 GHz 2.69-2.70 (10 MHz). This band is potentially useful in conjunction with 1.400-1.427 GHz for determination of biomass in soil moisture sensing and improving measurements of ocean salinity by improved sea surface temperature determination.

3) The band 4200-4400 is not allocated to EESS, and should therefore reference footnote 4. Further, I know of no U.S. passive satellite system either using or planning to use this band, only of spoken interest. Obtaining a 200 MHz allocation in this region is thus highly unlikely, and perhaps not even as useful as would be a strong allocation at 6.9 GHz. I would thus suggest reducing the bandwidth of this request and correspondingly tightening its interference threshold. I have proposed 100 MHz in my version of the table, although unless there are objections even a band as narrow as 50 MHz would be still be acceptable.

4) Although it is clear that a band around ~6.9 GHz is valuable for heavy convection, soil moisture, and possibly ocean wind direction, the specific request needs to be considered with care. The NASA AMSR-E sensor will use 6.75 to 7.10 GHz. Our aircraft sensor has seen heavy continental interference in this band, but much less so within a band immediately above from 7.15 to 7.50 GHz. For either band, we have no existing allocation to use to strengthen a case. In table 1, I am thus suggesting that we simply reference the AMSR-E band because we will soon have AMSR-E as a

major space instrument to use to develop a case, as well as to develop global interference data sets. Moreover, from a geophysical standpoint, 6.925 GHz lies closer to the octave scale suggested by the important window bands of 10.7, 18.7, and 37 than does 7.3 GHz.

The significance of the octave scale is that non-resonant window-channel brightness features tend to remain constant within an octave, but change over approximately one octave. A variety of non-resonant physical mechanisms are responsible for this progression, including Debye polarization of water, Rayleigh hydrometeor scattering and absorption, vegetation scattering and absorption, ocean surface spectral properties, and continuum water vapor absorption.

1,2,3,4) The required sensitivities for channels below 10 GHz could set at 0.05 K, driven by a requirement to measure ocean surface salinity to ~0.1 ppt.

5) Currently only 10.68-10.7 (20 MHz) is allocated as primary for EESS. While 10.6-10.68 (80 MHz) is not primary, a full 100 MHz near ~10.7 is currently used, and considered valuable. My understanding is that AMSR-E will use 10.6-10.8 (200 MHz), even though the subband 10.7-10.8 provides only footnote EESS protection (US211).

6) The band 15.35-15.4 GHz is not currently used, or (to my knowledge) planned for use in space. It could potentially be valuable as an intermediate window channel, improving on the octave-scale sampling suggested above. However, it is too distant from the 22.235 GHz water vapor line to be the most valuable of window bands for inclusion in water vapor sensing or surface correction schemes. I suspect that for this reason it has not been adopted in U.S. systems.

It may be possible to trade this allocation off in favor of a stronger allocation at either 18.6-18.8 or 21.2-21.4 GHz.

4,5,6) The sensitivity requirements at ~6, ~10, and ~15 GHz are driven by the need to measure ocean surface wind direction, with a sensitivity of 0.1K to properly discern the azimuthal brightness variations. Secondary drivers are precipitation and wind speed, with ~0.2K required sensitivities needed to observe climatologically relevant trends.

7) The band 18.6-18.8 (200 MHz) represents the best chance we have of obtaining a strong worldwide primary allocation for a window channel near the 22.235 GHz water vapor line. This band will be used by AMSR-E.

8) The DMSP SSM/I uses 19.3-19.4 GHz, and the TRMM TMI uses a band very close (if not identical). I don't know if this heritage was carried on to CMIS or SSMIS, but for the sake of completeness we should consider 19.3-19.4 along with 18.6-18.6 even though their functions are virtually redundant and there is not even footnote EESS protection for it. I would expect less success in obtaining an allocation for 19.34-19.35 than a primary worldwide allocation at 18.6-18.8, and thus would suggest coordinating future applications and allocation proposals around 18.6-18.8.

7,8) Since the bands 18.6-18.8 and 19.3-19.4 are both used to correct Tbs for measurement of integrated maritime water vapor, their interference thresholds should be as low as for those bands used for the direct vapor measurements. I have thus suggested 0.05K (see 9,10,11 below) as a sensitivity threshold.

9) The band 21.2-21.4 is used by TRMM TMI, and may be used in future sensors. This band has the advantage of being located at the lower-frequency "hinge point" of the 22.235 GHz line. The significance is that at this frequency the absorption cvuased by a fixed density of water vapor is larger independent of pressure, and so measurements of integrated water vapor over the ocean can be done more accurately than at frequencies where the absorption is pressure dependent. Moreover, 21.2-21.4 GHz is close to the window bands of either 19.3-19.4 or 18.6-18.8, providing the ability to correct for water vapor variations in wind retrievals with better accuracy than using band pairs that are further apart.

If there is no realistic chance of strengthening this "lower hinge point" allocation, then encouraging the designers of future systems to gravitate around the "upper hinge point" (the current primary allocation of 23.6-24.0) is warranted to insure that at least one of the two hinge points is protected. There is loss, however, in water vapor retrieval accuracy incurred by increasing the separation of the hinge point band from the associated window band, here assumed to be either 18.6-18.8 or 19.3-19.4 GHz. For the two hinge points in question, the separation increases from 2.6 to 5.1 GHz. Study suggests that the corresponding integrated water vapor retrieval errors will increase by about 10% [Gasiewski, 1993].

10) The band 22.21-22.50 (290 MHz) is allocated as co-primary for EESS, and used by SSM/I. This band spans the 22.235 GHz line peak, but is asymmetrically located, with a center frequency 100 MHz higher than the actual line center frequency. Its use for integrated water vapor retrieval along with current co-primary allocation and use within radioastronomy suggest that it be defended. Note that the current SSM/I band of 21.985-22.485 extends slightly lower than the allocated band (by 225 MHz). It is not clear whether interference has been seen by SSM/I users.

11) The band 23.6-24.0 (400 MHz) will be used by AMSR-E, is currently used by AMSU-A, and is allocated to EESS on a primary basis. As in the case of 21.2-21.4, this band is at a hinge point of the line, and thus preferred for maritime water vapor measurement.

9,10,11) The three bands 21.2-21.4, 22.21-22.50, and 23.6-23.6 GHz are all either used or potentially valuable for climatological water vapor measurements. The sensitivity between variations in vapor and brightness is ~0.5 (K/%RH), and radiatively significant changes in RH are of order 0.1%. Thus, all these bands should have sensitivity thresholds of 0.05K.

12) The band 31.3-31.8 (500 MHz) is used by AMSU-A, and is to a great extent redundant with 36-37 GHz. A subband of width 200 MHz from 31.3-31.5 is currently allocated to EESS on a primary basis. Note that both 31.3-31.5 and 31.5-31.8 could be used in parallel to help detect persistent low-level interference by subband diversity.

13) The band 36-37 (1000 MHz) is used by SSM/I, TMI, and AMSR-E. For reasons of heritage, a primary allocation for this band should be pursued. This band also follows the desirable octave scale with 6.9, 10.7, and 18.7 GHz.

14) The band 50.2-50.4 (200 MHz) is allocated co-primary, and is required as a surface channel for temperature sounding. Since this channel is effectively used to correct for the Tb's observed in several important low-altitude sounding channels, its sensitivity threshold must be as low as those others, i.e., 0.01K.

15) There are several key bands within the 5-mm complex that warrant primary allocation, particularly because of their importance in NWP forecasting and climatological records:

51.56 -51.96	(400 MHz) P
52.675-52.975	(300 MHz) P*
53.11 -53.47	(360 MHz) P
53.396-53.796	(400 MHz) P*
53.75 -53.94	(190 MHz) P
54.20 -54.60	(220 MHz) *
54.75 -55.15	(400 MHz) *
55.335-55.665	(330 MHz) *
55.90 -56.15	(250 MHz)
56.19 -56.24	(50 MHz)
56.30 -56.35	(50 MHz)
56.902-57.678	(776 MHz) *
58.20 -59.00	(800 MHz) MP
59.00 -59.30	(300 MHz) M
60.35 -60.50	(150 MHz) M
61.07 -61.22	(150 MHz) M

* Indicates an AMSU-A band or set of bands
P Indicates primary allocation
M Indicates a mesospheric sounding band

All of the above should be considered as requiring 0.01K sensitivity since they contribute to the climatological record. Deleting reference to pushbroom sensors and instead focusing on what is required from the geophysical applications perspective is suggested. Thus, footnote 3 is irrelevant. Also, not all of the above mesospheric sounding bands (labeled "M") will need be need allocated as primary, but at least one of them should be so allocated. Ideally, the strongest lines within 60.35-60.50 and 61.07-61.22 should be sought [e.g., see Liebe, 1983].

11,12,14,15) These bands are critical for NWP forecasting and (in some cases) climate and so should have an interference percentage prescribed in accordance to what Dave Staelin suggests, i.e., that of an area-interference product, and randomly distributed.

16) The EESS primary band 64-56 and the co-primary band 65-66 should be considered to be traded off to strengthen (if possible) any allocations from 50-61.5 GHz.

17) The band 86-92 (6 GHz) is allocated to EESS on a primary basis, and will be used by AMSR-E. Although TRMM and SSM/I use 84-87, future sensors vendors of future sensors will be encouraged to use 86-92 by virtue of its primary status. The difference in information content between the two bands is negligible.

18) The band 100-102 (2 GHz) is allocated as co-primary for EESS but is not particularly valuable for nadir sounding or imaging applications. It could have potential use for limb sounding of ozone, and may be useful in radioastronomy.

19) The band 112.75-118.75 (6 GHz) spans an extremely useful range of subbands located on the lower wing of the 118.7503 GHz oxygen resonance. The set of subbands is valuable for nadir temperature profiling, with subband width ranging from ~2 GHz to a few MHz. These bands are complimentary to those temperature sounding bands around 50-61.5 GHz in that they provide additional information on precipitation height along with the potential for better spatial resolution. Single sideband receivers can be used to observe the lower wing without the need for protection of the upper wing. Since the range of 105-116 is currently allocated on a primary basis for EESS, some bandwidth at the lower end of this range (105-108, for example) should be traded off to strengthen the existing co-primary allocation from 116 to 118.75.

20) The band 118.75-124.75 (6 GHz) consists of a set of subbands that are equally as valuable for vertical temperature profiling as those described in 19 (above). This band falls within the co-primary band from 116-126 GHz. Although strengthening the allocation from 118.75-124.75 would be useful to allow double sideband receivers to operate, the use of both the lower and upper wings of the 118.7503 GHz oxygen is no longer considered necessary. Only one side of the line (either the lower or upper wing) is currently needed using a single sideband receiver. Since the lower side already has a strong allocation over most of the necessary band the upper wing from 118.75-126 GHz (7.25 GHz) could be traded off for a stronger allocation from 116 -118.75 and at other bands.

19,20) These bands will likely be used for temperature sounding and are expected to contribute to the climatological records. A sensitivity requirement of 0.01K is thus suggested. In addition, since they will be used for NWP initialization an interference percentage consistent with the bands from 50-61.5 GHz is suggested.

21) The band 149-151 (2 GHz) has a partial co-primary allocation (from 150-151) for EESS, but been studied and determined to be of unique value for nadir water vapor profiling [Klein and Gasiewski, 2000]. Strengthening this allocation to primary across 2 GHz of spectrum is warranted, perhaps by trading off spectrum on the upper wing of the 118.7503 GHz oxygen line.

22) The band 156-158 (2 GHz) is valuable for water vapor profiling as a surrogate for the pair of bands 149-151 and 164-168. It is allocated as co-primary for EESS. If possible, future sensors should be engineered to use 149-151 and 164-168, which are preferable to the use of a single band at 156-158.

23) The band 164-168 (4 GHz) has a primary allocation for EESS, and is of unique value for nadir water vapor profiling. Maintaining at least 2 GHz (165-167) of this allocation is critical; yielding any of this band should only occur at the in association with a strengthening of the allocation 149-151.

21,23) Comparing 150 to 166 GHz, our studies show distinct differences in the peak response height and sign of the responses for these two channels. Indeed, these two channels are far enough apart from each other relative to their offset from the 183 GHz line center to warrant being used simultaneously for water vapor sounding. The fact that current systems do not use both is a technological shortcoming that could be corrected in future systems, particularly as data assimilation techniques become better understood.

If one considers a progression of sidebands spaced at octave increments from the 183 GHz line center, starting with a 1 GHz offset, one obtains approximately the following sequence of offsets: 1,3,7,17,33. These offsets coincide with 182, 180, 176, 166, and 150 GHz. Since 150 is close to the center of the absorption minimum between 118 and 183 GHz, a set that includes both 150 and 166 GHz is warranted purely from the standpoint of having the capability to observe water vapor at a variety of levels of opacity around the 183 GHz line.

I thus repeat my suggestion of three years ago that at least 1 GHz (preferably 2 GHz) of bandwidth around each of these bands (150 and 166) be retained for water vapor sounding purposes ad infinitum. Based on our studies, 149-151 should not be relinquished either at this time nor upon the demise of AMSU-B, MHS, CMIS, or other such instruments. If necessary, EESS could stand to give up 2 GHz within 164-168 as a compromise for stronger protection within 149-151.

24) The band 175-183.35 contains the critical nadir water vapor sounding subbands used on many spaceborne sensors, including the DMSP SSM/T-2, SSMIS, and AMSU-B. These bands lie on the lower wing of the strong 183.31 GHz water vapor line. A stronger allocation across this band to primary status is urged. Since single sideband receivers can now be built at these frequencies there is no reason to allocate both the upper and lower sidebands.

21,22,23,24) The bands 149-151, 156-158, 164-168, and 175-192 are all either used or potentially valuable for climatological water vapor measurements. The sensitivity between variations in vapor and brightness is ~0.5 (K/%RH), and radiatively significant changes in RH are of order 0.1%. Thus, all these bands should have sensitivity thresholds of 0.05K. In addition, since they will be used for NWP initialization an interference percentage consistent with the bands from 50-61.5 GHz is suggested.

25) The band 183.35-191.7 contains the upper-wing subbands of the 183.31 GHz water vapor line. Primary allocation to EESS of this band is desirable, but not necessary since single sideband receivers using the lower wing can be implemented.

26) The band 217-223 (6 GHz) is sufficient as a window channel for cloud and precipitation imaging and water vapor sounding. A primary allocation exists from 217 to 231 GHz, but is broader than necessary for EESS.

Bands from 275 to 1000 GHz

27) The band from 316-334.5 (18.5 GHz) contains the 325.153 GHz water vapor line, found to be potentially useful for water vapor sounding and cloud and precipitation imaging. A primary allocation is suggested. It is noted that among submillimeter-wavelength water vapor bands, this particular band is secondary in importance to another around the 380.1974 GHz water vapor line. Several subbands of varying bandwidth are contained within this band.

28) The band from 336-344 (8 GHz) will be useful for water vapor sounding and cloud and precipitation imaging. A primary allocation for this band is strongly urged.

29) The 361-399.5 (38.5 GHz) contains the 380.1974 GHz water vapor line, and is critical for water vapor profiling from geosynchronous orbit. A primary allocation is strongly urged. Several subbands of varying bandwidth are contained within this band.

28,29) The bands 336-344 and 361-399.5 are valuable for climatological water vapor measurements from geosynchronous orbit. The sensitivity between variations in vapor and brightness is ~0.5 (K/%RH), and radiatively significant changes in RH are of order 0.1%. Thus, all these bands should have sensitivity thresholds of 0.05K.

30) The band 418-432 (14 GHz) contains the 424.7631 GHz oxygen line, and is critical for temperature sounding from geosynchronous orbit. A primary allocation is strongly urged. Several subbands of varying bandwidth are contained within this band.

27,29,30) It is not anticipated that single sideband receivers will be available for use at these frequencies in the foreseeable future, thus, allocations on the both the upper and lower wings are required.

27,28,29,30) Since these bands will be critical for NWP forecasting from geosynchronous orbit they should have an interference percentage prescribed in accordance to what Dave Staelin suggests, i.e., that of an area-interference product, and randomly distributed.

31) The band 436-460 (24 GHz) contains the 448.0011 GHz water vapor line, and is potentially useful for water vapor sounding from geosynchronous orbit. A primary allocation could be suggested. Several subbands of varying bandwidth are contained within this band.

32) The band 480-504 (24 GHz) contains the 487.2494 GHz oxygen line and a window region near 498 GHz, and is potentially useful for temperature sounding from geosynchronous orbit. A primary allocation could be suggested. Several subbands of varying bandwidth are contained within this band.

33) Bands centered around each of the window minima as follows could be suggested for allocation at this time, each of width ~10 GHz:

610
670

870
930

These bands are potentially useful for cirrus ice path determination.

References:

Gasiewski, A.J., "Channel Ranking in Passive Microwave Wet-Path Delay Measurements," Proceedings of the 1993 International Geoscience and Remote Sensing Symposium, vol. 4, pp. 1765?1767, presented at Kogakuin University, Tokyo, Japan, August 18-21, 1993.

Klein, M., and A.J. Gasiewski, "The Sensitivity of Millimeter and Sub-millimeter Frequencies to Atmospheric Temperature and Water Vapor Variations," *J. Geophys. Res. - Atmospheres*, vol. 13, pp. 17481-17511, July 16, 2000.

Liebe, H.J., "An Atmospheric Millimeter Wave Propagation Model," NTIA report 83-137, U.S. Dept. of Commerce, 1983.

TABLE 1 OF SA.1029

AS PROPOSED FOR UPDATING BY A.J. GASIEWSKI, 9/14/01

Band Requirements and Interference Criteria for Passive Remote Sensing

Frequency (GHz)	**Reference bandwidth (MHz)**	**Required DT_e (K)**	**[1]Permissible interference level (dBW)**	**Percentage of time permissible inteference level can be exceeded (%)**
0.611	6	0.05	–181	1
1.4135	27	0.05	–174	1
2.695	10	0.05	–179	1
4.3[(4)]	100	0.05	–169	1
6.925[(4)]	350	0.1	–160	1
10.65	100	0.1	–166	1
15.375	50	0.1	–169	1
18.7	200	0.05	–166	1
19.35	100	0.05	-169	1
21.3	200	0.05	–166	1
22.335	290	0.05	–164	1
23.8	400	0.05	–163	0.01
31.55	500	0.05	–162	0.01
36.5	1000	0.05	–159	1
50.3	200	0.01	–173	0.01
52.6-59.3 (See notes 14-16 above)	(Varies - see notes 14-16)	0.01	(Varies - see notes 14-16)	0.01
89	6000	0.05	–151	1
112.75-118.75	(Varies see note 19)	0.01	(Varies - see note 19)	0.01
118.75-124.75	(Varies see note 20)	0.01	(Varies - see note 20)	0.01
150	2000	0.05	-156	0.01
157[3]	2000	0.05	-156	0.01
166	4000	0.05	-153	0.01

175-183.35	(Varies, see note 24)	0.05	(Varies, see note 24)	0.01
183.35-191.7	(Varies, see note 25)	0.05	(Varies, see note 25)	1
220	6000	0.1	-148	1
316-334.5	(Varies, see note 27)	0.05	(Varies, see note 27)	1
340	8000	0.05	-150	0.01
361-399.5	(Varies, see note 29)	0.05	(Varies, see note 29)	0.01
418-432	(Varies, see note 30)	0.01	(Varies, see note 30)	0.01
436-460	(Varies, see note 31)	0.05	(Varies, see note 31)	1
480-504	(Varies, see note 32)	0.05	(Varies, see note 32)	1
610	10000	0.1	-146	1
670	10000	0.1	-146	1
870	10000	0.1	-146	1
930	10000	0.1	-146	1

(1) Changes to values of "permissible interference level" made in revision 3 of this Recommendation will not alter previous sharing agreements between EESS (passive) and active services.

(3) This band is needed until 2018 to accommodate existing and planned sensors.

(4) This information is given for guidance only since no allocation has yet been made.