3rd Annual Passive Sensing Microwave Workshop Proceedings/Summary

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The efforts of the (international) Space Frequency Coordination Group (SFCG) and International Telecommunication Union-Radiocommunication Sector (ITU-R) prompted the conduct of a NOAA Passive Sensing Workshop in 2007. The workshop's objective was to finalize the results of two previous workshops. It also focused on the introduction and discussion of technical papers on the identification, evaluation and utilization of particular passive sensing microwave bands, emphasizing bands above 275 GHz. This paper summarizes the workshop, describes ITU-R recommendations which relate to passive sensing (RS.515, RS.1028, and RS.1029) and provides a table which is an initial guide for updating the recommendations.

Workshop attendees recommended several changes and some additions to the existing table. Variables addressed were vegetation biomass, cirrus cloud, ice water path, cloud ice, cloud liquid water, height and depth of melting layer, precipitation, soil moisture, and the water vapor profile. Observations of these variables spanned the range of 1.37 to 882 GHz. It is hoped that the presentation of these workshop results will lead to discussions of needs for additional table entries as the changes to the ITU-R recommendations go forward.

A summary of the workshop along with links to papers and presentations can be found at http://sfcgonline.org/PM%20Workshop/pmw.aspx.

What is an ITU-R Recommendation?

The ITU-R Recommendations are international technical standards developed by the Radiocommunication Sector of the ITU. They are the result of studies undertaken by Radiocommunication Study Groups on:

- the use of a vast range of wireless services, including popular new mobile communication technologies:

- the management of the radio-frequency spectrum and satellite orbits;
- the efficient use of the radio-frequency spectrum by all radiocommunication services;
- terrestrial and satellite radiocommunication broadcasting;
- radio wave propagation;
- systems and networks for the fixed-satellite service, for the fixed service and the mobile service;
- space operation, Earth exploration-satellite,
- Meteorological-satellite and radio astronomy services.

The ITU-R Recommendations are approved by ITU Member States. Their implementation is not mandatory; however, as they are developed by experts from administrations, operators, and the industry and other organizations dealing with radiocommunication matters from all over the world, they enjoy an esteemed reputation and are implemented worldwide.

What are the three ITU-R Recommendations of concern?

1. RS. 515 recommends frequency bands and associated bandwidths for passive sensing of the Earth's land, oceans and atmosphere. See the appendix to this paper for a table of requirements for passive sensing of environmental data
2. RS. 1028 recommends performance criteria in the form of measurement sensitivities and data availability for passive remote sensing of the Earth's land, oceans and atmosphere. See the appendix to this paper for the performance criteria and a description of terms used therein.

3. RS. 1029

   a. recommends

      i. That interference levels for space borne passive sensors of environmental data should be set at 20% of the radiometer threshold

      ii. Permissible interference levels and reference bandwidths for the frequency bands preferred for passive sensing of the Earth's land, oceans and atmosphere. Levels and bandwidths are given in a table of interference criteria.

      iii. That the interference level in the table should not be exceeded for more than a specified percentage of either sensor viewing area or measurement time.

   b. Provides a table of values for these parameters. This table is reproduced in the appendix to this paper.

What changes did the 3rd passive microwave workshop recommend?

Workshop attendees represented these agencies: CNES, Environment Canada, Joint Center for Satellite Data Assimilation, Meteo France, NASA, National Academies of Sciences, National Science Foundation, NOAA/NESDIS, NPOESS-IPO, and the UK Met Office. A table of changes to the aforementioned recommendations was developed and is presented here.

Table 1: "Change Table" Updating RS.515, RS.1028, RS.1029

Band (Upper and Lower bound)	Change Status (e.g., New, Modified, etc)	Measurement and Comments (Measurement function, priority, dependencies, alternatives/comparisons, etc.)	Performance		Scan Mode (N,L)	Source (1)
			Sensitivity (K)	Data Availability		
1.37-1.4 1.4-1.427	M	Vegetation ~~index~~ biomass (replace)			N	JP
2.64-2.655 2.655-2.69 2.69-2.7	M	Vegetation ~~index~~ biomass (replace)			N	JP
4.2-4.4 4.95-4.99	M	Soil moisture Soil moisture			N	JP
6.425-7.25	M	Soil moisture			N	JP
52.6-59.3	M	Cloud liquid water			N	MD

Band (Upper and Lower bound)	Change Status (e.g., New, Modified, etc)	Measurement and Comments (Measurement function, priority, dependencies, alternatives/comparisons, etc.)	Performance		Scan Mode (N,L)	Source (1)
			Sensitivity (K)	Data Availability		
50.2-50.4	M	Cloud liquid water			N	MD
86-92	M	Cloud liquid water			N	MD
100-102	M	Precip. over sea and land			N	MD
115.25-122.25	M	Cloud liquid water, precip. over sea and land, incl. light precip. and snowfall, ht. and depth of melting layer			N	MD
164-167	M	Water vapor profile, precip. over land and snowfall			N	MD
174.8-191.8	M	Snowfall, cloud ice water path retrieval			N	MD
239-247 241.7-244.7	N	Quasi window for cirrus clouds and cloud ice (Can the window, currently in Rec. 515-4, at 226-231.5 GHz be used? Avoid spectral lines)			N	JP MD
316-334	M	Cloud ice			N	JP
334-336	N	Cloud ice, Cirrus, quasi-window			N	JP
371-389	M	Cloud ice			N	JP
446.5-449.5 439.3-456.7	N	Cloud ice water path (integrated ice in clouds) and cirrus			N	MD JP
634.8-637.6	M	Cloud ice			N	JP
648.2-651.0	M	Cloud ice, paired with 634.8-637.6 GHz, note Rec. 515-4 already has 634-654 GHz			N	JP
662.5-666.5	N	Cirrus clouds and cloud ice water path			N	MD
866-882	N	Cloud ice			N	JP

Notes

(1) JP:Jeff Piepmeier NASA/GSFC

MD: Markus Dreis EUMETSAT

What next?

The next meeting of the ITU's World Radiocommunication Conference will be held in 2011. Changes and additions to existing recommendations will be considered during this meeting. The frequency spectrum above 275 GHz is unregulated at this writing. As scientists, it is important to make our voices heard by advising ITU participants of our interests and concerns. One way of making our voices heard is to provide national ITU representatives with updates to tables presented in this paper. If the reader needs to know how to contact their national representative, just speak to either of the authors:

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Appendix: Tables from RS. 515-4, RS. 1028-2, RS. 1029-2

Table: Requirements for passive sensing of environmental data, from RS. 515-4

Frequency band(s)[1] (GHz)	Total bandwidth required (MHz)	Spectral line(s) or centre frequency (GHz)	Measurement	Scan mode N, L[2]
1.37-1.4s, 1.4-1.427P	100	1.4	Soil moisture, ocean salinity, sea surface temperature, vegetation index	N
2.64-2.655s, 2.655-2.69s, 2.69-2.7P	45	2.7	Ocean salinity, soil moisture, vegetation index	N
4.2-4.4s, 4.95-4.99s	200	4.3	Sea surface temperature	N
6.425-7.25	200	6.85	Sea surface temperature	N
10.6-10.68p, 10.68-10.7P	100	10.65	Rain rate, snow water content, ice morphology, sea state, ocean wind speed	N
15.2-15.35s, 15.35-15.4P	200	15.3	Water vapour, rain rate	N
18.6-18.8p	200	18.7	Rain rates, sea state, sea ice, water vapour, ocean wind speed, soil emissivity and humidity	N
21.2-21.4p	200	21.3	Water vapour, liquid water	N
22.21-22.5p	300	22.235	Water vapour, liquid water	N
23.6-24P	400	23.8	Water vapour, liquid water, associated channel for atmospheric sounding	N
31.3-31.5P, 31.5-31.8p	500	31.4	Sea ice, water vapour, oil spills, clouds, liquid water, surface temperature, reference window for 50-60 GHz range	N
36-37p	1 000	36.5	Rain rates, snow, sea ice, clouds	N
50.2-50.4P	200	50.3	Reference window for atmospheric temperature profiling (surface temperature)	N
52.6-54.25P, 54.25-59.3p	6 700[3]	Several between 52.6-59.3	Atmospheric temperature profiling (O_2 absorption lines)	N
86-92P	6 000	89	Clouds, oil spills, ice, snow, rain, reference window for temperature soundings near 118 GHz	N

Table: Performance criteria for passive remote sensing of environmental data, from RS. 1028

Frequency band(s)[1] (GHz)	Total BW required (MHz)	Required ΔT_e (K)	Data availability[2] (%)	Scan mode (N, L)[3]
1.37-1.4s, 1.4-1.427P	100	0.05	99.9	N
2.64-2.655s, 2.655-2.69s, 2.69-2.7P	45	0.1	99.9	N
4.2-4.4s,	200	0.3/0.05[4]	99.9	N

4.95-4.99s				
6.425-7.25	200	0.3/0.05[4]	99.9	N
10.6-10.68p, 10.68-10.7P	100	1.0/0.1[4]	99.9	N
15.2-15.35s, 15.35-15.4P	200	0.1	99.9	N
18.6-18.8p	200	1.0/0.1[4]	95/99.9[4]	N
21.2-21.4p	200	0.2/0.05[4]	99/99.9[4]	N
22.21-22.5p	300	0.4/0.05[4]	99/99.9[4]	N
23.6-24P	400	0.05	99.99	N
31.3-31.5P, 31.5-31.8p	500	0.2/0.05[4]	99.99	N
36-37p	1 000	1.0/0.1[4]	99.9	N
50.2-50.4P	200	0.05	99.99	N
52.6-54.25P, 54.25-59.3p	6 700[5]	0.3/0.05[4]	99.99	N
86-92P	6 000	0.05	99.99	N
100-102P	2 000	0.005	99	L
109.5-111.8P	2 000	0.005	99	L
114.25-116.P	1 750	0.005	99	L

115.25-116P, 116.0-122.25p	7 000(5)	0.05/0.005(6)	99.99/99(6)	N, L
148.5-151.5P	3 000	0.1/0.005(6)	99.99/99(6)	N, L
155.5-158.5(7)p	3 000	0.1	99.99	N
164-167P	3 000(5)	0.1/0.005(6)	99.99/99(6)	N, L
174.8-182p, 182-185P, 185-190p, 190-191.8P	17 000(5)	0.1/0.005(6)	99.99/99(6)	N, L
200-209P	9 000(5)	0.005	99	L
226-231.5P	5 500	0.2/0.005(6)	99.99/99(6)	N, L
235-238p	3 000	0.005	99	L
250-252P	2 000	0.005	99	L
275-277	2 000(5)	0.005	99	L
294-306	12 000(5)	0.2/0.005(6)	99.99/99(6)	N, L
316-334	18 000(5)	0.3/0.005(6)	99.99/99(6)	N, L
342-349	7 000(5)	0.3/0.005(6)	99.99/99(6)	N, L
363-365	2 000	0.005	99	L
371-389	18 000(5)	0.3	99.99	N
416-434	18 000(5)	0.4	99.99	N
442-444	2 000(5)	0.4/0.005(6)	99.99/99(6)	N, L
496-506	10 000(5)	0.5/0.005(6)	99.99/99(6)	N, L
546-568	22 000(5)	0.5/0.005(6)	99.99/99(6)	N, L
624-629	5 000(5)	0.005	99	L
634-654	20 000(5)	0.5/0.005(6)	99.99/99(6)	N, L
659-661	2 000	0.005	99	L
684-692	8 000(5)	0.005	99	L
730-732	2 000(5)	0.005	99	L
851-853	2 000	0.005	99	L
951-956	5 000(5)	0.005	99	L

(1) P: Primary allocation, shared only with passive services (No. 5.340 of the Radio Regulations); p: primary allocation, shared with active services; s: secondary allocation.

(2) Data availability is the percentage of area or time for which accurate data is available for a specified sensor measurement area or sensor measurement time. For a 99.99% data availability, the measurement area is a square on the Earth of 2 000 000 km^2, unless otherwise justified; for a 99.9% data availability, the measurement area is a square on the Earth of 10 000 000 km^2 unless otherwise justified; for a 99% data availability the measurement time is 24 h, unless otherwise justified.

(3) N: Nadir, Nadir scan modes concentrate on sounding or viewing the Earth's surface at angles of nearly perpendicular incidence. The scan terminates at the surface or at various levels in the atmosphere according to the weighting functions. L: Limb, Limb scan modes view the atmosphere “on edge” and terminate in space rather than at the surface, and accordingly are weighted zero at the surface and maximum at the tangent point height.

(4) First number for sharing conditions circa 2003; second number for scientific requirements that are technically achievable by sensors in the next 5-10 years.

(5) This bandwidth is occupied by multiple channels.

(6) Second number for microwave limb sounding applications.

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

Description of terms used in performance criteria from RS. 1028

Sensitivity of radiometric receivers

Radiometric receivers sense the noise-like thermal emission collected by the antenna and the thermal noise of the receiver. By integrating the received signal the random noise fluctuations can be reduced and accurate estimates can be made of the sum of the receiver noise and external thermal emission noise power. Expressing the noise power per unit bandwidth as an equivalent noise temperature, the effect of integration in reducing measurement uncertainty can be expressed as given below:

$$\Delta T_e = \frac{\alpha(T_A + T_N)}{\sqrt{B\tau}}$$

where:

ΔT_e : radiometric resolution (r.m.s. uncertainty in the estimation of the total system noise, $T_A + T_N$)

α : receiver system constant, ≥ 1, depending on the system design

T_A : antenna temperature

T_N : receiver noise temperature

B : spectral resolution of spectroradiometer or bandwidth of a single radiometric channel

τ: integration time.

The receiver system constant, α, is a function of the type of detection system. For total power radiometers used by Earth exploration-satellite service sensors, this constant can be no smaller than unity. In practice, most modern total power radiometers closely approach unity.

Table: Interference criteria for passive remote sensing of environmental data (from RS. 1029-2)

Frequency band(s)[1] (GHz)	Total bandwidth required (MHz)	Reference bandwidth (MHz)	Maximum interference level (dBW)	Percentage of area or time permissible interference level may be exceeded[2] (%)	Scan mode (N, L)[3]
1.37-1.4s, 1.4-1.427P	100	27	–174	0.1	N
2.64-2.655s, 2.655-2.69s, 2.69-2.7P	45	10	–176	0.1	N
4.2-4.4s, 4.95-4.99s	200	200	–158/–166[4]	0.1	N
6.425-7.25	200	200	–158/–166[4]	0.1	N
10.6-10.68p, 10.68-10.7P	100	100	–156/–166[4]	0.1	N
15.2-15.35s, 15.35-15.4P	200	50	–169	0.1	N
18.6-18.8p	200	200	–153/–163[4]	5/0.1[4]	N
21.2-21.4p	200	100	–163/–169[4]	1/0.1[4]	N
22.21-22.5p	300	100	–160/–169[4]	1/0.1[4]	N
23.6-24P	400	200	–166	0.01	N
31.3-31.5P, 31.5-31.8p	500	200	–160/–166[4]	0.01	N

Table: Interference criteria for passive remote sensing of environmental data (from RS. 1029-2) (continued)

Frequency band(s)[1] (GHz)	Total bandwidth required (MHz)	Reference bandwidth (MHz)	Maximum interference level (dBW)	Percentage of area or time permissible interference level may be exceeded[2] (%)	Scan mode (N, L)[3]
36-37p	1 000	100	–156/–166[4]	0.1	N
50.2-50.4P	200	200	–166	0.01	N
52.6-54.25P, 54.25-59.3p	6 700[5]	100	–161/–169[4]	0.01	N
86-92P	6 000	100	–169	0.01	N
100-102P	2 000	10	–189	1	L
109.5-111.8P	2 000	10	–189	1	L
114.25-116P	1 750	10	–189	1	L
115.25-116P, 116-122.25p	7 000[5]	200/10[6]	–166/–189[6]	0.01/1[6]	N, L
148.5-151.5P	3 000	500/10[6]	–159/–189[6]	0.01/1[6]	N, L
155.5-158.5[7]p	3 000	200	–163	0.01	N
164-167P	3 000[5]	200/10[6]	–163/–189[6]	0.01/1[6]	N, L
174.8-182p, 182-185P, 185-190p, 190-191.8P	17 000[5]	200/10[6]	–163/–189[6]	0.01/1[6]	N, L
200-209P	9 000[5]	3	–194	1	L
226-231.5P	5 500	200/3[6]	–160/–194[6]	0.01/1[6]	N, L
235-238p	3 000	3	–194	1	L
250-252P	2 000	3	–194	1	L
275-277	2 000[5]	3	–194	1	L
294-306	12 000[5]	200/3[6]	–160/–194[6]	0.01/1[6]	N, L
316-334	18 000[5]	200/3[6]	–158/–194[6]	0.01/1[6]	N, L
342-349	7 000[5]	200/3[6]	–158/–194[6]	0.01/1[6]	N, L
363-365	2 000	3	–194	1	L
371-389	18 000[5]	200	–158	0.01	N
416-434	18 000[5]	200	–157	0.01	N
442-444	2 000[5]	200/3[6]	–157/–194[6]	1	N, L

Table: Interference criteria for passive remote sensing of environmental data (from RS. 1029-2) (end)

Frequency band(s)[1] (GHz)	Total bandwidth required (MHz)	Reference bandwidth (MHz)	Maximum interference level (dBW)	Percentage of area or time permissible interference level may be exceeded[2] (%)	Scan mode (N, L)[3]
496-506	10 000[5]	200/3[6]	–156/–194[6]	0.01/1[6]	N, L
546-568	22 000[5]	200/3[6]	–156/–194[6]	0.01/1[6]	N, L
624-629	5 000[5]	3	–194	1	L
634-654	20 000[5]	200/3[6]	–156/–194[6]	0.01/1[6]	N, L
659-661	2 000	3	–194	1	L
684-692	8 000[5]	3	–194	1	L
730-732	2 000[5]	3	–194	1	L
851-853	2 000	3	–194	1	L
951-956	5 000[6]	3	–194	1	L

[1] P: Primary allocation, shared only with passive services (No. 5.340 of the Radio Regulations); p: primary allocation, shared with active services; s: secondary allocation.

[2] For a 0.01% level, the measurement area is a square on the Earth of 2 000 000 km^2, unless otherwise justified; for a 0.1% level, the measurement area is a square on the Earth of 10 000 000 km^2 unless otherwise justified; for a 1% level, the measurement time is 24 h, unless otherwise justified.

[3] N: Nadir, Nadir scan modes concentrate on sounding or viewing the Earth's surface at angles of nearly perpendicular incidence. The scan terminates at the surface or at various levels in the atmosphere according to the weighting functions. L: Limb, Limb scan modes view the atmosphere "on edge" and terminate in space rather than at the surface, and accordingly are weighted zero at the surface and maximum at the tangent point height.

[4] First number for sharing conditions circa 2003; second number for scientific requirements that are technically achievable by sensors in next 5-10 years.

[5] This bandwidth is occupied by multiple channels.

[6] Second number for microwave Limb sounding applications.

[7] This band is needed until 2018 to accommodate existing and planned sensors.