3rd Annual Passive Sensing Microwave Workshop Proceedings/Summary

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NOAA Passive Sensing Workshop

- May 2007
- Prompted by
  - Space Frequency Coordination Group (SFCG)
  - International Telecommunication Union-Radiocommunication Sector (ITU-R)
- View workshop information at
  http://sfcgonline.org/PM%20Workshop/pmw.aspx

- Workshop objectives
  - finalize results of two previous workshops
  - present papers on
    - identification, evaluation and utilization of particular passive sensing microwave bands, emphasizing bands above 275 GHz.
  - Contributed to updates to passive spectrum recommendations
- This presentation
  - summarizes workshop
  - describes ITU-R recommendations
  - motivates updates to the recommendations

Workshop attendees

- recommended updates to frequency table used for sensing environmental variables
  - frequencies span 1.37 to 882 GHz

Recommendation updates

- Updates to frequency table for
    - vegetation biomass
    - cirrus cloud
    - ice water path
    - cloud ice
    - cloud liquid water
    - depth of melting layer
    - Precipitation
    - soil moisture
    - water vapor profile
- Tables are integral part of ITU-R recommendations
- Recommendations are keys to protecting the passive spectrum

What is a recommendation?

- international technical standards
  - developed by the Radiocommunication Sector of the ITU.
- result from studies by Radiocommunication Study Groups on
  - use of wireless services, including popular new mobile communication technologies:
  - the management of the radio-frequency spectrum and satellite orbits;
  - 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.
- approved by Member States
- implementation not mandatory, but
  - developed by experts from
    - Administrations
    - Operators
    - industry and other organizations
  - enjoy an esteemed reputation
  - implemented worldwide

three ITU-R Recommendations of concern

- RS. 515
- RS. 1028
- RS. 1029

RS. 515

- recommends passive sensing frequency bands/bandwidths

- See the backup slides for details

RS. 1028

- recommends performance criteria for passive sensing bands including

  – measurement sensitivities

  – data availability.

- backup slides have details

RS. 1029

- recommends
  - interference levels for space borne passive sensors of environmental data should be set at 20% of the radiometer threshold
  - 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.
  - interference level in the table should not be exceeded for more than a specified percentage of either sensor viewing area or measurement time.

- backup slides have details

changes recommended by workshop attendees

- A table, leading towards updates to
  - RS.515
  - RS.1028
  - RS.1029

changes recommended by workshop attendees

Band (Upper and Lower bound)	Change Status (e.g., New, Modified, etc)	Measurement and Comments (Measurement function, priority, dependencies, alternatives/comparisons, etc.)
1.37-1.4 1.4-1.427	M	Vegetation ~~index~~ biomass (replace)
2.64-2.655 2.655-2.69 2.69-2.7	M	Vegetation ~~index~~ biomass (replace)
4.2-4.4 4.95-4.99	M	Soil moisture Soil moisture
6.425-7.25	M	Soil moisture
52.6-59.3	M	Cloud liquid water
50.2-50.4	M	Cloud liquid water
86-92	M	Cloud liquid water
100-102	M	Precip. over sea and land
115.25-122.25	M	Cloud liquid water, precip. over sea and land, incl. light precip. and snowfall, ht. and depth of melting layer
164-167	M	Water vapor profile, precip. over land and snowfall

changes recommended by workshop attendees

Band (Upper and Lower bound)	Change Status (e.g., New, Modified, etc)	Measurement and Comments (Measurement function, priority, dependencies, alternatives/comparisons, etc.)
174.8-191.8	M	Snowfall, cloud ice water path retrieval
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)
316-334	M	Cloud ice
334-336	N	Cloud ice, Cirrus, quasi-window
371-389	M	Cloud ice
446.5-449.5 439.3-456.7	N	Cloud ice water path (integrated ice in clouds) and cirrus
634.8-637.6	M	Cloud ice
648.2-651.0	M	Cloud ice, paired with 634.8-637.6 GHz, note Rec. 515-4 already has 634-654 GHz
662.5-666.5	N	Cirrus clouds and cloud ice water path
866-882	N	Cloud ice

Who attended the workshop?

- Representatives from

  - CNES
  - Environment Canada
  - Meteo France
  - NASA
  - NOAA/NESDIS
  - NPOESS-IPO
  - UK Met Office
  - U.S. Joint Center for Satellite Data Assimilation
  - U.S. National Academies of Sciences
  - U.S. National Science Foundation

What next?

- spectrum above 275 GHz unallocated
  - international footnote describes use but needs update
- year 2011
  - next meeting of ITU-R World Radiocommunication Conference (WRC)
  - Changes and additions to Radio Regulations considered (part of Agenda Item 1.6.)
- scientists
  - make our voices heard
    - advise ITU-R participants of our interests and concerns
    - provide national ITU-R representatives with updates to tables presented in this presentation

Who are my ITU-R participants?

- ask
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Backup slides
RS. 515-4

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

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RS. 515-5

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

(continued)

Frequency band(s)[1] (GHz)	Total bandwidth required (MHz)	Spectral line(s) or centre frequency (GHz)	Measurement	Scan mode N, L[2]
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

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RS. 1028

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, 4.95-4.99s	200	0.3/0.05[4]	99.9	N
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

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

(continued)

Frequency band(s)[1] (GHz)	Total BW required (MHz)	Required ΔT_e (K)	Data availability[2] (%)	Scan mode (N, L)[3]
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

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

(continued)

Frequency band(s)[1] (GHz)	Total BW required (MHz)	Required ΔT_e (K)	Data availability[2] (%)	Scan mode (N, L)[3]
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

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

(continued)

Frequency band(s)[1] (GHz)	Total BW required (MHz)	Required ΔT_e (K)	Data availability[2] (%)	Scan mode (N, L)[3]
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

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

(continued)

Frequency band(s)[1] (GHz)	Total BW required (MHz)	Required ΔT_e (K)	Data availability[2] (%)	Scan mode (N, L)[3]
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

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

(continued)

Frequency band(s)[1] (GHz)	Total BW required (MHz)	Required ΔT_e (K)	Data availability[2] (%)	Scan mode (N, L)[3]
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

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

(continued)

Frequency band(s)[1] (GHz)	Total BW required (MHz)	Required ΔT_e (K)	Data availability[2] (%)	Scan mode (N, L)[3]
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 km² , unless otherwise justified; for a 99.9% data availability, the measurement area is a square on the Earth of 10 000 000 km² 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.

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RS. 1028

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.

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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

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RS. 1029

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

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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]
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

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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]
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

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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]
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

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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]
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.

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(2) For a 0.01% level, the measurement area is a square on the Earth of 2 000 000 km², unless otherwise justified; for a 0.1% level, the measurement area is a square on the Earth of 10 000 000 km² 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.