International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R RS.515-4

(05/2003)

Frequency bands and bandwidths used for satellite passive sensing

RS Series

Remote sensing systems

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Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R RS.515-4[*]

Frequency bands and bandwidths used for satellite passive sensing

(1978-1990-1994-1997-2003)

The ITU Radiocommunication Assembly,

considering

a) that environmental data relating to the Earth is of increasing importance;

b) that passive microwave sensors are used in remote sensing by Earth exploration and meteorological satellites in certain frequency bands allocated for such use in the Radio Regulations (RR);

c) that some of these bands are also allocated to other radio services;

d) that protection from interference on certain frequencies is essential for passive sensing measurements and applications;

e) that for measurements of known spectral lines, certain bands at specific frequencies are of particular importance;

f) that, for other types of passive sensor measurements, a certain number of frequency bands are in use, the exact positions of which in the spectrum are not of critical importance as long as the centre frequencies are more or less uniformly distributed in the spectrum;

g) that the preferred and essential frequencies and bandwidths need to be promulgated;

h) that new frequencies may be identified in the future which would enable new types of measurements,

recommends

1 that, based on Annexes 1 and 2, the frequency bands and the associated bandwidths for passive sensing of properties of the Earth’s land, oceans and atmosphere shown in Table 1 should be used for satellite passive remote sensing.

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[*] Radiocommunication Study Group 7 made editorial amendments to this Recommendation in 2010 in accordance with Resolution ITU-R 1.

TABLE 1

Requirements for passive sensing of environmental data

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 1 (*continued*)

Frequency band(s)[(1)] (GHz)	**Total bandwidth required (MHz)**	**Spectral line(s) or centre frequency (GHz)**	**Measurement**	**Scan mode N, L[(2)]**
100-102P	2 000	100.49	N_2O, NO	L
109.5-111.8P	2 000	110.8	O_3	L
114.25-116P	1 750	115.27	CO	L
115.25-116P, 116-122.25p	7 000[(3)]	118.75	Atmospheric temperature profiling (O_2 absorption line)	N, L
148.5-151.5P	3 000	150.74	N_2O, Earth surface temperature, cloud parameters, reference window for temperature soundings	N, L
155.5-158.5[(4)]p	3 000	157	Earth and cloud parameters	N
164-167P	3 000[(3)]	164.38, 167.2	N_2O, cloud water and ice, rain, CO, ClO	N, L
174.8-182p, 182-185P, 185-190p, 190-191.8P	17 000[(3)]	175.86, 177.26, 183.31, 184.75	N_2O, Water vapour profiling, O_3	N, L
200-209P	9 000[(3)]	200.98, 203.4, 204.35, 206.13, 208.64	N_2O, ClO, water vapour, O_3	L
226-231.5P	5 500	226.09, 230.54, 231.28	Clouds, humidity, N_2O (226.09 GHz), CO (230.54 GHz), O_3 (231.28 GHz), reference window	N, L
235-238p	3 000	235.71, 237.15	O_3	L
250-252P	2 000	251.21	N_2O	L
275-277	2 000[(3)]	276.33	NO, N_2O (276.33 GHz)	L
294-306	12 000[(3)]	301.44	NO, N_2O (301.44 GHz), O_3, O_2, HNO_3, HOCl	N, L
316-334	18 000[(3)]	325.15	Water vapour profiling (325.1 GHz), O_3, HOCl	N, L
342-349	7 000[(3)]	345.8, 346	CO (345.8 GHz), HNO_3, CH_3Cl, O_3, oxygen, HOCl	N, L
363-365	2 000	364.32	O_3	L
371-389	18 000[(3)]	380.2	Water vapour profiling	N
416-434	18 000[(3)]	425	Temperature profiling	N
442-444	2 000[(3)]	443	H_2O, O_3, HNO_3, N_2O, CO	N, L
496-506	10 000[(3)]	498.1, 498.2, 498.3, 498.4, 498.5, 498.6	O_3, CH_3Cl, N_2O, BrO, ClO, water vapour profiling	N, L

TABLE 1 (*end*)

Frequency band(s)(1) (GHz)	**Total bandwidth required (MHz)**	**Spectral line(s) or centre frequency (GHz)**	**Measurement**	**Scan mode N, L(2)**
546-568	22 000(3)	557	Water vapour profiling	N, L
624-629	5 000(3)	624.27, 624.34, 624.77, 625.37, 625.92, 627.18, 627.77, 628.46	HCl, BrO, O_3, HCl, SO_2, H_2O_2	L
634-654	20 000(3)	635.87, 642.85, 647.2, 649.45, 649.7, 650.28, 650.73, 651.77, 652.83	CH_3Cl, HOCl, ClO, water vapour, N_2O, BrO, O_3	N, L
659-661	2 000	660.49	BrO	L
684-692	8 000(3)	688	ClO, CO, CH_3Cl	L
730-732	2 000(3)	731	Oxygen, HNO_3	L
851-853	2 000	852	NO	L
951-956	5 000(3)	952, 955	Oxygen, NO	L

(1) P: Primary Allocation, shared only with passive services (RR No. 5.340); p: primary allocation, shared with active services; s: secondary allocation.

(2) 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.

(3) This bandwidth is occupied by multiple channels.

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

HNO_3:	Nitric acid	H_2O_2:	Hydrogen peroxide	SO_2:	Sulphur dioxide
CH_3Cl:	Methyl chloride	HOCl:	Hypochlorous acid	NO:	Nitric oxide
BrO:	Bromine monoxide	N_2O:	Nitrous acid	CO:	Carbon monoxide
HCl:	Hydrochloric acid	ClO:	Chlorine monoxide	O_3:	Ozone

Annex 1

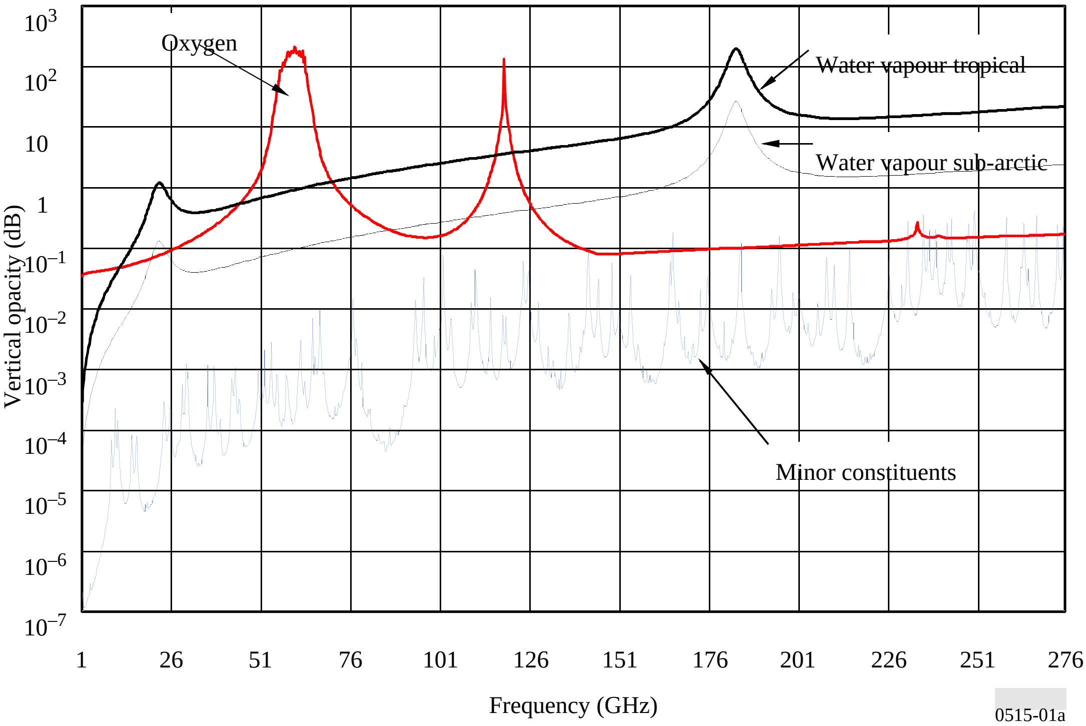
Selection of frequencies for satellite passive sensing

1 Introduction

Energy at microwave frequencies is emitted and absorbed by the surface of the Earth and by the atmosphere above the surface. The transmission properties of the absorbing atmosphere vary as a function of frequency, as shown in Figs. 1a and 1b. These Figures depict calculated one-way zenith (90° elevation angle) attenuation values for oxygen, water vapour and minor constituents. The calculations are for a path between the surface and a satellite. These calculations reveal frequency bands for which the atmosphere is effectively opaque and others for which the atmosphere is nearly transparent. For example, for nadir sounding, the regions or windows that are nearly transparent may be used to sense surface phenomena; the regions that are opaque are used to sense the atmosphere.

FIGURE 1a

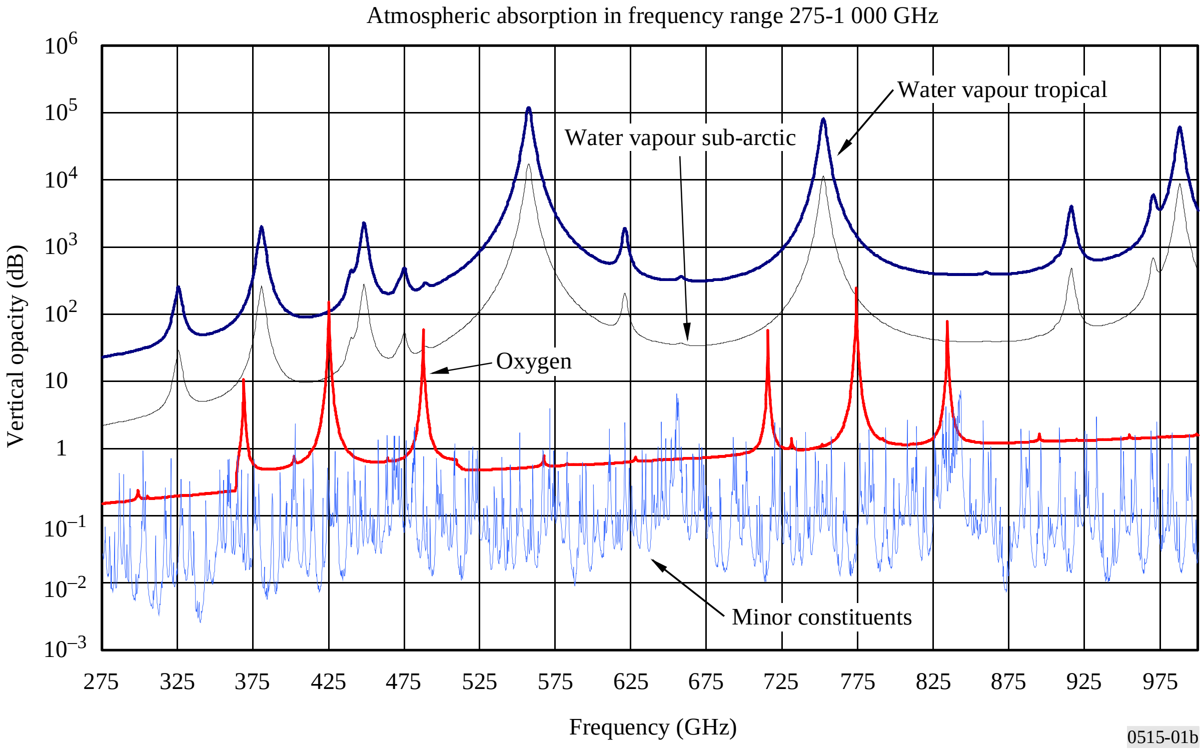
Atmospheric opacity in frequency range 1-275 GHz



The surface brightness temperature, the atmospheric temperature at points along the path, and the absorption coefficients are unknown and to be determined from measurements of the antenna temperature, T_A. The surface brightness temperature and the absorption coefficients in turn, depend upon the physical properties of the surface or atmosphere that are to be sensed. A single observation at a single frequency cannot be used to estimate a single physical parameter. Observations must be made simultaneously at a number of frequencies and combined with models for the frequency dependence and physical parameter dependence of the surface brightness temperature and of the absorption coefficient, before solutions can be obtained.

FIGURE 1b

Zenith attenuation versus frequency, 275-1 000 GHz



Operating frequencies for passive microwave sensors are primarily determined by the phenomena to be measured. For certain applications, such as those requiring measurements of microwave emissions from atmospheric gases, the choice of frequencies is quite restricted and is determined by the spectral line frequencies of the gases. Other applications have broad frequency regions where the phenomena can be sensed.

2 Atmospheric measurements

Atmospheric attenuation does not occur within a single atmospheric layer of constant temperature. The measured antenna temperature depends mostly upon the temperature in the region along the path where the attenuation (total to the satellite) is less than 10 dB, and little upon temperatures in regions where the attenuation is very small, or the total attenuation to the satellite is large. The temperature values can be sensed at different heights or distances along the path by selecting frequencies near the edges of the opaque regions with different attenuations, which provide different weighting functions or multipliers of $T(s)$, the atmospheric temperature at a given point.

A number of different frequencies may be chosen to provide a reasonable set of weighting functions for atmospheric temperature, water vapour, ozone, chlorine oxide, nitrous oxide and carbon monoxide profile measurements. For the last four molecular measurements, each individual line does not have enough fine structure, as in the O_2 temperature profiling band, or enough width, as in the water vapour band about 22.235 GHz, to allow for profile measurements about a line, given the satellite constraints on integration time. Hence, in order to achieve profiling information on these constituents, multiple line measurements will be necessary.

Atmospheric temperature profiles are currently obtained from spaceborne sounding instruments measuring in the infrared (IR) and microwave spectrums (oxygen absorption around 60 GHz).

As compared to IR techniques, the all-weather capability (the ability for a spaceborne sensor to "see" through most clouds) is probably the most important feature that is offered by microwave techniques. This is fundamental for operational weather forecasting and atmospheric sciences applications, since more than 60% of the Earth's surface, in average, is totally covered by clouds, and only 5% of any 20×20 km^2 spot (corresponding to the typical spatial resolution of the IR sounders) are completely cloud-free. This situation severely hampers operation of IR sounders, which have little or no access to large, meteorologically active regions.

The broad opaque region between 50 and 66 GHz is composed of a number of narrow absorption (opaque) lines and observations may be made either at the edges of the complex of lines or in the valleys between the lines. The next O_2 absorption spectrum around 118 GHz has a lower potential due to its particular structure (monochromatic, as compared to the rich multi-line structure around 60 GHz) and is more heavily affected by the attenuation caused by atmospheric humidity.

Clouds and rain can provide additional attenuation when they occur along the path. Both rain and clouds may be sensed in the atmospheric windows between 5 and 150 GHz. Multiple observations over a wide frequency range are required to separate rain from cloud and to separate these effects from surface emission.

Limb sounding geometry, i.e. with the atmosphere observed tangentially, can be used from a satellite or an airborne instrument to retrieve concentration profiles of trace species useful for investigations of atmospheric chemistry. Limb sounding is more sensitive and allows higher vertical resolution than nadir sounding. Submillimetre frequencies from about 500 GHz and higher, allow sounding down to the lower stratosphere. Millimetre frequencies, notably between 180 and 360 GHz, allow sounding to even lower altitudes, i.e. to the upper troposphere.

3 Land and ocean measurements

Emission from the surface of the Earth is transmitted through the atmosphere to the satellite. When the attenuation values are high, this emission cannot be sensed. When it is low, as required to sense the temperature of the lowest layer of the atmosphere, both the surface and atmospheric contributions are combined. Additional measurements within the window channels are required to separate the two types of contributions. Surface emission is proportional to the temperature and emissivity of the surface. The latter is related to the dielectric properties of the surface and to the roughness of the surface. If the emissivity is less than unity, the surface both emits and scatters radiation. The scattered radiation originates from downward atmospheric emission from above the surface. In a window channel with very small attenuation values, this latter contribution is negligible; otherwise it must be considered in the solution.

Surface brightness temperatures do not show the rapid variation with frequency exhibited by emission from atmospheric absorption lines. The relatively slow frequency variations of the effects due to surface parameters requires simultaneous observations over a broad frequency range within the atmospheric windows to determine their values. Separation of the parameters can only be accomplished when the parameters have different frequency dependences. The brightness temperature of the ocean surface is a function of salinity, temperature and wind. The wind affects the brightness temperature by roughening the surface and by producing foam which has dielectric properties different from the underlying water. Salinity is best sensed at frequencies below 3 GHz and, if extreme measurement accuracy is required, at frequencies below 1.5 GHz. Sea surface temperature is best sensed using frequencies in the 3 to 10 GHz range, with 5 GHz being near optimum. Wind affects observations at all frequencies but is best sensed at frequencies above 15 GHz.

Surface layers of ice or oil floating on the ocean surface have dielectric properties different from water and can be sensed due to the resultant change in brightness temperature. Oil slicks can change the brightness temperature above 30 GHz by more than 50 K and ice can change the brightness temperature by more than 50 K at frequencies from 1 to 40 GHz. Although ice and oil spills can provide a large change in brightness temperature, a number of observations in each of the atmospheric windows are required to separate the effects of ice and oil from rain and clouds.

The moisture content of the surface layers can be detected at microwave frequencies. The brightness temperature of snow and of soil both change with moisture content and with frequency. In general, the lower the frequency, the thicker the layer that can be sensed. Since the moisture at the surface is related to the profile of moisture below the surface, observations at higher frequencies can also be useful. In sensing the melting of snow near the surface, observations at 37 GHz and higher provide the most information. For sensing soil, especially soil under a vegetation canopy, frequencies below 3 GHz are of most interest. In practice, a number of frequencies are required, first to classify the surface as to roughness, vegetation cover, sea ice age, etc., and second, to measure parameters such as ice thickness or moisture content.

Annex 2

Factors related to determination of required bandwidths

1 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 in practice.

At wavelengths longer than 3 cm, a receiver noise temperature of less than 150 K can be obtained with solid-state parametric amplifiers. At wavelengths shorter than 3 cm, the most common type of receiver currently used today is the superheterodyne with a noise temperature ranging from several hundred degrees at 3 cm wavelength to perhaps 2000 K at 3 mm wavelength. Improvements in high electronic mobility transistors technology is going to render possible the utilization of low-noise preamplifiers, with a receiver noise temperature of about 300 K at 5 mm wavelength.

Beyond the improved receiver noise temperature that can be obtained with the introduction of low-noise preamplifiers, significant reductions in the ΔT_e values (or increased sensitivity) can only be accomplished in spaceborne radiometers by increased system bandwidths and by introducing instrument configurations that enable optimization of the integration time. Depending on the spatial resolution required, low-orbit spaceborne radiometers are limited to integration times of the order of seconds or less, due to the spacecraft relative velocity.

2 Characteristics of passive sensors

The typical sensor used to measure various atmospheric and surface features is the scanning sensor. Improved coverage width and reduced bandwidth can be obtained through the use of pushbroom sensors. Lower values of ΔT_e can also be obtained through the use of pushbroom sensors because a longer integration time per observation is possible.

The bandwidth requirements of a passive sensor measuring trace gases in the atmosphere are determined by the line widths of the observed gases and the opportunity of observing in the same window a number of lines of the same or different gases.

The width of emission lines of atmospheric gases mainly depends on pressure. This dependence dictates minimum bandwidth requirements (and also resolution). At ground level, line widths are of the order of a few GHz. In the stratosphere, they are reduced to a few MHz. Because of these large line widths at lower altitudes, millimetre-wave (above 100 GHz) limb sounders measuring the upper atmosphere require very broadbands on the order of 10 GHz.

Studies have been performed to determine the requirements for sensor sensitivity, spatial resolution, integration time and spectral resolution. These requirements are found in Recommendations ITU-R RS.1028 and ITU-R RS.1029.