International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R RS.1861

(01/2010)

Typical technical and operational characteristics of Earth exploration-satellite service (passive) systems using allocations between 1.4 and 275 GHz

RS Series

Remote sensing systems

International Telecommunication Union

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SM	Spectrum management
SNG	Satellite news gathering
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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.1861*

Typical technical and operational characteristics of Earth exploration-satellite service (passive) systems using allocations between 1.4 and 275 GHz

(Question ITU-R 243/7)

(2010)

Scope

This Recommendation provides typical technical and operational characteristics of Earth exploration-satellite service (passive) systems using allocations between 1.4 and 275 GHz for utilization in sharing studies.

The ITU Radiocommunication Assembly,

considering

a) that Earth exploration-satellite service (EESS) (passive) observations may receive emissions from active services;

b) that there are exclusive EESS (passive) allocations in which all emissions are prohibited by RR No. 5.340;

c) that EESS (passive) is allocated on a co-primary basis with active services in certain bands;

d) that studies considering protection for EESS (passive) systems are taking place within ITU-R;

e) that in order to perform compatibility and sharing studies with EESS (passive) systems, the technical and operational characteristics of those systems must be known,

recommends

1 that the technical and operational parameters presented in Annex 1 of this Recommendation should be taken into account in studies considering EESS (passive) systems using allocations between 1.4 and 275 GHz.

Annex 1

1 Introduction

Passive sensors are used in the remote sensing of the Earth and its atmosphere by Earth exploration and meteorological satellites in certain frequency bands allocated to the Earth exploration-satellite service (EESS) (passive). The products of these passive sensor operations are used extensively in meteorology, climatology, and other disciplines for operational and scientific purposes. However, these sensors are sensitive to any emissions within their allocated band. Therefore, any RF emissions above a certain level may constitute interference to the passive sensors using those bands.

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* This Recommendation should be brought to the attention of Radiocommunication Study Group 1.

This is mainly due to the fact that passive sensors may not be able to differentiate the wanted signal from the interference and that interference may not be identifiable in the passive sensor products.

2 Current missions and predicted deployments

Several administrations and at least one recognized international organization operated more than 24 satellites in the EESS (passive) at the end of the year 2007. An additional two to three are anticipated to be deployed per year for the foreseeable future. Individual satellites typically carry one to three passive sensing payloads operating below 275 GHz. Each payload may conduct measurements simultaneously at 3 to 15 frequencies as well as on two polarizations at a single frequency.

3 Typical orbits

EESS (passive) systems operate in non-geostationary satellite orbit (non-GSO). Orbits are typically circular with an altitude between 350 and 1 400 km. Many EESS (passive) systems operate in a sun-synchronous orbit. Some sensors make measurements at the same place on the Earth every day, while others will repeat observations only after a longer (often more than two weeks) repeat period.

In certain circumstances, multiple satellites operate in formation. Formation flying EESS satellites allow the capability to measure a portion of the atmosphere or surface of the Earth using both multiple instruments and multiple orientations. Measurements from multiple spacecraft will be separated within an amount of time shorter than the time constant of the phenomena being measured. Nominally this separation is on the order of 5 to 15 min, but can be as little as 15 s.

Two formations are used between multiple systems operating in non-GSO. In one formation, two or more satellites directly follow each other performing measurements of the same parcel of atmosphere or the Earth's surface as demonstrated by satellites A and B in Fig. 1. In the other formation, a nadir pointing passive sensor conducts a measurement while another spacecraft conducts a near-simultaneous measurement at the Earth's limb as demonstrated by satellites A and C in Fig. 1.

4 Types of measurements

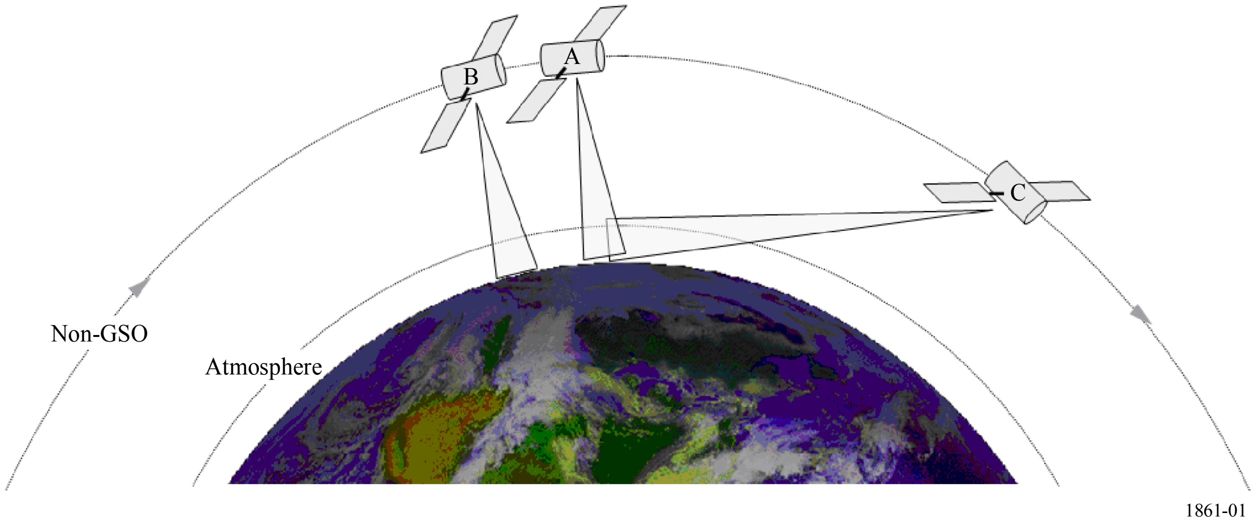
All EESS passive sensing systems perform a form of radiometry. Radiometry senses how much energy a body radiates given its temperature. The amount of energy radiated from a perfect "blackbody" varies with frequency and is given by Planck's equation. However, no substance is truly a perfect blackbody radiator. Frequencies of particular interest for EESS (passive) applications are provided in Recommendation ITU-R RS.515.

The amount of energy radiated is also dependent on the radiating substance. Within a passive sensor's field of view, there may be multiple radiators in *inter alia* atmosphere, water vapour, suspended ice particles, and cloud liquid water, emitting in the sensor's bandwidth. Measurements not conducted on the Earth's limb will also receive background emissions from water, soil, surface ice, or some combination of all three.

A single passive sensor cannot by itself identify how much energy is radiated by each substance in its field of view. For this reason, data products of most value are derived by comparing measurements from multiple sensors operating at multiple frequencies. By performing radiometric measurements at multiple frequencies, the types of each natural emitter (e.g. water vapour, suspended ice, O_3, etc.) and their concentrations may be derived. As the data from any one sensor may be compared with that of multiple other sensors, any interference received by one sensor may corrupt multiple other measurements.

FIGURE 1

Formation flying orientations



4.1 Fixed-pointing, multiple frequency and polarization radiometric sensing

Sensing concurrently at multiple frequencies and polarizations offers the possibilities of identifying the presence of multiple natural emitters present in the field of view of the sensor as well as to create profiles of their concentrations. Profiling (a.k.a. sounding) sensors may be nadir-pointing or pointed at the limb of the Earth. Applications of profiling sensors includes the determination of atmospheric chemistry profiles of H_2O, O_3, ClO, BrO, HCl, OH, HO_2, HNO_3, HCN, and N_2O through limb measurements.

Fixed pointing radiometers are also used to determine path delay of the radar signals used for altimeters caused by atmospheric water vapour.

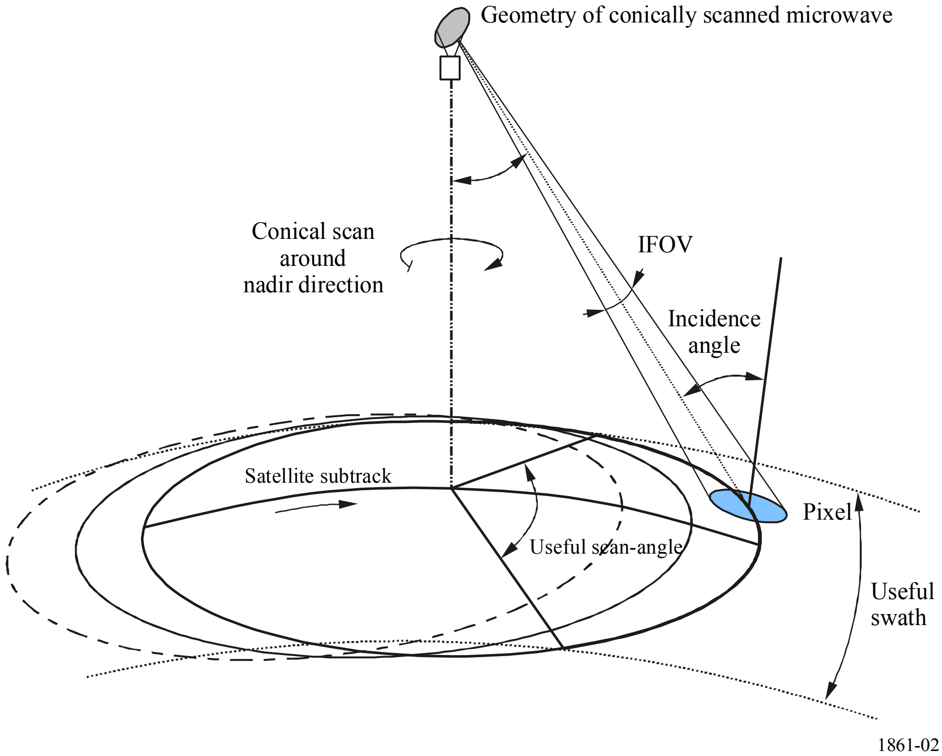
Radiometers designed for the whole Earth viewing perform continuous, hemispheric microwave soundings of temperature and humidity profiles as well as rain mapping.

4.2 Conical scanning radiometers

Many passive microwave sensors designed for imaging the Earth's surface features use a conical scan configuration turning around the nadir direction because it is important, for the interpretation of surface measurements, to maintain a constant ground incidence angle along the entire scan-lines since the footprints will remain constant in size, and also because the polarization characteristics of the signal have an angular dependence. Conical scanning antennas gather information over wide areas as shown in Fig. 2. Scans are typically performed by rotating the antenna at an offset angle from the nadir direction. Conical scanning radiometers are used to monitor various water processes including precipitation, oceanic water vapour, cloud water, near-surface wind speed, sea surface temperature, soil moisture, snow cover, and sea ice parameters. They can also be used to provide information on the integrated column precipitation content, its area distribution, and its intensity.

FIGURE 2

Geometry of conical scan passive microwave radiometers



4.3 Cross-track scanning radiometers

Scanning radiometric measurements gather information over wide areas creating virtual maps of the parameter being measured. This data product determines the horizontal spatial variability of a parameter rather than measuring the parameters at specific points. Scanning measurements are also typically performed at multiple frequencies and polarizations.

Typical applications of cross-track scanning radiometers include the measurement of temperature profiles in the upper atmosphere (especially the stratosphere) and to provide a cloud-filtering capability for tropospheric temperature observations. They also are used to provide daily global observations of temperature and moisture profiles at high temporal resolution, and to measure cloud liquid water content and provide qualitative estimates of precipitation rate.

Scans are typically performed in a cross-track pattern across the surface of the Earth as shown in Fig. 3. Cross-track scanning is performed by physically rotating a reflector 360°. As the reflector is directed away from the surface of the Earth, sensor channels are still used as calibrations are performed by measuring the cosmic background (i.e. cold sky) in addition to a known “warm” source on the spacecraft, as shown in Fig. 4.

FIGURE 3

Typical cross-track Earth scanning pattern

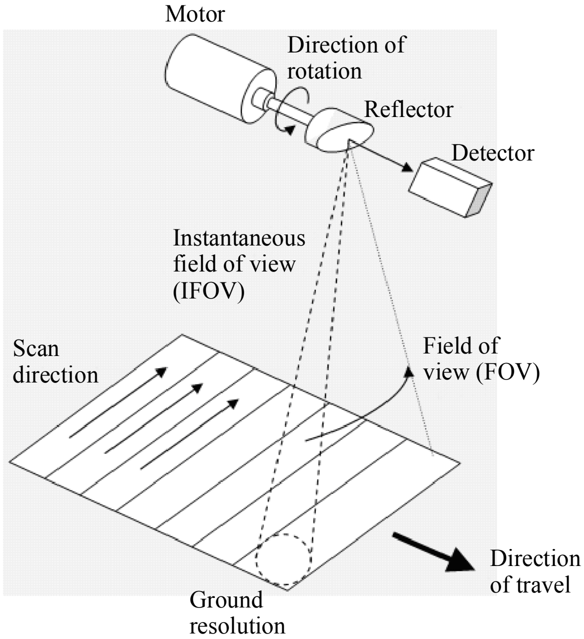
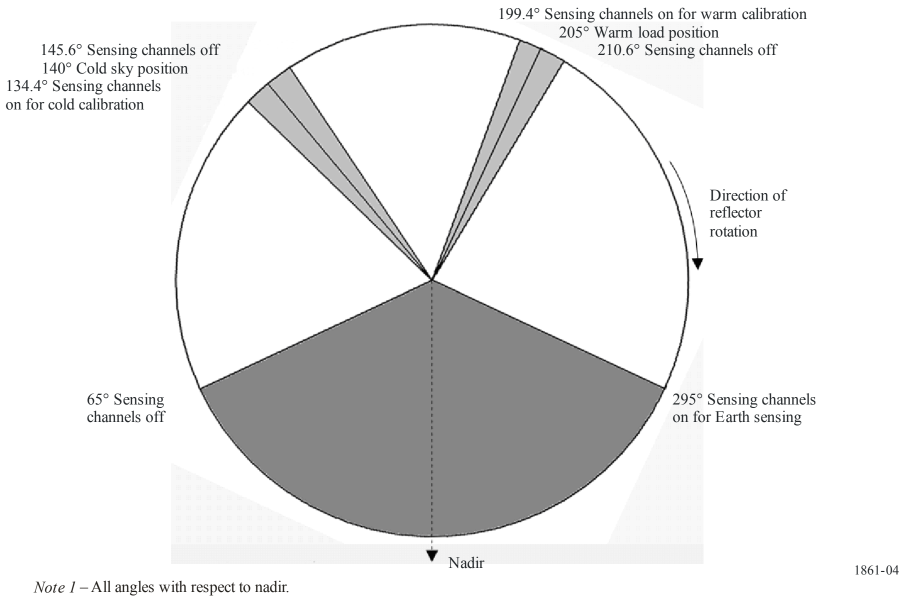


FIGURE 4

Typical sensing scanning pattern over 360°



Note 1 – All angles with respect to nadir.

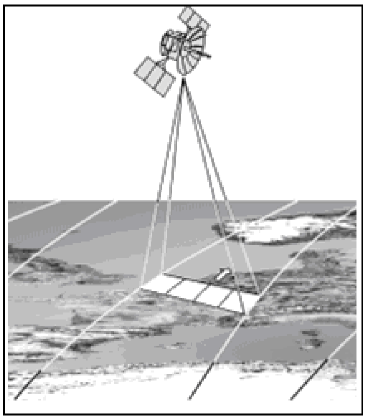
4.4 Push-broom radiometers

A "push-broom" (along track) sensor consists of a line of sensors arranged perpendicular to the flight direction of the spacecraft, as illustrated in Fig. 5. Different areas of the surface are detected as the spacecraft flies forward. The push-broom is a purely static instrument with no moving parts.

The major feature of the push-broom is that all resolution elements in a scan line are acquired simultaneously, and not sequentially as with mechanically scanned sensors, enabling this type of sensor to significantly increase the achievable radiometric resolution. Push-broom sensors can be used for a variety of applications, including temperature profiles measurements of the atmosphere, and soil moisture and ocean salinity measurements.

FIGURE 5

Typical push-broom radiometer configuration



1861-05

5 Definition of parameters

TABLE 1

List of technical and operational EESS parameters for passive sensors

Sensor type
Orbit parameters
Altitude
Inclination
Eccentricity
Repeat period
Sensor antenna parameters
Number of beams
Reflector diameter
Maximum antenna gain
Polarization
–3 dB beamwidth
Instantaneous field of view
Off-nadir pointing angle
Incidence angle at Earth

TABLE 1 (*end*)

–3 dB beam dimensions
Swath width
Main beam efficiency
Beam dynamics
Sensor antenna pattern
Cold calibration antenna gain
Cold calibration horizontal angle (degrees relative to satellite track)
Cold calibration vertical angle (degrees relative to nadir direction)
Sensor receiver parameters
Sensor integration time
Channel bandwidth
Horizontal resolution
Vertical resolution

TABLE 2

Definitions of parameters

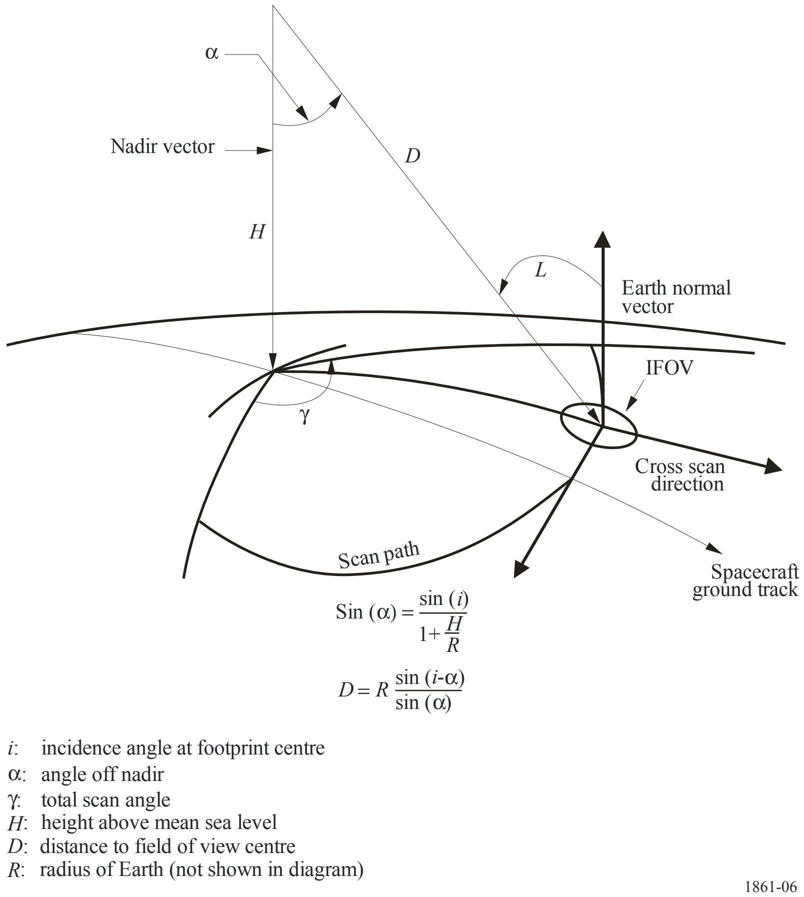
Parameter	**Definition**
Sensor type	Various types of radiometers are possible depending on the technology of the radiometer: interferometric radiometer, conical scan, nadir, push-broom, limb radiometer
Orbit parameters	
Altitude	The height above the mean sea level
Inclination	Angle between the equator and the plane of the orbit
Eccentricity	The ratio of the distance between the foci of the (elliptical) orbit to the length of the major axis
Repeat period	The time for the footprint of the antenna beam to return to (approximately) the same geographic location
Sensor antenna parameters Antenna characteristics vary among sensors. Measured antenna patterns are provided in § 6, where available. A reference radiation pattern is currently being developed for use in other cases	
Number of beams	The number of beams is the number of locations on Earth from which data are acquired at one time
Reflector diameter	Diameter of the antenna reflector
Maximum antenna gain	The maximum antenna gain can be the real one, or, if it is not known, it can be computed using the antenna efficiency η and *D* diameter of the reflector (when applicable), with the formula: $$\text{Maximum\_antenna\_gain} = \eta \left(\pi \frac{D}{\lambda} \right)^2$$
Polarization	Specification of linear or circular polarization
−3 dB beamwidth	The −3 dB beamwidth, θ_{3dB}, is defined as the angle between the two directions in which the radiation intensity is one-half the maximum value

TABLE 2 (*end*)

Parameter	Definition
Instantaneous field of view	The instantaneous field of view (IFOV) is the area over which the detector is sensitive to radiation. By knowing the altitude of the satellite, the dimension of the IFOV can be calculated on the Earth's surface at the nadir point: the IFOV is generally expressed in km × km. The IFOV is a measure of the size of the resolution element. In a scanning system the IFOV refers to the solid angle subtended by the detector when the scanning motion is stopped. For conical scan radiometers, two values are usually computed: – along-track: in the direction of the platform motion (along the in-track direction); – cross-track: in the direction orthogonal to the motion of the sensor platform. For nadir scan radiometers, such as that shown in Fig. 3, the nadir IFOV = $H\theta_{3dB}$, where H is the height of the satellite and θ_{3dB} is the half-power beamwidth. See also Fig. 6
Off-nadir pointing angle	The angle between the nadir and the pointing direction. It is the angle α in Fig. 6
Incidence angle at Earth	The angle between the pointing direction and the normal to the Earth's surface. It is the angle *i* as in Fig. 6
–3 dB beam dimensions	The linear dimensions of the beam on the Earth (at the –3 dB level)
Swath width	The swath width is defined as the linear ground distance covered in the cross-track direction. For a scanning radiometer, it depends on the angular field of view (AFOV) or scanning angle. For a nadir radiometer, it depends on the off nadir angle. The field of view (FOV) is the total range of viewing of a sensor into the direction of the target. The cross-track component of the FOV is equivalent to the swath width
Main beam efficiency	The main beam area is defined as the angular size of a cone with an opening angle equal to 2.5 times the measured –3 dB beamwidth. The main beam efficiency is defined as the ratio of the energy received in the main beam to the energy received in the complete antenna pattern
Beam dynamics	The beam dynamics is defined as follows: – For conical scans, it is the rotating speed of the beam; – For mechanical nadir scans, it is the number of scans per second
Sensor antenna pattern	Antenna gain as a function of off-axis angle
Cold calibration antenna gain	Antenna gain in the direction of (cold) space. This could be the maximum gain of the primary antenna or the secondary antenna
Cold calibration horizontal angle	Horizontal angle (degrees relative to satellite track) of the cold calibration measurement. This angle is measured in the tangent plane relative to the along-track direction
Cold calibration vertical angle	Vertical angle (degrees relative to nadir direction) of the cold calibration measurement. This angle is measured out from the tangent plane
Sensor receiver parameters	
Sensor integration time	The *sensor integration time* corresponds to the short period of time allocated for the radiative measurement of the instantaneous area of observation by the detector of a sensor
Channel bandwidth	The *channel bandwidth* is the range of frequencies around a centre frequency used by the passive sensor
Measurement spatial resolution	
Horizontal resolution Vertical resolution	The *spatial resolution* is often defined as the ability to distinguish between two closely spaced objects on an image. It is generally expressed in both horizontal (usually cross-track IFOV size) and vertical (along-track) resolutions. (Note that "vertical", in this sense, does not refer to altitude.)

FIGURE 6

Scanning configuration



Note that the field of view's projection on the Earth's surface becomes elliptical due to the increased incidence angle from nadir to the edge of the swath width (half swath).

6 Parameters of typical systems

This section provides typical parameters of passive sensors for EESS (passive) bands between 1 GHz and 275 GHz. Table 3 lists the EESS (passive) bands and the section in this text that contains the passive sensor parameters for each band. A consistent set of parameters is used for each band to support worst-case static analyses and dynamic analyses to determine interference levels into passive sensors.

TABLE 3

List of EESS (passive) bands

EESS (passive) band	Section (§) containing passive sensor parameters
1 400-1 427 MHz	6.1
6 425-7 250 MHz	6.2
10.6-10.7 GHz	6.3
18.6-18.8 GHz	6.4
21.2-21.4 GHz	6.5
23.6-24 GHz	6.6
31.3-31.8 GHz	6.7
36-37 GHz	6.8
50.2-50.4 GHz	6.9
52.6-54.25 GHz	6.10
54.25-59.3 GHz	6.11
86-92 GHz	6.12
114.25-122.25 GHz	6.13
148.5-151.5 GHz	6.14
155.5-158.5 GHz	6.15
164-167 GHz	6.16
174.8-191.8 GHz	6.17

6.1 Typical parameters of passive sensors operating in the 1 400-1 427 MHz band

Frequencies near 1 400 MHz are ideal for measuring soil moisture, and also for measuring sea surface salinity and vegetation biomass. Soil moisture is a key variable in the hydrologic cycle with significant influence on evaporation, infiltration and runoff. In the vadose zone[1], soil moisture governs the rate of water uptake by vegetation. Sea surface salinity has an influence on deep thermohaline circulation and the meridional heat transport. Variations in salinity influence the near surface dynamics of tropical oceans. To date, there is no capability to measure soil moisture and sea surface salinity directly on a global basis, so the protection of this passive band is essential.

Some remote sensing missions will collect soil moisture data in the entire passive microwave band under consideration from 1 400 to 1 427 MHz. Others will use the same band to collect measurements of ocean salinity with the goal of observing and modelling the processes that relate sea surface salinity variations to climatic changes in the hydrologic cycle, and to understand how these variations influence the general ocean circulation. Still other missions will use a different technological approach and will measure both soil moisture and ocean salinity.

Table 4 provides the characteristics and parameters of sensors on these missions.

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[1] The "vadose zone" is the portion of Earth between the land surface and the zone of saturation which extends from the top of the ground surface to the water table.

TABLE 4

EESS (passive) sensor characteristics in the 1 400-1 427 MHz band

	Sensor A1	**Sensor A2**	**Sensor A3**
Sensor type	Interferometric radiometer	Conical scan	Push broom
Orbit parameters			
Altitude	757 km	670 km	657 km
Inclination	98°		
Eccentricity	0		
Repeat period	3 days	3 days	7 days
Sensor antenna parameters			
Number of beams	1	1	3
Reflector diameter	N/A	6.2 m	2.5 m
Maximum beam gain	9 dBi	37 dBi	29.1, 28.8, 28.5 dBi
Polarization	V, H		
–3 dB beamwidth	71.6°	2.6°	6.1°, 6.3°, 6.6°
Off-nadir pointing angle	25°	35.5°	25.8°, 33.8°, 40.3°
Beam dynamics	Fixed	14.6 rpm	Fixed
Incidence angle at Earth	2°/48°	39.9°	28.7°, 37.8°, 45.6°
–3 dB beam dimensions	50 km (35 km centre of FOV)	50.1 × 38.5 km	94 × 76 km, 120 × 84 km 156 × 97 km
Instantaneous field of view	756 km	Same as –3 dB dimensions, above	
Main beam efficiency	N/A	91%	94%, 92.4%, 90.4%
Swath width	1 000 km	1 000 km	407 km
Sensor antenna pattern	Fig. 7a	Fig. 7b	Fig. 7c
Cold calibration ant. gain	N/A		
Cold calibration angle (degrees re. satellite track)	N/A		
Cold calibration angle (degrees re. nadir direction)	N/A		
Sensor receiver parameters			
Sensor integration time	1.2 s	84 ms	6 s
Channel bandwidth	27 MHz		26 MHz
Measurement spatial resolution			
Horizontal resolution	40 km	39 km	64, 75, 90 km
Vertical resolution	N/A		

FIGURE 7a

Sensor A1 antenna pattern for the 1 400-1 427 MHz band

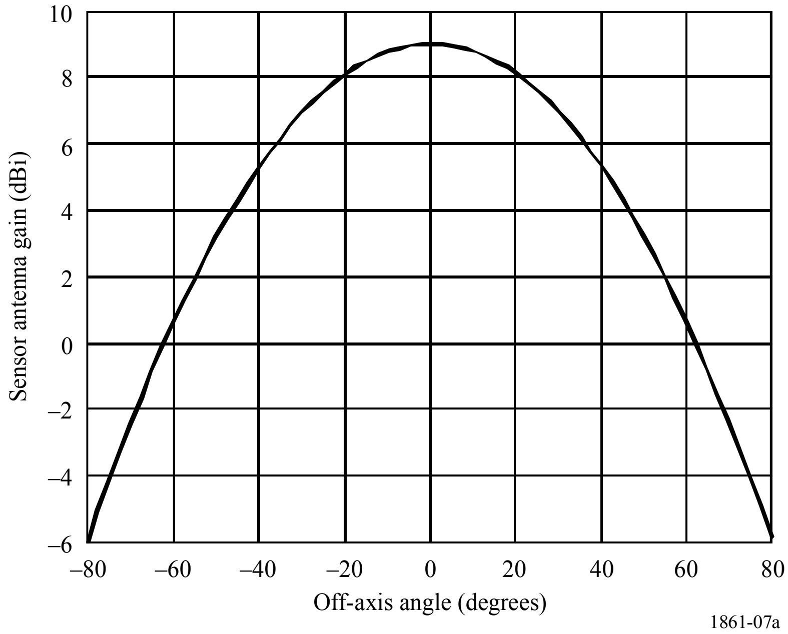


FIGURE 7b

Sensor A2 antenna patterns for the 1 400-1 427 MHz band

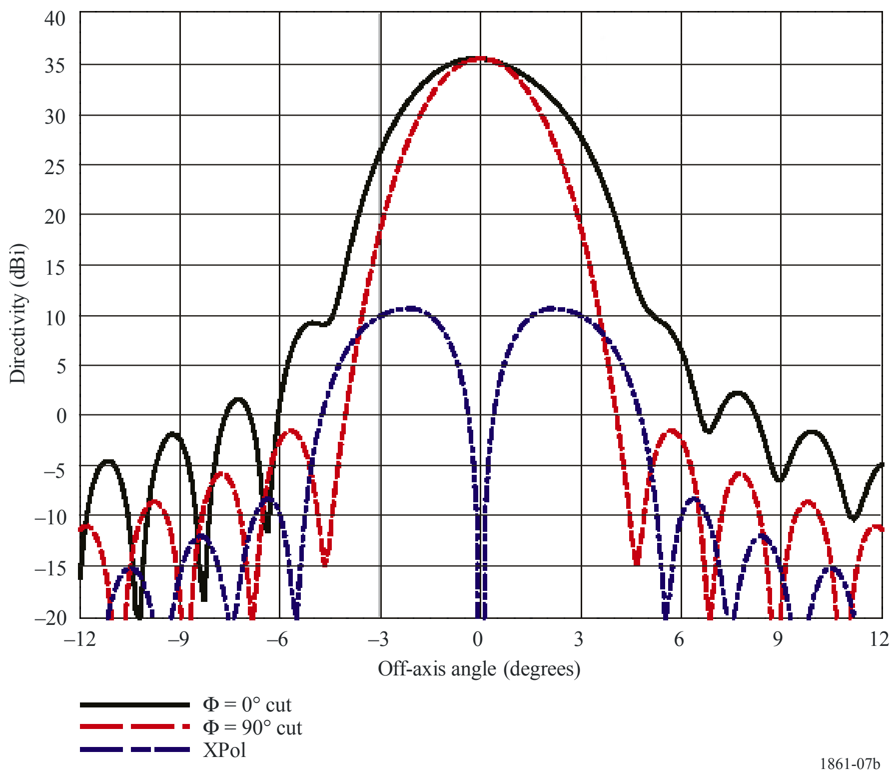
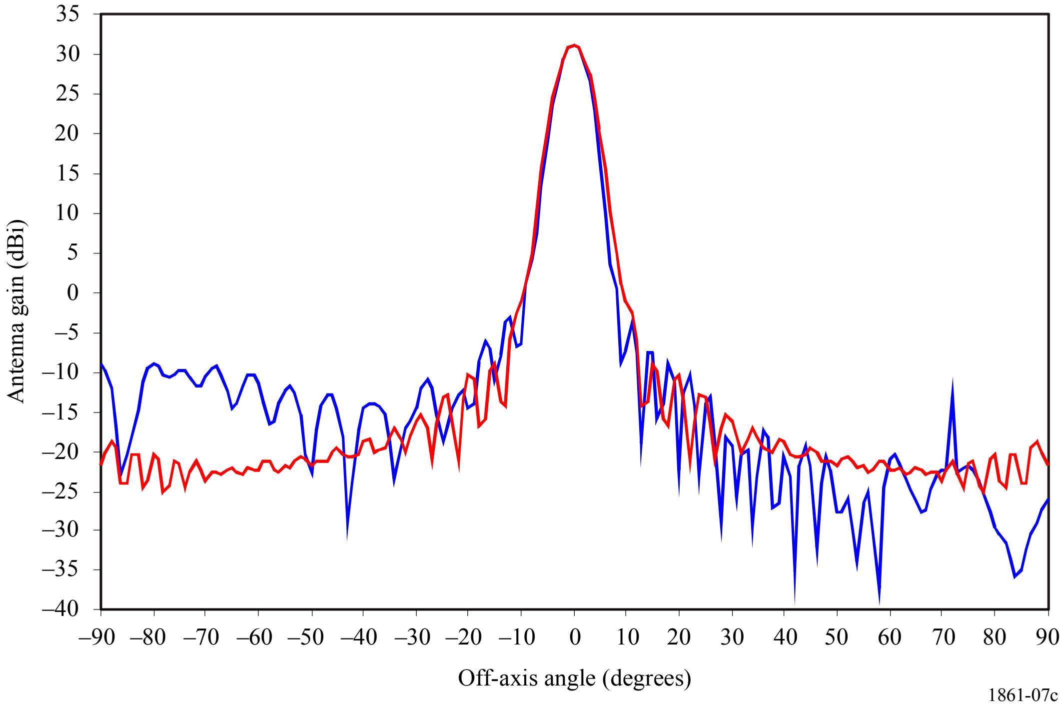


FIGURE 7c

Sensor A3 antenna patterns for the 1 400-1 427 MHz band



6.2 Typical parameters of passive sensors operating in the 6.425-7.25 GHz band

The 6-7 GHz band channel is essential for observing global soil moisture, global sea surface temperature, temperature of sea ice and sea surface wind through cloud, in combination with other channels.

In measurement of soil moisture, measurement in higher frequencies is strongly influenced by vegetation and the atmosphere, and the 6-7 GHz band is the most suitable for relatively higher spatial resolution measurements. In the case of measurement of sea surface temperature, measurement in higher frequencies is strongly influenced by the atmosphere and lower temperature is more difficult to measure in higher frequencies, making the 6-7 GHz band the most suitable.

Table 5 summarizes the parameters of passive sensors that are or will be operating in the 6.425-7.25 GHz band.

6.3 Typical parameters of passive sensors operating in the 10.6-10.7 GHz band

The band 10.6-10.7 GHz is of primary interest to measure rain, snow, sea state, and ocean wind. Table 6 summarizes the parameters of passive sensors that are or will be operating in the 10.6-10.68 GHz band.

TABLE 5

EESS (passive) sensor characteristics in the 6.425-7.25 GHz band

	Sensor B1	**Sensor B2**	**Sensor B3**	**Sensor B4**
Sensor type	Conical scan			
Orbit parameters				
Altitude	705 km	828 km	835 km	699.6 km
Inclination	98.2°	98.7°	98.85°	98.186°
Eccentricity	0.0015	0	0	0.002
Repeat period	16 days	17 days	N/A	16 days
Sensor antenna parameters				
Number of beams	1			
Reflector diameter	1.6 m	2.2 m	0.6 m	2.0 m
Maximum beam gain	38.8 dBi			40.6 dBi
Polarization	V, H			
–3 dB beamwidth	2.2°	1.65°		1.8°
Off-nadir pointing angle	47.5°	46.8°	55.4°	47.5°
Beam dynamics	40 rpm	31.6 rpm	2.88 s scan period	40 rpm
Incidence angle at Earth	55°	55.7°	65°	55°
–3 dB beam dimensions	40 km (cross-track)	24 km		35 km (cross-track)
Instantaneous field of view	43 km × 75 km	68 km × 40 km	112 km × 260 km	35 km × 61 km
Main beam efficiency	95.1%	95%		92%
Swath width	1 450 km	1 700 km	2 000 km	1 450 km
Sensor antenna pattern	See Rec. ITU-R RS.1813			
Cold calibration ant. gain	25.1 dBi	N/A		25.6 dBi
Cold calibration angle (degrees re. satellite track)	115.5º	N/A		115.5º
Cold calibration angle (degrees re. nadir direction)	97.0º	N/A		97.0º
Sensor receiver parameters				
Sensor integration time	2.5 ms	5 ms	N/A	2.5 ms
Channel bandwidth	350 MHz centred at 6.925 GHz	350 MHz centred at 6.625 GHz	350 MHz centred at 6.9 GHz	350 MHz centred at 6.925 GHz and at 7.3 GHz
Measurement spatial resolution				
Horizontal resolution	43 km	15-50 km	38 km	35 km
Vertical resolution	74 km	24 km	38 km	61 km

TABLE 6

EESS (passive) sensor characteristics in the 10.6-10.7 GHz band

	Sensor C1	Sensor C2	Sensor C3	Sensor C4	Sensor C5
Sensor type	Conical scan				
Orbit parameters					
Altitude	817 km	705 km	833 km	835 km	699.6 km
Inclination	98°	98.2°	98.7°	98.85°	98.186°
Eccentricity	0	0.0015	0	0	0.002
Repeat period	N/A	16 days	17 days	N/A	16 days
Sensor antenna parameters					
Number of beams	1		2	1	
Reflector diameter	0.9 m	1.6 m	2.2 m	0.6 m	2.0 m
Maximum beam gain	36 dBi	42.3 dBi	45 dBi	36 dBi	44.1 dBi
Polarization	H, V		H, V, R, L	H, V	
–3 dB beamwidth	2.66°	1.4°	1.02°	3.28°	1.2°
Instantaneous field of view	56 km × 30 km	51 km × 29 km	48 km × 28 km	76 km × 177 km	41 km × 21 km
Main beam efficiency		94.8%	95%		93%
Off-nadir pointing angle	44.3°	47.5°	47°	55.4°	47.5°
Beam dynamics	20 rpm	40 rpm	31.6 rpm	2.88 s scan period	40 rpm
Incidence angle at Earth	52°	55°	58.16°	65°	55°
–3 dB beam dimensions	56.7 km (cross-track)	27.5 km (cross-track)	42.9 km (cross-track)	N/A	23 km (cross-track)
Swath width	1 594 km	1 450 km	1 600 km	2 000 km	1 450 km
Sensor antenna pattern	See Rec. ITU-R RS.1813	Fig. 8a	Fig. 8b	See Rec. ITU-R RS.1813	
Cold calibration ant. gain	N/A	29.1 dBi	N/A		29.6 dBi
Cold calibration angle (degrees re. satellite track)	N/A	115.5º	N/A		115.5º
Cold calibration angle (degrees re. nadir direction)	N/A	97.0º	N/A		97.0º
Sensor receiver parameters					
Sensor integration time	1 ms	2.5 ms	2.47 ms	N/A	2.5 ms
Channel bandwidth	100 MHz	100 MHz centred at 10.65 GHz			
Measurement spatial resolution					
Horizontal resolution	38 km	27 km	15 km	38 km	23 km
Vertical resolution	38 km	47 km	15 km	38 km	41 km

FIGURE 8a

Sensor C1 antenna pattern envelope for the 10.6-10.7 GHz band

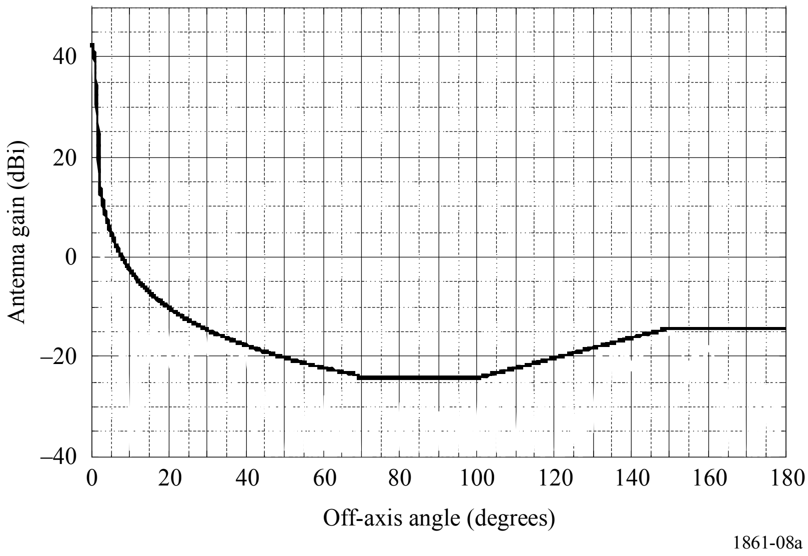
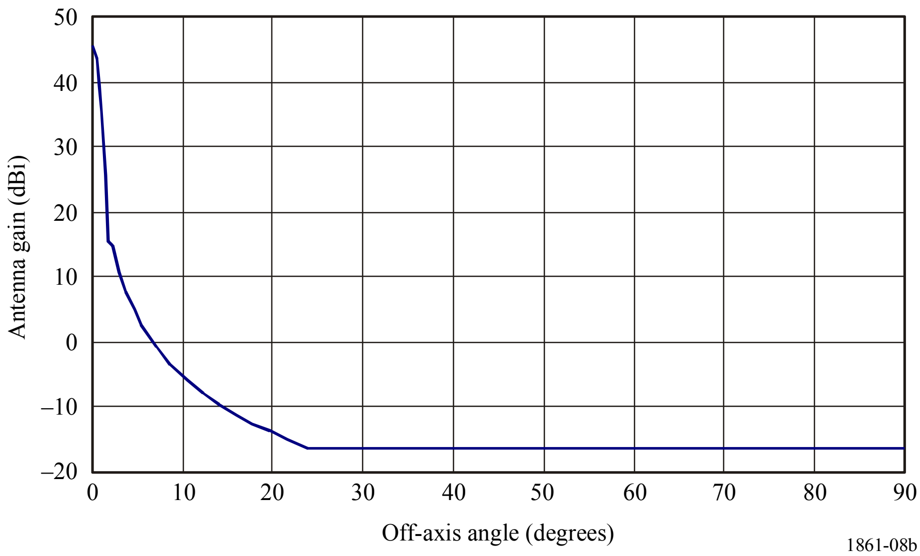


FIGURE 8b

Sensor C2 antenna pattern envelope for the 10.6-10.7 GHz band



6.4 Typical parameters of passive sensors operating in the 18.6-18.8 GHz band

The 18.6-18.8 GHz band is essential for observing global rain rates, sea state, sea ice, water vapour, ocean wind speed, soil emissivity, and humidity. Table 7 summarizes the parameters of passive sensors that are or will be operating in the 18.6-18.8 GHz band.

TABLE 7

EESS (passive) sensor characteristics in the 18.6-18.8 GHz band

	Sensor D1	Sensor D2	Sensor D3	Sensor D4	Sensor D5
Sensor type	Conical scan				
Orbit parameters					
Altitude	828 km	705 km	865.6 km	835 km	699.6 km
Inclination	98.7°	98.2°	20°	98.85°	98.186°
Eccentricity	0	0.0015	0	0	0.002
Repeat period	17 days	16 days	7 days		16 days
Sensor antenna parameters					
Number of beams	3	1		1	
Reflector diameter	2.2 m	1.6 m	0.65 m	0.6 m	2.0 m
Maximum beam gain		47.6 dBi			49.4 dBi
Polarization	V, H, LHC, RHC, +45°, −45°	V, H			
–3 dB beamwidth	0.64°	0.8°	0.67°	1.9°	0.65°
Instantaneous field of view	24 km × 15.5 km	27 km × 16 km	10 km	45 km × 104 km	22 km × 13 km
Main beam efficiency	95%	95.8%	96%		94%
Off-nadir pointing angle	46.6°	47.5°	44.5°	55.4°	47.5°
Beam dynamics	31.6 rpm	40 rpm	20 rpm	2.88 s scan period	40 rpm
Incidence angle at Earth	53.6°	55.0°	52.3°	65°	55.0°
–3 dB beam dimensions	9 km	13 km (cross-track)	10 km	28 km	16 km (cross-track)
Swath width	1 700 km	1 450 km		2 000 km	1 450 km
Sensor antenna pattern	See Rec. ITU-R RS.1813				
Cold calibration ant. gain	N/A	32.8 dBi	N/A		33.9 dBi
Cold calibration angle (degrees re. satellite track)	N/A	115.5º	N/A		115.5º
Cold calibration angle (degrees re. nadir direction)	N/A	97.0º	N/A		97.0º
Sensor receiver parameters					
Sensor integration time	1.2 ms	2.5 ms	N/A		2.5 ms
Channel bandwidth	200 MHz centred at 18.7 GHz		N/A	200 MHz centred at 18.7 GHz	
Measurement spatial resolution					
Horizontal resolution	9 km	16 km	40 km	38 km	13 km
Vertical resolution	9 km	27 km	40 km	38 km	22 km

6.5 Typical parameters of passive sensors operating in the 21.2-21.4 GHz band

The 21.2-21.4 GHz band in addition to the 23.6-24 GHz band are used for measurements of water vapour and liquid water both on the Earth's surface and in the atmosphere. They are on either side of the 22.235 GHz water-vapour spectral line. Atmospheric measurements are used with oxygen, O_2, temperature measurements to remove the effect of water vapour on temperature profiles. Table 8 summarizes the parameters of passive sensors that are or will be operating in the 21.2-21.4 GHz band.

TABLE 8

EESS (passive) sensor characterstics in the 21.2-21.4 GHz band

	Sensor E1	**Sensor E2**
Sensor type	Mechanical nadir scan	Push-broom[(1)]
Orbit parameters		
Altitude	833 km	850 km
Inclination	98.6°	98°
Eccentricity	0	
Repeat period	9 days	
Sensor antenna parameters		
Number of beams	1 beam; 30 earth fields per 8 s scan period	90
Maximum beam gain	34.4 dBi	45 dBi
Reflector diameter	0.3 m	0.9 m
Polarization	V	H, V
–3 dB beamwidth	3.3°	1.1°
Instantaneous field of view	Nadir FOV: 48.5 km Outer FOV: 149.1 × 79.4 km	16 km × 2 282 km
Main beam efficiency	95%	
Off-nadir pointing angle	±48.33° cross-track	
Beam dynamics	8 s scan period	N/A (beams are unchanging)
Incidence angle at Earth		
–3 dB beam dimensions	45 km	16 km
Total FOV cross/along-track	Outer FOV: 149.1 × 79.4 km Nadir FOV: 48.5 km	100/1.1°
Swath width	2 343 km	2 282 km
Sensor antenna pattern	−10 dBi back lobe gain	−12 dBi back lobe gain

(1) Push-broom is a concept that has not yet been implemented at this frequency.

TABLE 8 (*end*)

	Sensor E1	Sensor E2
Sensor antenna parameters (*cont.*)		
Cold calibration ant. gain	34.4 dBi	35 dBi
Cold calibration angle (degrees re. satellite track)	90°	
Cold calibration angle (degrees re. nadir direction)	83°	
Sensor receiver parameters		
Sensor integration time	158 m	N/A
Channel bandwidth	270 MHz centred at 23.8 GHz	N/A
Measurement spatial resolution		
Horizontal resolution	45 km	16 km
Vertical resolution	N/A	16 km

6.6 Typical parameters of passive sensors operating in the 23.6-24 GHz band

In case of a sounder, passive measurements around frequencies 23.8 GHz (total water vapour content), 31.5 GHz (window channel) and 90 GHz (liquid water) provide auxiliary data which play a predominant role in the retrieval process of temperature measurements performed in the O_2 absorption spectrum. These auxiliary measurements must have radiometric and geometric performances and availability criteria consistent with those of the temperature measurements. In case of a conical scanning radiometer, it is possible to measure horizontal water vapour distribution with other channels. The main characteristics of the sensors are given in Table 9.

TABLE 9

EESS (passive) sensor characteristics in the 23.6-24 GHz band

	Sensor F1	**Sensor F2**	**Sensor F3**	**Sensor F4**	**Sensor F5**	**Sensor F6**	**Sensor F7**	**Sensor F8**
Sensor type	Conical scan			Mechanical nadir scan		Conical scan	Push-broom	Conical scan
Orbit parameters								
Altitude	817 km	705 km	828 km	833 km 822 km*	824 km	835 km	850 km	699.6 km
Inclination	20°	98.2°	98.7°	98.6° 98.7°*	98.7°	98.85°	98°	98.186°
Eccentricity	0	0.0015	0	0 0.001	0			0.002
Repeat period	7 days	16 days	17 days	9 days 29 days*	9 days			16 days
Sensor antenna parameters								
Number of beams	1			30 earth fields per 8 s scan period	2	1	90	1
Reflector diameter	0.6 m	1.6 m	2.2 m	0.3 m 0.274 m*	0.203 m	0.6 m	0.9 m	48.5 dBi
Maximum beam gain	40 dBi	46.7 dBi	52 dBi	34.4 dBi	30.4 dBi	43 dBi	45 dBi	2.0 m
Polarization	H, V			V QV*	QV	H, V		H, V
−3 dB beamwidth	1. 81°	0.9°	0.64°	3.3°	5.2°	1.5°	1.1°	0.75°
Instantaneous field of view	63 km × 38 km	32 km × 18 km	18 km × 12 km	Nadir FOV: 48.5 km Outer FOV: 149.1 × 79.4 km 147 × 79 km*	Nadir FOV: 74.8 km Outer FOV: 323.1 × 141.8 km	36 km × 86 km	16 km × 2 282 km	26 km × 15 km
Main beam efficiency	96%	94.8%	95%					94%
Off-nadir pointing angle	44.5°	47.5°	46.6°	±48.33° cross-track	±52.725° cross-track	55.4°		47.5°

TABLE 9 (*end*)

	Sensor F1	Sensor F2	Sensor F3	Sensor F4	Sensor F5	Sensor F6	Sensor F7	Sensor F8
Sensor antenna parameters (*cont.*)								
Beam dynamics	31.9 rpm	40 rpm	31.6 rpm	8 s scan period	8/3 s scan period cross-track; 96 earth fields per scan period	2.88 s scan period	90 resolution elements/ line	40 rpm
Incidence angle at Earth	52.3°	55°	53.63°	0° (nadir) 57.5°*		65°		55°
–3 dB beam dimensions	38.7 km (cross-track)	18 km (cross-track)	14.1 km (cross-track)	45 km 48 km*	76 km	22 km	16 km	15 km (cross-track)
Swath width	1 607 km	1 450 km	1 688 km	2 343 km 2 186 km*	2 503 km	2 000 km	2 282 km	1 450 km
Sensor antenna pattern	See Rec. ITU-R RS.1813	Fig. 9b	See Rec. ITU-R RS.1813	Fig. 9c	See Rec. ITU-R RS.1813		−12 dBi back lobe gain	See Rec. ITU-R RS.1813
Cold calibration ant. gain	N/A	32.1 dBi	N/A	34.4 dBi	30.4 dBi	N/A	35 dBi	32.4 dBi
Cold calibration angle (degrees re. satellite track)	N/A	115.5º	N/A	90° −90° ± 3.9°*	0	N/A	90°	115.5º
Cold calibration angle (degrees re. nadir direction)	N/A	97.0º	N/A	83°	82.175°	N/A	83°	N/A
Sensor receiver parameters								
Sensor integration time	1 ms	2.5 ms	1.2 ms	158 ms	18 ms	N/A		2.5 ms
Channel bandwidth	400 MHz	400 MHz centred at 23.8 GHz		270 MHz centred at 23.8 GHz		400 MHz centred at 23.8 GHz	N/A	400 MHz centred at 23.8 GHz
Measurement spatial resolution								
Horizontal resolution	40 km	18 km	17.6 km	45 km 48 km*	75 km	38 km	16 km	15 km
Vertical resolution	N/A	30 km	N/A	45 km 48 km*	75 km	38 km	16 km	25 km

NOTE 1 – * Indicates that a particular sensor is flown on different missions, with different orbit and sensor parameters.

FIGURE 9a

Sensor F1 antenna pattern envelope for the 23.6-24 GHz band

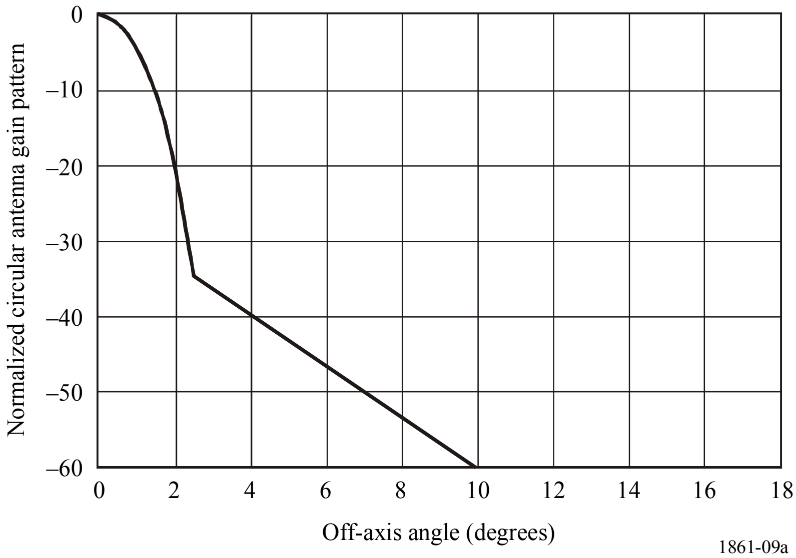


FIGURE 9b

Sensor F2 antenna pattern envelope for the 23.6-24 GHz band

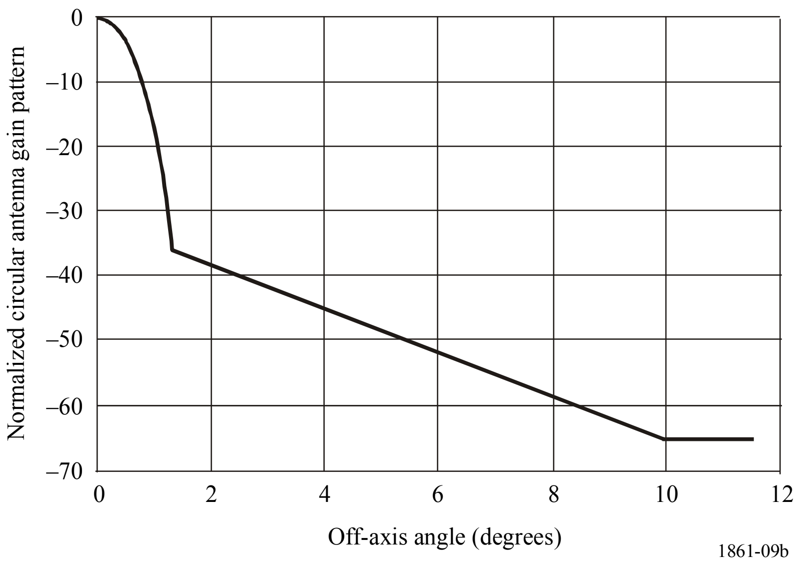
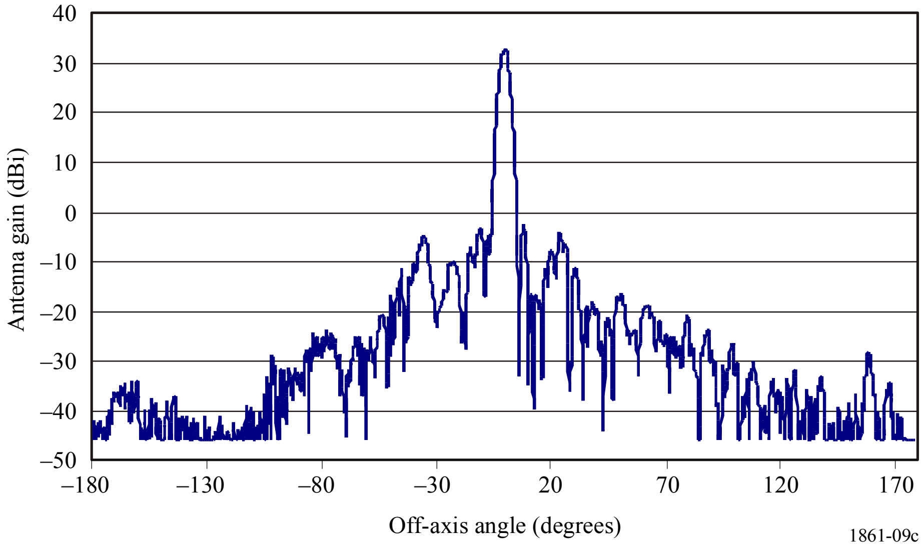


FIGURE 9c

Sensor F4 antenna pattern (23.8 GHz)



6.7 Typical parameters of passive sensors operating in the 31.3-31.8 GHz band

Passive measurements around frequencies 23.8 GHz (total water vapour content), 31.5 GHz (window channel) and 90 GHz (liquid water) provide auxiliary data which play a predominant role in the retrieval process of temperature measurements performed in the O_2 absorption spectrum. These auxiliary measurements must have radiometric and geometric performances and availability criteria consistent with those of the temperature measurements.

This band is one of the bands used for close-to-nadir atmospheric sounding in conjunction with the bands such as 23.8 GHz and 50.3 GHz for the characterization each layer of the Earth's atmosphere. The 31.3-31.5 GHz band will also be used in conjunction with the band 31.5-31.8 GHz as a "split window". This will allow a comparison of the measurements conducted in the two sub-bands to check the quality of the data. This will then allow using the full band when the quality is expected good to increase the sensitivity of the sensor.

Table 10 summarizes the parameters of passive sensors that are or will be operating in the 31.3-31.8 GHz band.

TABLE 10

EESS (passive) sensor characteristics in the 31.3-31.8 GHz band

	Sensor G1	**Sensor G2**	**Sensor G3**
Sensor type	Nadir scan		Conical scan
Orbit parameters			
Altitude	833 km 822 km*	824 km	835 km
Inclination	98.6°	98.7°	98.85°
Eccentricity	0.001	0	0
Repeat period	9 days 29 days*	9 days	

TABLE 10 (*end*)

	Sensor G1	Sensor G2	Sensor G3
Sensor antenna parameters			
Number of beams	30 earth fields per 8 s scan period	2	1
Maximum beam gain	34.4 dBi	30.4 dBi	45 dBi
Reflector diameter	0.30 m 0.274 m*	0.203 m	0.6 m
Polarization	V QV*	QV	H, V
–3 dB beamwidth	3.3°	5.2°	1.1°
Off-nadir pointing angle	±48.33° cross-track	±52.725° cross-track	55.4°
Beam dynamics	8 s scan period	8/3 s scan period cross-track; 96 earth fields per scan period	2.88 s scan period
Incidence angle at Earth	0 57.5°*	0	65°
–3 dB beam dimensions	49.1 km	75 km	16 km
Instantaneous field of view	Nadir FOV: 48.5 km Outer FOV: 149.1 × 79.4 km 147 × 79 km*	Nadir FOV: 74.8 km Outer FOV: 323.1.1 × 141.8 km	30 km × 69 km
Main beam efficiency	95%		
Swath width	2 343 km 2 186 km*	2 500 km	2 000 km
Sensor antenna pattern	See Rec. ITU-R RS.1813		
Cold calibration ant. gain	34.4 dBi	30.4 dBi	N/A
Cold calibration angle (degrees re. satellite track)	90° −90° ± 3.9°*	0	N/A
Cold calibration angle (degrees re. nadir direction)	83.33°	82.175°	N/A
Sensor receiver parameters			
Sensor integration time	158 ms	18 ms	N/A
Channel bandwidth	180 MHz centred at 31.4 GHz		0.5 GHz
Measurement spatial resolution			
Horizontal resolution	44 km 48 km*	75 km	38 km
Vertical resolution	44 km 48 km*	75 km	38 km

NOTE 1 – * Indicates that a particular sensor is flown on different missions, with different orbit and sensor parameters.

6.8 Typical parameters of passive sensors operating in the 36-37 GHz band

The band 36-37 GHz is vital for the study of global water circulation, rain rates, snow, sea ice, and clouds. Table 11 summarizes the parameters of passive sensors that are or will be operating in the 36-37 GHz band.

TABLE 11

EESS (passive) sensor characteristics in the 36-37 GHz band

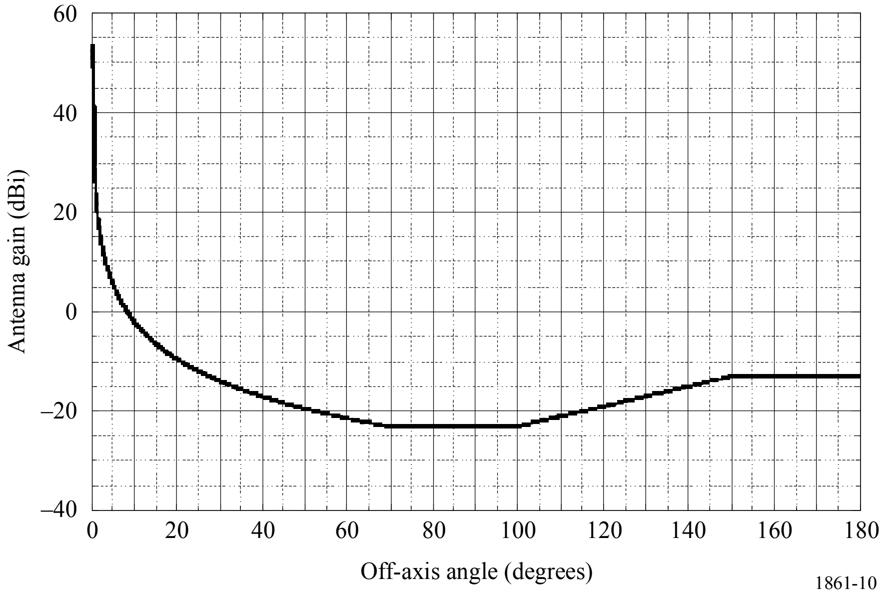
	Sensor H1	Sensor H2	Sensor H3	Sensor H4	Sensor H5
Sensor type	Conical scan				
Orbit parameters					
Altitude	865.6 km	705 km	828 km	835 km	699.6 km
Inclination	20°	98.2°	98.7°	98.85°	98.186°
Eccentricity	0	0.0015	0	0	0.002
Repeat period	7 days	16 days	17 days		16 days
Sensor antenna parameters					
Number of beams			2	1	
Reflector diameter	0.65 m	1.6 m	2.2 m	0.6 m	2.0 m
Maximum beam gain	45 dBi	53.1 dBi	55 dBi	46 dBi	54.8 dBi
Polarization	H	H, V			
–3 dB beamwidth	1.8°	0.42°	0.44°	1°	0.35°
Instantaneous field of view	62 km × 38 km	14 km × 8 km	16 km × 12 km	26 km × 60 km	12 km × 7 km
Main beam efficiency	96%	93.9%	95%		93%
Off-nadir pointing angle	44.5°	47.5°	46.8°	55.4°	47.5°
Beam dynamics	31.9 rpm	40 rpm	31.6 rpm	2.88 s scan period	40 rpm
Incidence angle at Earth	52.3°	55°	55.7°	65°	55°
–3 dB beam dimensions	38 km (cross-track)	8.2 km (cross-track)	12 km (cross-track)	15 km	6.8 km (cross-track)
Swath width	1 607 km	1 450 km	1 700 km	2 000 km	40 rpm
Sensor antenna pattern	See Rec. ITU-R RS.1813	See Fig. 10	See Rec. ITU-R RS.1813		
Cold calibration ant. gain	N/A	36.5 dBi	N/A		39.3 dBi
Cold calibration angle (degrees re. satellite track)	N/A	115.5º	N/A		115.5º
Cold calibration angle (degrees re. nadir direction)	N/A	97.0	N/A		97.0

TABLE 11 (*end*)

	Sensor H1	**Sensor H2**	**Sensor H3**	**Sensor H4**	**Sensor H5**
Sensor receiver parameters					
Sensor integration time	1 ms	2.5 ms	1.2 ms	N/A	2.5 ms
Channel bandwidth	1 GHz	1 GHz centred at 36.5 GHz			
Measurement spatial resolution					
Horizontal resolution	40 km	8.2 km	12 km	38 km	6.8 km
Vertical resolution	N/A	14 km	6 km	38 km	12 km

FIGURE 10

Sensor H2 antenna pattern envelope for the 36-37 GHz band



6.9 Typical parameters of passive sensors operating in the 50.2-50.4 GHz band

This frequency band is one of several bands between 50 GHz and 60 GHz that are used collectively to provide three-dimensional temperature profiles of the atmosphere. Table 12 summarizes the parameters of passive sensors that are or will be operating in the 50.2-50.4 GHz band.

TABLE 12

EESS (passive) sensor characteristics in the 50.2-50.4 GHz band

	Sensor I1	Sensor I2	Sensor I3	Sensor I4
Sensor type	Conical scan	Mechanical nadir scan	Push-broom	Mechanical nadir scan
Orbit parameters				
Altitude	828 km	833 km 822 km*	850 km	824 km
Inclination	98.7°	98.6° 98.7°*	98°	98.7°
Eccentricity	0	0 0.001*	0	0
Repeat period	17 days	9 days 29 days*		9 days
Sensor antenna parameters				
Number of beams	1	30 earth fields per 8 s scan period	90	2
Reflector diameter	2.2 m	0.15 m	0.5 m	0.203 m
Maximum beam gain		34.4 dBi	45 dBi	37.9 dBi
Polarization	V	V QV*	H, V	QH
−3 dB beamwidth	0.39°	3.3°	1.1°	2.2°
Instantaneous field of view	16 km × 12 km	Nadir FOV: 48.5 km Outer FOV: 149.1 × 79.4 km 147 × 79 km*	16 km × 2 282 km	Nadir FOV: 31.6 km Outer FOV: 136.7 × 60 km
Main beam efficiency	95%			95%
Off-nadir pointing angle	46.8°	±48.33° cross-track		±52.725° cross-track
Beam dynamics	31.6 rpm	8 s scan period	90 resolution elements per swath	8/3 s scan period cross-track; 96 earth fields per scan period
Incidence angle at Earth	55.7°	57.5°		
–3 dB beam dimensions	6 km	48 km (at nadir)	16 km (at nadir)	2.2°32 km
Swath width	1 700 km	2 343 km 2 186 km	2 282 km	2 500 km
Sensor antenna pattern	See Rec. ITU-R RS.1813			
Cold calibration ant. gain	N/A	34.4 dBi	35 dBi	37.9 dBi

TABLE 12 (*end*)

	Sensor I1	Sensor I2	Sensor I3	Sensor I4
Sensor antenna parameters (*cont.*)				
Cold calibration angle (degrees re. satellite track)	N/A	90° −90° ± 3.9°*	90°	0
Cold calibration angle (degrees re. nadir direction)	N/A	83.33°	83°	82.175°
Sensor receiver parameters				
Sensor integration time	1.2 ms	165 ms	N/A	18 ms
Channel bandwidth	134 MHz centred at 50.3 GHz	180 MHz centred at 50.3 GHz	N/A	180 MHz centred at 50.3 GHz
Measurement spatial resolution				
Horizontal resolution	6 km	48 km	16 km	32 km
Vertical resolution	6 km	48 km	16 km	32 km

NOTE 1 – * Indicates that a particular sensor is flown on different missions, with different orbit and sensor parameters.

6.10 Typical parameters of passive sensors operating in the 52.6-54.25 GHz band

This band is one of the bands used for close-to-nadir atmospheric sounding in conjunction with the bands at 23.8 GHz, 31.5 GHz and 50.3 GHz to characterize each layer of the atmosphere.

Table 13 summarizes the parameters of passive sensors that are or will be operating in the 52.6-54.25 GHz band.

TABLE 13

EESS (passive) sensor characteristics in the 52.6-54.25 GHz band

	Sensor J1	Sensor J2	Sensor J3	Sensor J4
Sensor type	Mechanical nadir scan	Conical scan	Mechanical nadir scan	Conical scan
Orbit parameters				
Altitude	833 km 822 km*	828 km	824 km	835 km
Inclination	98.6° 98.7°*	98.7°		98.85°
Eccentricity	0 0.001*	0		
Repeat period	9 days 29 days*	17 days	9 days	N/A
Sensor antenna parameters				
Number of beams	30 earth fields per 8 s scan period	1	2	1
Reflector diameter	0.15 m	2.2 m	0.203 m	0.6 m

TABLE 13 (*end*)

	Sensor J1	Sensor J2	Sensor J3	Sensor J4
Sensor antenna parameters (*cont.*)				
Maximum beam gain	34.4 dBi	54 dBi	37.9 dBi	39 dBi
Polarization	V, H QV, QH*	V	QH	V
–3 dB beamwidth	3.3°	0.39°	2.2°	2.2°
Instantaneous field of view	Nadir FOV: 48.5 km Outer FOV: 149.1 × 79.4 km 147 × 79 km*	16 km × 12 km	Nadir FOV: 31.6 km Outer FOV: 136.7 × 60 km	Outer FOV 18 × 43 km
Main beam efficiency	95%	95%	95%	
Off-nadir pointing angle	±48.33° cross-track	46.8°	±52.725° cross-track	55.4°
Beam dynamics	8 s scan period	31.6 rpm	8/3 s scan period cross-track; 96 earth fields per scan period	2.88 s scan period
Incidence angle at Earth	0 57.5°*	55.7°		65°
–3 dB beam dimensions	48 km	6 km	32 km	32 km
Swath width	2 343 km 2 186 km*	1 700 km	2 500 km	2 000 km
Sensor antenna pattern	See Rec. ITU-R RS.1813			
Cold calibration ant. gain	34.4 dBi	N/A	37.9 dBi	N/A
Cold calibration angle (degrees re. satellite track)	90° −90° ± 3.9°*	N/A	0	N/A
Cold calibration angle (degrees re. nadir direction)	83.33°	N/A	82.175°	N/A
Sensor receiver parameters				
Sensor integration time	165 ms	1.2 ms	18 ms	N/A
Channel bandwidth	400 MHz centred at 52.8 GHz 170 MHz centred at 53.596 GHz	960 MHz centred at 53.57 GHz	400 MHz centred at 52.8 GHz 170 MHz centred at 53.596 GHz	400 MHz centred at 52.8 GHz, 53.3 GHz, 53.8 GHz
Measurement spatial resolution				
Horizontal resolution	47 km 48 km*	6 km	32 km	32 km
Vertical resolution	47 km 48 km*	6 km	32 km	32 km

NOTE 1 – * Indicates that a particular sensor is flown on different missions, with different orbit and sensor parameters.

6.11 Typical parameters of passive sensors operating in the bands between 54.25 and 59.3 GHz

The band 54.25-59.3 GHz is of primary interest for atmospheric temperature profiling (O_2 absorption lines). Table 14 summarizes the parameters of passive sensors that are or will be operating between 54.25 and 59.3 GHz. The frequency range from 54.25 to 60.3 GHz is covered by many smaller bands with varying bandwidths and polarizations (see Tables 15 and 16).

TABLE 14

EESS (passive) sensor characteristics operating between 54.25 and 59.3 GHz

	Sensor K1	**Sensor K2**	**Sensor K3**	**Sensor K4**
Sensor type	Conical scan	Mechanical nadir scan	Mechanical nadir scan	Conical scan
Orbit parameters				
Altitude	828 km	824 km	833 km 822 km*	835 km
Inclination	98.7°		98.6° 98.7°*	98.85°
Eccentricity	0		0 0.001*	0
Repeat period	17 days	9 days	9 days 29 days*	
Sensor antenna parameters				
Number of beams	2		30 earth fields per 8 s scan period	1
Reflector diameter	2.2 m	0.203 m	0.15 m	0.6 m
Maximum beam gain	60 dBi	37.9 dBi	34.4 dBi	51 dBi
Polarization	See Table 15	See Table 16	See Table 17	See Table 18
–3 dB beamwidth	0.39°	2.2°	3.3°	0.6°
Instantaneous field of view	16 km × 12 km	Nadir FOV: 31.6 km Outer FOV: 136.7 × 60 km	Nadir FOV: 48.5 km (3.3°) Outer FOV: 149.1 × 79.4 km 147 × 79 km*	Outer FOV 18 × 43 km
Main beam efficiency	95%			
Off-nadir pointing angle	46.8°	±52.73° cross-track	±48.33° cross-track	55.4°
Beam dynamics	31.6 rpm	8/3 s scan period cross-track; 96 earth fields per scan period	8 s scan period	2.88 s scan period
Incidence angle at Earth	55.7°		0 57.5°*	65°

TABLE 14 (*end*)

	Sensor K1	Sensor K2	Sensor K3	Sensor K4
Sensor antenna parameters (*cont.*)				
−3 dB beam dimensions	3 km	31.6 km	48.5 km 48 km*	18 km × 43 km
Swath width	1 700 km	2 500 km	2 343 km	2 000 km
Sensor antenna pattern	See Rec. ITU-R RS.1813			
Cold calibration ant. gain	N/A	37.9 dBi	34.4 dBi	N/A
Cold calibration angle (degrees re. satellite track)	N/A	0	90° −90° ± 3.9°*	N/A
Cold calibration angle (degrees re. nadir direction)	N/A	82.175°	83.33°	N/A
Sensor receiver parameters				
Sensor integration time	1.2 ms	18 ms	165 ms	N/A
Channel bandwidth	See Table 15	See Table 16	See Table 17	See Table 18
Measurement spatial resolution				
Horizontal resolution	3 km	32 km	48 km	18 km
Vertical resolution	3 km	32 km	48 km	18 km

NOTE 1 – * Indicates that a particular sensor is flown on different missions, with different orbit and sensor parameters.

TABLE 15

Sensor K1 passive sensor characteristics for channels between 54.25 and 60.5 GHz

Centre frequency (GHz)	Channel bandwidth (MHz)	Polarization
54.380	440	V
54.905	350	V
55.490	340	V
56.660	300	V
59.380	280	V
59.940	440	V
60.3712	57.6	L
60.4080	16	L
60.4202	8.4	L
60.5088	44.8	L
60.434776	25	L

TABLE 16

Sensor K2 passive sensor characteristics for channels between 54.25 and 59.3 GHz

Centre frequency (GHz)	Channel bandwidth (MHz)	Polarization
54.4	400	QH
54.94	400	QH
55.5	330	QH
57.290344	330	QH
57.073344, 57.507344	78	QH
57.660544, 57.564544, 57.016144, 56.920144	36	QH
57.634544, 57.590544, 56.990144, 56.946144	16	QH
57.622544, 57.602544, 56.978144, 56.958144	8	QH
57.617044, 57.608044, 56.972644, 56.963644	3	QH

TABLE 17

Sensor K3 passive sensor characteristics for channels between 54.25 and 59.3 GHz

Centre frequency (GHz)	Channel bandwidth (MHz)	Polarization
54.4	400	H, QH*
54.94	400	V, QV*
55.5	330	H, QH*
57.290344	330	H, QH*
57.073344, 57.507344	78	H, QH*
57.660544, 57.564544, 57.016144, 56.920144	36	H, QH*
57.634544, 57.590544, 56.990144, 56.946144	16	H, QH*
57.622544, 57.602544, 56.978144, 56.958144	8	H, QH*
57.617044, 57.608044, 56.972644, 56.963644	3	H, QH*

NOTE 1 – * Indicates that a particular sensor is flown on different missions, with different parameters.

TABLE 18

Sensor K4 passive sensor characteristics for channels between 54.25 and 60.5 GHz

Centre frequency (GHz)	Channel bandwidth (MHz)	Polarization	Altitude of peak sensitivity (km)
54.64	400 MHz	V	10
55.63	400 MHz	V	14
57.290344 ± 0.322 ± 0.1	50 MHz	V	20
57.290344 ± 0.322 ± 0.05	20 MHz	V	25
57.290344 ± 0.322 ± 0.025	10 MHz	V	29
57.290344 ± 0.322 ± 0.001	5 MHz	V	35
57.290344 ± 0.322 ± 0.005	3 MHz	V	42

6.12 Typical parameters of passive sensors operating in the bands between 86 and 92 GHz

The 86-92 GHz passive sensor band is essential for the measurement of clouds, oil spills, ice, snow, and rain. It is also used as a reference window for temperature soundings near 118 GHz. Table 19 summarizes the parameters of passive sensors that are or will be operating between 86 and 92 GHz.

TABLE 19

EESS (passive) sensor characteristics operating between 86 and 92 GHz

	Sensor L1	Sensor L2	Sensor L3	Sensor L4	Sensor L5	Sensor L6	Sensor L7	Sensor L8
Sensor type	Conical scan			Mechanical nadir scan			Conical scan	
Orbit parameters								
Altitude	867 km	705 km	833 km	833 km 822 km*		824 km	835 km	700 km
Inclination	20°	98.2°	98.7°	98.6° 98.7°*		98.7°	98.85°	98.2°
Eccentricity	0	0.0015	0	0 0.001*		0		0.002
Repeat period	7 days	16 days	17 days	9 days 29 days*		9 days	N/A	16 days
Sensor antenna parameters								
Number of beams	1	2	1	30 earth fields per 8 s scan period	30 earth fields per 8 s scan period 1 beam (steerable in 90 earth fields per scan period)*	2		
Reflector diameter	0.65 m	1.6 m	2.2 m	0.15 m	0.3 m 0.22 m*	0.203 m	0.6 m	2 m
Maximum beam gain	50 dBi	60.5 dBi	56 dBi	34.4 dBi	47 dBi 44.8 dBi*	37.9 dBi	54 dBi	62.4 dBi
Polarization	H, V			H QV*		QV	H, V	
–3 dB beamwidth	0.43°	0.18°	0.39°	3.3°	1.1°	2.2°	0.4°	0.15°
Instantaneous field of view	10 km × 17 km	A: 6.2 km × 3.6 km B: 5.9 km × 3.5 km	16 km × 12 km	Nadir FOV: 48.5 km Outer FOV: 149.1 × 79.4 km 147 × 79 km*	Nadir FOV: 16 km (1.1°) Outer FOV: 53 × 27 km*	Nadir FOV: 31.6 km × 31.6 km Outer FOV: 136.7 × 60 km	12 km × 28 km	A: 5.1 km × 2.9 km B: 5.0 km × 2.9 km
Main beam efficiency	96.2%	96%	95%				N/A	91%

TABLE 19 (*end*)

	Sensor L1	**Sensor L2**	**Sensor L3**	**Sensor L4**	**Sensor L5**	**Sensor L6**	**Sensor L7**	**Sensor L8**
Sensor antenna parameters (*cont.*)								
Off-nadir pointing angle	44.5°	47.5°	46.98°	±48.33° cross-track	±48.95° 49.4°*	±52.725° cross-track	N/A	47.5°
Beam dynamics	20 rpm	40 rpm	31.6 rpm	8 s scan period	8/3 s scan period	8/3 s scan period cross-track; 96 earth fields per scan period	2.88 s scan period	40 rpm
Incidence angle at Earth	53.5°	A :55.0° B :54.5°	55.77°	30 positions 57.5°*	Various angles from 0° 59°*		35°	55°
Swath width	1 700 km	1 450 km	1 700 km	2 343 km 2 186 km*	2 343 km 2 193 km*	2 500 km	2 000 km	1 450 km
Cold calibration ant. Gain	N/A	40.4 dBi	N/A	34.4 dBi	34.4 dBi 44.8 dBi*	37.9 dBi	N/A	43.4 dBi
Cold calibration angle (degrees re. satellite track)	N/A	115.5º	N/A	90° −90° ± 3.9°*	End of scan (at 48.95°) −90° ± 3.9°*	0	N/A	115.5º
Cold calibration angle (degrees re. nadir direction)	N/A	97.0º	N/A	83.33°	83.33° 73.6 (66° to 81°)*	82.175°	N/A	97.0º
Sensor receiver parameters								
Sensor integration time	2 ms	1.2 ms		180 ms 165 ms*	185 ms 18 ms*	18 ms	N/A	1.2 ms
Channel bandwidth	2 700 MHz centred at 89 GHz	3 000 MHz centred at 89 GHz	6 000 MHz centred at 89 GHz		Centred at 89 GHz ± 500 MHz, each with a bandwidth of 1 000 MHz 2 800 MHz centred at 89 GHz*	2 000 MHz centred at 87-91.9 GHz	2 GHz	3 000 MHz centred at 89 GHz
Measurement spatial resolution								
Horizontal resolution	10 km	3.5 km	6 km	40.5 km 48 km*	40.5 km 16 km*	32 km	19 km	2.9 km
Vertical resolution	N/A	6.1 km	6 km	48 km	16 km	32 km	6 km	5.1 km

NOTE 1 – * Indicates that a particular sensor is flown on different missions, with different orbit and sensor parameters.

6.13 Typical parameters of passive sensors operating in the bands between 114.25 and 122.25 GHz

The band 114.25-122.25 GHz is of primary interest for atmospheric temperature profiling (O_2 absorption lines). Table 20 summarizes the parameters of passive sensors that are or will be operating between 114.25 and 122.25 GHz.

TABLE 20

EESS (passive) sensor characteristics operating between 114.25 and 122.25 GHz

	Sensor M1
Sensor type	Limb sounder
Orbit parameters	
Altitude	705 km
Inclination	98.2°
Eccentricity	0.0015
Repeat period	16 days
Sensor antenna parameters	
Number of beams	2
Reflector diameter	1.6 m × 0.8 m
Maximum beam gain	60 dBi
Polarization	2 orthogonal
–3 dB beamwidth	0.19° × 0.245°
Instantaneous field of view	6.5 km × 13 km
Main beam efficiency	N/A
Off-nadir pointing angle	Limb
Beam dynamics	N/A
Incidence angle at Earth	N/A
–3 dB beam dimensions	3 km
Swath width	N/A
Sensor antenna pattern	N/A
Cold calibration ant. gain	N/A
Cold calibration angle (degrees re. satellite track)	N/A
Cold calibration angle (degrees re. nadir direction)	N/A
Sensor receiver parameters	
Sensor integration time	0.166 s
Channel bandwidth	N/A
Measurement spatial resolution	
Horizontal resolution	13 km
Vertical resolution	6.5 km

6.14 Typical parameters of passive sensors operating in the bands between 148.5 and 151.5 GHz

The 148.5-151.5 GHz passive sensor band is essential for the measurement of N_2O, Earth's surface temperature, and cloud parameters. It is also used as a reference window for temperature soundings. Table 21 summarizes the parameters of passive sensors that are or will be operating between 148.5 and 151.5 GHz.

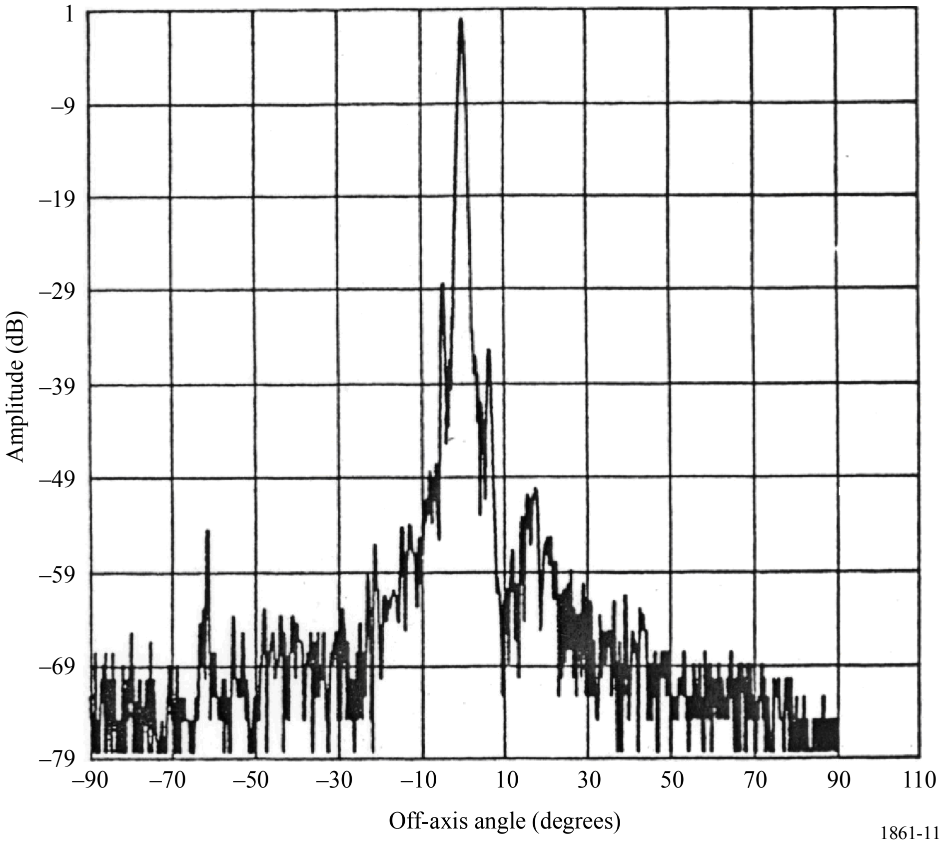
TABLE 21

EESS (passive) sensor characteristics operating between 148.5 and 151.5 GHz

	Sensor N1
Sensor type	Cross-track nadir scan
Orbit parameters	
Altitude	705 km
Inclination	98.2°
Eccentricity	0.0015
Repeat period	16 days
Sensor antenna parameters	
Number of beams	1
Reflector diameter	0.219 m
Maximum beam gain	45 dB
Polarization	Linear
–3 dB beamwidth	1.1°
Main beam efficiency	> 95%
Off-nadir pointing angle	±48.95°
Beam dynamics	Scan period of 8/3 s
Incidence angle at Earth	56.9°
–3 dB beam dimensions	13.5 km
Swath width	1 650 km
Sensor antenna pattern	See Fig. 11
Cold calibration ant. gain	45 dB
Cold calibration angle (degrees re. satellite track)	90°
Cold calibration angle (degrees re. nadir direction)	65-81°
Sensor receiver parameters	
Sensor integration time	18 ms
Channel bandwidth	4 000 MHz @ 150 GHz
Measurement spatial resolution	
Horizontal resolution	13.5 km
Vertical resolution	13.5 km

FIGURE 11

Sensor N1 antenna pattern for the 148.5 and 151.5 GHz band



6.15 Typical parameters of passive sensors operating in the bands between 155.5-158.5 GHz

The band 155.5-158.5 GHz is of primary interest to measure Earth and cloud parameters. Table 22 summarizes the parameters of passive sensors that are or will be operating between 155.5-158.5 GHz.

TABLE 22

EESS (passive) sensor characteristics operating between 155.5-158.5 GHz

	Sensor O1	Sensor O2
Sensor type	Conical scan	Cross-track nadir scan
Orbit parameters		
Altitude	865 km	822 km
Inclination	20°	98.7°
Eccentricity	0	0.001
Repeat period	7 days	29 days
Sensor antenna parameters		
Number of beams		1
Reflector diameter	0.65 m	0.22 m
Maximum beam gain	60 dBi	44.8 dBi
Polarization	H, V	QV
–3 dB beamwidth		1.1°
Instantaneous field of view		Nadir FOV: 16 km Outer FOV: 53 × 27 km
Main beam efficiency	96%	95%
Off-nadir pointing angle	44.5°	49.45°
Beam dynamics	20 rpm	Scan period of 8/3s
Incidence angle at Earth	52.3°	59°
–3 dB beam dimensions	3 km	16 km
Swath width		2 193 km
Sensor antenna pattern		
Cold calibration ant. gain	N/A	44.8 dBi
Cold calibration angle (degrees re. satellite track)	N/A	−90° ± 3.9°
Cold calibration angle (degrees re. nadir direction)	N/A	73.6 (66° to 81°)
Sensor receiver parameters		
Sensor integration time	N/A	18 ms
Channel bandwidth	2 GHz	< 2.8 GHz
Measurement spatial resolution		
Horizontal resolution	6 km	16 km
Vertical resolution	6 km	16 km

6.16 Typical parameters of passive sensors operating in the bands between 164 and 167 GHz

The band 164-167 GHz is of primary interest to measure N_2O, cloud water and ice, rain, CO, and ClO. Table 23 summarizes the parameters of passive sensors that are or will be operating between 164 and 167 GHz.

TABLE 23

EESS (passive) sensor characteristics operating between 164 and 167 GHz

	Sensor P1	**Sensor P2**
Sensor type	Conical scan	Mechanical nadir scan
Orbit parameters		
Altitude	828 km	824 km
Inclination	98.7°	
Eccentricity	0	
Repeat period	17 days	9 days
Sensor antenna parameters		
Number of beams	2	
Reflector diameter	0.48 × 0.71 m	0.127 m
Maximum beam gain	54 dBi	43.9 dBi
Polarization	V	QH
–3 dB beamwidth	0.39°	1.1°
Instantaneous field of view	16 km × 12 km	Nadir FOV: 15.8 km Outer FOV: 68.4 × 30 km
Main beam efficiency	95%	
Off-nadir pointing angle	46.8°	±52.725° cross-track
Beam dynamics	31.6 rpm	8/3 s scan period cross-track; 96 earth fields per scan period
Incidence angle at Earth	55.5°	0°
–3 dB beam dimensions	6 km	1.1°16 km
Swath width	1 700 km	2 500 km
Sensor antenna pattern		
Cold calibration ant. gain	N/A	43.9 dBi
Cold calibration angle (degrees re. satellite track)	N/A	0
Cold calibration angle (degrees re. nadir direction)	N/A	82.175°
Sensor receiver parameters		
Sensor integration time	1.2 ms	18 ms
Channel bandwidth	1 425 MHz centred at 166 ± 0.7875 GHz	3 000 MHz centred at 164-167 GHz
Measurement spatial resolution		
Horizontal resolution	12 km	32 km
Vertical resolution	12 km	32 km

6.17 Typical parameters of passive sensors operating in the bands between 174.8 and 191.8 GHz

The 174.8-191.8 GHz passive sensor band is essential for N_2O and O_3 measurements, in addition to water vapour profiling. Table 24 summarizes the parameters of passive sensors that are or will be operating between 174.8 and 191.8 GHz.

TABLE 24

EESS (passive) sensor characteristics operating between 174.8 and 191.8 GHz

	Sensor Q1	**Sensor Q2**	**Sensor Q3**	**Sensor Q4**	**Sensor Q5**	**Sensor Q6**	**Sensor Q7**
Sensor type	Conical scan	Cross-track scan	Limb sounder	Mechanical nadir scan	Conical scan	Nadir scan	
Orbit parameters							
Altitude	828 km	705 km		824 km	835 km	867 km	822 km
Inclination	98.7°	98.2°		98.7°	98.85°	20°	98.7°
Eccentricity	0						0.001
Repeat period	17 days	16 days		9 days	N/A	7 days	29 days
Sensor antenna parameters							
Number of beams	2	1	2	96 earth fields per scan period	6		1 (steerable in 90 earth fields per scan period)
Reflector diameter	0.48 × 0.71 m	0.219 m	1.6 × 0.8 m	0.127 m	0.6 m	0.2 m	0.22 m
Maximum beam gain	54 dBi	45 dBi	60 dBi	43.9 dBi	60 dBi	49 dBi	44.8 dBi
Polarization	V	Linear	V	QH	V	H	QV
−3 dB beamwidth	0.39°	1.1°	0.19° × 0.245°	1.1°	0.2°	0.66°	1.1°
Instantaneous field of view	16 km × 12 km	14 km	4.5 km × 9 km	Nadir FOV: 15.8 km Outer FOV: 68.4 × 30 km	Outer FOV: 8 × 19 km	At nadir 10 km × 10 km At swath limit 14 km × 22 km	Nadir FOV: 16 km Outer FOV: 53 × 27 km
Main beam efficiency	95%		N/A	95%	N/A	97%	95%
Off-nadir pointing angle	46.8°	±48.95°	N/A	±52.725° cross-track	55.4°	42°	49.4°

TABLE 24 (*continued*)

	Sensor Q1	Sensor Q2	Sensor Q3	Sensor Q4	Sensor Q5	Sensor Q6	Sensor Q7
Sensor antenna parameters (*cont.*)							
Beam dynamics	31.6 rpm	8/3 s scan period	Scans continuously in tangent height from the surface to ~92 km in 24.7 s 240 scans/ orbit	8/3 s scan period cross-track	2.88 sscan period	1 revolution per 1.639 s	8/3 s scan period cross-track
Incidence angle at Earth	55.5	56.9°	N/A		65°	55°	59°
–3 dB beam dimensions	3 km	13.5 km	3 km	16 km	8 km × 19 km	10 km × 10 km	16 km
Swath width	1 700 km	1 650 km	N/A	2 500 km	2 000 km	1 700 km	2 193 km
Sensor antenna pattern		See Fig. 12					
Cold calibration ant. gain	N/A	45 dB	N/A	43.9 dBi	N/A		44.8 dBi
Cold calibration angle (degrees re. satellite track)	N/A	90°	N/A	0	N/A		−90° ± 3.9°
Cold calibration angle (degrees re. nadir direction)	N/A	65° to 81°	N/A	82.175°	N/A		73.6 (66° to 81°)

TABLE 24 (*end*)

	Sensor Q1	**Sensor Q2**	**Sensor Q3**	**Sensor Q4**	**Sensor Q5**	**Sensor Q6**	**Sensor Q7**
Sensor receiver parameters							
Sensor integration time	1.2 ms	18 ms	0.166 s	18 ms	N/A	7.34 ms	18 ms
Channel bandwidth	1 275 MHz centred at 183.31 ± 0.7875 GHz, 3 500 MHz centred at 183.31 ± 3.1 GHz, 4 500 MHz centred at 183.31 ± 7.7 GHz	1 000 MHz centred at 183.31 ± 1.00 GHz, 2 000 MHz centred at 183.31 ± 3.00 GHz, 4 000 MHz centred at 183.31 ± 7.00 GHz	N/A	See Table 25	1.5 GHz centred at 183.31 ± 7 GHz, 1.0 GHz centred at 183.31 ± 3 GHz, 0.5 GHz centred at 183.31 ± 1 GHz	6 channels from 200 MHz to 2 GHz centred at 183.31 GHz	0.5 GHz centred at 183.311 ± 1 GHz, 1.0 GHz centred at 183.311 ± 3 GHz, 1.1 GHz centred at 190.311 ± 1 GHz
Measurement spatial resolution							
Horizontal resolution	6 km	13.5 km	9 km	16 km	8 km	10 km cross-track	16 km
Vertical resolution	6 km	13.5 km	4.5 km	16 km	8 km	10 km	16 km

FIGURE 12

Sensor Q2 antenna pattern for the 174.8 and 191.8 GHz band

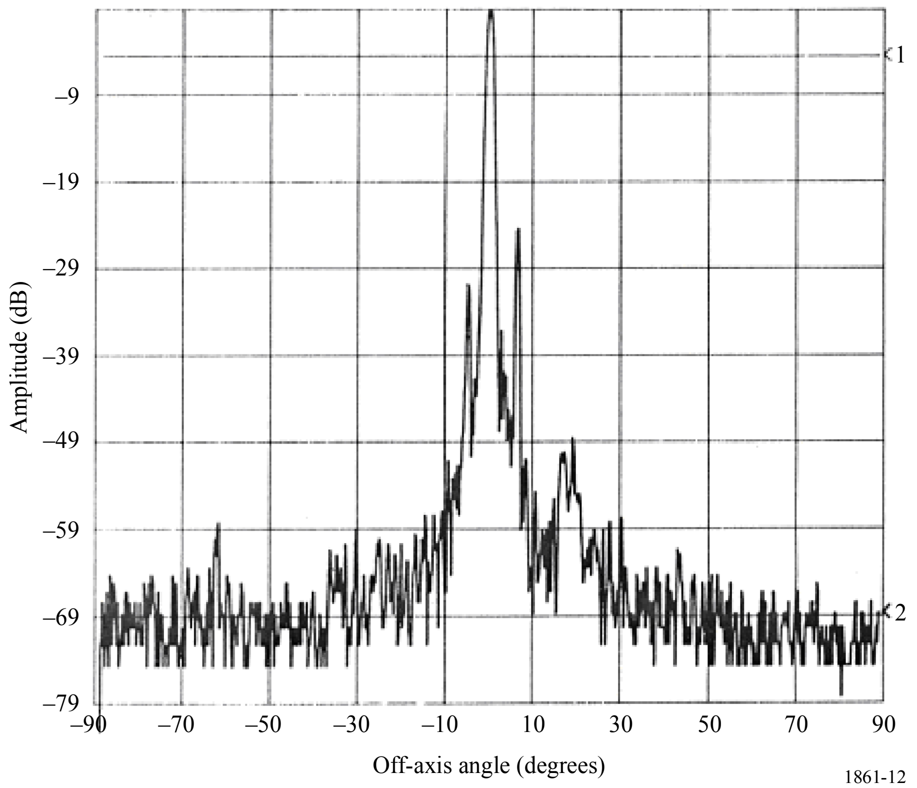


TABLE 25

Sensor Q4 passive sensor characteristics for channels between 174.8 and 191.8 GHz

Centre frequency (GHz)	Channel bandwidth (MHz)	Polarization
183.31 ± 4.5	2 000	QH
183.31 ± 1.8	1 000	QH
190.31	< 2 200	V

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