International Telecommunication Union

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Radiocommunication Sector of ITU

Recommendation ITU-R RS.2105-0

(07/2017)

Typical technical and operational characteristics of Earth exploration-satellite service (active) systems using allocations between 432 MHz and 238 GHz

RS Series

Remote sensing systems

International Telecommunication Union

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RECOMMENDATION ITU-R RS.2105-0

Typical technical and operational characteristics of Earth exploration-satellite service (active) systems using allocations between 432 MHz and 238 GHz

(2017)

Scope

This Recommendation provides technical and operational characteristics of Earth exploration-satellite service (active) systems using allocations between 432 MHz and 238 GHz for utilisation in sharing and compatibility studies.

Keywords

EESS (active), Earth exploration-satellite service, remote sensing, synthetic aperture radar, altimeters, precipitation radar, scatterometers, cloud profile radar

The ITU Radiocommunication Assembly,

considering

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

b) that EESS (active) is co-allocated with active services in certain bands;

c) that studies considering protection for and from EESS (active) systems are taking place within ITU-R;

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

recognizing

a) that Recommendation ITU-R RS.577 provides information on the bandwidths of active sensor systems envisaged to operate in the allocated bands between 432 MHz and 238 GHz;

b) that several ITU-R Recommendations and Reports provide information on the current and future characteristics of EESS (active) systems operating in several frequency bands (see Annex, Table 2),

recommends

that the technical and operational parameters presented in the Annex of this Recommendation should be taken into account in studies considering EESS (active) systems using allocations between 432 MHz and 238 GHz.

Annex

Technical and operational parameters of EESS (active) systems using allocations between 432 MHz and 238 GHz

1 Introduction

Active 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) (active). The products of these active sensor operations are used extensively in meteorology, climatology, and other disciplines for operational and scientific purposes.

The technical and operational parameters presented in this Recommendation shall be used in studies considering EESS (active) systems using allocations between 432 MHz and 238 GHz. However, it should be noted that some of the EESS (active) systems are under development and the typical values for certain parameters provided should be considered preliminary as these still may change.

2 Active sensor types and typical characteristics

There are five active spaceborne sensor types addressed in this Recommendation:

Type 1: Synthetic aperture radars (SAR) – Sensors looking to one side of the nadir track, collecting a phase and time history of the coherent radar echo from which a radar image of the Earth's surface from the returned echo or topography from interferometric returns can be produced.

Type 2: Altimeters – Sensors looking at nadir, measuring the precise time between a transmit event and receive event, to extract the precise altitude of the Earth's ocean surface.

Type 3: Scatterometers – Sensors pointing at various look angles relative to the sides of the nadir track, using the measurement of the return echo power variation with aspect angle to determine the roughness of land surface or to determine the wind direction and speed on the Earth's ocean surface.

Type 4: Precipitation radars – Sensors scanning perpendicular to nadir track which measure the radar echo from rainfall in order to determine the rainfall rate over the Earth's surface and the three-dimensional structure of rainfall.

Type 5: Cloud profile radars – Sensors looking at nadir which measure the radar echo return from clouds in order to determine the cloud reflectivity profile over the Earth's surface.

Some typical characteristics of spaceborne active sensors are shown below in Table 1. The actual characteristic values of the systems operating in the various frequency bands provided in § 7 of this Recommendation may vary considerably from these typical characteristic values reflected in Table 1.

TABLE 1

Typical characteristics of active spaceborne sensors

Characteristic	Sensor type				
	SAR	**Altimeter**	**Scatterometer**	**Precipitation radars**	**Cloud profile radars**
Service area	Land/coastal/ ocean	Ocean/ice/coastal/ Inland water	Ocean/ice/land/coastal	Land/ocean	Land/ocean
Antenna beam	Fan beam	Pencil beam	– Fan beams – Pencil beams	Pencil beam	Pencil beam
Viewing geometry	Side-looking at 10°-55° off nadir	– Nadir-looking – Multi incidence looking	– Three/six fan beams in azimuth – One or more conically scanning beams	Scanning across-track around Nadir	Nadir-looking
Footprint/dynamics	– Fixed to one side – ScanSAR – Spotlight	– Fixed at nadir – Multi incidence looking	– Fixed in azimuth – Multiple conically scanning beams	Scanning across nadir track	Fixed at nadir
RF Bandwidth	20- 1 200 MHz	320-500 MHz	5-80 kHz (ocean) or 1-4 MHz (land)	14 MHz	300 kHz
Transmit peak power (W)	1 500-7 600	20	100-5 000	600	1 000-1 500
Waveform	Linear FM pulses	Linear FM pulses	Interrupted CW or short pulses (ocean) or linear FM pulses (land)	Short pulses	Short pulses
Transmit duty cycle (%)	1-30	46	31 (ocean) or 10 (land)	0.9	1-14

3 Typical orbits

EESS (active) systems operate in non-geostationary satellite orbit (non-GSO). Orbits are typically circular with an altitude between 350 and 1 400 km. Some EESS (active) systems operate in a sun-synchronous orbit. Some sensors make measurements over the same area 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 different Earth system characteristics (land, ocean, atmosphere, cryosphere and solid Earth) using both multiple instruments and 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 a few seconds.

4 Active sensors interference and performance criteria

The criteria for performance, interference and data availability are provided in Recommendation ITU-R RS.1166 for the various types of active spaceborne sensors. Performance criteria for active spaceborne sensors are needed in order to develop interference criteria. Interference criteria, in turn, can be used to assess the compatibility of other active services and active sensors operating in common frequency bands.

5 Sharing considerations for active sensors

5.1 Existing ITU-R Recommendations and Reports

The sharing considerations for sharing between spaceborne active sensors in the EESS (active) and other services are provided in the ITU-R Recommendations and Reports listed in Table 2. These Recommendations and Reports are concerned with specific frequency bands or ranges of frequencies and the other services operating in those bands.

The sharing considerations for spaceborne active sensors include the level of the power flux-density (pfd) and received interference power at the Earth's surface, the type of transmitted RF signal, the dynamics of the antenna coupling with systems of other services, and the types of systems in the other services.

TABLE 2

List of ITU-R Recommendations with sharing considerations for active sensors

ITU-R RS.1260	Feasibility of sharing between active spaceborne sensors and other services in the range 420-470 MHz
ITU-R RS.1261	Feasibility of sharing between spaceborne cloud radars and other services in the range of 92-95 GHz
ITU-R RS.1280	Selection of active spaceborne sensor emission characteristics to mitigate the potential for interference to terrestrial radars operating in frequency bands 1-10 GHz
ITU-R RS.1281	Protection of stations in the radiolocation service from emissions from active spaceborne sensors in the band 13.4-13.75 GHz
ITU-R RS.1282	Feasibility of sharing between wind profiler radars and active spaceborne sensors in the vicinity of 1 260 MHz
ITU-R RS.1347	Feasibility of sharing between radionavigation-satellite service receivers and the Earth exploration-satellite (active) and space research (active) services in the 1 215-1 260 MHz band
ITU-R RS.1628	Feasibility of sharing in the band 35.5-36 GHz between the Earth exploration-satellite service (active) and space research service (active), and other services allocated in this band
ITU-R RS.1632	Sharing in the band 5 250-5 350 MHz between the Earth exploration-satellite service (active) and wireless access systems (including radio local area networks) in the mobile service
ITU-R RS.1749	Mitigation technique to facilitate the use of the 1 215-1 300 MHz band by the Earth exploration-satellite service (active) and the space research service (active)
ITU-R RS.2043	Characteristics of synthetic aperture radars operating in the Earth exploration-satellite service (active) around 9 600 MHz
ITU-R RS.2065	Protection of space research service (SRS) space-to-earth links in the 8 400-8 450 MHz and 8 450-8 500 MHz bands from unwanted emissions of synthetic aperture radars operating in the earth exploration-satellite service (active) around 9 600 MHz
ITU-R RS.2066	Protection of the radio astronomy service in the frequency band 10.6-10.7 GHz from unwanted emissions of synthetic aperture radars operating in the Earth exploration-satellite service (active) around 9 600 MHz

TABLE 2 (*end*)

List of ITU-R Reports with sharing considerations for active sensors

ITU-R RS.2068	Current and future use of the band near 13.5 GHz by spaceborne active sensors
ITU-R RS.2094	Studies related to the compatibility between Earth exploration-satellite service (active) and the radiodetermination service in the 9 300-9 500 MHz and 9 800-10 000 MHz bands and between Earth exploration-satellite service (active) and the fixed service in the 9 800-10 000 MHz band
ITU-R RS.2178	The essential role and global importance of radio spectrum use for Earth observations and for related applications
ITU-R RS.2273	Potential interference from EESS (active) scatterometers into ARNS systems in the frequency band 1 215-1 300 MHz
ITU-R RS.2274	Spectrum requirements for spaceborne synthetic aperture radar applications planned in an extended allocation to the Earth exploration-satellite service around 9 600 MHz
ITU-R RS.2310	Worst-case interference levels from mainlobe-to-mainlobe antenna coupling of systems operating in the radiolocation service into active sensor receivers operating in the Earth exploration-satellite service (active) in the 35.5-36.0 GHz band
ITU-R RS.2311	Pulsed radio frequency signal impact measurements and possible mitigation techniques between Earth exploration-satellite service (active) systems and RNSS systems and networks in the band 1 215-1 300 MHz
ITU-R RS.2313	Sharing analyses of wideband Earth exploration-satellite service (active) transmissions with stations in the radio determination service operating in the frequency bands 8 700-9 300 MHz and 9 900-10 500 MHz
ITU-R RS.2314	Sharing analyses of wideband EESS SAR transmissions with stations in the fixed, mobile, amateur, and amateur-satellite services operating in the frequency bands 8 700-9 300 MHz and 9 900-10 500 MHz

5.2 Power flux-density levels due to active spaceborne sensors

The characteristics of the various types of active spaceborne sensors as shown in Table 1 indicate that the transmitted peak power and therefore the power levels received at the Earth's surface will vary significantly. Table 3 shows the active sensor pfd levels at the Earth's surface for some typical sensor configurations.

TABLE 3

Typical pfd levels at Earth's surface

Parameter	**Sensor type**				
	SAR	**Altimeter**	**Scatterometer**	**Precipitation radars**	**Cloud profile radars**
Transmit peak power (W)	1 500	20	100	578	630
Antenna gain (dBi)	36.4	43.3	34	47.7	63.4
Altitude (km)	695	1 344	1 145	350	400
pfd (dB(W/m^2))	−59.67	−77.25	−78.17	−46.55	−31.64

5.3 Dynamics of antenna coupling with systems of other services

The viewing geometry and footprint/dynamics of the active sensors are shown in Table 1. All five types of active sensors are mounted on spacecraft looking down at the Earth’s surface.

The SARs have a look angle, which is the angle between nadir and the beam centre, of 10 degrees to 55 degrees. The scatterometers have a look angle of about 40 degrees from nadir.

The altimeters, precipitation radars and the cloud profile radars are nadir looking. Typical terrestrial search radars cover low elevation angles, therefore they do not have mainlobe-to-mainlobe coupling with altimeters, precipitation radars, or cloud profile radars.

The spaceborne sensor beams scan past the terrestrial systems as the spacecraft proceeds in its orbit. For a sensor beamwidth of 2 degrees, the beam scans past the terrestrial system in about 2-3 seconds. The SARs typically look down to the side of the nadir track either at a commanded look angle or at various look angles for ScanSAR modes. The scatterometers are either fixed at various azimuth angles or are conically scanned about nadir with one or more beams. For a sensor beamwidth of 2 degrees, the conically scanning beam scans past the terrestrial system in less than 25 milliseconds for a scan rate of 15 rpm. Typical terrestrial search radars also scan 360 degrees in azimuth at rates of 5 to 10 rpm so that the terrestrial radar beam with a 1-degree beamwidth scans past the spaceborne sensor in only 30 to 60 milliseconds. The precipitation radars typically are nadir looking and scan across the nadir track. For a sensor beamwidth of 0.7 degrees, the cross-track scanning beam of the precipitation radar scans past the terrestrial system in only 12.5 milliseconds at a scan rate of about 57 deg./s. The altimeters and cloud profile radars are typically nadir looking.

6 Definition of parameters

This section provides definitions of the parameters used to characterize the operations of the active sensors provided in this Recommendation.

TABLE 4

Definitions of parameters

Parameter	Definition
Sensor type	One of the five types described in the Introduction of this Recommendation
Orbit parameters	
Type of orbit	Such as: circular or elliptical, sun-synchronous (SSO) or non-sun-synchronous (NSS)
Altitude (km)	The height above the mean sea level
Inclination (degrees)	Angle between the equator and the plane of the orbit
Ascending Node LST	The local solar time (LST) of the ascending node is that local solar time for which the ascending orbit of the spacecraft crosses the equator
Eccentricity	The ratio of the distance between the foci of the (elliptical) orbit to the length of the major axis
Repeat period (days)	The time for the footprint of the antenna beam to return to (approximately) the same geographic location.

TABLE 4 (*continued*)

Parameter	Definition
Sensor antenna parameters Antenna characteristics vary among sensors.	
Antenna type	Such as: Parabolic offset fed to active phased array, Passive waveguide to active phased array, Planar slotted waveguide array
Number of beams	The number of beams is the number of locations on Earth from which data are acquired at one time.
Antenna diameter (or size)	Diameter of the antenna reflector (when applicable), or length and width of the planar array (when applicable).
Antenna Peak (Transmit & Receive) Gain (dBi)	The maximum (peak) antenna gain can be the measured value, or, if it is not known, it can be computed. For the case of parabolic reflectors, the maximum antenna gain can be estimated by using the antenna efficiency η and D diameter of the reflector (when applicable): $\text{Maximum\_antenna\_gain} = \eta\left(\pi \frac{D}{\lambda}\right)^2$ For the case of planar array antennas, the maximum gain can be estimated by using the length l and width w of the planar array (when applicable) with the formula: $\text{Maximum\_antenna\_gain} = \eta\, 4\pi\, l\, w / \lambda^2$
Polarization	Specification of linear (H or V) or circular polarization (RHCP or LHCP). NOTE: where “HV” polarization is listed, “H” polarization is transmitted and “V” polarization is received and vice versa for “VH” polarization.
−3 dB beamwidth (degrees)	The −3 dB beamwidth (also called, half power beamwidth), θ_{3dB}, is defined as the angle between the two directions in which the radiation intensity is one-half the maximum value.
Instantaneous field of view IFOV	The instantaneous field of view (IFOV) is the area over which the measurement is made by the detector. 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 radars, 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 radars, such as that shown in Fig. 1, the nadir IFOV = $H\theta_{3dB}$, where H is the height of the satellite and θ_{3dB} is the half-power beamwidth.
Antenna incidence angle at Earth (degrees)	The angle between the pointing direction and the normal to the Earth’s surface. It is the angle i as in Fig. 1 (in some cases, the off-nadir angle is provided).
Azimuth scan rate (rpm)	The azimuth scan rate is the number of 360 degrees revolutions per minute that the antenna scans in azimuth.

TABLE 4 (*continued*)

Parameter	Definition
Antenna beam look angle (degrees)	The antenna beam look angle, α, is the angle between the antenna boresight axis and nadir, sometimes called the off-nadir pointing angle. Some systems provide instead the information of the incident angle, *i*. They are the angle α and i, as shown in Fig. 1
Antenna beam azimuth angle (degrees)	The antenna beam azimuth angle is the angle between the antenna boresight axis and velocity vector in the plane defined by the velocity vector and the negative orbit normal vector (see Fig. 2).
Antenna elevation beamwidth (degrees)	The antenna elevation beamwidth is the angle in the elevation or cross-track direction between the −3 dB points of the beam.
Antenna azimuth. beamwidth (degrees)	The antenna azimuth beamwidth is the angle in the azimuth or along-track direction between the −3 dB points of the beam.
Swath width (km)	The swath width is defined as the linear ground distance covered in the cross-track direction.
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 nadir scans, it is the number of scans per second.
Sensor antenna pattern	Antenna gain as a function of off-axis angle.
Transmitter characteristics	
RF centre frequency (MHz)	The RF centre frequency is that frequency about which the bandwidth of the transmitted signal is centred.
RF bandwidth (MHz)	The RF bandwidth is the −3 dB bandwidth of the transmitted signal. For compatibility analysis, this is also typically used as the receiver bandwidth.
Transmit Pk pwr (W)	The transmit peak power is the peak power of the envelope of the transmitted waveform.
Transmit Ave. pwr (W)	The transmit average power is the product of the peak power of the envelope of the transmitted waveform times the transmit duty cycle.
Pulsewidth (μs)	The pulsewidth is the half power duration of the transmitted pulse.
Pulse repetition frequency (PRF) (Hz)	The pulse repetition frequency is the frequency of the transmitted pulse waveforms.
Chirp rate (MHz/μs)	The chirp rate for a linear FM (LFM) pulse is the ratio of the RF bandwidth in MHz and the pulsewidth in μsec.
Transmit duty cycle (%)	The transmit duty cycle is the product of the transmitted pulsewidth and the pulse repetition frequency.
Operational duty cycle (%)	The percentage of time that the transmitter is active per orbit (this may vary according to the operational mode).
e.i.r.p. ave (dBW)	The average effective isotropically radiated power (e.i.r.p.) is the amount of power that a theoretical isotropic antenna would radiate to produce the average power density observed in the direction of maximum antenna gain; the e.i.r.p. is the product of the transmit average power and the antenna peak gain in dBW.

TABLE 4 (*end*)

Parameter	Definition
e.i.r.p. peak (dBW)	The peak effective isotropically radiated power (e.i.r.p.) is the amount of power that a theoretical isotropic antenna would radiate to produce the peak power density observed in the direction of maximum antenna gain; the peak e.i.r.p. is the product of the transmit peak power and the antenna peak gain in dBW.
Sensor receiver parameters	
Sensor dwell time	The *sensor dwell time* corresponds to the period of time allocated for the echo measurement of the instantaneous area of observation by the detector of a sensor.
Sensitivity (dBZ)	The sensitivity of a precipitation radar or cloud profile radar is the *minimum* detectable reflectivity Z (mm^6/m^3) of the precipitation or cloud profile radar in dBZ.
System noise figure (dB) or System noise temperature (K)	The system noise figure is the ratio of the input signal-to-noise power ratio $(S/N)_i$ to the output signal-to-noise power ratio $(S/N)_o$. The system noise temperature is effectively the antenna noise temperature plus the first stage receiver noise temperature; the other system noise temperature contributions can usually be neglected when the first stage receiver gain is greater than 16 dB.
Measurement spatial resolution	
Range 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 range or horizontal (usually cross-track) and azimuth, or vertical (along-track) resolutions. (Note that “vertical”, in this sense, does not refer to altitude.)
Azimuth resolution	

FIGURE 1

Scanning configuration typical of conical scanning scatterometers

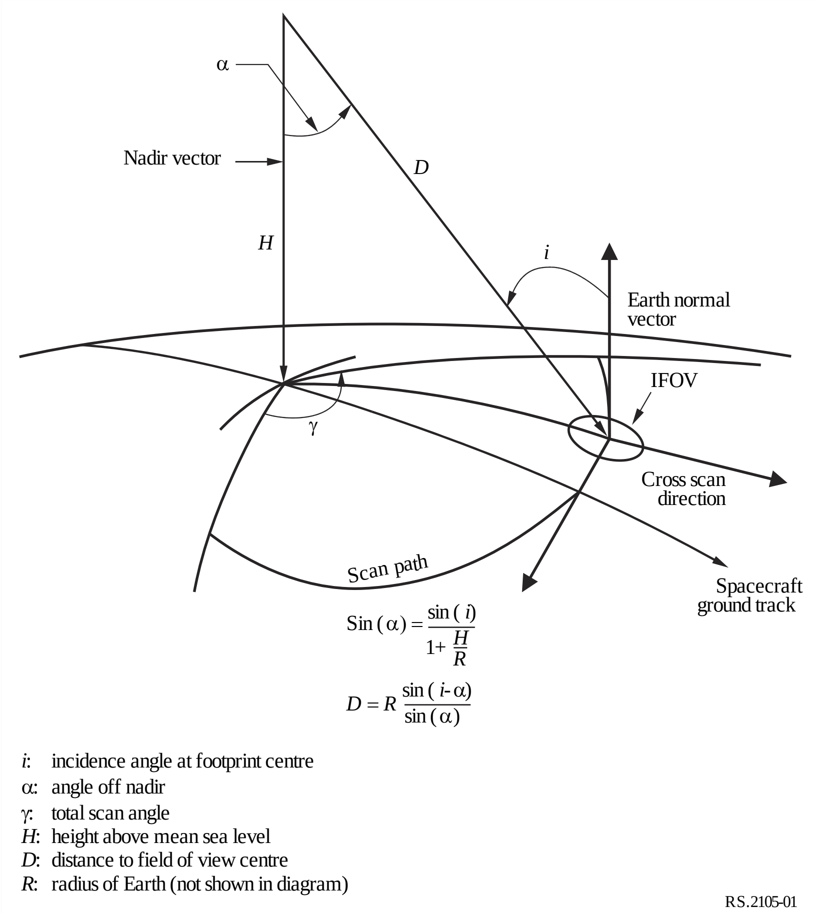
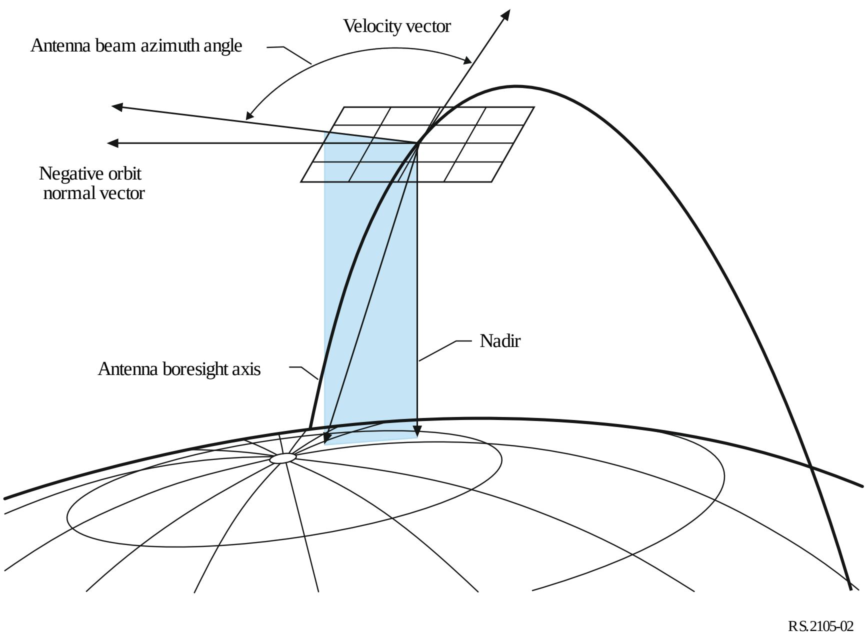


FIGURE 2

Plane defined by velocity vector and negative orbit normal vector



7 Parameters of typical systems

This section provides typical parameters of active sensors for EESS (active) bands between 432 MHz and 238 GHz. A consistent set of parameters is used for each band to support worst-case static analyses and dynamic analyses.

7.1 Typical parameters of active sensors operating in the 432-438 MHz band

The 435 MHz SARs are active microwave sensors using the frequency band 432-438 MHz to achieve weather -independent and day and night land observation. The lower frequencies enable penetration of the vegetation canopies in order to provide global vegetation models to improve the quantification of the global terrestrial carbon cycle. Typical characteristics of 435 MHz SARs are shown in Table 5.

TABLE 5

Characteristics of EESS (active) missions in the 432-438 MHz band

Parameter	SAR-A1
Sensor type	SAR
Type of orbit	SSO
Altitude (km)	665
Inclination (degrees)	98.1
Ascending node LST	06:00
Repeat period, days	17
Number of beams	1
Antenna diameter	12 m
Antenna Pk Xmt Gain (dBi)	33.3
Antenna Pk Rcv Gain (dBi)	33.3
Polarization	linear H, V
Azimuth scan rate (rpm)	0
Antenna beam look angle (degrees)	25, 29, 31[1]
Antenna beam azimuth angle (degrees)	90
Antenna elev. beamwidth (degrees)	4.8
Antenna az. beamwidth (degrees)	3.2
RF centre frequency (MHz)	435
RF bandwidth (MHz)	6
Transmit Pk pwr (W)	270
Transmit Ave. pwr (W)	27
Pulsewidth (μs)	29.8, 32.8, 32.2[1]
Pulse Repetition frequency max (Hz)	3348, 3047, 3104[1]

[1] Three swaths; each value given corresponds to a different swath. The three swaths are implemented by satellite roll rotation so that the antenna beam look angles change. This rotation is performed sequentially at intervals of several months, to achieve a specific coverage (depending on mode of operation). Global coverage is achieved in five months.

TABLE 5 (*end*)

Parameter	SAR-A1
Chirp rate (MHz/µs)	0.200, 0.182, 0.1861
Transmit duty cycle (%)	Approx. 10
e.i.r.p. ave (dBW)	46
e.i.r.p. peak (dBW)	56
System noise figure (dB)	3

7.2 Typical parameters of active sensors operating in the 1 215-1 300 MHz band

The 1.25 GHz SARs are active microwave sensors using the frequency band 1 215-1 300 MHz to achieve weather-independent and day and night land observation. The SARs may have several modes, including fine resolution mapping modes, medium resolution mapping modes, and scanSAR modes. Typical characteristics of SARs operated in the 1 215-1 300 MHz band are shown in Table 6.

Table 6 shows the characteristics of the typical land scatterometer operated in the band 1 215-1 300 MHz.

TABLE 6

Characteristics of EESS (active) missions in the band 1 215-1 300 MHz

Parameter	SAR-B1	SCAT-B1	SCAT-B2	SAR-B2
Sensor type	SAR	Scatterometer	Scatterometer	SAR
Type of orbit	Circular, SSO	Circular, SSO	Circular, SSO	Circular, SSO
Altitude (km)	757	670	657	628
Inclination (degrees)	98	98	98	97.9
Ascending node LST	18:00	18:00	18:00	12:00*
Repeat period (days)	12	3	7	14
Antenna type	Linear array fed reflector	Offset parabolic reflector	Three-feed offset parabolic reflector	Planar phased array
Number of beams	1	1	3	1
Antenna size/diameter	15 m	6 m	2.5 m	9.9 m × 2.9 m
Antenna peak transmit gain (dBi)	35	36	28.1	34.7
Antenna peak receive gain (dBi)	45	36	28.1	36.6
Polarization	Dual/quad, linear H,V	Dual, linear H,V	Dual, linear H,V	Dual/quad, circular, linear H,V
Azimuth scan rate (rpm)	0	13.0-14.6	0	0
Antenna beam look angle (degrees)	30 (transmit), 20-40 (receive)	34	25.9/33.9/40.3	7.2-59

TABLE 6 (*end*)

Parameter	SAR-B1	SCAT-B1	SCAT-B2	SAR-B2
Antenna beam azimuth angle (degrees)	90	0-360	99.7/74.8/96.5	±90 ±3.5
Antenna elev. beamwidth (degrees)	20.9	2.5	6.5/6.7/7.1	4.3 to 4.6
Antenna az. beamwidth (degrees)	0.89	2.5	6.5/6.7/7.1	1.3 to 2.1
RF centre frequency (MHz)	1 215-1 300	1 215-1 300	1 260	1 236.5/1 257.5
RF bandwidth (MHz)	25	1	4	14-78
Transmit Pk pwr (W)	3 200	200	200	3 944-6 120
Transmit Ave. pwr (W)	614.4	28	–	453-454
Pulsewidth (µs)	60	15	1 000	18-71
Pulse repetition frequency (PRF) (Hz)	1 500-2 000	3 500	100	1 050-3 640
Chirp rate (MHz/µs)	0.42	0.067	0.004	0.21-1.95
Transmit duty cycle (%)	19.2	5.25	10	6.8-11.5
e.i.r.p. peak (dBW)	71.5	60	51.1	70.7-74.5
System noise figure (dB)	3.9	4.0	7.0	4.9

7.3 Typical parameters of active sensors operating in the 3 100-3 300 MHz band

Typical characteristics of 3.1 GHz SAR are shown in Table 7.

TABLE 7

Characteristics of EESS (active) missions in the 3 100-3 300 MHz band

Parameter	SAR-C1
Sensor type	SAR
Type of orbit	Circular, SSO
Altitude (km)	500
Inclination (degrees)	97.3
Ascending node LST	06:00
Repeat cycle, days	31
Antenna type	–
Number of beams	9
Antenna diameter or size	–
Antenna peak gain (dBi)	37.6
Polarization	VV
Azimuth scan rate (rpm)	0
Antenna beam look angle (degrees)	25-47
Antenna beam azimuth angle (degrees)	90

TABLE 7 (*end*)

Parameter	SAR-C1
Antenna elevation beamwidth (degrees)	2.5
Antenna azimuth beamwidth (degrees)	1
RF centre frequency (MHz)	3 200
RF bandwidth (MHz)	60
Transmit Pk pwr (W)	3 000
Transmit Ave. pwr (W)	300
Pulsewidth (µs)	27
Chirp rate (MHz/µs)	2.22
Transmit duty cycle (%)	10
System Noise Figure (dB)	2

7.4 Typical parameters of active sensors operating in the 5 250-5 570 MHz band

The typical characteristics of for several types of SAR sensors, altimeters and scatterometers operating in the 5 250-5 570 MHz are shown in Tables 8A, 8B and 8C.

It should be noted that the service area for most of these active sensors is global, as it is the case for SAR-D4, SAR-D5, SAR-D6, and SAR-D1 (a two-satellite constellation).

TABLE 8A

Characteristics of SAR sensors in the 5 250-5 570 MHz band

Mission	SAR-D1	SAR-D2	SAR-D3	SAR-D4	SAR-D5	SAR-D6
Sensor type	SAR	SAR	SAR	SAR	SAR	SAR
Type of orbit	Circular SSO	SSO, circular	SSO	Near circular	Near circular	Near circular
Altitude (km)	693	764	536	792-813	586.9-615.2	586.9-615.2
Inclination (degrees)	98.18	98.6	97	98.6	97.74	97.74
Ascending Node LST	18:00/6:00[2]	10:30	6:00	6:00	6:00	6:00 (TBC)
Repeat period (days)	12	35	13	24	12	12 (TBC)
Antenna type	Phase array	Phase array	Planar Phased Array	Planar Phased Array	Planar Phased Array	Planar Phased Array
Number of beams	1	1	1	1	1	1
Antenna size/diameter	12.3 m × 0.8 m	10 m × 1.3 m	10 m × 3 m	15 m × 1.5 m	6.88 m × .37 m	6.88 m × 1.37 m
Antenna Pk Xmt gain (dBi)	43.5 to 45.3	40 to 45	35	49[3]	45[3]	45[3]

[2] This system is a two-satellites constellation.

[3] Lower gain can be used for the wider beams.

TABLE 8A (*end*)

Mission	SAR-D1	SAR-D2	SAR-D3	SAR-D4	SAR-D5	SAR-D6
Antenna Pk Rcv gain (dBi)	43.5 to 44.8	40 to 45	35	49[3]	45[3]	45[3]
Polarization	V, H	H, V	Linear H,V	HH, HV, VH, VV	HH, VV, HV, VH, CH, CV	HH, VV, HV, VH, CH, CV
Antenna beam look angle (degrees)	20-47[4]	15-45	10-45	9-50	16-51	16-53
Antenna beam azimuth angle (degrees)	90	90	90	0	0	0
Antenna elev. beamwidth (degrees)	6 to 8	2.5	4.6	1.88 (for focused beam)	2.05 (for focused beam)	2.05 (for focused beam)
Antenna az. beamwidth (degrees)	0.3	0.3	1.4	0.19	0.42 (for focused beam)	0.42 (for focused beam)
Swath width (km)	20-410	10-405	10-225	18-500	20-500	20-500
RF centre frequency (MHz)	5 405	5 331	5 350	5 405	5 405	5 405
RF bandwidth (MHz)	100	16	18.75-75	11.6, 17.3, 30, 50, 100	14-100	14-300
Transmit Pk pwr (W)	4 140	2 500	4 000	2 400 or 3 700	1 490	1 990
Transmit Ave. pwr (W)	370	200	260	300	180	240
Pulsewidth (μs)	5 to 53	16 to 41	2 0	21, 42	10 to 50	10 to 50
Pulse repetition frequency (PRF) Hz	1 450-2 000	1 600-2 10 0	3 250	1 000-2 800	2 000-7 000	2 000-7 000
Chirp rate (MHz/μs)	0.34-3.75	0.39	0.937-3.75	0.27 to 2.38	0.14 to 10	0.14 to 10
Transmit duty cycle (%)	0.5-9.0 depending on ops mode	8.61	6.5	Variable, max 8%	Variable, max 12%	Variable, max 12%
e.i.r.p. ave (dBW)	70 (for 9% duty cycle)	68.0	68	Approx. 73[5]	67.67	69.0
e.i.r.p. peak (dBW)	80	78.0	71.0	83.5[6]	76.7	78.0
System noise figure (dB)	3.2	4.5	5.8	6	6	6

4 Antenna beam "incident angles".

5 Average e.i.r.p. over a pulse repetition interval.

6 Max e.i.r.p. during pulse transmission.

TABLE 8B

Characteristics of altimeters in the 5 250-5 570 MHz band

Mission	ALT-D1	ALT-D2 (Note 1)	ALT-D3	ALT-D4 (Note 1)	ALT-D5	ALT-D6
Sensor type	Altimeter	Altimeter	Altimeter	Altimeter	Altimeter	Altimeter
Type of orbit	NSS	Circular, SSO	SSO	NSS	NSS	Circular, SSO
Altitude (km)	1 336	814	963	1 336	890	1000
Inclination (degrees)	66	98.65	99.3	66	78	99.4
Ascending node LST	NSS	22:00	06:00	NSS	NSS	–
Repeat period (days)	10	27	14	10	21	14
Antenna type	Parabolic reflector	Parabolic reflector	Parabolic reflector	Parabolic reflector	Parabolic reflector	Parabolic Reflector
Number of beams	1	1	1	1	1	1
Antenna size/diameter	1.2 m	1.2 m	1.4 m	1.2 m	1.2 m	1.5 m
Antenna Pk Xmt gain (dBi)	32	34.5	35	33.5	32.0	33.6
Antenna Pk Rcv gain (dBi)	32	34.5	43	33.5	32.0	33.6
Polarization	linear	linear	linear VV	linear	linear	linear
Azimuth scan rate (rpm)	0	0	0	0	0	0
Antenna beam look angle (degrees)	0	0	0	0	0	0
Antenna beam azimuth angle (degrees)	0	0	0	0	0	0
Antenna elev. beamwidth (degrees)	3.4	3.4	2.3	3.4	3.4	3
Antenna az. beamwidth (degrees)	3.4	3.4	2.3	3.4	3.4	3
Swath width (km)	79.4	48.4	38.7	97	52.9	51.4
RF centre frequency (MHz)	5 300	5 410	5 250	5 410	5 300	5300
RF bandwidth (MHz)	100, 320	320	160	320	100, 320	100, 320
Transmit Pk pwr (W)	17	32	20	25	17	15.8
Transmit Ave. pwr (W)	0.51	0.4 (LRM),0.25 (SAR)	8.2	< 2	0.51	0.51, 0.71
Pulsewidth (μs)	106.0	49	102.4	32	106.0	110.5
Pulse Repetition Frequency (PRF) Hz	300	275 (LRM),157 (SAR)	670	2 060-9 280	300	294, 412

TABLE 8B (*end*)

Mission	ALT-D1	ALT-D2 (Note 1)	ALT-D3	ALT-D4 (Note 1)	ALT-D5	ALT-D6
Chirp rate (MHz/μs)	0.9, 3.0	6.5	1.56	9.69	0.9, 3.0	0.9, 2.9
Transmit duty cycle (%)	3.1	1.5 (LRM), 0.7 (SAR)	40.96	30	3.1	3.2, 4.5
e.i.r.p. ave (dBW)	29.5	30.8 (LRM), 28.4 (SAR)	44.1	36.51	29.2	30.7, 32.1
e.i.r.p. peak (dBW)	44.8	49.5	48	47.47	44.3	45.6
System noise figure (dB)	4.45	3.8	3.5	3.5	4.45	5.75

NOTE 1 − Dual frequency radar altimeter (C/Ku Band) which performs measurements either in low resolution mode (LRM) or synthetic aperture radar mode (Nadir-SAR). LRM mode is the conventional altimeter pulse limited mode with interleaved C/Ku Band pulses, while Nadir-SAR mode is the high along track resolution mode based on SAR processing. The system is a two-satellite constellation.

TABLE 8C

Characteristics of scatterometers in the 5 250-5 570 MHz band

Mission	SCAT-D1	SCAT-D2
Sensor type	Scatterometer	Scatterometer
Type of orbit	SSO	SSO
Altitude (km)	832	832
Inclination (degrees)	98.7	98.7
Ascending node LST	21:30	21:30
Repeat period (days)	29	29
Antenna type	Six fan beam-antennas (slotted WG arrays)	Six fan beam-antennas (slotted WG arrays)
Number of beams	6	6
Antenna size/diameter	2.251 m × 0.337 m (mid), 3.003 m × 0.253 m (side)	2.757 m × 0.315 m (mid), 3.02 m × 0.315 m (side)
Antenna Pk Xmt gain (dBi)	24-32	23-31[7]
Antenna Pk Rcv gain (dBi)	24-32	23-31
Polarization	linear VV for all beams	linear VV for all 6 beams + VH/HV and linear HH for the 2 mid-beams
Azimuth scan rate (rpm)	0	0
Antenna beam look angle (degrees)	22-45.6 (mid beams) 29.5-53.4 (side beams)	17.5-45.5 (mid beams) 24-54 (side beams)
Antenna beam azimuth angle (degrees)	45, 90, 135, 225, 270, 315	45, 90, 135, 225, 270, 315
Antenna elev. beamwidth (degrees)	23.6 (mid beams) 23.9 (side beams)	28 (mid beams) 30 (side beams)

[7] Antenna gain varies depending on antenna location (mid or side), and incident angle.

TABLE 8C (*end*)

Mission	SCAT-D1	SCAT-D2
Antenna az. beamwidth (degrees)	1.5 (mid beams) 1.2 (side beams)	1.3
Swath width (km)	550 on each side of the orbit plane	665 on each side of the orbit plane
RF centre frequency (MHz)	5 255	5 355
RF bandwidth (MHz)	0.5	2
Transmit Pk pwr (W)	120	2 512
Transmit Ave. pwr (W)	29 (mid beams) 36.5 (side beams)	92
Pulsewidth (μs)	10 000	1 000
Pulse repetition frequency (PRF) Hz	28.259	32
Chirp rate (MHz/μs)	0.00002	0.00002
Transmit duty cycle (%)	28.29	3.68
e.i.r.p. ave (dBW)	39-47	42-50
e.i.r.p. peak (dBW)	53	57-65
System noise figure (dB)	3.0	3.5

7.5 Typical parameters of active sensors operating in the 8 550-8 650 MHz band

The typical characteristics of 8.6 GHz SARs are shown in Table 9.

TABLE 9

Characteristics of EESS (active) missions in the 8 550-8 650 MHz band

Parameter	SAR-E1
Sensor type	SAR
Type of orbit	Circular, NSS
Altitude, km	400
Inclination (degrees)	57
Repeat period (days)	3
Number of beams	1
Antenna type	Slotted waveguide
Antenna (Transmit & Receive) peak gain (dBi)	44.0
Polarization	Linear H,V
Azimuth scan rate (rpm)	0
Antenna beam look angle (degrees)	20-55
Antenna beam azimuth angle (degrees)	90
Antenna elev. beamwidth (degrees)	2.5
Antenna az. beamwidth (degrees)	0.4
RF centre frequency (MHz)	8 600
RF bandwidth (MHz)	10, 20

TABLE 9 (*end*)

Parameter	SAR-E1
Transmit Pk pwr (W)	3 500
Transmit Ave. pwr (W)	243
Pulsewidth (µs)	40
Pulse Repetition Frequency (PRF) (Hz)	1 395-1 736
Chirp rate (MHz/µs)	1.0, 0.5
Transmit duty cycle (%)	7
System noise figure (dB)	4.3

7.6 Typical parameters of active sensors operating in the 9 200-10 400 MHz band

The typical characteristics of 9.6 GHz SARs are shown in Table 10. Additional information is contained in Recommendation ITU-R RS.2043.

TABLE 10

Characteristics of EESS (active) missions in 9 200-10 400 MHz band

Parameter	SAR-F1	SAR-F2	SAR-F3	SAR-F4	SAR-F5	SAR-F6
Sensor type	SAR	SAR	SAR	SAR	SAR	SAR
Type of orbit	Circular, SSO	Circular, SSO	SSO	SSO	SSO	Circular, SSO
Altitude (km)	514	620	512	620	514	514
Inclination (degrees)	97.4	97.8	97.9	97.8	97.44	97.4
Ascending node LST	18:00	06:00	06:00	06:00	18:00	18:00
Repeat period (days)	11	16	5	16	11	11
Antenna type	Active phased array	Planar array	Offset linear array fed reflector	Planar array	Active phased array	Active phased array
Number of beams	1	1	1	1	1	1
Antenna (Transmit & Receive) peak gain (dBi)	45.5	45.5	46	46.8	43.4	47
Polarization	Linear VV	Linear HH	Linear VV, VH	Linear HH	Linear HH,VV	Linear HH, VV
Azimuth scan rate (rpm)	0	0	0	0	0	0
Antenna beam look angle (degrees)	15-60	21-44	30-40	37.8	15-45	18-50
Antenna beam azimuth angle (degrees)	90	90	90	90	90	90
Antenna elev. beamwidth (degrees)	2.54	1.32	1.5	1.34	2.5	1.13
Antenna az. beamwidth (degrees)	0.37	0.32	0.5	0.32	0.4	0.53

TABLE 10 (*end*)

Parameter	SAR-F1	SAR-F2	SAR-F3	SAR-F4	SAR-F5	SAR-F6
RF centre frequency (MHz)	9 650	9 600	9 600	9 500	9 650	9 800
RF bandwidth (MHz)	150, 300	41-118	10	40-300	5-300	1 200
Transmit Pk pwr (W)	2 000	7 600	3 000	7 600	2 260	7 000
Transmit Ave. pwr (W)	400	836	270	836	452	2 100
Pulsewidth (μs)	47	18-31	20-30	18-31	47	50
Pulse Repetition Frequency (PRF) (Hz)	2 000-6 500	2 850-3 230	1 000-3 000	1 000-3 000	3 000-6 500	6 000
Chirp rate (MHz/μs)	3.2, 6.8	3.81	0.5-0.67	3.81-9.7	0.85-6.38	24
Transmit duty cycle (%)	20	7-11	2-9	7-11	20	30
System noise figure (dB)	2.9	1.0	3	1.0	5.0	3

7.7 Typical parameters of active sensors operating in the 13.25-13.75 GHz band

The typical characteristics of the 13.5 GHz altimeter are shown in Table 11A.

The typical ocean scatterometer, operating around 13.4 GHz, infers the ocean surface wind speed and direction from measurements of the ocean surface backscatter coefficient from several different azimuth angles as the antenna beams rotate about nadir. Table 11B shows the characteristics of the 13.4 GHz scatterometer.

Typical characteristics of 13.5 GHz precipitation radars are shown in Table 11C.

TABLE 11A

Characteristics of altimeters in the 13.25-13.75 GHz band

Mission	ALT-G1	ALT-G3	ALT-G4	ALT-G5	ALT-G6 (Note 1)	ALT-G7 (Note 1)	ALT-G8
Sensor type	Altimeter	Altimeter	Altimeter	Altimeter	Altimeter	Altimeter	Altimeter
Type of orbit	SSO	SSO	NSS	NSS	SSO	NSS	Circular SSO
Altitude (km)	764	963	1 336	717	814	1 336	1000
Inclination (degrees)	98.6	99.3	66	92	98.65	66	99.4
Ascending node LST*	10:30	06:00	NA	NA	22:00	NA	–
Repeat period (days)	35	14	10	369[8]	27	10	14
Number of beams	1	1	1	1	1	1	1
Antenna diameter	1.2 m	1.4 m	1.2 m	2 reflectors 1.2 × 1.1 m	1.2 m	1.2 m	1.5 m
Antenna Pk Xmt gain (dBi)	41.2	43	43.2	42	42	42.1	42.2
Antenna Pk Rcv gain (dBi)	41.2	43	43.2	42	42	42.1	42.2

[8] 30 day subcycle.

TABLE 11A (*end*)

Mission	ALT-G1	ALT-G3	ALT-G4	ALT-G5	ALT-G6 (Note 1)	ALT-G7 (Note 1)	ALT-G8
Polarization	linear	VV	linear	linear	linear	linear	linear
Azimuth scan rate (rpm)	0	0	0	0	0	0	0
Antenna beam look angle (degrees)	0	0	0	0	0	0	0
Antenna beam azimuth angle (degrees)	0	0	0	0	0	0	0
Antenna elev. beamwidth (degrees)	1.2	0.9	1.27	1.2	1.27	1.35	1.5
Antenna az. beamwidth (degrees)	1.2	0.9	1.27	1.1	1.27	1.35	1.5
RF centre frequency (MHz)	13 575	13 580	13 575	13 575	13 575	13 575	13.575
RF bandwidth (MHz)	320, 80, 20	320	320	320	350	320	320
Transmit Pk pwr (W)	60	20	25	25	7.1	8	5.6
Transmit Ave. pwr (W)	2.16	8.2	5.41	2.22	0.66	<4	1.27
Pulsewidth (μs)	20	102.4	106.0	45	49	32	110.5
Pulse Repetition Frequency (PRF) (Hz)	1 795.33	2 000	2 060	1 970 (LRM) 1818.1 (SAR mode)	1 924 (LRM) 1782.5 (SAR mode)	2 060- 9 280	2 060
Chirp rate (MHz/μs)	16, 4, 1	3.12	3.02	7.11	7.14	9.69	2.9
Transmit duty cycle (%)	3.6	40.96	21.63	8.88	1.35-2.65, 9.31	30	22.7
e.i.r.p. ave (dBW)	44.5	52.1	49.33	45.5	40.2	48.02	43.2
e.i.r.p. peak (dBW)	59.0	56.0	56	60.0	50.5	51.03	49.7
System noise figure (dB)	2.5, 3.0	2.8	2.6	1.9[9]	3.1	2.5	5.75

NOTE 1 – ALT-G5 and ALT-G6 are dual frequency radar altimeters (C/Ku Band) which performs measurements either in low resolution mode (LRM) or synthetic aperture radar mode (Nadir-SAR). LRM mode is the conventional altimeter pulse limited mode with interleaved C/Ku Band pulses, while Nadir-SAR mode is the high along track resolution mode based on SAR processing. The ALT-G6 system is in preparation and will be a two-satellite constellation with two satellites in the same orbit with 180 deg. phase difference.

9 Receiver Noise figure.

TABLE 11B

Characteristics of scatterometers in the 13.25-13.75 GHz band

Mission	SCAT-G1	SCAT-G2	SCAT-G3	SCAT-G4
Sensor type	Scatterometer	Scatterometer	Scatterometer	Scatterometer
Type of orbit	SSO	SSO	SSO	SSO
Altitude (km)	803	963	720	836
Inclination (degrees)	98.6	99.3	98.28	98.75
Ascending Node LST	06:00	06:00	12:00 (desc node)	06:00
Repeat period (days)	4	14	2	5.5
Number of beams	2	2	2	4
Antenna diameter	1 m	1.3 m	1 m	3 m
Antenna Pk Xmt gain (dBi)	41	42	39.5	48
Antenna Pk Rcv gain (dBi)	41	42	39.5	48
Polarization	H (inner), V (outer)	HH, VV	HH, VV	HH, VV
Azimuth scan rate (rpm)	18	19.0	21.14	15
Antenna beam look angle (degrees)	40, 46	35, 41	43.63 (HH), 49.09 (VV)	36, 40
Antenna beam azimuth angle (degrees)	0-360	0-360	0-360	0-360
Antenna elev. beamwidth (degrees)	1.6	1	1.67	0.9
Antenna az. beamwidth (degrees)	1.6	1	1.47	0.3
RF centre frequency (MHz)	13 402	13 255.5	13 515	13 350
RF bandwidth (MHz)	0.53	3-6	0.4	2
Transmit Pk pwr (W)	100	120	100	1 000
Transmit Ave. pwr (W)	30.6	28.8	27	450
e.i.r.p. peak (dBW)	61.0	62.8	20	78.0
Pulsewidth (μs)	1 700	650-1 200	1 350	1 500
Pulse repetition frequency (PRF) (Hz)	180	100-200	200	300
Chirp rate (MHz/μs)	0.000311765	0.005	0.0003	0.0013
Transmit duty cycle (%)	30.6	24	27.0	45
e.i.r.p. ave (dBW)	55.9	56.6	53.8	74.5
e.i.r.p. peak (dBW)	61.0	62.8	59.5	78.0
System noise figure (dB)	3.4	4.2	3.0	3.5

TABLE 11C

Characteristics of precipitation radars in the 13.25-13.75 GHz band

Mission	PR-G1	PR-G2	PR-G3
Sensor type	Precip. Radar	Precip. Radar	Precip. Radar
Type of orbit	NSS	NSS	NSS
Altitude (km)	410	407	400
Inclination (degrees)	50	65	50
Repeat period (days)	11	82	6
Number of beams	2	1	4
Antenna diameter	2 m	2.1 × 2.1 m	5.3 m
Antenna Pk (Xmt & Rcv) gain (dBi)	47	47.4	55
Polarization	HH	H	HH,HV
Azimuth scan rate, sec per scan	0.7 s/scan	0.7 s/scan	0.42 s/scan
Antenna beam look angle (degrees)	±20	±17	±31
Antenna beam azimuth angle (degrees)	±90	±90	±90
Antenna elev. beamwidth (degrees)	0.7	0.7	0.28
Antenna az. beamwidth (degrees)	0.7	0.7	0.28
RF centre frequency (MHz)	13 647, 13 653	13 597, 13 603	13 626, 13 642, 13 658, 13 674
Number of beams	2	49	4
RF bandwidth (MHz)	0.6 × 2	0.6 + 0.6	8 × 4
Transmit Pk pwr (W)	1 000	1 000	2 000
Transmit Ave. pwr (W)	7.2	12.1	360
Pulsewidth (μs)	1.6	1.6	40
Pulse repetition frequency (PRF) (Hz)	4 500	4 485	4 500
Chirp rate (MHz/μs)	NA*	NA*	0.2
Transmit duty cycle (%)	0.72	1.21/0.67	18
e.i.r.p. ave (dBW)	55.6	55.7	80.6
e.i.r.p. peak (dBW)	77.0	77.4	88.0
System noise figure (dB)	5	5.1	3.5

* Unmodulated pulse.

7.8 Typical parameters of active sensors operating in the 17.2-17.3 GHz band

Typical characteristics of 17.25 GHz SAR radars are shown in Table 12.

TABLE 12

Characteristics of EESS (active) missions in the 17.2-17.3 GHz band

Parameter	SAR-H1
Sensor type	SAR
Type of orbit	Circular SSO
Altitude (km)	512
Inclination (degrees)	97.9
Ascending node LST	06:00
Repeat period (days)	5
Antenna type	Offset linear array fed reflector
Number of beams	1
Antenna (Transmit & Receive) peak gain (dBi)	49
Polarization	Linear VV, VH
Azimuth scan rate (rpm)	0
Antenna beam look angle (degrees)	30-40
Antenna beam azimuth angle (degrees)	90
Antenna elev. beamwidth (degrees)	0.9
Antenna az. beamwidth (degrees)	0.3
RF centre frequency (MHz)	17 250
RF bandwidth (MHz)	10
Transmit Pk pwr (W)	4 000
Transmit Ave. pwr (W)	360
Pulsewidth (µs)	20-30
Pulse repetition frequency (PRF) (µs)	1 000-3 000
Chirp rate (MHz/µs)	0.5-0.67
Transmit duty cycle (%)	2-9
System noise figure (dB)	5

7.9 Typical parameters of active sensors operating in the 24.05-24.25 GHz band

The typical characteristics of spaceborne radars operating in the 24.05–24.25 GHz band are shown in Table 13 with typical parameter values including the characteristics of the example radar. The spectrum is intended for use by precipitation radars and scatterometers.

TABLE 13

Characteristics of EESS (active) missions in the 24.05-24.25 GHz band

Parameter	SCAT-I1	PR-I1
Sensor type	Scatterometer	Precip. Radar
Type of orbit	Circular, NSS	Circular, NSS
Altitude (km)	803	350
Inclination (degrees)	98.6	35
Repeat period (days)	4	46
Antenna type	0.56 m dia offset reflector	1.18 m Slotted waveguide array
Number of beams	2	1
Antenna (Transmit & Receive) peak gain, (dBi)	41	47.4
Polarization	H (inner), V (outer)	H
Azimuth scan rate, rpm or sec/scan	18	0.6 s/scan
Antenna beam look angle (degrees)	40, 46	±17
Antenna beam azimuth angle (degrees)	0-360	±90
Antenna elev. beamwidth (degrees)	1.6	0.71
Antenna az. beamwidth (degrees)	1.6	0.71
RF centre frequency (MHz)	24 150	24 150
RF bandwidth (MHz)	0.53	0.6
Transmit Pk pwr (W)	100	578
Transmit Ave. pwr (W)	30.6	2.57
Pulsewidth (µs)	1700	1.6
Pulse repetition frequency (PRF), (Hz)	180	2776
Chirp rate (MHz/µs)	0.0003118	NA
Transmit duty cycle (%)	30.6	0.44
System noise figure (dB)	5	7

7.10 Typical parameters of active sensors operating in the 35.5-36.0 GHz band

Typical characteristics of SAR, radar altimeters and precipitation radars operating in 35.5-36.0 GHz are shown in Table 14.

TABLE 14

Characteristics of EESS (active) missions in the 35.5-36 GHz band

Parameter	ALT-J1	ALT-J2 (Note 1)	SAR-J1 (Note 2)	PR-J1	PR-J2	PR-J3	PR-J4
Sensor type	Altimeter	Altimeter	SAR	Precip. Radar	Precip. Radar	Precip. Radar	Precip. Radar
Type of orbit	SSO	NSS	SSO	SSO	NSS	NSS	NSS
Altitude (km)	800	970	780	650	407	410	600[1]
Inclination (degrees)	98.53	78	98.6	98.2	65	50	50
Ascending node LST*	18:00	NA	18:00	13:00	NA	NA	NA
Repeat period (days)	35	22	11	53	82	11	6
Antenna size/diameter	1.0 m	3.8 m × 4.17 m	3 m × 0.6 m (xmt), 3 m × 2 m (rcv)	2.5 m × 5 m	0.8 × 0.81.6 m	1.2 m	2.1 m
Antenna Pk Xmt gain (dBi)	49.3	61.5	49.5	60.4	47.4	47	55
Antenna Pk Rcv gain (dBi)	49.3	61.5	55.0	60.4	47.4	47	55
Polarization	circular	H, V	H,V	H,V	H	HH	HH, HV
Azimuth scan rate (rpm)	0	0	0	0	0.7 s/scan[10]	0.7 s/scan	0.42 s/scan
Antenna beam look angle (degrees)	0	0	30	±2.4	±17	±20	±31
Antenna beam azimuth angle (degrees)	0	0	90	90	90	±90	±90
Antenna elev. beamwidth (degrees)	0.6	0.13	2.9	0.2	0.7	0.7	0.28
Antenna az. beamwidth (degrees)	0.6	0.13	0.16	0.1	0.7	0.7	0.25
RF centre frequency (MHz)	35 750	35 600	35 750	35 600	35 547, 35 553	35 547, 35 553	35 526, 35 542, 35 558, 35 574
RF bandwidth (MHz)	480	200	40	2.5	0.6+0.6, 0.3+0.3	0.6 × 2	8 × 4
Transmit Pk pwr (W)	2	1 500	3 000	1 500	140	150	300
Transmit Ave. pwr (W)	0.856	33.66	300	19.3	2.56	27	54
Pulsewidth (µs)	107	5.1	36.1	1.67	1.6, 3.2	1.6/10/20 /40	40
Pulse repetition frequency (PRF) max (Hz)	4 000	4 400	2 770	7 700	4 485	4 500	4 500
Chirp rate (MHz/µs)	4.49	39.22	1.108	1.54	NA*	0.015-0.375	0.2
Transmit duty cycle (%)	42.8	2.24	10.0	1.28	1.83	0.7-18	18
e.i.r.p. ave (dBW)	48.6	76.8	84.3	73.3	47.1	61.4	72.4
e.i.r.p. peak (dBW)	52.3	93.3	74.3	92.2	68.9	68.8	79.8
System noise figure (dB)	3.9	4	4.5	4	6.3	6	3.5

* Unmodulated pulse.

10 The azimuth scan rate in seconds per scan is the time needed to scan from side to side (across-track) during one cycle.

Notes to Table 14:

NOTE 1 – This altimeter system is a Radar Interferometer instrument containing two Ka-band SAR antennas at opposite ends of a 10-meter boom with both antennas transmitting and receiving the emitted radar pulses along both sides of the orbital track. Look angles are limited to less than 4.5 degrees providing a 120-km wide swath. The 200-MHz bandwidth achieves cross-track ground resolutions varying from about 10 m in the far swath to about 60 m in the near swath. A resolution of about 2 meters in the along track direction is derived by means of synthetic aperture processing.

NOTE 2 – Ka-Band SAR mission for single pass interferometry still in conceptual phase. Under consideration a single satellite with multiple antennas or two satellites in formation.

7.11 Typical parameters of active sensors operating in the 78-79 GHz band

The typical characteristics of spaceborne radars operating in the 78-79 GHz band are shown in Table 15 with typical parameter values including the characteristics of the example radar.

TABLE 15

Typical characteristics of EESS (active) missions in the 78-79 GHz band

Parameter	PR-K1
Sensor type	Precip. Radar
Type of orbit	Circular, NSS
Altitude (km)	400
Inclination (degrees)	60
Repeat period (days)	23
Antenna type	Parabolic reflector
Antenna (Transmit & Receive) peak gain (dBi)	61.7
Polarization	Linear H
Azimuth scan rate (rpm)	0.197
Antenna beam look angle (degrees)	0
Antenna beam azimuth angle (degrees)	±17
Antenna elev. beamwidth (degrees)	0.71
Antenna az. beamwidth (degrees)	0.71
RF centre frequency (MHz)	78.500
RF bandwidth (MHz)	0.8
Transmit Pk pwr (W)	1 000
Transmit Ave. pwr (W)	14
Pulsewidth (μsec)	3.33
Pulse Repetition Frequency (PRF), (Hz)	4 250
Chirp rate (MHz/μs)	N/A
Transmit duty cycle (%)	1.42
System noise figure (dB)	3

7.12 Typical parameters of active sensors operating in the 94-94.1 GHz band

Table 16 shows typical characteristics of the CPR operating in the 94–94.1 GHz band

TABLE 16

Characteristics of EESS (active) missions in the 94-94.1 GHz band

Parameter	CPR-L1	CPR-L2
Sensor type	Cloud profiling radar	Cloud profiling radar
Type of orbit	SSO	SSO
Altitude (km)	705	393
Inclination (degrees)	98.2	97
Ascending Node LST	13:30	10:30[11]
Repeat period (days)	16	25
Antenna type	Parabolic reflector to offset cassegrain antenna	Parabolic reflector
Antenna diameter	1.85-2.5 m	2.5 m
Antenna (transmit and receive) peak gain (dBi)	63.1-65.2	65.2
Polarization	linear	LHC, RHC
Incidence angle at Earth (degrees)	0	0
Azimuth scan rate (rpm)	0	0
Antenna beam look angle (degrees)	0	0
Antenna beam azimuth angle (degrees)	0	0
Antenna elev. beamwidth (degrees)	0.12	0.095
Antenna az. beamwidth (degrees)	0.12	0.095
Beam width (degrees)	0.095-0.108	0.095
RF centre frequency (MHz)	94.050	94.050
RF bandwidth (MHz)	0.36	7
Transmit Pk pwr (W)	1 000	1 430
Transmit Ave. pwr (W)	21.31	28.8
Pulsewidth (μs)	3.33	3.3
Pulse repetition frequency (PRF) (Hz)	4 300	6 100-7 500
Chirp rate (MHz/μs)	N/A[12]	2.1
Transmit duty cycle (%)	1.33	2.01
Minimum sensitivity (dBz)	−30 to −35	−30 to −35
Horizontal resolution	0.7-1.9 km	800 m
Vertical resolution	250-500 m	500 m
Doppler range	±10 m/s	±10 m/s
Doppler accuracy	1 m/s	1 m/s
System noise figure (dB)	7	7

[11] Descending.

[12] The sensor uses an unmodulated pulse.

7.13 Typical parameters of active sensors operating in the 133.5-134 GHz band

Table 17 shows typical characteristics of a CPR with a centre frequency of 133.75 GHz. Very high frequencies are needed for sensitivity to small ice particles.

TABLE 17

Characteristics of EESS (active) missions in the 133.5-134 GHz band

Parameter	CPR-M1
Sensor type	Cloud profiling radar
Type of orbit	SSO
Altitude (km)	705
Inclination (degrees)	98.2
Ascending node LST	13:30
Repeat period (days)	16
Antenna diameter (m)	3
Antenna (transmit and receive) peak gain (dBi)	75
Polarization	linear
Azimuth scan rate (rpm)	0
Antenna beam look angle (degrees)	0
Antenna beam azimuth angle (degrees)	0
Antenna elev. beamwidth (degrees)	0.043
Antenna az. beamwidth (degrees)	0.043
RF centre frequency (GHz)	133.75
RF bandwidth (MHz)	0.65
Transmit Pk power (W)	300
Pulsewidth (μs)	1.6
Pulse repetition frequency (PRF), (Hz)	4 000
Range resolution	250 m
Horizontal resolution	0.2 × 0.7 km
System noise figure (dB)	8

7.14 Typical parameters of active sensors operating in the 237.9-238 GHz band

Table 18 shows typical characteristics of a CPR with a centre frequency of 237.95 GHz. Very high frequencies are needed for sensitivity to small ice particles.

TABLE 18

Characteristics of EESS (active) missions in the 237.9-238 GHz band

Parameter	CPR-N1
Sensor type	Cloud profiling radar
Type of orbit	SSO
Altitude (km)	705
Orbital inclination (degrees)	98.2
Ascending node LST	13:30
Repeat period (days)	16
Antenna diameter	3 m
Antenna (Transmit & Receive) peak gain (dBi)	78
Polarization	Linear
Azimuth scan rate (rpm)	0
Antenna beam look angle (degrees)	0
Antenna beam azimuth angle (degrees)	0
Antenna elev. beamwidth (degrees)	0.024
Antenna az. beamwidth (degrees)	0.024
RF centre frequency (GHz)	237.95
RF bandwidth (MHz)	0.65
Transmit Pk power (W)	80
Pulsewidth (μs)	1.6
Pulse repetition frequency (PRF) (Hz)	4 000
Range resolution	250 m
Horizontal resolution	0.1 × 0.7 km
System noise figure (dB)	11