

RECOMMENDATION ITU-R RS.1166-4

Performance and interference criteria* for active spaceborne sensors

(1995-1998-1999-2006-2009)

Scope

This Recommendation reflects the performance and interference criteria for spaceborne active sensors in the bands allocated to the EESS (active). The Annex presents the technical bases for development of performance and interference criteria for various types of spaceborne active sensors. The sensor types include altimeters, scatterometers, precipitation radars, synthetic aperture radars and cloud profile radars.

The ITU Radiocommunication Assembly,

considering

- a) that spaceborne active microwave remote sensing requires specific frequency ranges depending on the physical phenomena to be observed;
- b) that certain frequency bands have been allocated for spaceborne active microwave remote sensing;
- c) that these bands are also allocated to other radio services;
- d) that studies have established measurement sensitivity requirements;
- e) that performance requirements for active sensors can be stated in terms of precision of measurement of physical parameters and availability, measured at the satellite, assuming that degradation from other elements in the system will be small;
- f) that performance objectives for active spaceborne microwave sensors are a prerequisite for the establishment of the associated interference criteria;
- g) that interference criteria are needed to ensure that systems can be designed to achieve adequate performance in the presence of interference, assess compatibility with systems in other services and, if needed, to assist in developing sharing criteria;
- h) that Annex 1 presents the technical bases for performance and interference criteria based on representative active sensors,

* Interference criteria do not imply automatically sharing criteria.

recommends

1 that the performance criteria given in Table 1 should be applied to instruments used in active sensing of the Earth's land, oceans and atmosphere:

TABLE 1

Frequency band	Performance criteria for remote sensing instruments				
	Scatterometer	Altimeter	SAR imager	Precipitation radar	Cloud profile radars
432-438 MHz			Minimum reflectivity of -21 dB		
1 215-1 300 MHz			Minimum reflectivity of -32 dB		
3 100-3 300 MHz		Sea level precision ≤ 3 cm	Minimum reflectivity of -26 dB		
5 250-5 570 MHz	Wind speed ≥ 3 m/s	Sea level precision ≤ 3 cm	Minimum reflectivity of -24 dB		
8 550-8 650 MHz	Wind speed ≥ 3 m/s	Sea level precision ≤ 3 cm	Minimum reflectivity of -21 dB		
9 300-9 900 MHz ⁽¹⁾	Wind speed ≥ 3 m/s	Sea level precision ≤ 3 cm	Minimum reflectivity of -18 dB		
13.25-13.75 GHz	Wind speed ≥ 3 m/s	Sea level precision ≤ 3 cm		Minimum rain rates from 0.7-0.75 mm/h	
17.2-17.3 GHz	Wind speed ≥ 3 m/s			Minimum rain rates from 0.7-0.75 mm/h	
24.05-24.25 GHz				Minimum rain rates from 0.7-0.75 mm/h	
35.5-36 GHz	Wind speed ≥ 3 m/s	Sea level precision ≤ 3 cm		Minimum rain rates from 0.1-0.2 mm/h	-17 dBZ $\pm 10\%$
78-79 GHz					-27 dBZ $\pm 10\%$
94-94.1 GHz					-30 dBZ $\pm 10\%$
133.5-134 GHz					-34 dBZ $\pm 10\%$
237.9-238 GHz					-44 dBZ $\pm 10\%$

dBZ: "Unit" radar reflectivity used in meteorology which represents a logarithmic power ratio (in decibels, or dB) with respect to radar reflectivity factor, Z, referred to a value of 1 mm⁶/m³.

SAR: Synthetic aperture radar.

⁽¹⁾ See the relevant decisions of WRC-07.

2 that the interference and data availability criteria given in Table 2 be applied for instruments used for active sensing of the Earth's land, oceans and atmosphere.

TABLE 2

Sensor type	Interference criteria		Data availability criteria (%)	
	Performance degradation	I/N (dB)	Systematic	Random
Synthetic aperture radar	10% degradation of standard deviation of pixel power	−6	99	95
Altimeter	4% degradation in height noise	−3	99	95
Scatterometer	8% degradation in measurement of normalized radar backscatter to deduce wind speeds	−5	99	95
Precipitation radar	7% increase in minimum rainfall rate	−10	N/A	99.8
Cloud profile radar	10% degradation in minimum cloud reflectivity	−10	99	95

For bands with secondary allocation, the interference criteria are provided only to indicate performance degradation with regard to primary services.

Annex 1

Performance and interference criteria for spaceborne active sensors

1 Introduction

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 radionavigation and radiolocation systems and active sensors in common frequency bands.

This Annex presents the technical basis for development of performance and interference criteria for various types of spaceborne active sensors. The sensor types include altimeters, scatterometers, precipitation radars, synthetic aperture radars, and cloud profile radars.

Although the criteria are based on current and planned space science system designs and associated operating requirements, it is anticipated that future space science systems can be designed to accept at least the same levels of interfering signals and associated spatial and temporal conditions.

2 Altimeters

This section presents information on the performance and interference criteria for spaceborne altimeters in the frequency bands 3.1-3.3 GHz, 5.25-5.57 GHz, 8.55-8.65 GHz, 9.5-9.8 GHz, 13.25-13.75 GHz and 35.5-35.6 GHz.

2.1 Performance criteria

Spaceborne altimeters produce, after data processing, measurement of sea level with a precision of less than 3 cm. The noise level in height measurements from altimeters is around 2-2.4 cm for low sea-states. An increase of 0.1 cm in the height noise due to interference would not materially affect the data and would be acceptable. In other words, a 4% degradation in height noise would be consistent with mission objectives.

A requirement for altimeter missions is acquisition of 90% of all possible data over oceans. The design goal is higher than the minimum requirement and has been established as 95% of all possible data. Observations must be taken as close to the land-sea interface as possible (below 15 km from the land-sea interface, altimeter waveform distortions occur and prevent accurate height estimation). The budget for lost data must accommodate all sources of loss including those due to spacecraft systems, the altimeter instrument, manoeuvres, etc.

The availability requirement for altimetry data is 95%, assuming that the associated individual outages are brief and randomly dispersed over all observation time and areas (i.e. most outages lasting 2 s or less).

The impact of interference that is always present at a given geographical location is much more serious than that of random interference, because measurements can never be obtained from those geographical areas. In that event the requirement for altimeters is to obtain valid data for 99% of all geographical areas of interest.

2.2 Interference criteria

Typical altimeters have link budgets that result in S/N of 13 dB (except for 35.5-36 GHz altimeters) in the receiver range resolution bandwidth of 39.9 dB/Hz. The altimeter height noise varies as $1 + 2/(S/N)$. For a return signal having a S/N of 13 dB before interference, the addition of interference causes the following increase in height measurement noise:

Interference level	S/N (dB)		Degradation (%)	
	Non-white interference	White interference	Non-white interference	White interference
None	13	13	Baseline	Baseline
10 dB below noise	12.6	12.99	1	0.05
3 dB below noise	11.25	12.5	4.5	1
Equal to noise	10	11.5	9	3.8
10 dB above noise	2.6	3	91	82

For 35.5-36 GHz altimeters, atmospheric effects and technological constraints result in a less favourable link budget (S/N close to 10 dB) and so the sensitivity to interference level is higher, the following values have to be taken into account:

Interference level	S/N (dB)		Degradation (%)	
	Non-white interference	White interference	Non-white interference	White interference
None	10	10	Baseline	Baseline
10 dB below noise	9.6	9.98	1.7	0.08
6 dB below noise	9.0	9.9	4.2	0.5
3 dB below noise	8.2	9.5	8.4	1.2
1.5 dB below noise	7.7	9.1	11.8	3.8
Equal to noise	7.0	8.5	17	6.9
10 dB above noise	-0.4	0	167	150

Degradation of height measurement noise in excess of 4% will not allow mission requirements to be met. To allow for non-Gaussian interference, the threshold for interference is set at 3 dB below the noise floor. As can be seen, the performance degradation increases sharply for interference levels above the noise floor.

The criterion for harmful interference to altimeters is, therefore, an aggregate interfering signal power level of -117 dB(W/320 MHz) at 13-14 GHz and a level of -119 dB(W/450 MHz) at 35.5-36.0 GHz which would cause an unacceptable increase in the height measurement noise.

In shared frequency bands, availability of altimeter data shall exceed 95% of all locations in the sensor service area in the case where the loss occurs randomly and shall exceed 99% of all locations in the case where the loss occurs systematically at the same locations.

3 Scatterometers

This section presents information on performance and interference criteria for spaceborne scatterometers in the frequency bands 5.25-5.57 GHz, 8.55-8.65 GHz, 9.5-9.8 GHz, 13.25-13.75 GHz, 17.2-17.3 GHz and 35.5-36.0 GHz. It provides performance and interference criteria for active spaceborne scatterometers that can be used to analyse the compatibility of active spaceborne scatterometers and radionavigation and radiolocation systems in these bands.

Unwanted radio frequency emissions reaching the scatterometer's receiver can corrupt the radar's scatterometer measurement of σ_0 , where σ_0 is the normalized radar backscatter coefficient. The amount of degradation will depend on the statistics of the external interference.

3.1 Performance criteria

In scatterometer systems, an estimate of the echo return signal power is made by first measuring the "signal + noise" power (i.e. the echo return plus the system noise contribution), and then subtracting the "noise-only" power (an estimate of the system noise alone, or "noise floor"). The system noise includes thermal emissions from the Earth, as well as those introduced by the antenna, waveguides, and the receiver noise figure. To optimize system performance, the "signal + noise" and the "noise-only" measurements are made over different bandwidths and/or at different times. This strategy

relies on the fact that the nominal system noise is inherently white during the measurement sequence (stationary, and with a flat spectral power distribution).

If external interference is present, the new composite background noise is the sum of the interference and the nominal system noise. Depending on the strength, modulation, antenna gain pattern, and geometry of the interfering source, the composite noise may not be white over the measurement sequence. The “noise-only” measurement will then not correspond to the noise of the “signal + noise” measurement and errors in the estimation of σ_0 will result.

The estimated σ_0 error that results from a given “noise-only” measurement error can be quantified with the following equation:

$$\sigma_0 \text{ Error (dB)} = 10 \log [1 + (\alpha - 1) / \text{SNR } \sigma_0] \quad (1)$$

where:

$\text{SNR } \sigma_0 \text{ (dB)} = 10 \log (S/N)$ = signal-to-noise ratio of the σ_0 estimation process

with:

S : echo return power spectral density

N : nominal noise floor power spectral density (approximately -200 dB(W/Hz) at the scatterometer receiver input for both “fan beam” and “spot beam” antennas)

and

$$\alpha \text{ (dB)} = 10 \log ([N + (I_{s+n} / B_{s+n})] / [N + (I_n / B_n)]) \quad (2)$$

with:

I_{s+n} : average power from interfering source in B_{s+n} during the “signal + noise” measurement period

B_{s+n} : “signal + noise” measurement bandwidth

I_n : average power from interfering source in B_n during the “noise-only” measurement period

B_n : “noise-only” measurement bandwidth.

The impact of external interference is most severe for winds with low speed. The lowest wind speed to be measured by spaceborne scatterometers is 3 m/s. Results of computer simulations conducted for non-stationary interference to the NSCAT scatterometer have shown that a maximum value of α (see equation (2)) that will allow performance requirements to be met for 3 m/s wind speeds is 0.7 dB.

Scatterometers in the future may employ spot beam antennas rather than fan beam antennas as are used for NSCAT. The main differences, besides the antenna pattern, between the two types of scatterometers are the transmitted e.i.r.p. and receive antenna gain. Results of computer simulations conducted for non-stationary interference have shown that a maximum value of $\alpha = 6 \text{ dB}$ (see equation (2)) can be tolerated with the “spot beam” antenna and still meet the performance requirements for 3 m/s wind speeds.

The allowable loss of scatterometer data due to interference from radio frequency stations randomly distributed across the oceans is 5% of the data taken over the global oceans. The allowable loss for systematic interference is 1%. Systematic interference is defined as the loss of coverage at the same points on the oceans for most passes over those points. These maximum allowable losses have been derived from the NSCAT science requirement for measuring 90% of global vector winds over the oceans and taking into consideration other randomly distributed data losses introduced mainly in areas with intense rainfall.