

RECOMMENDATION ITU-R SA.1166-1

**PERFORMANCE AND INTERFERENCE CRITERIA FOR
ACTIVE SPACEBORNE SENSORS**

(Question ITU-R 140/7)

(1995-1997)

The ITU Radiocommunication Assembly,

considering

- a) that certain frequency bands have been allocated for spaceborne active microwave remote sensing;
- b) that these bands are also allocated to other radio services;
- c) that performance criteria are a necessary prerequisite to the establishment of interference and sharing criteria;
- 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 criteria for sharing frequency bands among services;
- h) that Annex 1 presents the technical bases for performance and interference criteria based on representative active sensors,

recommends

1 that the performance criteria suitable for active sensing of the Earth's land, oceans and atmosphere are as follows:

1.1 400-500 MHz

1.1.1 Synthetic aperture radars (SARs)

- The performance criterion for SARs is to collect SAR imagery with a minimum reflectivity of –39 dB.

1.2 13-14 GHz

1.2.1 Altimeters

- The performance criterion for altimeters is to measure the sea level with a precision of at least 3 cm.
- An increase in height noise of 0.1 cm, corresponding to 4% degradation in height noise in the presence of a systematic height noise of 2-2.4 cm, would be consistent with mission objectives.

1.2.2 Scatterometers

- The performance criterion for scatterometers is measurement of wind speeds equal to or greater than 3 m/s.

1.2.3 Precipitation radars

- The science requirement for precipitation radars is to achieve, after data processing, measurement of rain rates equal to or greater than 0.7 mm/h.
- An increase in measurable rain rate to 0.75 mm/h would not materially affect the data and would be acceptable as a performance criterion.

1.3 92-95 GHz

1.3.1 Cloud profiling radars

- The performance criterion for cloud profiling radars is to measure the reflectivity profile for all clouds within the field of view with a minimum reflectivity of -30 dBZ.
- A degradation of Z_{min} by less than 10% in the presence of interference would be consistent with mission objectives;

2 that the interference criteria suitable for active sensing of the Earth's land, oceans and atmosphere are as follows:

2.1 400-500 MHz

2.1.1 SARs

- The interfering signal power should not exceed -138 dBW (corresponding to an interference to noise ratio of -6 dB) in a reference bandwidth of 10 MHz for more than 1% of the images in the sensor service area. This interference level may be exceeded upon consideration of the interference mitigation effect of SAR processing discrimination and the modulation characteristics of the radiolocation/radionavigation systems operating in the band.

2.2 Near 5.3 GHz and 13-14 GHz

2.2.1 Altimeters

- To prevent an unacceptable increase in the height measurement noise, the criterion for harmful interference to altimeters is an aggregate interfering signal power level of -119 dB(W/320 MHz) into the 13-14 GHz altimeter receiver and a level of -123 dB(W/100 MHz) in the altimeter receiver operating near 5.3 GHz.

2.2.2 Scatterometers

- For scatterometers with fan beam antennas, the maximum interference power spectral density that the scatterometer can sustain without degraded measurement accuracy is -174 dBW into the scatterometer receiver over any 2 kHz bandwidth within a 1 MHz processing channel bandwidth.
- For scatterometers with spot beam antennas, the maximum interference power spectral density that the scatterometer can sustain without degraded measurement accuracy is -155 dBW into the scatterometer receiver over any 10 kHz bandwidth within an overall 1 MHz processing channel bandwidth.

2.2.3 Precipitation radars

- The criterion for harmful interference to precipitation radars is an aggregate interference signal power level of -150 dB(W/600 kHz) into the precipitation radar receiver which corresponds to a degradation in the system noise level of 10% due to noise-like interference.

2.3 92-95 GHz

2.3.1 Cloud profiling radars

- The criterion for harmful interference to cloud profiling radars is an aggregate interference signal power level of -155 dB(W/300 kHz) into the cloud profiling radar receiver which corresponds to a degradation in the system noise level of 10% due to noise-like interference.

3 that in shared frequency bands, availability of active sensor data as enumerated above should:

- for altimeters and scatterometers, exceed 95% of all locations in the sensor service area in the case where the loss occurs randomly and exceed 99% of all locations of interest in the case where the loss occurs systematically at the same locations;
- for precipitation radars, exceed 99.8% at all locations in the sensor service area.

4 that the performance and interference criteria for active sensing of the Earth's land, ocean, and atmosphere by SAR near 400 MHz, near 1.25 GHz, 5.3 GHz, at 8.6 GHz, and 9.6 GHz are as follows:

- that a degradation of the normalized standard deviation of power received from a pixel by less than 10% in the presence of interference would be consistent with mission objectives;

- that the criterion for harmful interference to SARs is that the aggregate interference power to noise power ratio should be less than -6 dB, which corresponds to an interference level of -138 dB(W/10 MHz) for a SAR operating near 400 MHz, for example. This level may be exceeded upon consideration of the interference mitigation effect of SAR processing discrimination and the modulation characteristics of the radiolocation/radionavigation systems operating in the band;
- that the maximum allowable interference level should not be exceeded for more than 1% of the images in the sensor service area.

ANNEX 1

Performance and interference criteria for active spaceborne sensors at 13-14 GHz

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 bases for development of performance and interference criteria for the types of active sensors that operate in the 13-14 GHz area of the spectrum. The sensor types include altimeters, scatterometers and precipitation 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

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 but no further than 30 km from land. 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 is 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 signal-to-noise ratios (S/N) of 13 dB 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

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) 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

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:

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

where:

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

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 $\alpha = 6$ 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 rain fall.

3.2 Interference criteria

Figure 1a is a plot of equation (2) for a scatterometer with a receiver noise floor of $N = -200$ dB(W/Hz). It shows α as a function of the power spectral density of the interfering signal (I_{s+n}/B_{s+n}). Note that different results for α will be obtained depending on how the interference is changing over time or over bandwidth. Figure 1a contains a family of plots for several values of the parameter $10 \log [(I_{s+n}/B_{s+n})/(I_n/B_n)]$.

The time separation of the “signal + noise” measurement period from the centre of the “noise-only” measuring period is approximately 0.23 s. During this time the angle from the spacecraft scatterometer to a specific point on the ground will change by approximately 0.1° . Due to the narrow beamwidth of the fan beam antenna (0.42° , 3 dB beamwidth), changes of several dB in received interference levels should be expected as the scatterometer side lobes move through a

transmitter beam. Engineering judgement has led to a value of 6 dB as the assumed maximum expected change in $10 \log [(I_{s+n}/B_{s+n})/(I_n/B_n)]$ during the measurement period. From Fig. 1a, it is therefore concluded that the maximum interference power spectral density that any one of the six fan beam antennas of the NSCAT scatterometer can sustain without degraded measurement accuracy is -207 dB(W/Hz) or -174 dBW over any 2 kHz bandwidth within the 1 MHz bandwidth of the processing channel.

For white-noise like interference, the maximum acceptable interference spectral power density would be approximately -194 dB(W/Hz) at the input of the receiver which translates to an interference criterion of -161 dBW over any 2 kHz bandwidth within the 1 MHz bandwidth of the processing channel.

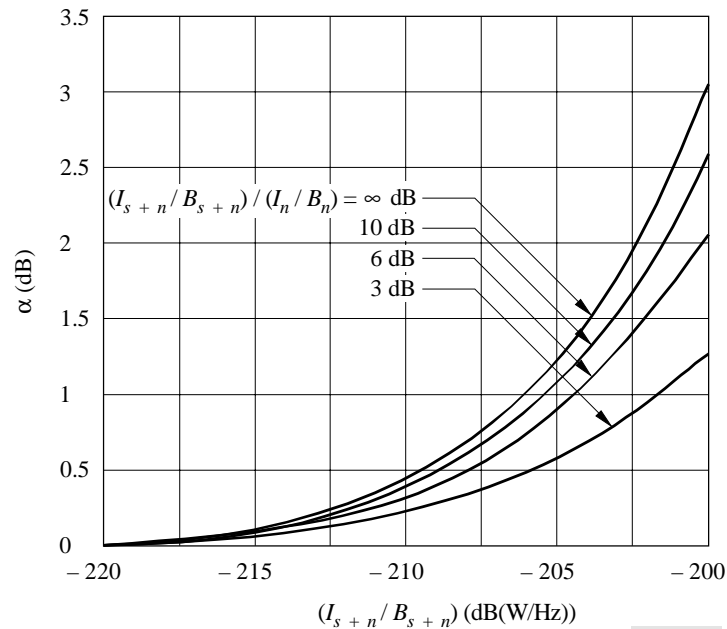
In the case of non-white noise, the interference criterion for a scatterometer which uses a spot beam antenna can be determined for the worst case assumption of $10 \log [(I_{s+n}/B_{s+n})/(I_n/B_n)] = \pm \infty$. This situation represents the case in which the interference is present for either the “signal + noise” or the “noise-only” measurement, but not for both simultaneously.

From Fig. 1b it is therefore concluded that the maximum interference power spectral density that the “spot beam” antenna of an NSCAT-like scatterometer can sustain without degradation in the measurement is -195 dB(W/Hz). This requirement must hold for any 10 kHz bandwidth within the overall 1 MHz processing channel.

For white-noise like interference, the maximum interference spectral power density would be approximately -185 dB(W/Hz) at the input of the receiver for a scatterometer with a “spot beam” antenna.

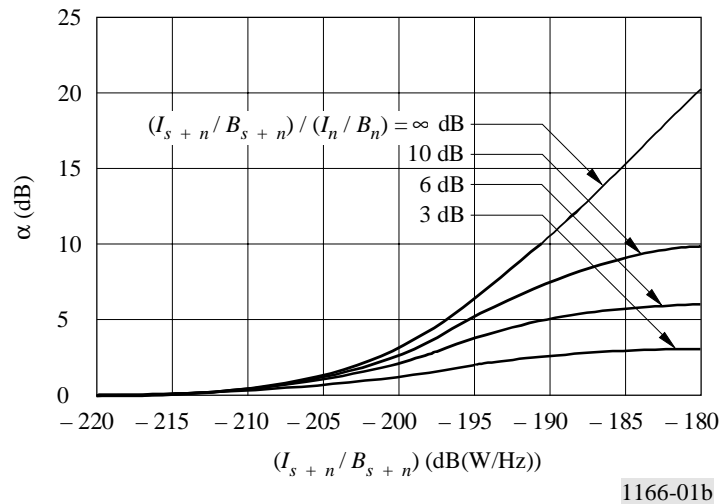
In shared frequency bands, availability of scatterometer data shall exceed 95% of all locations in the sensor service area in the case where the loss occurs randomly and shall exceed 99% of all locations in the case where the loss occurs systematically at the same locations.

FIGURE 1a



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FIGURE 1b



4 Precipitation radars

The first spaceborne precipitation radar will be the TRMM Precipitation Radar (PR) which is planned for launch in 1997.

Mission objectives and the design of the TRMM PR have been examined in order to develop performance and interference criteria that can subsequently be used to assess the compatibility of the PR and systems in the radionavigation and radiolocation services. Interference criteria are presented for both the level of interference that constitutes harmful interference and for the amount of data loss due to interference that are consistent with meeting mission objectives.

4.1 Performance criteria

The science requirement for the TRMM PR is to achieve, after data processing, measurement of rain rates equal to or greater than rain rates of 0.7 mm/h. An increase in measurable rain rate to 0.75 mm/h would not materially affect the data and would be acceptable as a performance criterion.

TRMM will obtain rainfall measurements everywhere within latitudes between $\pm 35^\circ$ as determined by the inclination of its orbit. Obtaining all potential rain measurements is important, however, measurements in the Inter-Tropical Convergence Zone (ITCZ), which is an area bounded by the Earth's equator and 10° N latitude, and the wide belt area extending from the Maritime continent to the South Pacific (called Australian Monsoon Trough and South Pacific Convergence Zone or SPCZ) are of particular importance. These most important areas are generally bounded by latitudes of (0° - 10° N) and by (50° - 180° E and 0° - 10° S). Tropical rainfall is critical to distributing water across the Earth. Precipitation is greatest near the equator and more than two-thirds of it falls in the tropics. This precipitation releases energy that helps to power global atmospheric circulation, thus shaping both weather and climate. Tropical rainfall also plays a key role in the sporadic "El Niño" climate anomalies that trigger floods and draughts around the globe. Obtaining multi-year science data sets of tropical and subtropical rainfall measurements is key to understanding how interactions between the sea, air and land masses produce changes in global rainfall and climate. Such measurements can only be obtained by the use of satellites.

With the preceding background, the scientists on the TRMM project have determined that the needed availability of rainfall data is a function of where the rainfall occurs. The most critical area is in the ITCZ and in the vicinity of special "ground truth" sites that are being established in order to correlate the PR data with simultaneous terrestrial measurements. A criterion for loss of data in the ITCZ when interference occurs randomly is 0.2% of the possible data.

4.2 Interference criteria

An increase in rain rate measurement from 0.7 to 0.75 mm/h corresponds to a degradation in the system noise level of 10% due to noise-like interference. Therefore, the interference should be 10 dB below the system noise level. Since the system noise level is -140 dBW and the final bandwidth of the PR is 600 kHz, the criteria for the harmful interference level is -150 dB(W/600 kHz). Outside the 12 MHz band between 13.793 GHz and 13.805 GHz, the allowable interference level is much higher due to the band-pass filtering in the receiver; -115 dBW for 13.790-13.793 GHz and 13.805-13.808 GHz, -90 dBW for 13.75-13.79 GHz and 13.808-13.850 GHz, and -70 dBW for 13.85-13.86 GHz.

In shared frequency bands, availability of precipitation radar data shall exceed 99.8% of all locations in the sensor service area in the case where the loss occurs randomly.
