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Characterization and assessment of aggregate interference to the Earth exploration-satellite service (passive) sensor operations from multiple sources of man-made emissions

RS Series

Remote sensing systems

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

RECOMMENDATION ITU-R RS.1858

Characterization and assessment of aggregate interference to the Earth exploration-satellite service (passive) sensor operations from multiple sources of man-made emissions

(Question ITU-R 243/7)

(2010)

Scope

This Recommendation provides information on the characterization and assessment of aggregate interference to passive sensor operations from multiple sources of man-made emissions. First, various sources of interference are enumerated. Next, the statistical moments of the aggregate interference are determined. Finally, results of a dynamic simulation that validates the aggregation methodology are discussed.

The ITU Radiocommunication Assembly,

considering

a)   that 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);

b)   that the products of these passive sensor operations are essential to and used extensively in meteorology, climatology, and other disciplines for operational and scientific purposes;

c)   that passive sensors operating in the EESS (passive) are sensitive to any emissions within their allocated band;

d)   that any man-made emissions in bands allocated to the EESS (passive) may constitute degradation to the passive sensors using those bands and, subsequently, may impact their intended operations;

e)   that passive sensors may not be able to differentiate natural emissions from man-made emissions, and that man-made emission power may not be identifiable in the passive sensor products;

f)   that it is necessary to characterize the sources of degradation to passives sensors;

g)   that it is necessary to develop appropriate methodologies to assess the aggregate impact of interference on passive sensor operations,

noting

a)   that Recommendations ITU-R RS.515, ITU-R RS.1028 and ITU-R RS.1029 provide general EESS (passive) operational characteristics, performance and protection criteria;

b)   that Recommendation ITU-R SM.1633 considers the impact of man-made emissions to EESS (passive) in certain bands in the range 1.4 to 60 GHz resulting from certain active services in specific adjacent or nearby bands;

c)   that Recommendation ITU-R SM.1542 provides some information regarding techniques that the EESS (passive) sensors may employ to mitigate effects of unwanted emissions,

recommends

1   that the methodology in Annex 1 should be used to assess the aggregate interference to passive sensors caused by interference from multiple sources of man-made emissions.

Annex 1

Characterization of interference to EESS (passive) sensors from multiple sources of man-made emissions, and a methodology to assess the interference

1   Introduction

The EESS (passive) sensor is essentially a radiometer designed to measure natural emissions in a frequency range of interest. EESS (passive) sensors are vulnerable to emission power from terrestrial transmitters, including single high-power transmitters, and from the aggregate emissions of densely deployed low-power transmitters. Space-borne transmitters may add indirectly to the energy received by the sensor via reflections off the Earth into the sensor antenna, or directly through the main beam and side lobes of the antenna. Man-made emissions have various characteristics that differentiate them from natural microwave emissions. Though these characteristics are present in individual sources in varying degrees, the aggregate of a large number of sources may not possess characteristics that allow them to be distinguished from natural planetary emissions.

Parameters that are required to characterize the interference to EESS (passive) sensors include:
–   frequency range of EESS (passive) sensor operation;
–   power from all man-made emission sources toward the sensor;
–   receptivity of the EESS (passive) sensor operation to the man-made emission power present;
–   scattering from the Earth's surface, from atmospheric constituents, and from other objects; atmospheric absorption, and space loss.

In order to characterize the degradation to EESS (passive) sensor operations from all sources of man-made emissions it is necessary to:
–   establish a reference for measuring degradation to EESS (passive) sensor operations;
–   characterize the sources of man-made emissions according to their classification and emission characteristics;
–   assess the classification sources of man-made emissions regarding the significance of their impact on the operation of EESS (passive) sensors;
–   assess the degradation caused by each significant class of emission, and their aggregate effect on passive sensor operations.

2 Characterization of interference sources

An important characteristic of sources of man-made emissions with regard to EESS (passive) sensor data degradation is the amount and variability of power that those sources emit into the passband of the EESS (passive) sensor. The degradation of EESS (passive) sensor operation from man-made signals can be characterized by the aggregate of the sources of man-made emissions in relation to the receptivity of the EESS (passive) sensor to the emission power characteristics present. The receptivity of the passive sensor to man-made emission power is dependent on the operational parameters of the sensor in relation to the specific characteristics of the man-made emission power. The total *permissible* emission power at the sensor, given by the Recommendation ITU-R RS.1029, can be used as a reference for interference assessment.

Individual sources are characterized first in terms of their service classifications, and second by the types of emissions. Concerning service classification, the sources of all man-made emission power are subdivided into a set of distinctly defined groups:

– radiocommunication and radiodetermination services;

– other sources.

Radiocommunication and radiodetermination services are those enumerated in Article 1 of the Radio Regulations (RR). To facilitate analysis, the radiocommunication services are grouped under the following two headings:

1 terrestrial;

2 space.

While other sources of man-made emission are grouped under the following three headings:

1 short-range radiocommunication devices[1] (SRDs);

2 ISM[2] equipment;

3 electrical apparatus or installations[3].

Concerning types of emission, radiocommunication services and other sources are organized as defined by the RR:

1 power resulting from the emissions within the necessary bandwidth[4];

2 power resulting from the emissions from the out-of-band domain[5]; and

3 power resulting from the emission from the spurious domain[5].

Consideration should be given to the sensor operation in a purely passive band, the sensor operation in a mixed passive-active band, application of mitigation techniques, or other circumstances that are relevant to the assessment of the impact of man-made emissions on the sensor's operation. The purely passive bands are those listed in RR No. 5.340. Note, however, that some of the bands listed in RR No. 5.340 allow for specific active service notifications as indicated by the footnote. Therefore, care must be exercised to accurately reflect the conditions present for that specific sensor.

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[1] Recommendation ITU-R SM.1538-2.

[2] RR No. 1.15.

[3] RR No. 15.12.

[4] RR No. 1.152.

[5] Defined as provided in Recommendation ITU-R SM.1541-1.

3 Methodology for interference aggregation

In ITU-R studies involving multiple radiocommunication services that affect the EESS (passive), the following general principles apply:

– all relevant RR provisions and ITU-R Recommendations should be taken into account:

  a) all relevant criteria of the interference should be considered, particularly the differences between in-band and unwanted emissions of the affected radiocommunication services;

  b) the relative impact of each affected radiocommunication service, in relation to the other affected radiocommunication services on the passive service should be considered on a band-by-band basis;

– for the passive bands listed in RR No. 5.340, the provision states that "all emissions are prohibited".

The interference criteria from Recommendation ITU-R RS.1029 determines an interference threshold and a percentage of area or time for which the threshold should not be exceeded. This percentage is called the data availability criterion. Generally the first step in interference assessment is to calculate the aggregate interference within the sensor antenna footprint believed to produce the greatest amount of interference. This is commonly done by doing a worst-case static calculation. If this calculation results in an interference level that exceeds the permissible value, then dynamic simulations are conducted to determine whether the aggregate interference complies with the data availability criterion on a global or regional basis. However, not only are global or regional statistics of concern, but also statistics of the interference from the worst-case antenna footprint are of concern. For example, the emitters in that footprint may be operating intermittently, or the directions in which their antennas are pointing may be changing. Therefore, the interference power from the worst-case footprint will have a probability distribution, just as interference on a global or regional basis will have a probability distribution due to the geographical variation in emitter deployment. The main difference is that interference on a global basis would be analysed using dynamic simulation, while interference from a worst-case footprint could also be analysed using Monte Carlo methods in those cases where it may be difficult to accumulate sufficient data in a reasonable amount of time by using dynamic simulation.

These simulations, whether dynamic or Monte Carlo, are commonly conducted when there is only a single type of interfering service involved. The question is how to proceed when there are multiple interfering services, because it may not always be practical to incorporate all interfering services in a single simulation.

One way to proceed is to assume that the time-varying aggregate interference from any radiocommunication service consists of both long-term and short-term components. Short-term interference events from different services are generally not correlated and do not occur at the same time. Hence, short-term interference does not aggregate in power, but rather in time. On the other hand, long-term interference aggregates in power rather than in time. The problem with this approach is the fact that there is no long-term interference criterion that exists for passive sensing, so there is no way to decide whether the long-term component of the aggregate interference is excessive. Furthermore, as will be seen later, any given interference scenario generally exhibits both short-term and long-term components, which means that the interference aggregates both in power and in time.

Another way to proceed, which does not require a distinction between short-term and long-term interference, is to employ the method of statistical moments, which is the subject of the rest of this annex. To deal with the aggregate interference level within the sensor band, we can start with a statistical description of the interference from each service. The ultimate aim is to determine the aggregate interference level that is exceeded a small percentage of the time.

Let μ_k and σ_k^2 denote the mean (W) and the variance (W^2) of the interference level at the passive sensor from the k-th service. In a dynamic or Monte Carlo simulation, μ_k would be the sum of the interference levels obtained from a large number of samples of interference power at the input of the passive sensor, divided by the number of samples for the k-th service. σ_k^2 would be the sum of the squares of the deviations of the interference samples of interference power at the input of the passive sensor from μ_k, divided by the number of samples. Knowledge of the probability distribution for the interference from each individual service is not required.

Under the assumption that the interference contributions from the different active services are independent of one another, the moments of the aggregate distribution can be written:

$$\mu = \sum_{k=1}^{K}\mu_k \quad \text{and} \quad \sigma^2 = \sum_{k=1}^{K}\sigma_k^2 \tag{1}$$

where K is the number of interfering services. This is true regardless of the probability distribution for the interference from each individual service. In fact, if the interfering services are statistically independent, the means and variances of the interference levels are the only additive quantities that exist in a statistical sense. The moments themselves are not what are of ultimate interest. What is ultimately needed is the aggregate level P that is exceeded a small percentage of the time, for example 0.1 or 0.01%. The level exceeded a small percentage of the time is the mean level plus a certain number of standard deviations from the mean.

Therefore P can be written as $\mu + c\sigma$, where c is a constant that is determined by making use of all the statistical information derived from dynamic simulation of each service. For the k-th service, determine the moments and the cumulative distribution of the interference, and calculate

$$c_k = \frac{P_k - \mu_k}{\sigma_k} \tag{2}$$

where P_k is the interference level from the k-th service that is exceeded a small percentage of the time. Calculate c_k in this way for each service. A reasonable estimate of c for the aggregate distribution is a weighted average of each individual c_k:

$$c = \frac{\sum\limits_{k} P_k c_k}{\sum\limits_{k} P_k} \tag{3}$$

Therefore, the dominant interfering service, defined as the service having the largest value of P_k, has the greatest weight in determining c. The value of c from equation (3) can then be used to estimate the aggregate interference level exceeded a small percentage of the time.

When out-of-band interfering services are included in the aggregate, it is most convenient to base the calculated margin on the co-channel interference levels, and to consider the out-of-band suppression that already exists to be a part of any mitigation that might be provided by these services.

To make this methodology work in practice, currently-used dynamic or Monte Carlo simulation programs need to be modified so that they compute not only the cumulative distributions of the interference, but also the moments described above. If this is not done, calculation of the moments can become laborious. Of course, if simulations are conducted that already include all potential interfering services, the aggregate interference level exceeded a small percentage of the time can be determined directly without calculating statistical moments. This is true whether or not the interfering services are independent of one another.

4 An example that assumes normal composite statistics

The simplest situation is where the probability distribution for the aggregate interference level from all services is assumed to approach a normal distribution as the number of interfering services increases. If this is assumed to be the case, and if P is the aggregate level exceeded no more than one per cent of the time, then from tables of the integral of the normal probability distribution we obtain $P = \mu + 2.33\sigma$. If, instead, the data availability requirement is 0.1% or 0.01%, then from tables of the integral of the normal probability distribution c would be 3.09 or 3.72 respectively.

Suppose the passive service has an interference criterion of -160 dB(W/100 MHz) (or 10^{-16} (W/100 MHz)), with a data availability requirement of 0.1%. There are initially two interfering services, and dynamic simulations have determined that the means and standard deviations of the interference levels from these two services (assumed co-channel with the sensor) are $\mu_1 = \sigma_1 = 10^{-17}$ (W/100 MHz) and $\mu_2 = \sigma_2 = 2 \times 10^{-17}$ (W/100 MHz) respectively. From equation (1), the aggregate moments are $\mu = 3 \times 10^{-17}$ (W/100 MHz) and $\sigma = 2.24 \times 10^{-17}$ (W/100 MHz). Under the assumption that the statistics of the aggregate interference are normal, the aggregate level exceeded no more than 0.1% of the time is then:

$$P = \mu + 3.09\sigma = 9.91 \times 10^{-17} \quad W/100\ MHz \tag{4}$$

which is just below the sensor's assumed interference criterion. Now suppose that a third service comes on line, and that dynamic simulation determines that the mean and standard deviation of its interference level at the sensor are $\mu_3 = \sigma_3 = 3 \times 10^{-17}$ (W/100 MHz). Under the assumption that the statistics of the aggregate interference are normal, the new aggregate level exceeded no more than 0.1% of the time is then 1.76×10^{-16} (W/100 MHz), which exceeds the sensor's assumed interference criterion by 2.5 dB.

It should be emphasized that, for simplicity, this example assumes normal statistics, which is not usually a valid assumption.

5 Dynamic simulation results

Dynamic simulation of the aggregation methodology was performed. The aggregate interference into the EESS (passive) band 1 400-1 427 MHz caused by unwanted emissions from fixed, radiolocation, and space operations transmitting stations was calculated. Three scenarios were considered, ranging from a case in which one of the three interfering services is dominant, to one in which the interference produced by each radiocommunication service is comparable in statistical terms. The dynamic simulations produced a database of interference levels for 52 000 time steps. At each time step, the interference produced by each service, the aggregate interference produced by all three services, identification of the service producing the highest interference level, and the percentage of the aggregate interference level represented by the dominant interfering service, were all determined.

One of the goals was to determine whether interference from different radiocommunication services aggregates on a power basis or on a percentage of time basis. Examining the dynamic simulation results on a time step by time step basis indicated that there were time steps during the simulation for which only one dominant interfering radiocommunication service was present, which is typical of cases where interference from different sources aggregate on a percentage of time or area basis. On the other hand, there were other time steps in the same scenario where the aggregate interference was clearly the result of the simultaneous aggregation of interference power from different radiocommunication services on a power basis. The simulations therefore show that the interference in any given scenario does not aggregate purely on a power basis or purely on a time

basis. Because interference aggregating in power is usually associated with long-term interference, and that aggregating in time is associated with short-term interference, this says that the often-made distinction between long-term and short-term interference is not very useful in determining the aggregate interference in most scenarios. This is a good reason for proposing the method of statistical moments as a way to determine aggregate interference from multiple services.

For each scenario, the mean and variance of the aggregate interference were calculated from the means and variances of the simulation data for each of the radiocommunication services. The calculated mean and variance of the aggregate interference were found to equal the sum of the means and variances of the individual services obtained from the simulation data, in agreement with equation (1). In addition, the simulations showed that the assumption of normal statistics is usually not a valid one. It turns out that when equation (3) is used to calculate c, good agreement is obtained for all three simulated scenarios. Therefore the method of statistical moments appears to be a reasonable way to determine aggregate interference levels, even if the probability distribution of the aggregate level is unknown.