

# EUROCONTROL Guidelines on the Assessment of Ground-based Surveillance Interrogations

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#### **Abstract**

These EUROCONTROL Guidelines describe verification methods and processes that can be used by Member States to support their obligations on spectrum protection detailed in Article 6 of Commission Implementing Regulation (EU) No 1207/2011, as amended by Regulation (EU) 2017/386 of 6 March 2017 and Regulation (EU) 2020/587 of 29 April 2020. These guidelines also include optional verifications that are out of scope of Article 6 but enable States to further ensure the performance of the surveillance infrastructure.

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# **DOCUMENT CHANGE RECORD**

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Released Issue 2.0	08/09/2020	Update to reflect the repeal of Article 6 point 2 of Commission Implementing Regulation (EU) No 1207/2011 by Commission Implementing Regulation (EU) No 2020/587  Section 1.1, Section 2.2 and Section 2.3 are updated  Previous Section 2.5 is moved to Section 2.4  Section 2.5 is removed  Clarification on the reference version of ICAO Annex 10, Volume IV  Annex H is updated; Mode S replies from test aircraft measured in April 2017 are replaced by Mode S replies from test aircraft measured in 2019.  New section 7.2.5 to inform about the deployment of centralised monitoring system.	Section 1.1 Section 2.2 Section 2.3 Section 2.4  Section 1.8  Section 4.1.2 Section 4.3.2 Annex H  Section 7.2.5

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### **EXECUTIVE SUMMARY**

This EUROCONTROL Guidelines document proposes verification methods and processes that can be performed by States to support their obligations on spectrum protection detailed in Article 6 of Commission Implementing Regulation (EU) No 1207/2011 laying down requirements for the performance and the interoperability of surveillance for the single European sky, as amended by Regulation (EU) 2017/386 of 6 March 2017 and Regulation (EU) 2020/587 of 29 April 2020.

This document develops an approach to translate the regulatory requirement of the SPI IR into quantifiable terms, namely aircraft transponder rate of replies and occupancy.

This document defines a process to assess the compliance with point 1 of Article 6, including the management of issues that may arise. Different methods of analysis supporting the process are described in this document, allowing States to select the most efficient method for their environment. In particular, this document recommends that States verify that the aircraft transponder occupancy generated by interrogations eliciting or not eliciting a reply remains below a maximum threshold for any aircraft transponder flying in its airspace. It also recommends that States verify that the maximum rate of replies per second (peak rates) of any aircraft transponder flying in its airspace does not exceed the minimum reply rates capability defined in ICAO Annex 10, Volume IV.

This document identifies steps to assess the compliance with point 3 of Article 6.

The document also includes an optional process to support the assessment of the configuration of ground-based surveillance interrogators in order to ensure that they do not trigger too many replies from aircraft transponders.

It is recommended that States document the result of their assessment by using the template provided in Section 8.

### 1 Introduction

### 1.1 Purpose of the document

This EUROCONTROL¹ Guidelines document describes different methods that can be used by States to support them in meeting their obligations on spectrum protection detailed in Article 6 of Commission Implementing Regulation (EU) No 1207/2011 [RD 1], (hereinafter referred to as SPI IR - Surveillance Performance and Interoperability Implementing Rule) as amended by Regulation (EU) 2017/386 of 6 March 2017 [RD 2] and Regulation (EU) 2020/587 of 29 April 2020 [RD 3].

These obligations are designed to ensure that ground-based surveillance interrogators do not overinterrogate airborne aircraft transponders and do not trigger too many replies, thereby protecting the performance of ATC surveillance in Europe.

Furthermore, these guidelines include additional optional verifications (that are out of scope of the Article 6) to ensure that ground-based surveillance interrogators are correctly configured prior to their putting into service (optional Verification 4) and that they do not trigger too many all-call replies (optional Verification 5).

It is to be noted that these guidelines support EASA 'Acceptable Means of Compliance and Guidance Material to Commission Implementing Regulation (EU) No 1207/2011' [RD 4].

#### 1.2 Intended audience

These guidelines are intended to support States in performing their regulatory obligations and the competent authorities to which part (or all) of the tasks may have been delegated.

Civil and military operators of ground-based surveillance interrogators should also consider the content of these guidelines to ensure effective collaboration at national and European level.

#### 1.3 EUROCONTROL Guidelines

EUROCONTROL Guidelines, as defined in EUROCONTROL Regulatory and Advisory Framework (ERAF), are advisory materials and contain:

"Any information or provisions for physical characteristic, configuration, material, performance, personnel or procedure, the use of which is recognised as contributing to the establishment and operation of safe and efficient systems and services related to ATM in the EUROCONTROL Member States."

Therefore, the application of the EUROCONTROL Guidelines document is not mandatory.

In addition, the EUROCONTROL Regulatory and Advisory Framework specifies that:

"EUROCONTROL Guidelines may be used, inter alia, to support implementation and operation of ATM systems and services, and to:

- complement EU legislation;
- indicate harmonisation targets for ATM Procedures;
- encourage the application of best practice;
- provide detailed procedural information."

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<sup>&</sup>lt;sup>1</sup> EUROPEAN ORGANISATION FOR THE SAFETY OF AIR NAVIGATION

#### 1.4 Structure of the document

**Section 2** presents the **SPI IR Article 6** and provides the necessary clarification for each of the two points of the article.

**Section 3** defines the verifications to be performed by States to meet their obligations detailed in **SPI IR Article 6**. In addition, this Section recommends optional verifications that States can perform to further ensure a performing surveillance infrastructure.

**Section 4** defines a process to assess the compliance with point 1 of the **SPI IR Article 6**. This section identifies methods of analysis that can be selected to fulfil the process.

**Section 5** defines a process to support the optional assessment and approval of the configuration of ground-based surveillance interrogators prior to their putting into service or approving their transmissions. The purpose is to ensure that each interrogator configuration does not trigger too many replies from aircraft transponders. Over time, the configuration of all ground-based surveillance interrogators which are already in service should also be assessed following these guidelines.

**Section 6** identifies the additional information and processes that are required to correctly manage issues that may arise during the analysis and verifications performed by States.

**Section 7** provides detailed information on the various methods identified in Section 4 that can be used to assess the compliance with point 1 of the **SPI IR Article 6**.

Section 8 provides a template to document the assessments performed by States.

#### 1.5 Conventions

Throughout this document, recommendations are indicated by the use of the words "these guidelines recommend".

Squared brackets are used to indicate a referenced document listed in **Annex C**. For example, **[RD** 1] indicates referenced document number 1.

Text extracted from Regulations or ICAO SARPs are presented in italic.

#### 1.6 Abbreviations

The list of abbreviations used throughout these guidelines can be found in **Annex A**.

#### 1.7 Definitions

The list of definitions used throughout these guidelines can be found in **Annex B**.

#### 1.8 References

The list of documents referenced throughout these guidelines can be found in **Annex C**.

With regard to the editions and amendments of ICAO Annex 10, Volume IV the following is to be duly considered:

 At the date of publication of the Regulation, the rates of ICAO Annex 10, Volume IV, Fourth Edition, Amendment 85 (July 2010) were applicable. At the date of publication of these guidelines, Amendment 90 (July 2018) of ICAO Annex 10, Volume IV, Fifth Edition changed section 3.1.2.10.3.7.3 with regard to Mode S minimum reply rate capability for transponder used in conjunction with ACAS.

- A number of aircraft in operation are equipped with transponders that are certified against values that were specified in ICAO Annex 10, Volume IV, Third Edition (Amendment 77) and therefore differ with other aircraft certified against values in recent Amendments.
- Surveillance service providers are required to comply with Annex VIII (Part-CNS) to Commission Implementing Regulation (EU) 2017/373 by demonstrating that their working methods and operating procedures are compliant with the international Standards and Recommended Practices (SARPs) of Annex 10 'Aeronautical Telecommunications' to the Chicago Convention on International Civil Aviation. In particular, the rates of reply per second of the transponder on board any aircraft flying over a Member State shall be computed and compared to the minimum reply rates supported by transponder accepted in the airspace, specified in the ICAO Annex 10, Volume IV, Fourth Edition including all amendments up to and including No 89.

ICAO Annex 10 Volume IV Requirement	Annex 10 Vol IV, Ed 3 Amendment 77	Annex 10 Vol IV, Ed 4 Amendment 85	Annex 10 Vol IV, Ed 5 Amendment 89	Annex 10 Vol IV, Ed 5 Amendment 90	ICAO values used by these Guidelines
Minimum reply rate for Mode A/C per second (3.1.1.7.9.1)	1200	500	500	500	500
Minimum reply rate for Mode S replies per second (3.1.2.10.3.7.3)	50	50	50	50	50
Minimum reply rate for long Mode S	16 of 50 replies for levels 2, 3, 4	16 of 50 replies for levels 2, 3, 4	16 of 50 replies for levels 2, 3, 4	16 of 50 replies for levels 2, 3, 4	16 of 50 replies
replies per second (3.1.2.10.3.7.3)	24 of 50 replies for level 5	24 of 50 replies for level 5	24 of 50 replies for level 5	24 of 50 replies for level 5	
ACAS equipped – ACAS coordination replies per second (3.1.2.10.3.7.3)	at least 3 of 50 Mode S replies	at least 3 of 50 Mode S replies	at least 3 of 50 Mode S replies	60 Modes S replies	Recommended to use real measurements or at least 3 of 50 Mode S replies for coordination (does not include ACAS tracking messages detailed in these guidelines)
Maximum number of Modes S all-call replies (3.1.2.11.1.1.2)	N/A	N/A	On average no more than 6 Modes S all-call replies per 200ms and no more than 26 per 18 seconds	On average no more than 6 Modes S all-call replies per 200ms and no more than 26 per 18 seconds	On average no more than 6 Modes S all-call replies per 200ms and no more than 26 per 18 seconds

These guidelines consider the minimum capabilities of aircraft transponders as defined by ICAO Annex 10 (blue cells) and the maximum number of Modes S all-call replies triggered on average by ground-based surveillance interrogators for the optional verifications 4 and 5 (brown cells).

Table 1 – Comparison of requirements in different Amendments of ICAO Annex 10

Considering the above, these guidelines are aligned with the regulatory working methods applicable to surveillance service providers detailed in Regulation (EU) 2017/373 Part-CNS (CNS.TR.100).

As a result, these guidelines makes use of the reply rates specified in sections 3.1.1.7.9.1 and 3.1.2.10.3.7.3 which remain unchanged from ICAO Annex 10, Volume IV, Fourth Edition, Amendment 85 up to ICAO Annex 10, Volume IV, Fifth Edition, Amendment 89.

#### 1.9 ACAS considerations

ACAS is out of scope of the **SPI IR Article 6** which prescribes obligations on ground-based surveillance interrogators. However, ACAS interrogations and replies are transmitted over the same surveillance RF link and affect the aircraft transponder occupancy. In addition, the rate of ACAS replies is taken into account in the minimum reply rates specified in the ICAO Annex 10, Volume IV **[RD 5]**. Therefore, these guidelines recommend that States consider ACAS interrogations and replies to assess the compliance with point 1 of the **SPI IR Article 6**.

#### 1.10 Maintenance of the document

These EUROCONTROL Guidelines have been prepared by EUROCONTROL in cooperation with the operational stakeholders and national supervisory authorities.

These EUROCONTROL Guidelines have been published under the EUROCONTROL Regulatory and Advisory Framework (ERAF) and are maintained by EUROCONTROL in accordance with this Framework.

The maintenance procedures for these guidelines are described in detail in **Annex D**.

# 2 Regulating the spectrum used by European surveillance systems

### 2.1 1030/1090 MHz Radio Frequency bands

Cooperative surveillance systems use two frequencies to build a picture of the air situation: 1030 MHz for interrogating aircraft transponders and 1090 MHz for the aircraft transponder replies or spontaneous message transmissions (squitters).

The 1030/1090 MHz radio frequency (RF) band is a critical resource for ATC. Aircraft surveillance is based on numerous cooperative surveillance systems all relying on the good operation of this RF link. It is used by **Mode A/C** radars, **ELS** and **EHS Mode S** radars, **ADS-B**, **Multilateration** systems for airport surface surveillance (**MLAT**) or over a wide area (**WAM**), and **military systems**. In addition, air-air anti-collision systems (**ACAS**) and future **ADS-B IN** applications also share the same link

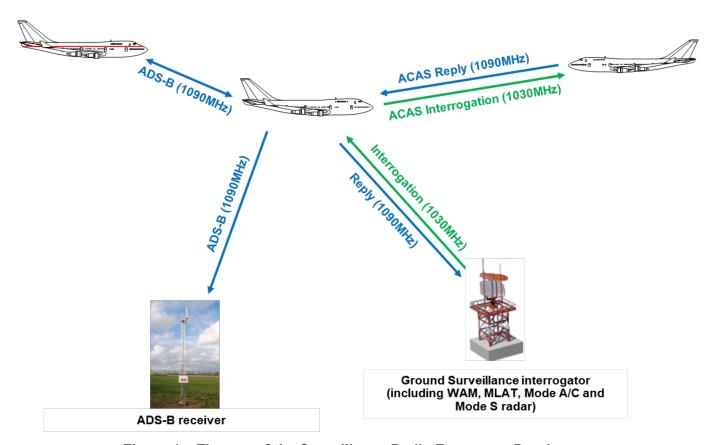


Figure 1 – The use of the Surveillance Radio Frequency Bands

The 1030/1090 MHz RF link can experience a degraded performance when:

- transponders are interrogated beyond their capability;
- there are too many transmissions on the frequencies;
- there are unexpected transmissions on the frequencies (e.g. non-ATC, noise); or
- transponder interoperability issues occur.

Excessive activity on the 1030/1090 MHz RF link can **result in a loss of aircraft** surveillance leading to possible traffic restrictions, delays and/or network capacity restrictions.

A bad RF environment could also result in the need to deploy **more surveillance sensors** to be able to maintain the right level of performance (e.g. more ADS-B stations) or the need to **deploy other technical systems operating on a different RF link**.

The 1030/1090 MHz RF link is a common resource shared between multiple airborne and ground users with a performance that depends on systems operating within several countries, calling for collaborative and harmonised practices between States.

One of the goals of the Surveillance Performance Interoperability Implementation Rule (**SPI IR**) is to sustain the performance of the 1030 MHz and 1090 MHz frequencies in the Single European Sky airspace thereby avoiding the need to deploy a new surveillance RF link. Article 6 of the **SPI IR** supports this goal by mitigating the number of interrogations received by transponders ensuring they operate within their capacity limits.

Annex F provides more background information on the SPI IR.

# 2.2 Regulatory provisions on spectrum (SPI IR Article 6)

The SPI regulation "lays down requirements on the systems contributing to the provision of surveillance data, their constituents and associated procedures in order to ensure the harmonisation of performance, the interoperability and the efficiency of these systems within the European air traffic management network (EATMN) and for the purpose of civil- military coordination".

**Article 6** of the **SPI IR** (as amended), details the provisions relating to spectrum protection:

#### Article 6

#### **Spectrum protection**

- 1. By 2 January 2020 at the latest Member States shall ensure that a secondary surveillance radar transponder on board any aircraft flying over a Member State is not subject to excessive interrogations that are transmitted by ground-based surveillance interrogators and which either elicit replies or whilst not eliciting a reply are of sufficient power to exceed the minimum threshold level of the receiver of the secondary surveillance radar transponder.
- 2. For the purpose of paragraph 1, the sum of such interrogations shall not cause the secondary surveillance radar transponder to exceed the rates of reply per second, excluding any squitter transmissions, specified in paragraph 3.1.1.7.9.1 for Mode A/C replies and in paragraph 3.1.2.10.3.7.3 for Mode S replies of Annex 10 to the Chicago Convention, Volume IV, Fourth Edition
- 3. By 2 January 2020 at the latest Member States shall ensure that the use of a ground based transmitter operated in a Member State does not produce harmful interference on other surveillance systems.
- 4. In the event of disagreement between Member States regarding the measures detailed in paragraphs 1 and 3 the Member States concerned shall bring the matter to the Commission for action.

As illustrated in Figure 1, aircraft are subject to multiple sources of interrogations (both ground and air-based). However, it is important to note that the obligations on States relate to the civil and military ground-based surveillance interrogations upon which States can take action.

For the purpose of these guidelines it is essential to develop an understanding of the term "excessive" defined in point 1 of Article 6 of the **SPI IR**. Indeed, as the performance of the 1030/1090 MHz RF link depends on systems installed throughout Europe, there is a need for States to share the same understanding of that term.

Secondly, the term "harmful interference" used in point 3 of Article 6 will be clarified to ensure that all States share the same understanding of that term.

Finally, these guidelines recommend that the above points are verified by States on a regular basis (e.g. new installation, new configurations) as described by the following sections.

# 2.3 Defining "excessive interrogations" for Art. 6 point 1

All interrogations from surveillance interrogators with a power level that exceeds the minimum threshold level of an aircraft transponder, eliciting or not a reply, are processed by the transponder and have an impact on the occupancy of the transponder. An aircraft transponder which is too occupied may not be able to process all received interrogations.

In addition, an aircraft transponder which is subject to too many interrogations may not be able to reply to all interrogations when the number of triggered replies exceeds its capability.

Therefore it is necessary to ensure that an aircraft transponder does not generate an excessive number of replies and that its occupancy remains below a maximum threshold.

The minimum reply rates capability of aircraft transponder is defined in ICAO Annex 10, Volume IV **[RD 5]**. The values used for the purpose of the Minimum Operational Performance Specification for Secondary Surveillance Radar Mode S Transponders **[RD 16]** are aligned with the values used by these guidelines (See Section 1.8). Some aircraft transponders have been designed and tested to strictly meet this minimum capability; they may not be able to generate a number of replies higher than this minimum capability or may have an unexpected behaviour if the number of triggered replies exceeds the minimum capability.

Therefore, these guidelines recommend that States verify that the occupancy generated by interrogations eliciting or not eliciting a reply remains below a maximum threshold for any aircraft transponder flying in its airspace. They also recommend that States verify that the maximum rate of replies per second (peak rates) of any aircraft transponder flying in its airspace does not exceed the minimum reply rates capability defined in ICAO Annex 10, Volume IV [RD 5]. For the purpose of these guidelines, values from ICAO Annex 10, Volume IV, Fifth Edition, Amendment 89 are used (see Section 1.8 for clarification on applicable ICAO Amendments).

The following sections define the minimum reply rates capability of aircraft transponders, assess the various factors affecting the transponder occupancy and provide in conclusion the maximum values of the reply rates and the maximum transponder occupancy threshold that will be used for verification.

## 2.3.1 ICAO Annex 10, Volume IV defined minimum reply rates

The minimum reply rate capability for Mode A/C replies is provided in section 3.1.1.7.9.1 of ICAO Annex 10, Volume IV **[RD 5]**:

"3.1.1.7.9.1 All transponders shall be capable of continuously generating at least 500 replies per second for a 15-pulse coded reply. Transponder installations used solely below 4 500 m (15 000 ft), or below a lesser altitude established by the appropriate authority or by regional air navigation agreement, and in aircraft with a maximum cruising true airspeed not exceeding 175 kt (324 km/h) shall be capable of generating at least 1 000 15-pulse coded replies per second for a duration of 100 milliseconds. Transponder installations operated above 4 500 m (15 000 ft) or in aircraft with a maximum cruising true airspeed in excess of 175 kt (324 km/h), shall be capable of generating at least 1 200 15-pulse coded replies per second for a duration of 100 milliseconds."

While old aircraft transponders (ICAO Annex 10, Volume IV, Third Edition Amendment 77 or before) have the capability to reply to 1200 Mode A/C interrogations per second, aircraft transponders compliant with more recent versions of the ICAO Annex 10, Volume IV (Amendment 85 or above) are only capable to reply to 500 Mode A/C interrogations per second. Therefore, these guidelines recommend that States verify that transponders are not required to reply to more than 500 Mode A/C replies per second.

The minimum reply rates capability for Mode S replies are provided in section 3.1.2.10.3.7.3 of ICAO Annex 10, Volume IV [RD 5]:

"3.1.2.10.3.7.3 Minimum reply rate capability, Mode S. A transponder capable of transmitting only short Mode S replies shall be able to generate replies at the following rates:

- 50 Mode S replies in any 1-second interval
- 18 Mode S replies in a 100-millisecond interval
- 8 Mode S replies in a 25-millisecond interval
- 4 Mode S replies in a 1.6-millisecond interval

In addition to any downlink ELM transmissions, a level 2, 3 or 4 transponder shall be able to generate as long replies at least:

- 16 of 50 Mode S replies in any 1-second interval
- 6 of 18 Mode S replies in a 100-millisecond interval
- 4 of 8 Mode S replies in a 25-millisecond interval
- 2 of 4 Mode S replies in a 1.6-millisecond interval

In addition to downlink ELM transmissions, a level 5 transponder shall be able to generate as long replies at least:

- 24 of 50 Mode S replies in any 1-second interval
- 9 of 18 Mode S replies in a 100-millisecond interval
- 6 of 8 Mode S replies in a 25-millisecond interval
- 2 of 4 Mode S replies in a 1.6-millisecond interval

In addition, a transponder within an ACAS installation shall be able to generate as ACAS coordination replies at least 3 of 50 Mode S replies in any 1-second interval."

Based on aircraft fleet monitoring performed in 2019 in the European core area, less than 1% of flights are operated with a level 5 transponder. Therefore, for the purpose of these guidelines the verification of Mode S long replies will use the minimum reply rate capability required for a level 2, 3 or 4 transponder.

As **SPI IR Article 6(1)** only refers to rates of reply per second, these guidelines only verify the following rates:

- the number of Mode A/C replies per second interval (500 Mode A/C replies per second),
- the number of Mode S replies per second interval (50 Mode S replies in any 1-second interval), and
- the number of Mode S long replies per second interval (16 of 50 Mode S replies in any 1-second interval)

These rates may correspond to the maximum capability of some aircraft transponders. Therefore, they will be assess by verifying the maximum number of Mode A/C replies and the maximum number of Mode S replies per second (peak reply rates per second) transmitted by any aircraft transponder flying in State airspace.

ICAO Annex 10, Volume IV **[RD 5]** specifies the minimum reply rates capability for Mode A/C and Mode S replies, whatever they are triggered by airborne or ground-based surveillance interrogators. Those rates do take into account ACAS replies but do not take into account ADS-B extended squitters and acquisition squitter. Section 2.3.3 explains how to take into account replies triggered by airborne surveillance interrogators (ACAS).

#### 2.3.2 Transponder occupancy

#### 2.3.2.1 Transponder minimum triggering level (MTL)

All interrogations and pulses received by a transponder, with a power level above its minimum triggering level (MTL<sup>2</sup>), are detected and processed. ICAO Annex 10, Volume IV, paragraph 3.1.2.10.1 **[RD 5]** defines an MTL of –74 dBm ±3 dB for a Mode S transponder.

For the purpose of these guidelines the typical MTL value of -74dBm is used.

#### 2.3.2.2 Definition and values

The ICAO definition of transponder occupancy can be found in Annex 10, Volume IV **[RD 5]** and is typically expressed as a percentage of time: "A state of unavailability of the transponder from the time it detects an incoming signal that appears to cause some action or from the time of a self-initiated transmission, to the time that it is capable of replying to another interrogation."

The various system interactions that contribute to transponder occupancy are described in the Appendix M of the Aeronautical Surveillance Manual (ICAO Doc 9924) [RD 8].

Standardised and typical occupancy values for different types of interrogations, eliciting or not a reply, have been defined:

- Standardised values are calculated using the maximum times specified in the ICAO Annex 10 Volume IV, and therefore provide the maximum transponder occupancy (i.e. the worst case scenario).
- Typical values are weighted averages of the values really measured on real transponders, and therefore provide the mean transponder occupancy (i.e. the average scenario).

The standardised and typical occupancy values are provided in **Annex N** of these guidelines.

#### 2.3.2.3 Ground-based surveillance interrogations

All interrogations from civil and military ground-based surveillance interrogators with a power level exceeding the minimum threshold level of an aircraft transponder, eliciting or not a reply, are processed by the transponder and have an impact on the occupancy of the transponder.

<sup>&</sup>lt;sup>2</sup> The terms "minimum triggering level", "minimum trigger threshold level" and "minimum threshold level" are equivalent.

Indeed all Mode S selective interrogations received by an aircraft transponder have first to be decoded to determine if the transponder is being specifically addressed (and requiring the transmission of a reply). Therefore, the occupancy of an aircraft transponder increases with the air traffic density and the number of ground-based surveillance interrogators within its range.

Similarly, an aircraft transponder within the range of a WAM omnidirectional antenna receives the interrogations addressed to all aircraft. The number of selective interrogations received by the aircraft transponder that are addressed to other aircraft may be very high in a high-traffic density region therefore generating an important occupancy of the transponder.

Furthermore, transponders are also occupied by other interrogation types e.g. Mode A/C interrogations (with or without short P4), All-Call interrogations, special military interrogations.

As a result, for a transponder there is a direct link between the number of interrogations which are received above its minimum triggering level (MTL) and its occupancy. The more an aircraft transponder is occupied, the less it is able to detect interrogations and provide the requested replies.

Ensuring that the transponder does not receive an excessive number of interrogations above its MTL (as foreseen by **SPI IR Article 6 point 1**) means verifying that its occupancy remains below a maximum threshold which is determined in the section below.

#### 2.3.2.4 Maximum threshold for transponder occupancy

Ensuring that a transponder does not receive an excessive number of interrogations is equivalent to verifying that its occupancy remains below a maximum threshold.

To identify the order of magnitude of a maximum threshold for transponder occupancy, one can refer to existing values used by standards, model calculations, RF recordings and measurements:

- 1. For the design and testing of Mode S ground stations **[RD 12]**, the hypothesis was that the probability of reply of an aircraft transponder is 90%, implying a maximum transponder occupancy of 10%.
- 2. Model calculations making use of the standardised transponder occupancy values (ICAO Doc 9924) conclude that when only considering interrogations addressed to the aircraft and replies triggered at the minimum reply rate capability (specified in ICAO Annex 10, Volume IV), the transponder occupancy is 10% (see **Annex I.1**).
- 3. Interrogations received on 1030 MHz and replies on 1090 MHz recorded on board a test aircraft during a 2-day test flight in April 2017 were used to compute the transponder occupancy within the proximity of two large European airports (see **Annex I.2**).

The transponder occupancy is very sensitive to the MTL used for the analysis. As recommended in Section 2.3.2.1, the MTL value used for the analysis is -74dBm. However, the transponder occupancy has also been computed using a MTL value of -77dBm close to Airport A to see the impact of the MTL on the transponder occupancy.

Both the transponder occupancy per second and the average value over 1 minute were computed, using standardised and typical occupancy values (ICAO Doc 9924 [RD 8]):

- Occupancy close to Airport A using standardised values (MTL of -74dBm):
  - Average value over 1 minute: 15.13%
  - Maximum occupancy per second: 19%
- Occupancy close to Airport A using typical values (MTL of -74dBm):
  - Average value over 1 minute: 11.06%
  - Maximum occupancy per second: 14%
- Occupancy close to Airport A using standardised values (MTL of -77dBm):

- Average value over 1 minute: 21.57%
- Maximum occupancy per second: 25.90%
- Occupancy close to Airport A using typical values (MTL of -77dBm):
  - Average value over 1 minute: 16.06%
  - Maximum occupancy per second: 19.60%
- Occupancy close to Airport B using standardised values (MTL of -74dBm):
  - Average value over 1 minute: 7.39%
  - Maximum occupancy per second: 9.6%
- Occupancy close to Airport B using typical values (MTL of -74dBm):
  - Average value over 1 minute: 5.50%
  - Maximum occupancy per second: 7.10%
- 4. FAA flight test conducted in April 2011 in the Northeast corridor measured transponder occupancy (see Annex I.3). The maximum transponder occupancy per second occurs when the flight test aircraft is located in the New York airport area. Within that area, the maximum transponder occupancy per second is close to 29% using standardised values and close to 24% using typical values.

However, the values of the maximum transponder occupancy have been obtained by adding the maximum occupancy due to Mode S, to the maximum occupancy due to Mode A/C. The maximum occupancy due to Mode S and Mode A/C may not have happened at the same time (same second), which means that the real maximum transponder occupancy may have been lower than the values provided above (29% and 24%).

Based on the above, the transponder occupancy of an aircraft flying above a State is expected to be below 20% (10% of occupancy due to interrogations triggering a reply and 10% of occupancy due to interrogations without reply).

#### 2.3.3 ACAS

ACAS is out of scope of the **SPI IR Article 6** which prescribes obligations on ground-based surveillance interrogators. However, ACAS interrogations and replies are transmitted over the same surveillance RF link as illustrated in Figure 1, and affect the reply rate and the occupancy of aircraft transponders. In addition, the rate of ACAS replies are taken into account in the minimum reply rates capability specified in the ICAO Annex 10, Volume IV **[RD 5]** (see section 2.3.1).

Therefore, these guidelines recommend that States consider ACAS replies when verifying the ICAO minimum reply rates capability, and also consider ACAS interrogations and replies in the calculation of the transponder occupancy.

The rate of ACAS interrogations and replies can be retrieved from the analysis of RF measurements. It depends on the traffic density and is particularly important near large airports at peak time(s). For reference, the maximum number of ACAS replies per second measured on board a test aircraft during a 2-day test flight in April 2017, and during 3 test flights of 1 day in 2019 is provided in **Annex G**. This Annex shows that the maximum number of ACAS replies per second exceeds 10 replies per second at several places in Europe, in general in the vicinity of large airports (up to 24 ACAS replies per second).

In regards to the minimum reply rates capability of 50 Mode S replies per second specified in the ICAO Annex 10, Volume IV, it is necessary to consider ACAS replies in the assessment of aircraft transponder reply rates, particularly in the vicinity of airports. In the absence of RF measurements, these guidelines recommend to use values resulting from ACAS reply simulations, or use the values measured during previous test flights (see **Annex G**) and consider that ACAS installations shall be able to generate at least 10 of 50 Mode S replies per second in the vicinity of large airports and 5 of 50 Mode S replies per second elsewhere.

The aircraft transponder occupancy is also affected by ACAS activity, particularly in the vicinity of airports, enforcing the need to consider ACAS activity in the calculation of the transponder occupancy. In the absence of RF measurements, these guidelines recommend to use values resulting from ACAS interrogation and reply simulations, or reserve a 2% margin to cover their impact which corresponds to the design limit indicated in section 7.1.2.6.2.1 of **[RD 15]**.

#### 2.3.4 ADS-B extended squitters

ADS-B extended squitters (DF 17) are spontaneous periodic transmissions on 1090 MHz at rates defined in ICAO Annex 10, Volume IV. Therefore, the transmission of ADS-B extended squitters by Mode S aircraft transponders is outside the scope of the **SPI IR Article 6**.

In addition, the transmission of ADS-B extended squitters by Mode S aircraft transponders is not included in the transponder minimum reply rates capability specified by ICAO [RD 5].

"3.1.2.10.3.7.1 All reply rates specified in 3.1.2.10.3.7 shall be in addition to any squitter transmissions that the transponder is required to make."

Therefore the ADS-B extended squitters are not taken into account when assessing the reply rates per second of aircraft transponders.

Nevertheless, when a transponder transmits ADS-B on 1090 MHz, this results in transponder occupancy and this is taken into account by these guidelines to determine the maximum threshold for transponder occupancy.

### 2.3.5 Acquisition squitter

The Mode S acquisition squitters are also spontaneous periodic transmission on 1090 MHz. Therefore, the transmission of acquisition squitters by Mode S aircraft transponders is outside the scope of the **SPI IR Article 6**.

In addition, the transmission of ADS-B acquisition squitters by Mode S aircraft transponders is not included in the transponder minimum reply rates capability specified by ICAO [RD 5] (see Section 2.3.4).

Therefore the acquisition squitter is not taken into account when assessing the reply rates per second of aircraft transponders.

Nevertheless, as for ADS-B extended squitters (see Section 2.3.4), they are also taken into account by these guidelines to determine the maximum threshold for transponder occupancy.

#### 2.3.6 Conclusions

The above sections have developed an approach to translate the regulatory requirement of the **SPI IR** into quantifiable terms, namely aircraft transponder rate of replies and occupancy. Both of these values can be assessed by States.

For the purpose of these guidelines, ensuring that a transponder does not receive an excessive number of interrogations which elicit replies means verifying that its maximum rate of replies per second (peak rates) does not exceed the following values:

- 1. 500 Mode A/C replies per second
- 2. 50 Mode S replies in any 1-second interval
- 3. 16 Mode S long replies in any 1-second interval.

For the purpose of these guidelines, ensuring that a transponder does not receive an excessive number of interrogations above its MTL (as foreseen by SPI IR Article 6 point 1) means verifying that its maximum transponder occupancy remains below 20% using ICAO standardised values.

### 2.4 Clarifying "harmful interference" for Art. 6 point 3

#### 2.4.1 Harmful interference definition

The SPI IR provides a high-level definition of harmful interference as:

"(5) 'harmful interference' means interference that prevents the achievement of the performance requirements:"

In the context of the **SPI IR**, harmful interference should be understood as being related to the radio equipment directive 2014/53/EU (RED) **[RD 13]** which establishes a regulatory framework for placing radio equipment on the EU market. It ensures a single market for radio equipment by setting essential requirements for safety and health, electromagnetic compatibility, and the efficient use of the radio spectrum. It is to be noted that a number of non-EU states either apply RED (e.g. Iceland, Liechtenstein, and Norway) or have established mutual recognition agreements<sup>3</sup>. These guidelines assume that all States subject to the **SPI IR** are subject to RED or similar regulatory requirements applicable to radio equipment.

Point 2 of RED "Article 3: Essential requirements" requires that radio equipment shall not produce harmful interference:

"2. Radio equipment shall be so constructed that it both effectively uses and supports the efficient use of radio spectrum in order to avoid harmful interference."

A further detailed description of harmful inference is provided in RED:

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<sup>&</sup>lt;sup>3</sup> Refer to the 'Blue Guide' on the implementation of EU product rules, Chapter 2.8 Geographical application (https://ec.europa.eu/growth/content/%E2%80%98blue-guide%E2%80%99-implementation-eu-product-rules-0\_en)

"(10) In order to ensure that radio equipment uses the radio spectrum effectively and supports the efficient use of radio spectrum, radio equipment should be constructed so that: in the case of a transmitter, when the transmitter is properly installed, maintained and used for its intended purpose it generates radio waves emissions that do not create harmful interference, while unwanted radio waves emissions generated by the transmitter (e.g. in adjacent channels) with a potential negative impact on the goals of radio spectrum policy should be limited to such a level that, according to the state of the art, harmful interference is avoided; and, in the case of a receiver, it has a level of performance that allows it to operate as intended and protects it against the risk of harmful interference, in particular from shared or adjacent channels, and, in so doing, supports improvements in the efficient use of shared or adjacent channels."

### 2.4.2 Applicability of RED to ground-based transmitters

The radio equipment directive 2014/53/EU (RED) is applicable to ground-based surveillance interrogators as these are ground-based radio transmitters and receivers. However, it is to be noted that RED does not apply to equipment used in specific cases:

#### "Article 1: Subject matter and scope

3. This Directive shall not apply to radio equipment exclusively used for activities concerning public security, defence, State security, including the economic well-being of the State in the case of activities pertaining to State security matters, and the activities of the State in the area of criminal law."

#### 2.4.3 Product compliance with RED

With regard to RED, it is the responsibility of the manufacturer or its authorised representative to carry out the conformity assessment procedure as indicated in point (29) and (41) of the Directive for their products:

- "(29) The manufacturer, having detailed knowledge of the design and production process, is best placed to carry out the conformity assessment procedure. Conformity assessment should therefore remain solely the obligation of the manufacturer."
- "(41) Manufacturers should draw up an EU declaration of conformity to provide information required under this Directive on the conformity of radio equipment with the requirements of this Directive and of the other relevant Union harmonisation legislation."

When manufacturers comply with voluntary harmonised standards (prepared by ETSI) and listed in the Official Journal of the European Union (OJEU), conformity to RED is presumed. Otherwise, manufacturers must demonstrate their compliance to RED.

It is to be noted that ETSI is currently drafting a harmonised standard for SSR radar sensors:

Air Traffic Control Surveillance Radar Sensors;

Secondary Surveillance Radar (SSR);

Part 1: Harmonised Standard for access to radio spectrum for SSR Interrogator.

DEN/ERM-TGAERO-30-1 (EN 303 363-1)

The document is the first part of a multi-part deliverable covering ATC Secondary Surveillance Radar systems for civil air navigation operating in the frequencies 1030 MHz and 1090 MHz.

ETSI also drafting a harmonised standard for Multilateration (MLAT) equipment:

Advanced Surface Movement Guidance and Control System (A-SMGCS);

Part 5: Harmonized Standard for access to the radio spectrum for Multilateration (MLAT) equipment;

Sub-part 1: Receivers and Interrogators

DEN/ERM-TGAERO-37-5-1 (EN 303 213-5-1)

Sub-part 2: Reference and vehicle transmitters DEN/ERM-TGAERO-37-5-2 (EN 303 213-5-2)

ETSI also started working on harmonised standard for WAM:

Air Traffic Control Surveillance;

Wide Area Multilateration (WAM) systems Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU

DEN/ERM-TGAERO-36 (EN 303 489)

The manufacturer's compliance to RED may be documented separately or part of the EC declaration of conformity/suitability for use (DoC/DSU)<sup>4</sup> that must be provided to the air navigation service provider (ANSP).

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<sup>&</sup>lt;sup>4</sup> DoC/DSU are referenced in the technical file of the EC Declaration of verification of systems (DoV) to be prepared by the ANSP. See SPI IR Articles 10 and 11.

# 3 Verifications supporting SPI IR Article 6

#### 3.1 Overview of the verifications

For all SES implementing rules for interoperability, manufacturers need to verify the constituents they place on the market and ANSPs need to verify their systems before putting them into service. Although the interoperability Regulation<sup>5</sup> is repealed, the SES regulatory requirements concerning the verification of compliance remain applicable through Article 139 of the EASA Basic Regulation<sup>6</sup>. With regard to the **SPI IR**, a number of verification of compliance requirements are relevant.

- Article 10 is applicable to manufacturers who must deliver the EC declaration of conformity (DoC) or the EC declaration of suitability for use (DSU) to their customers. This declaration is in addition to the obligation to demonstrate compliance to RED (see Section 2.4.3).
- Article 11 is applicable to ANSPs who must deliver the EC declaration of verification of systems (DoV) and its technical file to the national supervisory authority (NSA) before a new system is put into service.
- Article 6 is applicable to States who can make use of information documented in technical file of the DoV made available before a new system is put into service or any other source of information made available to State authorities.

This section defines several verifications to be performed by States to meet their obligations detailed in **SPI IR Article 6**. In addition, these guidelines recommend optional verifications that States can perform to further ensure a performing surveillance infrastructure. States could delegate the verification tasks to one or more national competent authorities (e.g. one nominated for civil and one nominated for military depending on the tasks). With regard to the execution of the verifications tasks, these guidelines refer equivalently to State or its delegated competent authorities.

The scope of each verification is outlined in the below table.

Verification Number	Description	When	In scope of Article 6
1	Aircraft transponder occupancy analysis	After a new system is put into service and/or Periodic evaluation at national level	Yes, Article 6(1)
2	Aircraft transponder reply rates analysis	After a new system is put into service and/or Periodic evaluation at national level	Yes, Article 6(1)

<sup>&</sup>lt;sup>5</sup> Regulation (EC) No 552/2004 of the European Parliament and of the Council of 10 March 2004 on the interoperability of the European Air Traffic Management network

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<sup>&</sup>lt;sup>6</sup> Regulation (EU) 2018/1139 of the European Parliament and of the Council of 4 July 2018 on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency

3	Ensure that ground based transmitter does not produce harmful interference	Upon release of a DoV and technical file (for a new or upgraded system)	Yes, Article 6(3)
4	Analysis of ground- based surveillance interrogators configuration	Upon release of a DoV and technical file (for a new or upgraded system)	No, optional best practice
5	Aircraft transponder All-Call replies analysis	After a new system is put into service and/or Periodic evaluation at national level	No, optional best practice

Table 2 – Summary of required verifications to assess compliance with SPI IR Article 6

To support the verifications, these guidelines recommend that:

• States identify a point of contact for the nominated competent authority or authorities in the State.

More information about points of contact is provided in Section 6.1.4.

 States implement a process to handle over-interrogation report suspected to come from a ground-based surveillance interrogator located inside their own State with the support of local operators.

More information on the process is provided in Section 6.1.2.

States implement a process to handle unexpected interferences detected on 1030/1090 MHz.

More information on the process is provided in Section 6.1.3.

• States provide the list of operators (ANSP, military, manufacturer, airport operator) in their own State and communicate a point of contact (preferably 24-7) for each of them.

More information about points of contact is provided in Section 6.1.4.

# 3.2 VERIFICATION 1: Aircraft transponder occupancy analysis

**VERIFICATION 1** will determine whether the maximum transponder occupancy due to interrogations which either elicit replies or whilst not eliciting a reply are of sufficient power to exceed the minimum threshold level of the transponder of -74dBm, is below **20%**.

Transponder occupancy can be computed using standardised and typical occupancy values as detailed in **Annex N**. For the purpose of **VERIFICATION 1**, the guidelines make use of the standardised values to calculate the maximum transponder occupancy.

The transponder occupancy will be computed on 1-second period.

Section 4.1 presents two methods that can be applied to perform **VERIFICATION 1**: the use of a RF Model or the analysis of airborne RF measurement. The duration of **VERIFICATION 1** will depend on the selected method.

These guidelines recommend that States repeat **VERIFICATION 1** regularly, typically every 2 years. When the measured maximum transponder occupancy is close to the 20% limit, or if there is a significant change in the ground-based surveillance infrastructure (e.g. WAM deployed, transition from ELS to EHS surveillance, airspace redesign) that may have a non-negligible impact on the RF environment; then these guidelines recommend to perform the verification annually.

# 3.3 VERIFICATION 2: Aircraft transponder reply rates analysis

**VERIFICATION 2** will determine whether the replies of transponders on-board any aircraft flying over a State do not exceed the minimum reply rates specified in the Annex 10 to the Convention on International Civil Aviation, Volume IV **[RD 5]**, in section 3.1.1.7.9.1 for Mode A/C replies and in section 3.1.2.10.3.7.3 for Mode S replies.

The reply rates of aircraft transponder will be computed per second. They shall satisfy the following conditions:

- 1. less than or equal to 500 Mode A/C replies per second
- 2. less than or equal to 50 Mode S replies in any 1-second interval
- 3. less than or equal to 16 Mode S long replies in any 1-second interval

If one of the three conditions above is not met, then the reply rates of the transponder exceed the minimum reply rates specified in Annex 10, Volume IV and does not meet the obligations of **SPI IR Article 6(1)**.

Section 4.3 presents several methods that can be applied to perform **VERIFICATION 2**, therefore the duration of evaluation to assess **VERIFICATION 2** will depend on the selected method.

These guidelines recommend that States repeat **VERIFICATION 2** regularly, typically every 2 years. When the measured number of transponder replies is close to the above limits, or if there is a significant change in the ground-based surveillance infrastructure (e.g. WAM deployed, ELS to EHS surveillance, airspace redesign) that may have a non-negligible impact on the RF environment; then these guidelines recommend to perform the verification annually.

# 3.4 VERIFICATION 3: Ground-based transmitter does not produce harmful interference

The **SPI IR Article 6(3)** and in particular the word "harmful interference" has been clarified in Section 2.4 which describes the relationship with the radio equipment directive 2014/53/EU (RED) **[RD 13]**.

When purchasing any ground-based surveillance interrogator, ANSPs should have received from the manufacturer of the ground-based transmitter, evidence of the necessary compliance with the radio equipment directive 2014/53/EU (RED) **[RD 13]** or any equivalent national regulations for non-EU states (see Section 2.4.1 on the applicability of RED).

States have to ensure that ground based transmitters operated on their territory are compliant to **Article 6(3)**. To this effect, the NSA can verify whether the technical file of the DoV provided by the ANSP indicates whether the ground based surveillance interrogator complies with RED. This verification is to be applied to new systems being put into service as well as all existing systems in service.

In the absence of such information, these guidelines recommend that the NSA requests the ANSP to provide copies of the declaration of conformity to RED or evidence thereof. Depending on the internal State organisation, this request may be coordinated with the national radio regulator and/or the national radio frequency manager appointed by the State<sup>7</sup>.

# 3.5 VERIFICATION 4 (Optional): Analysis of ground-based surveillance interrogators configuration

This optional verification is based on existing practices performed within some States. It relies on collaboration between the manufacturers, ANPS, military authorities, NSAs and other State authorities (e.g. frequency managers) before a ground-based surveillance interrogator is put into service.

Although, the **SPI IR** does not cover military operations and training (see recital (14) of the **SPI IR**), this verification takes into account military operations which may have a detrimental impact on the performance of the surveillance service and the safety of ATS.

A misconfigured ground-based surveillance interrogator can have a detrimental impact on the performance of the surveillance service in terms of excessive interrogations from ground-based surveillance interrogators or rates of reply per second for aircraft transponders, both subject to **SPI IR Article 6.** For the purpose of this optional verification, States are to verify that civil and military ground-based surveillance interrogators are correctly configured to ensure they will not over-interrogate and/or trigger too many replies from aircraft transponders before they are put into service or start transmitting.

Prior to the putting into service or approving the transmissions of any civil or military ground-based surveillance interrogator, it is recommended to verify that the configuration (**MIP**, **IRF**, number of BDS extracted every scan...) does not trigger too many replies from aircraft transponders.

It is also recommended to verify that the configuration of ground-based surveillance interrogators which are already in operation do not trigger too many replies from aircraft transponders.

For this purpose, a State process to assess and approve the configuration of ground-based surveillance interrogators (including fixed and mobile military radars for permanent or temporary operation, test radars, WAM systems...) is further described in Section 5.

# 3.6 VERIFICATION 5 (Optional): Measuring the number of triggered call replies per interrogator

This verification is optional as it not required by **SPI IR Article 6**, however it is strongly recommended as it will support the below referred ICAO Annex 10 requirement and will help to reduce the number of Mode S replies.

1090 MHz congestion is a critical concern for the performance of surveillance systems and the collision avoidance systems. One of the main causes of the congestion is the excessive number of All-Call replies.

ICAO Annex 10 Volume IV (from Amendment 89 applicable November 2014) **[RD 5]** requires that a Mode S interrogator shall not trigger, on average, more than 6 All-Call replies per beam (200 ms) and more than 26 All-Call replies in 18 seconds.

"3.1.2.11.1.1.2 Maximum number of Mode S all-call replies triggered by an interrogator. For aircraft that are not locked out, a Mode S interrogator shall not trigger, on average, more than 6 all-call replies per

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<sup>&</sup>lt;sup>7</sup> Refer to Annex III Part B of Commission Implementing Regulation (EU) 2019/123 of 24 January 2019 laying down detailed rules for the implementation of air traffic management (ATM) network functions

period of 200 ms and no more than 26 all-call replies counted over a period of 18 seconds."

**VERIFICATION 5** will determine whether a transponder on board any aircraft flying over a State does not reply, on average, to more than 6 all-call interrogations from the same ground-based surveillance interrogator per period of 200 milliseconds and no more than 26 interrogations over a period of 18 seconds.

To facilitate the execution of this verification, these guidelines recommend that States extend the scope of **VERIFICATION 2** by assessing the number of All-Call replies triggered by ground-based surveillance interrogators.

# 4 Process to support VERIFICATIONS 1 and 2

The overall purpose of point 1 of the **SPI IR Article 6** is to ensure that aircraft transponders operating in the airspace of a State are not over interrogated and that interrogations do not trigger too many replies.

States are advised to detect areas where the transponder occupancy is considered critical or where the number of transponder replies exceeds the minimum reply rates specified in the Annex 10 to the Convention on International Civil Aviation, Volume IV [RD 5]. In such places, actions are required at least to investigate the impact on surveillance performance and possibly for deployment of solutions to reduce the transponder occupancy and the number of triggered replies.

These guidelines propose a series of verification steps, either by simulation or analysis of RF measurements, to ensure that aircraft transponders are not occupied more than 20% when using standardised values and that the number of transponder replies does not exceed the minimum reply rates specified in the Annex 10 Volume IV.

The responsibility on States is to cover all systems operating on 1030/1090 MHz including ANSP systems, Military systems and systems used by manufacturers for testing or integration.

The process to assess the compliance with point 1 of the **SPI IR Article 6** relies on national verifications and analysis performed by States, which can be complemented by additional processes performed at the European level by a civil-military organisation such as EUROCONTROL.

The following sections contain the different recommended steps to assess the compliance with point 1 of the SPI IR Article 6(1).

#### 4.1 Method selection for VERIFICATION 1

#### 4.1.1 Introduction

To compute the occupancy of an aircraft transponder, both the number of interrogations received on 1030 MHz and the number of replies on 1090 MHz need to be determined. They can be simulated using a RF Model or extracted from real RF measurements.

It is difficult to compute an accurate transponder occupancy using ground RF measurements only as the 1030 MHz transmissions are not all received on the ground. Therefore, it is not possible to compute the exact number of interrogations that an aircraft transponder would receive using ground monitoring systems. On the other hand, airborne RF measurements made on-board a test aircraft allow a precise measurement of the number of interrogations received on 1030 MHz by the test aircraft and the number of replies generated by the test aircraft on 1090 MHz. Consequently, the transponder occupancy of the test aircraft can be accurately computed.

Therefore, these guidelines recommend that States use one of the two methods to evaluate the transponder occupancy:

- Method 1-1: RF Model
- Method 1-2: Analysis of airborne RF measurements

States could combine the two methods for the verification in case the test aircraft would only fly in a limited part of the airspace which is insufficient to assess their complete airspace.

#### 4.1.2 How to select the appropriate method

To select the appropriate method, it is first recommended to determine whether airborne RF measurements in State's airspace are available.

- 1) If the State has airborne RF measurements that are less than one year old, these can be used to compute an accurate transponder occupancy using Method 1-2 which is further described in Section 4.2.2 and Section 7.2.5.
- 2) When the airborne RF measurements are more than 1 year and less than 3 years old, they are considered outdated but may be used to estimate the maximum transponder occupancy of aircraft operating in the airspace of the State and to select the appropriate method:
  - If the maximum transponder occupancy is or below 10%, a RF Model can be used. This corresponds to Method 1-1 which is further described in Section 4.2.1 and Section 7.1.
  - If the maximum transponder occupancy is above 10%, then one should consider that the measurements are no longer valid due to likely changes in the ground-based surveillance service and the 20% threshold defined in Section 3.2 may have been exceeded. In this event, these guidelines recommend that the State re-conducts the airborne RF measurements. This corresponds to Method 1-2 which is further described in Section 4.2.2 and Section 7.2.5.

Note: States may use the EUROCONTROL 1030/1090 MHz airborne RF measurements recorded on-board a test aircraft during a one-day test flight in August 2019 and a two-day test flight in December 2019. The trajectories of the test flights are provided in **Annex H**. In particular, a geographical representation of the maximum number of Mode S replies per second, with and without the TCAS replies, and the maximum number of long Mode S replies per second over a one-minute period transmitted by the test aircraft during the test flights in August 2019 and in December 2019 are provided.

- 3) In the absence of airborne RF measurements, the method selection will then depend on the number of overlapping ground-based surveillance interrogators:
  - In regions impacted by a low number of ground-based surveillance interrogators, a RF Model (Method 1-1) can be used to complete **VERIFICATION 1**.
  - In regions impacted by a high number of ground-based surveillance interrogators, these
    guidelines recommend to perform airborne RF measurement analysis (Method 1-2) to
    complete VERIFICATION 1.

To determine if a region is impacted by a low or high number of ground-based surveillance interrogators, the number of overlapping Mode S radar surveillance coverage can be used. **Annex E** provides a reference indication of the redundancy of surveillance coverage (i.e. number of overlapping surveillance coverage) considering operational Mode S radars (civil and military) at 30000ft in the ICAO EUR region and the ICAO MID region. This reference indication is derived from the Mode S interrogator code allocation plan published at the end of the MICA Cycle 28 (effective date: 16 August 2018). An update of the surveillance coverage redundancy of Mode S radars can be provided by EUROCONTROL on request. Low impacted regions can be considered to be those where surveillance coverage redundancy is equal or lower than  $\underline{20}$ , and high where the surveillance coverage redundancy is greater than  $\underline{20}$ .

These guidelines recommend that the selected method is documented using the proposed template in Section 8.

#### 4.2 Method evaluation for VERIFICATION 1

#### 4.2.1 Method 1-1: RF Model

A RF Model can be used to estimate the occupancy per second of simulated aircraft transponder in the airspace of a State due to interrogations addressed to the simulated aircraft, triggering a reply or not, and to other aircrafts from ground-based surveillance interrogators and airborne interrogators (ACAS).

To determine the compliance with **SPI IR Article 6(1)** in all the airspace of a State using the RF Model will require a lot of simulations and analysis effort. Therefore, these guidelines propose a sampling method at representative points of the highest RF activity in the airspace.

These guidelines recommend that the transponder occupancy is calculated at the following points:

- the aircraft transponder should be simulated at high altitude (e.g. 30000ft or above) where it
  should be interrogated by the greatest number of ground-based surveillance interrogators
  due to coverage redundancy (Annex E provides an example of the surveillance coverage
  redundancy of Mode S radar at 30000ft);
- the aircraft transponder should be simulated at low altitude (e.g.15000ft), within the proximity
  of an airport of a highly dense area, to ensure it is subject to the greatest number of ACAS
  interrogations;

Abnormal and unexpected events (such as military mobile interrogators operating on II 00, TRD interrogators, ground interrogators operation different from what is expected, high radar reinterrogation rate ...) may not be simulated. That is why this method is acceptable if the maximum transponder occupancy remains below 10%. If the calculated maximum transponder occupancy is greater than 10%, then it is recommended to use the second method, the analysis of airborne RF measurement, to complete VERIFICATION 1 and assess the compliance with SPI IR Article 6(1).

Please refer to Section 7.1.2 for more information about the RF Model.

#### RECOMMENDATION:

Use a RF Model to assess the compliance with SPI IR Article 6(1) is acceptable provided that:

- the configuration of all interrogators affecting the State airspace is known;
  - Note: it may be difficult to have the exact configuration of military interrogators. In this case a default conservative MIP will be used for unknown configurations. Only fixed military interrogators will be considered (no military exercise).
- an airborne environment (airborne scenario) has been defined for a peak day and has been updated to take into account the evolution of aircraft traffic since its establishment;
- the RF Model supports time-based simulations;
  - Note: in case a RF Model supporting time-based simulations would not be available, a RF Model that uses a statistical approach may be acceptable if supported by a demonstration showing that it calculates the peak transponder occupancy.
- the RF Model has been calibrated;
- the minimum simulation period is 2 hours;
  - Note: the simulation period of 2 hours is only applicable to time-based simulations.

- if the maximum transponder occupancy computed on 1-second period using standardised values is above **10**% more than 1% of the time, then Method 1-2 is to be used:
  - Note: 1% of the time is only applicable to time-based simulations.
- If the RF Model cannot simulate accurately the ACAS activity (issue with ACAS calibration demonstration), the ACAS occupancy can be estimated by using a 3% occupancy as recommended by ICAO.

#### 4.2.2 Method 1-2: Periodic analysis of airborne RF measurements

The analysis of airborne RF measurements can be used to measure the occupancy of a test aircraft transponder in the airspace of a State due to interrogations received from ground-based surveillance interrogators and airborne interrogators, eliciting or not a reply. The interrogations received by the test aircraft on 1030 MHz and its replies on 1090 MHz are used to compute its transponder occupancy.

As the test aircraft flies its trajectory, the computed transponder occupancy is calculated instantaneous. That means that the period used for the calculation of the occupancy should be relatively short to ensure that the transponder occupancy in a specific region is correctly assessed. Consequently, these guidelines recommend to assess **VERIFICATION 1** on a period of maximum 5 minutes (300 seconds). Considering that the maximum transponder occupancy shall not be higher than 20% during more than 1% of the time, the computed transponder occupancy per second shall not be higher than 20% more than 3 seconds in 5 minutes.

It is not possible to assess the compliance with **SPI IR Article 6(1)** in all the airspace of a State using the analysis of airborne RF measurements. The trajectory of the test aircraft should be defined in order to fly close to large airport(s) in the airspace of a State, at high altitude in zones that are representative of the highest RF activity and above specific surveillance areas such as cone of silence of radars for example.

Please refer to Section 7.2.5 for more information about the periodic analysis of airborne RF measurement.

#### **RECOMMENDATION:**

A periodic airborne RF measurements recording analysis to assess the compliance with **SPI IR Article 6(1)** is acceptable provided that:

- The test aircraft flies in normal peak traffic hour.
- The test aircraft flies close to large airport(s),
- The test aircraft flies at high altitude and in an area of high traffic density,
- The test aircraft flies in area of high level of ground interrogator coverage redundancy,
- The transponder occupancy will be evaluated during 5-minute periods,
- If the aircraft cannot fly in high traffic density area the transponder occupancy due to ACAS can be estimated by using a 3% occupancy as recommended by ICAO.

## 4.3 Method selection for VERIFICATION 2

#### 4.3.1 Introduction

To compute the number of replies of an aircraft transponder, the number of replies transmitted on 1090 MHz needs to be calculated. This number can be obtained using RF simulation or analysing real RF measurements performed on the ground or in the air.

These guidelines recommend that States use one of the methods identified below to evaluate the number of replies:

- Method 2-1: Simple theoretical calculation (basic RF Simulation) in a protected environment where transponder on board any aircraft flying over the State is interrogated by a very low number of ground-based surveillance interrogators.
- Method 2-2: Simulation of the 1030/1090 MHz RF environment using a RF Model in environments which are relatively protected from neighbouring interrogators and where the number of ground-based surveillance interrogator remains relatively low.
- Method 2-3: Periodic (off-line) analysis of 1030/1090 MHz RF environment recorded on the ground in regions where the number of ground-based surveillance interrogators is relatively high.
- Method 2-4: Permanent (on-line) analysis of 1030/1090 MHz RF environment on the ground in regions where the number of ground-based surveillance interrogators is very high.
- Method 2-5: Periodic analysis of 1030/1090 MHz RF airborne recording in regions where the number of ground-based surveillance interrogators is very high.

## 4.3.2 How to select the appropriate method

To select the appropriate method, it is first recommended to determine whether ground or airborne RF measurements in State's airspace are available.

- 1) If the State has RF measurements that are less than one year old, these can be used to compute the maximum number of replies per second of aircraft transponder(s) using Method 2-3, which is further described in Section 4.4.3 and Section 7.2.1, for ground RF measurements, and Method 2-5, which is further described in Section 4.4.5 and Section 7.2.5, for airborne RF measurements.
- 2) When the RF measurements are more than 1 year and less than 3 years old, they are considered outdated but may be used to estimate the maximum number of replies per second of aircraft transponder(s) operating in the airspace of the State and to select the appropriate method. For ground RF measurements, a group of aircraft transponders with high number of replies are analysed:
  - If the maximum number of replies per second of any aircraft transponder is below 30% of the ICAO minimum reply rates, the Simple theoretical calculation can be used. This corresponds to Method 2-1 which is further described in Section 4.4.1 and Section 7.1.1.

Note: All other methods can also be used.

• If the maximum number of replies per second of any aircraft transponder is equal or above 30% and below 50% of the ICAO minimum reply rates, a RF Model can be used. This corresponds to Method 2-2 which is further described in Section 4.4.2 and Section 7.1.2.

Note: All other methods using ground/airborne RF measurements can also be used.

- If the maximum number of replies per second of any aircraft transponder is equal or above 50% and below 90% of the ICAO minimum reply rates, a periodic analysis of ground RF measurement can be used. This corresponds to Method 2-3 which is further described in Section 4.4.3 and Section 7.2.1.
  - Note: The permanent analysis of ground RF measurements and the periodic analysis of airborne RF measurements can also be used.
- If the maximum number of replies per second of any aircraft transponder is equal or above 90% of the ICAO minimum reply rates, it is recommended to use the permanent analysis of ground RF measurements. This corresponds to Method 2-4 which is further described in Section 4.4.4 and Section 7.2.2.
- If the maximum number of replies per second of any aircraft transponder is equal or above 90% of the ICAO minimum reply rates, the periodic analysis of airborne RF measurements can be used to complement the permanent analysis of ground RF measurements in order to identify ground interrogators that trigger excessive replies. This corresponds to Method 2-5 which is further described in Section 4.4.5 and Section 7.2.5.

Note: States may use the EUROCONTROL 1030/1090 MHz airborne RF measurements recorded on-board a test aircraft during a one-day test flight in August 2019 and a two-day test flight in December 2019. The trajectories of the test flights are provided in **Annex H**. In particular, a geographical representation of the maximum number of Mode S replies per second, with and without the TCAS replies, and the maximum number of long Mode S replies per second over a one-minute period transmitted by the test aircraft during the test flights in August 2019 and in December 2019 are provided.

Figure 2 illustrates which method can be used depending on the estimated maximum number of Mode S replies per second of transponder aircraft flying in the airspace of a State.

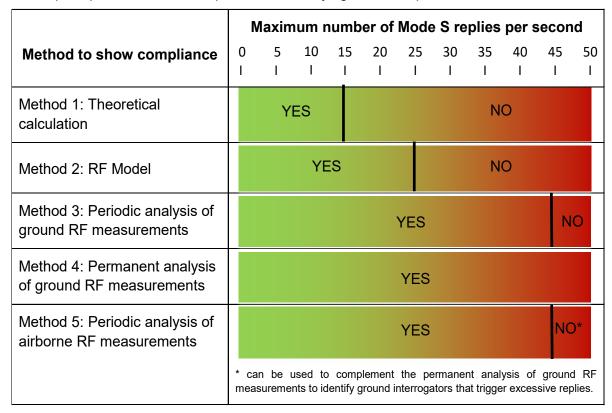


Figure 2 – Method to assess compliance vs number of Mode S replies

Figure 3 illustrates which method can be used depending on the estimated maximum number of Mode S long replies per second of transponder aircraft flying in the airspace of a State.

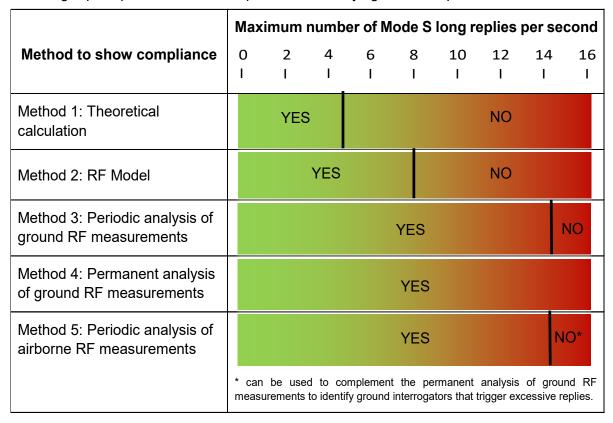


Figure 3 – Method to assess compliance vs number of Mode S long replies

Figure 4 illustrates which method can be used depending on the estimated maximum number of Mode A/C replies per second of transponder aircraft flying in the airspace of a State.

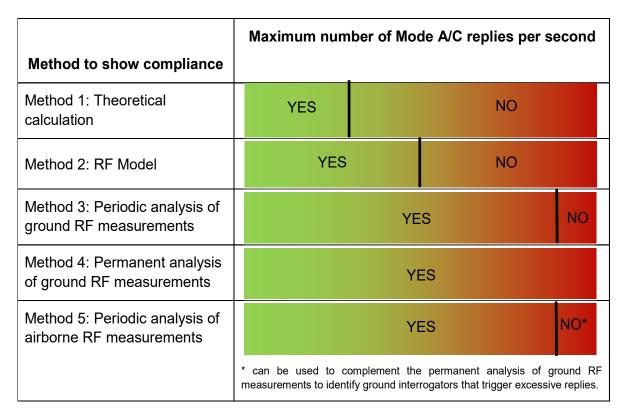


Figure 4 - Method to assess compliance vs number of Mode A/C replies

In the absence of recent ground or airborne RF measurements, these guidelines recommend that the State performs a preliminary ground or airborne RF recording analysis to assess the reply rate of transponder on board aircrafts flying in its airspace. This preliminary RF recording will be used to complete **VERIFICATION 2**.

Note: If this preliminary RF recording is an airborne RF measurement, it may be use for **VERIFICATION 1**.

#### 4.4 Method evaluation for VERIFICATION 2

## 4.4.1 Method 2-1: Simple theoretical calculation

A simple theoretical calculation may be used by the State to compute an approximate number of interrogations from ground-based surveillance interrogators an aircraft transponder would receive per second, and the approximate number of replies it would transmit.

The rates of replies of the simulated aircraft transponder should be calculated at high altitude (e.g. 30000ft or above) where it should be interrogated by the greatest number of ground-based surveillance interrogators due to coverage redundancy (**Annex E** provides an example of the surveillance coverage redundancy of Mode S radar at 30000ft).

The computed rates of replies of the simulated aircraft transponder will be compared to the minimum reply rates specified in the ICAO Annex 10 Volume IV.

Due to the inaccuracy of the results, this method is only acceptable if the analysis results of outdated RF measurements or preliminary recordings are below **30%** of the minimum reply rates specified in the ICAO Annex 10 Volume IV.

Please refer to Section 7.1.1 for more information about the simple theoretical calculation.

#### RECOMMENDATION:

Use of a simple theoretical calculation to assess the compliance with **SPI IR Article 6(1)** is acceptable provided that:

- the analysis of outdated RF measurements or preliminary recordings show that the reply rates of analysed aircraft are always below 30% of the minimum reply rates specified in the ICAO Annex 10 Volume IV;
- the configuration of all interrogators affecting the State airspace is known;
  - Note: it may be difficult to have the exact configuration of military interrogators. In this case a default conservative MIP will be used for unknown configurations. Only fixed military interrogators will be considered (no military exercise).
- if the computed number of replies is above **30**% of the minimum reply rates specified in the ICAO Annex 10 Volume IV, these guidelines recommend to apply another method (Method 2-2, 2-3, 2-4, or 2-5);

#### 4.4.2 Method 2-2: RF Model

A RF Model can be used to estimate the number of Mode A/C replies, the number of Mode S replies and the number of Mode S long replies per second of a simulated aircraft transponder due to interrogations from ground-based surveillance interrogators and airborne interrogators.

To determine the compliance with **SPI IR Article 6(1)** in all the airspace of a State using the RF Model will require a lot of simulations and analysis effort. Therefore, these guidelines propose a sampling method at test points that are representative of the highest RF activity in the airspace.

These guidelines recommend that the reply rates are calculated at the following points:

- the aircraft transponder should be simulated at high altitude (e.g. 30000ft or above) where it should be interrogated by the greatest number of ground-based surveillance interrogators due to coverage redundancy (Annex E provides an example of the surveillance coverage redundancy of Mode S radar at 30000ft);
- the aircraft transponder should be simulated at low altitude (e.g.15000ft), within the proximity
  of airport of a highly dense area, to ensure it is subject to the greatest number of ACAS
  interrogations;

Abnormal and unexpected events (such as military mobile interrogators operating on II 00, TRD interrogators, ground interrogators operation different from what is expected, high radar reinterrogation rate ...) are not simulated. That is why this method is acceptable if the maximum reply rates simulated by the RF Model remains below 50% of the minimum reply rates specified in the ICAO Annex 10 Volume IV. If a maximum reply rate greater than 50% is calculated, then it is recommended to use another method based of RF measurements to complete VERIFICATION 2 and assess the compliance with SPI IR Article 6(1).

The computed number of replies per second shall not exceed the minimum reply rates specified in the ICAO Annex 10 Volume IV.

Please refer to Section 7.1.2 for more information about the RF Model.

#### RECOMMENDATION:

Use a RF Model to assess the compliance with SPI IR Article 6(1) is acceptable provided that:

- the analysis of outdated RF measurements or preliminary recordings show that the reply rates of analysed aircraft are always below 50% of the minimum reply rates specified in the ICAO Annex 10 Volume IV;
- the configuration of all interrogators affecting the State airspace is known;
  - Note: it may be difficult to have the exact configuration of military interrogators. In this case a default conservative MIP will be used for unknown configurations. Only fixed military interrogators will be considered (no military exercise).
- an airborne environment has been defined for a peak day and has been updated to take into account the evolution of aircraft traffic since its establishment;
- the RF Model supports time-based simulations;
  - Note: in case a RF Model supporting time-based simulations would not be available, a RF Model that uses a statistical approach may be acceptable if supported by a demonstration showing that it calculates the peak transponder occupancy.
- the RF Model has been calibrated;
- the minimum simulation period is 2 hours;
  - Note: the simulation period of 2 hours is only applicable to time-based simulations.
- if the computed maximum reply rates is above **50**% of the minimum reply rates specified in the ICAO Annex 10 Volume IV during the simulation period, then these guidelines recommend to apply another method (Method 2-3, 2-4 or 2-5) based of RF measurements:

## 4.4.3 Method 2-3: Periodic analysis of ground RF measurements

The periodic analysis of 1090 MHz RF band recorded on the ground can be used to count per second the number of Mode A/C replies, the number of Mode S short replies and the number of Mode S long replies of aircraft transponders. The computed number of replies per second shall not exceed the minimum reply rates specified in the ICAO Annex 10 Volume IV to assess the compliance with SPI IR Article 6(1).

If the number of replies per second is too high, the analysis of the associated 1030 MHz RF recordings can be used to identify the potential source of the problem. However, the analysis of 1030 MHz transmissions is limited on the ground. Therefore, the ground recording analysis may be complemented by airborne recording analysis in order to identify ground interrogators that trigger excessive replies.

It may not be possible to analyse all the airspace of a State using the periodic analysis of ground RF measurements. Due to the garbling of aircraft replies, only replies from aircraft at short distance are correctly decoded by the ground RF measurement system in high traffic density area (the **Annex M** provides an example of the probability of detection of Mode S long replies from aircraft using ground RF measurements).

The compliance will be demonstrated using a sampling method. Only few zones/aircraft, which are representative of the highest RF activity, will be used to assess the compliance. The Section 7.2.4 provides guidelines to select carefully the places where to deploy RF measurement systems in order to assess the compliance with the Article 6(1).

The 1030/1090 MHz RF bands are periodically recorded on the ground and analysed:

Aircraft with the highest number of replies are analysed.

- Aircraft at highest altitude are analysed to ensure they are interrogated by a maximum number of radar.
- At proximity of airport, aircraft at low altitude are analysed to ensure they are interrogated by a maximum number of ACAS systems.
- ACAS interrogations and replies are available in the ground RF measurements and should be used to assess the compliance with SPI IR Article 6(1).
- The RF Measurement should last an entire day to ensure that the pic of traffic in the day is recorded (ACAS activity depends on the density of aircraft)

Periodic ground RF measurements campaign may be sufficient in area where the aircraft reply rates are always below the minimum reply rates specified in the ICAO Annex 10 Volume IV.

However, because the RF recordings are done periodically, abnormal and unexpected events (e.g. military mobile interrogators operating on II 00, TRD interrogators ...) that may affect the aircraft transponders may not happen during the recording period. That is why it is not acceptable to use the periodic analysis of ground RF measurements to assess the compliance with **SPI IR Article 6(1)** when the analysis results are very close (above 90%) or above the minimum reply rates specified in the ICAO Annex 10 Vol IV. In this case, the permanent analysis of ground RF measurements is the only method which enables a real-time monitoring of the frequency bands and which allows to react on specific issues and unexpected events.

Please refer to Section 7.2.1 for more information about the periodic analysis of ground RF measurements.

#### RECOMMENDATION:

Use periodic ground RF measurements analysis to assess the compliance with **SPI IR Article 6(1)** is acceptable provided that:

- the analysis of outdated RF measurements or preliminary recordings show that the reply rates of analysed aircraft are always below 90% of the minimum reply rates specified in the ICAO Annex 10 Volume IV:
- the place of ground RF measurement is carefully chosen;
- the aircraft that are analysed are carefully chosen;
- if the computed maximum reply rates are above **90**% of the minimum reply rates specified in the ICAO Annex 10 Volume IV, then these guidelines recommend to apply another method (Method 2-4) which is based on the permanent analysis of ground RF measurements.

It is also recommended to use the number of ACAS replies obtained from analysis to verify if the peak reply rates of the analysed aircraft exceed the minimum reply rates specified in the ICAO Annex 10 Volume IV.

## 4.4.4 Method 2-4: Permanent analysis of ground RF measurements

The permanent analysis of 1090 MHz RF band recorded on the ground can be used to count per second the number of Mode A/C replies, the number of Mode S replies and the number of Mode S long replies of transmitted by aircraft transponders. To determine compliance with **SPI IR Article 6(1)**, the computed number of replies per second shall not exceed the minimum reply rates specified in the ICAO Annex 10 Volume IV.

If the number of replies per second is too high, the analysis of the associated 1030 MHz RF recordings can be used to identify the potential source of the problem. However, the analysis of 1030 MHz transmissions is limited on the ground. Therefore, the ground recording analysis may be complemented by airborne recording analysis in order to identify ground interrogators that trigger excessive replies.

It may not be possible to analyse all the airspace of a State when using the permanent analysis of ground RF measurements. Due to the garbling of aircraft replies, only replies from aircraft at short distance are correctly decoded by the ground RF measurement system in high traffic density area (the **Annex M** provides an example of the probability of detection of Mode S long replies from aircraft using ground RF measurements).

The compliance will be demonstrated using a sampling method. Only few zones/aircraft, which are representative of the highest RF activity, will be used to assess the compliance. The Section 7.2.4 provides guidelines to select carefully the places where to deploy RF measurement systems in order to assess the compliance with the Article 6(1).

The 1030/1090 MHz RF bands are permanently recorded on the ground and analysed:

- Aircraft with the highest number of replies are analysed.
- Aircraft at highest altitude are analysed to ensure they are interrogated by a maximum number of radars.
- At proximity of airport, aircraft at low altitude are analysed because they may be subject to a higher level of ACAS interrogations.
- ACAS interrogations and replies are available in the ground RF Measurements and should be used to assess the compliance with SPI IR Article 6(1).

These guidelines recommend to set up a permanent ground recording system in the area where the aircraft reply rates are very close or above the minimum reply rates specified in the ICAO Annex 10 Volume IV.

Please refer to Section 7.2.2 for more information about the permanent analysis of ground RF measurements.

#### **RECOMMENDATION:**

Use permanent ground RF measurements recording analysis to assess the compliance with SPI IR Article 6(1) if the analysis of outdated RF measurements or preliminary recordings show that some of the reply rates of the analysed aircraft are above 90% of the minimum reply rates specified in the ICAO Annex 10 Volume IV. This method is the best solution provided receivers are installed at key points (the continuous coverage is not required).

Carefully choose the place of ground RF measurement.

Carefully choose the aircraft that are analysed.

Use the number of ACAS replies obtained from analysis to verify if the peak reply rates of the analysed aircraft exceed the minimum reply rates specified in the ICAO Annex 10 Volume IV.

In addition, this method also enables the monitoring of 1030/1090 MHz frequency band for real time reaction to 1030/1090 MHz RF issues.

The permanent analysis of ground RF measurements may be complemented by the periodic analysis of airborne RF measurements (Method 2-5) in order to identify ground interrogators that trigger excessive replies.

#### 4.4.5 Method 2-5: Periodic analysis of airborne RF measurements

Airborne 1030 MHz and 1090 MHz RF measurements can be performed during test flights. The analysis of the 1090 MHz RF recordings can be used to count per second the number of Mode A/C replies, the number of Mode S replies and the number of Mode S long replies transmitted by the test aircraft. To determine compliance with **SPI IR Article 6(1)**, the computed number of replies per second shall not exceed the minimum reply rates specified in the ICAO Annex 10 Volume IV during the flight duration. If the number of replies per second is too high, the analysis of the associated 1030 MHz RF recordings can be used to identify the potential source of the problem.

The trajectory of the test aircraft should be defined in order to fly close to large airport(s) in the airspace of a State, at high altitude in zones that are representative of the highest RF activity and above specific surveillance areas such as the cone of silence of radars for example.

It may not be possible to assess the compliance with **SPI IR Article 6(1)** in all the airspace of a State using the analysis of airborne RF measurements. The compliance will be demonstrated using a sampling method. **Only few zones, which are representative of the highest RF activity, will be used to assess the compliance.** 

The periodic analysis of airborne RF measurements can also be used to complement the permanent analysis of ground RF measurements in order to identify ground interrogators that trigger excessive replies.

Refer to Section 7.2.5 for more information about the periodic analysis of airborne RF measurement.

#### RECOMMENDATION:

If the analysis of outdated RF measurements or preliminary recordings show that the reply rates of the analysed aircraft are always below **90**% of the minimum reply rates specified in the ICAO Annex 10 Volume IV, then the periodic airborne RF measurements can be used to assess the compliance with **SPI IR Article 6(1)**.

If the analysis of outdated RF measurements or preliminary recordings show that some of the reply rates of the analysed aircraft are above **90**% of the minimum reply rates specified in the ICAO Annex 10 Volume IV, then the periodic airborne RF measurements can be used to complement the permanent analysis of ground RF measurements (Method 2-4).

Choose carefully the trajectory of the test aircraft to ensure that the test aircraft flies at places that are representative of the highest RF activity.

Use the number of ACAS replies from test aircraft to verify if the peak reply rates exceed the minimum reply rates specified in the ICAO Annex 10 Volume IV.

## 4.5 Verification results and resolution of problems

#### 4.5.1 Documentation

Following the verifications, these guidelines recommend that States document the results using the proposed template in section 8.

#### 4.5.2 Results that exceed recommended thresholds

If the maximum transponder occupancy is above the 20% threshold determined by these guidelines, or if the number of transponder replies does exceed the minimum reply rates specified in the ICAO Annex 10 Volume IV, then further analysis and resolution actions will need to be performed by the State.

- For VERIFICATION 1, when the maximum transponder occupancy is close to or above the 20% threshold, it is recommended to analyse recent airborne RF measurements or plan new airborne RF measurements. The analysis of interrogations received by the test transponder on 1030 MHz should help to identify the cause of the high transponder occupancy.
- For VERIFICATION 2, the ground-based interrogator triggering the aircraft transponder replies on 1090 MHz can be determined by analysing the 1030 MHz interrogations on the basis of the interrogator identifier code (except those using II code 0). If it is not possible to find the cause of the high number of Mode S replies on 1090 MHz with ground RF measurement, then it may be required to perform airborne RF measurements.

## 4.5.3 Resolving problems

When the analysis reveals that one ground-based surveillance interrogator is degrading the surveillance service e.g. triggering too many replies from aircraft transponders, these guidelines recommend to perform the following steps to resolve the problem:

- 1. The ground-based surveillance interrogator degrading the surveillance service needs to be located and identified. This interrogator may be located within the State or a neighbouring State.
  - If the ground-based surveillance interrogator is located within the State, the State competent authority will have the necessary information for its identification. Such information may not be available for interrogators installed in neighbouring States.
  - See Section 6.1.1 for more information about the identification of interrogators.
- 2. These guidelines recommend that such problems are reported to EUROCONTROL which may support the competent authority in identifying the interrogator and resolving the problem. Such reports will assist the Network Manager's monitoring task<sup>8</sup> [RD 14].
- 3. In case the ground-based surveillance interrogator degrading the surveillance service is located within the State, the State competent authority needs to contact the responsible operator to correct the problem (see below Step 6).
- 4. In case the ground-based surveillance interrogator degrading the surveillance service is located in a neighbouring State, the competent authority needs to contact the other State (see Section 6.1.4 for points of contact) to report the problem. On request, EUROCONTROL may contact the other State.
- 5. The competent authority of the neighbouring State has to report the problem to the operator for corrective actions.
- 6. The operator has to verify the configuration of the interrogator to confirm the problem.
- 7. Upon confirmation, the operator has to provide a modification plan to the responsible State authority. These guidelines recommend that this plan is provided to EUROCONTROL.

<sup>&</sup>lt;sup>8</sup> Commission Implementing Regulation (EU) 2019/123, Article 7, point 3 (g) (iii) [RD 14]

- 8. The modification plan has to be verified and validated by the responsible competent authority, with the support of EUROCONTROL if requested. The responsible competent authority has to ensure that the new configuration will not trigger too many replies (See configuration assessment as described in Section 5.5 of **VERIFICATION 4**).
- 9. Once validated, the modification of the configuration of the problematic surveillance interrogator needs to be applied as soon as possible in order to reduce the number of interrogations and triggered replies.
- 10. A new analysis has to confirm that the problem has disappeared and these guidelines recommend to notify the results to EUROCONTROL.
- 11. In case the problem cannot be resolved, it may be necessary to escalate the problem at higher level (see Section 6.1.6).

In the case the problematic interrogator is located in a country which is not subject to the **SPI IR**, the resolution will follow the same steps as described above. But the resolution of the problem may require the support of international organisations (e.g. ICAO, NATO).

Note: even in case of compliance with the **SPI IR**, if the analysis of replies enables the identification of a ground-based surveillance interrogator that triggers too many replies, the operator responsible of the interrogator has to be contacted and the configuration of the ground-based surveillance interrogator has to be modified.

The guidelines recommend that States implement a process to handle over-interrogation report, i.e. high number of interrogations and/or high number of triggered replies, suspected to come from a ground-based surveillance interrogator located inside their own State with the support of local operators. More information on the process is provided in Section 6.1.2.

If the analysis shows that the problem is due to the high number of interrogators, then it may be necessary to review the configuration of all Mode S interrogators affecting the State and to rationalise the surveillance infrastructure. A solution may not be straightforward. The rationalisation will require the support of States and discuss appropriate actions in the context of EUROCONTROL working arrangements.

Technical options to reduce interrogations and replies are provided in Section 6.1.5.

# 5 Process to support VERIFICATION 4 (Optional)

#### 5.1 Overview

The following process does not directly support a State obligation under SPI IR Article 6.

Although optional, these guidelines strongly recommend **VERIFICATION 4** as it will help States fulfil their obligations. The configuration of each ground-based surveillance interrogator installed in the State is to be assessed to ensure it does not lead to excessive interrogations and/or replies from aircraft transponders.

These guidelines recommend that States establish a process to assess and approve the configuration of ground-based surveillance interrogators prior to the putting into service or approving the transmissions. If it has not been the case, the configuration of all ground-based surveillance interrogators that are already in service should also be assessed following these guidelines.

These guidelines recommend the use of a RF Model to perform the assessment of new ground-based surveillance interrogator(s) in their environment before they are put into service or approved to start transmissions on 1030 MHz. Furthermore, such simulations can be coordinated with operators in the early steps of a procurement process, preferably before contract signature.

These guidelines recommend that States re-assess the configuration of ground-based surveillance interrogator(s) when an ANSP submits an updated DoV and technical file. It is to be noted that not all operators of systems transmitting on the 1030/1090 MHz RF link are required to submit a DoV to the national supervisory authority, therefore States will also need to be attentive to those operators.

## 5.2 State approval of Mode S and Mode A/C transmissions

Prior to the putting into service or approving the transmissions of any ground-based surveillance interrogator, civil or military, these guidelines recommend to verify that the interrogator is correctly configured by ensuring it does not trigger too many replies from aircraft transponders. Extending the obligations under the **SPI IR**, States could define a national approval, authorisation or licensing process before ground based-interrogators start transmitting.

Any ground-based surveillance interrogator (fixed and mobile interrogator for permanent or temporary operation), including the ground-based interrogators operating without an allocated IC (military interrogators, WAM and MLAT systems operating on II 00), military interrogators operating on II 15 and matching SI codes, and TRD Mode S radars transmitting on II 14 or matching SI codes, should not start transmission without the State approval.

As part of its national approval process, the State could delegate part (or all) of the pre-operational verification task to one or several local competent authorities (e.g. one nominated for civil and one nominated for military), or to a central civil-military organisation. The process should also cover existing ground-based surveillance interrogators that are already in operation and any configuration modifications.

## 5.3 Coordination with military authorities

During a military exercise, military mobile interrogators may be deployed and operated temporarily on II 00. Military authorities may not want to provide detailed information about the mode of operation of such interrogators. As a result, it may be more efficient for the State to delegate the assessment of the ground-based interrogator configuration(s) to a competent military authority. Military authorities should inform the State when mobile interrogators are deployed, and confirm that their configuration has been duly assessed and will not trigger excessive interrogations nor too many replies from aircraft transponders.

States need to be informed of fixed Military Mode S radars which are deployed on a permanent basis and which operate with an allocated interrogator code (MICA process). The State may also delegate the assessment of the configuration of these interrogators to the competent military authority.

## 5.4 Interrogator configuration parameters to be assessed

To assess the configuration of the ground-based surveillance interrogator, these guidelines recommend that the operator (ANSP, military, manufacturer...) of the interrogator provides the competent authority with the following minimum configuration parameters:

- Surveillance interrogator name;
- Latitude and longitude position (in decimal degrees) of interrogator(s);
  - o A WAM surveillance interrogator is made of several interrogators.
- Ground altitude above mean sea level (in meter) of interrogator(s);
  - o A WAM surveillance interrogator is made of several interrogators.
- Antenna centre height above ground (in meter) of interrogator(s);
  - o A WAM surveillance interrogator is made of several interrogators.
- MIP (Mode Interlace Pattern) defining the sequence of interrogations that is periodically repeated by the interrogators (All-Call interrogations with SLO if applied and probability of reply, Mode A/C interrogations with short P4 or not, Roll-Call period ...);
- Mode S All-Call IRF;
- Mode A/C Only All-Call IRF (P1 P3 short P4);
- Mode A/C IRF (P1 P3) for Mode S radar operating in Mixed Mode MIP or SSR Mode A/C radar;
- Rotation period or interrogation period for non-rotating interrogators (WAM) (in second);
- Number of ELS interrogation per aircraft, per second or per period (every scan, 1 scan on two, every surveillance period ...):
  - Number of DF4 request (per second or per period)
  - Number of DF5 request (per second or per period)
- List of BDS extracted with the occurrence of extraction per aircraft, and per second or per period (every scan, 1 scan on two, every surveillance period ...):

- Periodicity of BDS 1,0, BDS 1,7, BDS 1,D, BDS 2,0 extraction in second/period, or only at acquisition and change (Comm-B broadcast)
- o Periodicity of BDS 3,0 extraction in second/period, or only on request
- o Periodicity of BDS 4,0, BDS 5,0 and BDS 6,0 extraction in second/period
- Other extracted BDS periodicity in second/period
- Number of Military interrogations per type of interrogation, per second or per period;
- Range of radar or region of interest for WAM/MLAT;
- The number of transmitters that may interrogate simultaneously the same aircraft for WAM and MLAT;
- Maximum number of re-interrogation, if available on the radar;
- Power of transmission:
  - Main beam (in dBm)
  - o SLS (in dBm)

And the interrogator characteristics:

- Antenna diagram,
- Interrogator manufacturer and model

Several configurations may be provided for the same ground surveillance interrogator, in particular for TRD interrogators.

For more information on the above parameters and guidance on Mode S interrogators configuration to reduce 1030/1090 MHz RF scarce resource saturation, please refer to *Guidance material on Mode S interrogation configuration to reduce 1030/1090 RF usage, SNI-WP3-Del3.5* [RD 6].

## 5.5 Assessment of interrogator configurations

The competent authority needs to ensure that the interrogator configuration is acceptable and does not trigger too many replies: Mode A/C replies, short and long Mode S replies.

In particular, the competent authority needs to ensure that the Mode S interrogator does not trigger an excessive number of All-Call replies as specified in section 3.1.2.11.1.1.2 of the ICAO Annex 10 Volume IV Amendment 89 [RD 5]:

"3.1.2.11.1.1.2 Maximum number of Mode S All-Call replies triggered by an interrogator. For aircraft that are not locked out, a Mode S interrogator shall not trigger, on average, more than 6 All-Call replies per period of 200 ms and no more than 26 All-Call replies counted over a period of 18 seconds."

It is to be noted that the below verification tasks are based on analysis and assumptions (e.g. theoretical beam width may be different to real one). They will, however, also support the operational assessment of **VERIFICATION 5** described in Section 3.6.

 A simple method to assess the Modes S interrogator configuration and to compute the number of Mode S All-Call replies triggered by a Mode S radar is provided in **Annex J**. By applying that method, if it is determined that the Mode S interrogator configuration would trigger more than 6 All-Call replies in average in the beam, then these guidelines recommend to modify the configuration.

- 2. The competent authority needs to ensure that selective interrogations from Mode S interrogators will not trigger too many long Mode S replies. There is no fixed or reference value to determine whether the number of long Mode S replies is too high. Indeed, what would be acceptable in an environment with a low number of Mode S interrogators may not be acceptable in an environment with high number of Mode S interrogators. These guidelines recommend to adjust the number of selective interrogations to avoid unnecessary BDS register extractions (see section 6.1.5).
- 3. The competent authority needs to ensure that the interrogation pattern of a WAM/MLAT system is adapted to the interrogation period (typically 1 second) to prevent over-interrogation of aircraft. For example, a WAM/MLAT system extracting 3 BDS every second (interrogation period) may not be acceptable. These guidelines recommend to adjust the number of selective interrogations to avoid unnecessary BDS register extractions (see section 6.1.5).

Competent authorities are highly recommended to consult document **[RD 6]** to get more information on the assessment of ground-based surveillance interrogator configurations.

Should the above tasks determine an inappropriate or incorrect configuration, these guidelines recommend that the competent authority does not allow the putting into service of the ground-based interrogator (or approve the start of transmissions on 1030 MHz) and instructs the operator to modify the configuration for re-assessment. When it is assessed that the configuration of an operating ground-based interrogator is inappropriate or incorrect, these guidelines recommend that the competent authority considers taking it out of service or instructs immediate action by the operator.

## 5.6 Assessing the interrogator in its environment

These guidelines recommend that the competent authority evaluates the operational impact of the new ground-based surveillance interrogator(s) on aircraft transponders by using a RF model, particularly in environments where the number of ground-based surveillance interrogators is already high.

To perform the evaluation, it is necessary to have the up-to-date information about ground-based surveillance interrogators (Position, MIP, IRF, Power, number of extracted BDS ...) located within both the State and neighbouring States in a range of approximately 300 NM. This information is required to define a reliable RF Model and perform accurate simulations of aircraft transponders in the 1030/1090 MHz environment.

It is recognised that ground-based surveillance interrogator locations and parameters may be sensitive or confidential (e.g. the position and the configuration of military interrogators) meaning that adjacent States may not be willing to share this information. However, the lack of shared information will be detrimental to the RF Models developed by all neighbouring States. This is further discussed in Section 7.1.3.1.

On the basis of the RF Model the competent authority can assess whether the putting into service of the ground-based surveillance interrogator will lead to transponder occupancy exceeding 20% or reply rates exceeding the minimum reply rates specified in the ICAO Annex 10, Volume IV.

# 6 Management and Support

## 6.1 Management of RF issues

## 6.1.1 Identification of interrogators

When performing the analysis of the RF measurements made on the ground or on-board a flying test aircraft, it may happen that an interrogator with an incorrect or unexpected behaviour is detected. It is then necessary to identify this interrogator and contact the responsible operator. The identification requires detailed characteristics of interrogator to recognise its interrogation pattern.

This identification is performed by the State competent authority using the information of ground-based surveillance interrogators installed in the own State, and using the information available on the EUROCONTROL MICA website for ground-based surveillance interrogators installed in neighbouring States.

The MICA website contains information of Mode S radars with a fixed position which have been allocated an interrogator code in the ICAO EUR region and the ICAO MID region: approximate position, rotation period, display of Mode S radar coverage per IC in Google Map. For more information about the MICA website, what information is available and who has access to this information, please refer to Section 6.2.1.1. Information about military mobile interrogators operating on II code = 0 is not available on the MICA website.

In case the competent authority cannot identify the interrogators with incorrect or unexpected behaviour, he can contact EUROCONTROL which may have more information about ground-based surveillance interrogators (e.g. IRF, MIP...) and will support the State in the identification of those interrogators.

There is currently no list of SSR Mode A/C radars and WAM/MLAT systems deployed in the European region. Therefore, these guidelines recommend that States initiate actions to build such a list which can be provided to EUROCONTROL to build a shared data repository.

With regard to WAM/MLAT systems, these guidelines recommend that States advise operators to make use of an interrogator code different from II code = 0 in order to be able to identify the interrogations of those systems. Indeed if all WAM and MLAT systems are configured to operate on II code = 0, it is more difficult to identify their interrogations, particularly when mobile military Mode S radars are deployed and operated on II code = 0 in the same area.

## 6.1.2 Handling of over-interrogations and configuration issues

Over-interrogations are often due to configuration issues; therefore, the two are closely related. A ground-based surveillance interrogator degrading the surveillance service within the State may be identified:

- During the execution of VERIFICATION 1 or 2
- By a neighbouring State.

These guidelines recommend that States implement a process to handle these issues i.e. high number of interrogations and/or high number of triggered replies, suspected to come from a ground-based surveillance interrogator located inside their own State. This process can be developed with the operators of ground-based surveillance interrogators and needs to include at least the following steps:

Verification of the interrogator configuration;

- Elaboration of a modification plan of the interrogator configuration in order to reduce the number of interrogations and/or the number of triggered replies;
- Validation of the modification plan, including the verification of new interrogator configuration;
- Implementation of the modification plan;
- Verification of new interrogator configuration.

## 6.1.3 Handling of interferences

According to ITU Constitution CS 1003 and the ITU Radio Regulations Article 1.169: "Interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs or repeatedly interrupts a radiocommunication service operating in accordance with the Radio Regulations" are defined as harmful interferences.

Such harmful interferences may be due to:

- the wrong transmission (e.g. transmission during idle mode) of a ground-based surveillance interrogator authorised to operate on the 1030/1090 MHz frequency bands;
- transmitter operating on the 1030/1090 MHz frequency bands without authorisation to use these frequencies;
- transmitter operating on adjacent frequencies and affecting the 1030/1090 MHz frequency bands:

Following ITU Radio Regulations Article 15, States (administrations<sup>9</sup>) are to take the necessary steps to handle harmful interferences detected on 1030/1090 MHz. In particular, according to ITU Radio Regulations Article 15.19 and 15.20, when interferences are detected on 1030/1090 MHz, they have to be reported to the administration. Furthermore, ITU Radio Regulations Article 15.28 and 15.37 require the administration to take immediate actions to identify the source of the interfering transmission and to stop it.

These guidelines recommend that such reports are also reported to EUROCONTROL Network Manager to assist its monitoring task.

#### 6.1.4 Points of contact

The verification processes defined in these guidelines underline the need to identify a point of contact for each nominated competent authority in States and operators of ground-based interrogators.

At national level, these guidelines recommend that States request operators (ANSP, military, manufacturer, airport operator) to communicate a point of contact (preferably 24-7) for the ground-based surveillance interrogators that they manage.

At international level, these guidelines recommend that States provide these points of contact (nominated competent authorities and operators) to any relevant international organisation performing central monitoring tasks (Network Manager) or oversight. The sharing of these points of contact can lead to the maintenance of a central list that can be used by States to coordinate ground-interrogator deployments, assessments or issues.

<sup>&</sup>lt;sup>9</sup> ITU Radio Regulations Article 15 employs the term administration which is typically the State national radio regulator.

#### 6.1.5 Technical options to reduce RF issues

An approach to manage RF issues is to take a series of actions to limit their occurrence. The following non-exhaustive actions may be taken to improve the surveillance infrastructure and reduce the number of replies:

- Reduce the number of All-Call replies triggered by Mode S radars; e.g. 3 All-Call replies in average in the beam (or less) instead of 6 All-Call replies as specified in section 3.1.2.11.1.1.2 of the ICAO Annex 10 Volume IV.
  - For short-range Mode S radar (e.g. <100NM), the acquisition of aircraft could be done using ADS-B extended squitters, reducing even more the number of required All-Call replies.
- Re-extend the surveillance map and lockout map of Mode S radar in order to reduce the airspace where the Mode S aircraft transponder is not lockout-out.
  - Note: the extension of the surveillance coverage will increase the area where the aircraft transponder is selectively interrogated by the Mode S radar, and may increase the number of Mode S long replies from the Mode S aircraft transponder.
- Reduce the transmission power of the ground-based surveillance interrogators, in particular for radars providing a short-range coverage.
- Cluster Mode S radars to reduce the number of All-Call replies. In the future, cluster of Mode S radars will also be used to reduce the number of selective interrogations and replies.
- Do not extract BDS registers when they are not operationally used.
- Reduce the frequency of extraction of BDS registers. For example, it may not be useful to extract BDS 40, 50 and 60 every scan.
  - The data sharing of surveillance data or the use of ADS-B data should reduce the need to extract transponder registers. ADS-B version 2 format includes the transmission of selected altitude, selected heading, and barometric pressure setting in the target state and status messages.
- Another option is to use the data-link map and data-link interface to extract registers only where or when necessary, however this option requires changes in the Mode S radars.

#### 6.1.6 Resolution of issues between States

The availability of State technical reports or completed templates, as the one in Section 8 will also assist the resolution of issues between States.

In the event of unresolved issues between States, such as:

- problems due to Mode S interrogators outside the State(s) for which no solution has been found;
- problems due to military Mode S interrogators;
- if the replies of a transponder on-board an aircraft flying over a State exceeds the minimum reply rates specified in the ICAO Annex 10 Volume IV, but the source of the problem in the other States cannot be identified, e.g. it comes from large number of interrogators in several States.

These guidelines recommend that the State(s) report their unresolved issues to international and/or civil/military institutions (EUROCONTROL, EASA, European Commission, ICAO, EDA) through official correspondence and request supporting actions as required in Article 6(4).

## 6.2 **EUROCONTROL** support to States and Operators

EUROCONTROL provides support to States and operators in standardising, deploying and monitoring the surveillance infrastructure. This support complements the monitoring tasks conducted under Article 7.3(g)(iii) of Commission Implementing Regulation (EU) 2019/123 **[RD 14]** (the network functions regulation)

Through this monitoring function and its working arrangements, States and operators may ask the support of EUROCONTROL to help them to implement the recommendations identified in these guidelines. This support is outlined below.

#### 6.2.1 Available interrogator information

#### **6.2.1.1** Mode S radar

The EUROCONTROL Mode S Interrogator Code Allocation (MICA) cell coordinates the allocation of Interrogator Code (IC) to fixed Mode S radar, civil and military, in the ICAO EUR region and in the ICAO MID region. The information about fixed Mode S radar operated on an eligible interrogator code is available on the MICA website.

At least one MICA Focal Point is nominated per States, and up to four for some States (2 civil Focal Points (main and backup) and 2 military Focal Points (main and backup)). MICA Focal Points from ICAO EUR region have access to some information (position, rotation period, interrogator code) of Mode S radar installed in other States from ICAO EUR region. They can also display in Google Map the coverage per IC of Mode S radar installed in States from ICAO EUR region and ICAO MID region.

Beyond the information made available on the MICA website, EUROCONTROL has additional detailed information than may be relevant for supporting actions.

#### 6.2.1.2 Mobile military interrogators

No IC allocation is required for mobile military interrogators operating on II code 0. Therefore, no information is currently available on the MICA website for these systems.

#### 6.2.1.3 Mode A/C radar

No IC allocation is required for Mode A/C radar. Therefore, no information is currently available on the MICA website for these systems.

#### 6.2.1.4 WAM and MLAT

WAM and MLAT interrogators do not rely on All-Call interrogations to acquire aircraft and are typically operated on II code 0 (they can also be operated on any other II code). Therefore, the IC allocation process is not applicable to WAM/MLAT systems and no information is currently available on the MICA website for these systems.

In Section 6.1.1 of these guidelines it is recommended that WAM/MLAT systems use a different interrogator code from II code = 0 in order to be able to identify their interrogations. The MICA website could be updated to include a list of deployed WAM/MLAT systems and their interrogator code.

## 6.2.2 RF Measurement (VERIFICATION 1 and 2)

EUROCONTROL could provide support to States for the RF measurements described in these guidelines. In particular, EUROCONTROL has the necessary equipment, software and expertise to record and analyse the 1030/1090 MHz RF bands.

EUROCONTROL is also conducting regular ground and airborne RF measurement campaigns. States can make use of the analysis of these RF measurements to determine whether the requirements of **SPI IR Article 6** are met.

## 6.2.3 RF Model (VERIFICATION 1 and 2)

EUROCONTROL has developed a 1030/1090 MHz RF Model. It is composed of 2 modules:

- Time-based simulation of a test aircraft transponder for a given duration (e.g. 1 minute, 10 minutes, 1 hour...), at a specific location and using a time interval defined by the user
  - Simulate interrogations from ground-based (rotating) surveillance interrogators (Mode A/C radars, Mode S radars, WAM/MLAT ...) and airborne surveillance interrogators (ACAS) to all aircraft that are received by the test aircraft transponder.
  - Simulate replies from the test aircraft transponder
  - o Compute the corresponding transponder occupancy of the test aircraft
- Statistical simulation of 1090 MHz message transmitted by aircraft transponders and received at a given point of interest (e.g. ground ADS-B receiver).

The first module (time-based simulation of test aircraft transponder) may be used to simulate an aircraft transponder in the State airspace and assess **VERIFICATION 1** and **2**.

EUROCONTROL has developed ground and airborne scenarios to perform the simulation:

- A ground scenario containing the configuration of ground-based surveillance interrogators (Position, MIP, IRF, Power, number of extracted BDS ...). However, this scenario contains mainly radar interrogators and some information is missing, particularly concerning MLAT/WAM systems.
- A realistic air scenario containing the information of aircraft (position, altitude, Mode S or Mode A/C, speed, heading, TCAS capability ...) based on the recordings on a day of high traffic (9 September 2016). However all countries are not covered.

## 6.2.4 Assessment of interrogator configurations

EUROCONTROL could support States with the analysis of ground-based surveillance interrogators configuration as foreseen under optional **VERIFICATION 4**. To facilitate this task, the detailed interrogator characteristics and configuration parameters identified in Section 5.4 need to be provided to EUROCONTROL. The availability of such information may also be used to evaluate the operational impact of new ground-based surveillance interrogators on aircraft transponders using the RF Model available at EUROCONTROL.

The results of the EUROCONTROL assessment (configuration assessment and RF simulation) could be provided within the frame of the Mode S IC Allocation process.

# 7 Detailed presentation of methods for VERIFICATIONS 1 and 2

#### 7.1 Simulation of RF environment

#### 7.1.1 Simple theoretical calculation

A simple theoretical calculation may be used by the States to compute very approximately the number of interrogations a simulated aircraft transponder flying over a State would receive from ground-based surveillance interrogators per second, and the number of replies it would transmit. This method can be used to perform **VERIFICATION 2** and partially assess the compliance with **SPI IR Article 6(1)** (see Section 4.4.1).

Only one aircraft transponder is simulated with this method; interrogations to other aircraft and ACAS activity are not computed. Therefore, this method cannot be used to compute the occupancy of an aircraft transponder and perform **VERIFICATION 1**; it cannot be used to assess completely the compliance with **SPI IR Article 6(1)**.

This method is fast and simple if the number of ground-based surveillance interrogators is very low, and if the number of simulated points is low.

However, this method presents some limitations:

- The computed number of interrogations and replies are average values. That means that in reality the maximum number of replies per second of an aircraft transponder flying above the State may be much higher than the computed values (for example in the case several systems interrogate simultaneously the same aircraft);
- ACAS interrogations and replies are not computed, but it is important to reserve a margin to cover them in real environment;
- Abnormal and unexpected behaviours (such as military mobile interrogators operating on II 00, TRD interrogators, ground interrogators operation different from what is expected, high radar re-interrogation rate ...) are not simulated.

Please refer to **Annex K** for more information about the simple theoretical calculation.

#### **7.1.2 RF Model**

A RF Model can be used to estimate:

- the number of interrogations from ground-based surveillance interrogators and airborne interrogators, eliciting or not a reply, that are processed per second by a simulated aircraft transponder; and
- the number of Mode A/C replies, the number of Mode S replies and the number of Mode S long replies per second of the simulated aircraft transponder

It is recommended to choose a RF Model that supports time-based simulation in order to mimic the interrogations from (rotating antenna) interrogators and replies from simulated aircraft transponder during a chosen period. The chosen period will be long enough (typically 2 hours) to encounter different configurations of interrogations, e.g. simultaneous interrogations of several interrogators or no interrogation.

It is not recommended to choose a RF Model that uses a statistical approach and computes only the average number of interrogations and replies per second.

A RF Model can be used to assess the compliance with **SPI IR Article 6(1)** (see Section 4.2.1 for **VERIFICATION 1**, and Section 4.4.2 for **VERIFICATION 2**).

The results of a RF Model depend a lot on the applied hypothesis. That is why it is important to validate and calibrate the RF Model to ensure that the results are aligned with the reality, e.g. comparing the results of the RF Model to results of RF recording analysis.

The RF Model can be run locally by a State, or can be run centrally at the European level by an international civil-military organisation (international organisation to be defined) using a European-coordinated process.

Running a RF Model centrally provides several advantages:

- One unique ground surveillance interrogators scenario and one unique airborne scenario will be created and maintained, instead of one ground and one air scenario per State.
- The (sensitive) information of ground-based surveillance interrogators will only be available to a single international civil-military organisation.
- If information of ground-based surveillance interrogators installed in third countries is required (in the case these interrogators would affect the traffic in States), it may be easier for the international civil-military organisation to get the information.
- The work needed to calibrate and configure the RF Model is done only once.
- The purpose is to use the same RF Model with the same programing, the same ground and air scenarios for all RF simulations in States. Therefore, the results of the RF simulations can easily be compared as the same hypothesis and parameters have been used for all RF simulations.

An important limitation of the central processing is that only one RF Model is chosen and used centrally.

Please refer to **Annex L** for more information.

## 7.1.3 Required information for RF simulation

In order to simulate the 1030/1090 MHz RF environment, using either a simple theoretical calculation or a RF Model, it is necessary to have up-to-date information about ground-based surveillance interrogators (see Section 7.1.3.1).

In addition, a RF Model requires a realistic air scenario (see Section 7.1.3.2).

#### 7.1.3.1 Ground-based surveillance interrogator scenario

In order to simulate the RF environment it is necessary to have the up-to-date information about ground-based surveillance interrogators (Position, MIP, IRF, Power, number of extracted BDS ...) located within the State and in the neighbouring countries up to ~300 NM around the simulated aircraft transponder. The neighbouring countries can be either States or third countries.

Some information about ground-based surveillance interrogators may be sensitive or confidential information (e.g. the position and the configuration of military interrogators). In this case, it may not be acceptable to share this information with other States. However, this information is required to perform accurate simulations of the 1030/1090 MHz environment.

This simulation of the 1030/1090 MHz RF environment could be done centrally by a civil-military organisation. In this case, it may be acceptable to share this information only with the international civil-military organisation. Other States would not have access to it. Therefore, it may be easier to run a RF Model centrally at the European level by an international civil-military organisation that would distribute the results to the States.

Some arrangements will also be required with third countries to share information. Such information may only be shared with the international civil-military organisation.

A central repository may be used to share the configurations of ground-based surveillance interrogators. If the RF Model is run locally by each State, then the information about surveillance interrogators will have to be shared between the States. If the RF Model is run centrally by a civil-military organisation, then the information will have to be shared with the civil-military organisation only.

The central repository would contain the up-to-date information and configuration of ground-based surveillance interrogators installed in States. The States would report any modification or addition of any ground-based surveillance interrogator on their territory using the central repository.

#### 7.1.3.2 Airborne scenario

In order to program a RF Model, a realistic air scenario corresponding to a peak of traffic is required in order to compute:

- ACAS interrogations and replies
- Selective interrogations to other aircraft that may affect the occupancy of the simulated aircraft transponder

The air scenario contains the information of aircraft (position, altitude, Mode S or Mode A/C, speed, heading, TCAS capability ...). It can be extracted from surveillance data recordings (ASTERIX Cat. 48) at a moment where the number of aircraft is high (e.g. peak day of the year). Once an air scenario has been created, it can be used during several years, but it has to be updated with additional aircraft in order to take into account the evolution of aircraft traffic.

## 7.2 Methods using RF Measurement

The analysis of 1030/1090 MHz RF measurements can also be used to assess the compliance with the **SPI IR Article 6(1)**.

However, both the analysis of interrogations received on 1030 MHz and the replies on 1090 MHz are necessary to compute the occupancy of an aircraft transponder to assess completely the compliance with the **SPI IR Article 6(1)**. The analysis of 1030 MHz transmissions is limited with ground RF measurement and therefore it is not possible to compute the exact number of interrogations an aircraft transponder receives. Consequently, the analysis of ground RF measurement alone is insufficient to assess completely the compliance with the **SPI IR Article 6(1)**.

The analysis of 1030/1090 MHz RF measurements can be done using one of the following approaches:

- Periodic analysis of ground RF measurement
- Permanent analysis of ground RF measurement
- Periodic analysis of airborne RF measurement

These measurements can be done locally by a State (local system) or by a common central system.

## 7.2.1 Periodic analysis of ground RF measurement

The periodic analysis of 1090 MHz RF band recorded on the ground can be used to count every second the number of Mode A/C replies, the number of Mode S short replies and the number of Mode S long replies of analysed aircraft. This method can be used to perform **VERIFICATION 2** and partially assess the compliance with **SPI IR Article 6(1)** (see Section 4.4.3).

The periodic analysis of 1030 MHz RF band recorded on the ground can be used to identify the source of interrogations. However, the analysis of 1030 MHz transmissions is limited on the ground. Therefore, this method is insufficient to assess completely the compliance with **SPI IR Article 6(1)**.

The analysis of ground 1090 MHz RF recordings presents some limitations:

- Difficulties to decode aircraft replies in high traffic density area where the high number of replies may create a lot of garbling, particularly when an omni directional antenna is used to receive and record messages on 1090 MHz. In case of garbling, only replies with highest power may be decoded. That is why aircraft transponder at short distance will generally be analysed.
- Not all replies of analysed aircraft on 1090 MHz may be correctly detected/decoded. Therefore, the reply rate of analysed aircraft may be inferior to the reality.
- Difficulties to count the number of Mode C (altitude) replies from an aircraft if other aircrafts fly at the same altitude in the same region and transmit Mode C replies.
- Difficulties to count the number of Mode A code replies from an aircraft if this Mode A code corresponds to the altitude (Mode C) replied by other aircrafts which fly in the same region.

In addition, because the RF recordings are done on the ground, the analysis of 1030 MHz is limited:

- The place where the ground recording is done may be in the visibility of very few ground-based surveillance interrogators or in the visibility of no interrogator at all.
  - It is not possible to know the number of interrogations received by an aircraft transponder that do not trigger a reply. Therefore, it is not possible to compute an accurate transponder occupancy and perform **VERIFICATION 1**. That is the reason why the periodic analysis of ground RF measurements is not proposed as a method to assess the full compliance with **SPI IR Article 6(1)**.
- It may not be possible to determine the causes of excessive number of replies.
  - For example, it is possible to identify the interrogators triggering too many All-Call replies using the Interrogator Code contained in the All-Call replies, but it is not possible to identify the interrogator triggering too many Roll-Call replies (Mode S short or long replies).

In addition, because the RF recordings are done periodically, the analysis presents some limitations:

- The recording campaign is limited in time. Therefore, abnormal and unexpected events (e.g. Military mobile interrogators operating on II 00, TRD interrogators ...) that may affect the aircraft transponders may not happen during the recording period. That is why it is not acceptable to use the periodic analysis of ground RF measurements to perform VERIFICATION 2 and assess the compliance with SPI IR Article 6(1) when the analysis results are very close (above 90%) to the minimum reply rates specified in the ICAO Annex 10 Vol IV.
- It is not possible to detect in real-time a deterioration of the RF environment (increase in the number of aircraft transponder replies).

• It is not possible to have trend analysis showing the evolution of the number and the type of interrogations and replies over time.

The analysis of periodic ground RF recordings presents some advantages:

- No need to know the exact configuration of the ground-based surveillance interrogators to perform VERIFICATION 2 and assess the compliance with SPI IR Article 6(1), on the contrary to Method 2-1: Simple theoretical calculation and Method 2-2: RF Model (see Section 7.1).
- Periodic ground RF measurements are relatively easy to setup and more affordable than airborne RF measurements or permanent ground RF measurements.

## 7.2.2 Permanent analysis of ground RF measurement

The permanent analysis of 1090 MHz RF band recorded on the ground can be used to count every second the number of Mode A/C replies, the number of Mode S replies and the number of Mode S long replies of analysed aircraft. This method can be used perform **VERIFICATION 2** and partially to assess the compliance with **SPI IR Article 6(1)** (See Section 4.4.4).

In case a permanent analysis of ground RF measurements is put in place, it is recommended that the ground RF measurement system reports in pseudo real-time a deterioration of the RF environment to enable a quick reaction.

The analysis of ground 1090 MHz RF recordings presents some limitations that have been presented in the previous section.

The permanent analysis of 1030 MHz RF band recorded on the ground can be used to identify the source of interrogations. However, the analysis of 1030 MHz transmissions is limited on the ground. It is not possible to know the number of interrogations received by an aircraft transponder that do not trigger a reply. Therefore, it is not possible to compute an accurate transponder occupancy and perform **VERIFICATION 1**. That is the reason why the permanent analysis of ground RF measurements is not proposed as a method to assess the full compliance with **SPI IR Article 6(1)**.

The analysis of permanent ground RF recordings presents some advantages:

- No need to know the exact configuration of the ground-based surveillance interrogators to perform VERIFICATION 2 and partially assess the compliance with SPI IR Article 6(1), on the contrary to Method 2-1: Simple theoretical calculation and Method 2-2: RF Model (see Section 7.1).
- Abnormal and unexpected behaviours that affect the aircraft transponders can be identified
- Detect in real time a change in the ground interrogator environment (e.g. new radar or WAM is deployed) if this change affects aircraft replies.
- Detect in real-time a deterioration of the RF environment when this deterioration causes an increase in the number of transponder replies.
- Provide a trend analysis showing the evolution of the number and the type of interrogations and replies over time.

When a deterioration of the 1090 MHz RF environment is identified, the following immediate actions can be considered:

All operators (civil, military, manufacturers) of surveillance systems in the impacted region
can be contacted to verify if ground surveillance interrogators are correctly configured (refer
to Section 6.1.4 for points of contact);

- Transmissions from TRD interrogators can be stopped;
- A special MIP can be created to provide a minimum service (e.g. less EHS extraction) and thereby reducing the number of interrogations and replies triggered by ground surveillance interrogators in the impacted region.

In addition, permanent ground 1030 MHz RF monitoring will detect in real-time (limited by the line of sight of the monitoring system)

- Deterioration of operation of known surveillance ground interrogators which are in line of sight, or
- Unexpected interrogations from unknown interrogators

When a deteriorated 1030 MHz RF environment is identified, the following immediate actions can be considered:

- Contact the Mode S operator to verify the radar configuration parameters (refer to Section 6.1.4 for points of contact);
- Use 1030 MHz and 1090 MHz recordings to try to locate the unknown interrogator.

It is recommended to set up a permanent ground recording system in area where the aircraft reply rates are very close or above the minimum reply rates specified in the ICAO Annex 10 Volume IV.

### 7.2.3 Central analysis of ground RF measurement

A central and global approach should be more effective in case the number of interrogations and replies would be too high in a region. The complete and global overview of interrogations of ground-based surveillance interrogators should help to rationalise interrogations and to reduce the number of triggered replies.

The central analysis of ground 1030/1090 MHz RF measurements provides several advantages:

- The number of places where ground RF measurements systems should be deployed may be reduced as the same site could be used by several neighbouring States;
- The analysis of the same recording can be used for several neighbouring States;
- The analysis of 1030 MHz transmissions is limited on the ground. The place where the ground recording is done may be in the visibility of very few ground-based surveillance interrogators. However, more permanent ground RF measurement systems are deployed, better will be the visibility of the overall ground surveillance interrogators operating on 1030 MHz.
  - The interrogations received by one permanent ground RF measurement system may be used by the central processor to explain the aircraft transponder replies received by another permanent ground RF measurement system.
  - More permanent ground RF measurement systems are deployed, better will be the 1030 MHz picture and more accurate will be the transponder occupancy computation (VERIFICATION 1 for compliance with SPI IR Article 6(1)).
- Provide a global picture of the RF environment
  - o Global trend analysis showing the evolution of the number and the type of interrogations and replies over time over all Europe.

- The global picture of the RF environment should be accessible to States in the central processor dashboard (website)
- The identification and analyse of problems may be easier if RF measurements from several States are available at the same time

## 7.2.4 Where to locate ground RF measurement systems

It may not be possible to correctly detect or decode some aircraft transponder replies on 1090 MHz due to garbling and simultaneous transmissions, particularly in high traffic density areas. As a result, only the reply that was transmitted with the highest power is likely to be decoded,

This means that the RF measurements will be heavily influenced by the number of aircrafts within range and/or transponders that transmit at high power levels, and that ground RF measurement systems will not be able to provide a uniform and continuous measurement of the complete airspace. Therefore, RF measurement systems need to record at locations that are representative of the highest RF activity.

The number of representative locations within a State will depend on its size, on the ground-based surveillance interrogator environment and on the traffic density.

An example is provided in the figure below.



Figure 5 – Proposition for 1030/1090 MHz receiver locations in EUROCONTROL member states

For ground RF measurements, it is also recommended to find one or several locations that meet one or more of the following conditions:

- at location(s) where the number of overlapping Mode S radar surveillance coverage is the highest in the State (Annex E provides an example of the surveillance coverage redundancy of Mode S radar at 30000ft);
- at proximity of large airports or the busiest airport in the State, as this is typically where the highest ACAS activity is encountered;

- at elevated location(s) with a good line of sight to optimize the reception of 1030 MHz interrogations transmitted by ground-based surveillance interrogators;
- at proximity of surveillance interrogator manufacturer location(s) to monitor the interrogations of test interrogators;
- at coastal location(s) to monitor the interrogations from vessels equipped with surveillance interrogators.

## 7.2.5 Deployment of centralised monitoring system

An initial version of the centralised 1030/1090 MHz monitoring tool EMIT (European Monitoring of Interrogators and Transponders) has been deployed by EUROCONTROL. The tool relies on a ground network of receivers continuously measuring the messages received on 1030 MHz and 1090 MHz.

1030/1090 MHz receivers are being installed at sites across Europe and are collecting data that are transferred to EMIT tool. Partners hosting a receiver have access to the EMIT tool.

The network will comprise eighty (80) 1030/1090 MHz receivers when fully deployed.

The tool will be used to analyse and monitor the transponder loads and the RF usage across Europe, and to find ways of improving the situation where necessary.

## 7.2.6 Periodic analysis of airborne RF measurement

The analysis of airborne RF measurement is used:

- to count every second the number of Mode A/C replies, the number of Mode S replies and the number of Mode S long replies of the test aircraft, in order to perform VERIFICATION 2 and partially assess the compliance with SPI IR Article 6(1) (see Section 4.4.5)
- to measure the occupancy of the test aircraft transponder due to interrogations received from ground-based surveillance interrogators and airborne interrogators, eliciting or not a reply, in order to perform **VERIFICATION 1** and assess the full compliance with **SPI IR Article 6(1)** (See Section 4.2.2)

The 1030/1090 MHz RF bands are recorded on-board the test aircraft and analysed:

- Recording and analysis of the interrogations received on 1030 MHz by the test aircraft (interrogations addresses to the test aircraft or to other aircraft);
- Recording and analysis of the replies transmitted by the test aircraft transponder on 1090 MHz;
- Measurement of activity on the suppression bus in order to compute the transponder occupancy.
- ACAS interrogations and replies are available in the airborne RF measurements and are to be used to assess the compliance with **SPI IR Article 6**.

The periodic analysis of 1030/1090 MHz RF bands recorded on-board the test aircraft presents some limitations:

• The recording campaign is limited in time. Therefore, abnormal and unexpected behaviours that may affect the aircraft transponder may not happen during the recording period.

- The recording campaign is to be done at peak time. This is to guarantee that the maximum number of TCAS replies and the maximum transponder occupancy is recorded.
- The test aircraft needs to fly where there is the maximum redundancy of ground-based surveillance interrogators and at highest altitude to ensure it is interrogated by a maximum number of interrogators.
- The test aircraft needs to fly within the proximity of airport(s) where the density of aircraft is the highest (maximum ACAS activity).
- Flight costs are relatively high. This cost may be reduced if the recording is combined with other flight tests e.g. ANSP flight test.

The advantage of the 1030/1090 MHz RF bands recording on-board the test aircraft:

- Very good picture of the overall 1030/1090 MHz RF environment
- 100 % level of confidence of 1090 MHz transmissions done by the test aircraft
- The analysis of the interrogations on the 1030 MHz RF band allows the identification of interrogations which affect the occupancy of the transponder and which trigger replies from the test aircraft (e.g. it is necessary to have interrogations on 1030 MHz to determine which surveillance interrogator triggers long Mode S replies).
- Determination of sources of interrogations including military (e.g. it is possible to identify the area where interrogators are operating on II 00),
- There is no need to know the configuration of the ground-based surveillance interrogators affecting the test aircraft (contrary to the RF Model, please refer to Section 7.1.3). Therefore, there is no need to share the configurations of interrogators (no central repository is required) and this method is not impacted by interrogator information that may be confidential.
- It is possible to determine the interrogation pattern of surveillance interrogators using the 1030 MHz.

Airborne RF measurement may be done by an ANSP, EUROCONTROL or any other organisation using a test aircraft to do airborne analysis.

The central processing of airborne RF measurement provides also some advantages. It will be cheaper, easier and faster to setup and analyse one unique test flight passing above several States than to organize one test flight per State.

# 8 Template to document State verifications and results

The following table provides a template to report the actions taken by States to fulfil their obligations under **SPI IR Article 6**. The intent of the template is to record the processes applied by the States and the acceptability of the results.

Step	Analysis	Status	Results	Source / Evidence / Justification					
VERIFI	VERIFICATION 1 – SPI IR Article 6(1)								
1	Availability of Airborne RF measurement < 1 year old	YES/NO	<ul> <li>☐ YES → go to Step 5 and report Periodic Airborne RF</li> <li>Measurement</li> <li>☐ NO → go to Step 2</li> </ul>	Airborne RF Measurement Ref:					
2	Availability of Airborne RF measurement < 3 years old	YES/NO	$\Box$ YES → go to Step 3 $\Box$ NO → go to Step 4	Airborne RF Measurement Ref:					
3	Analysis of transponder occupancy in Airborne RF measurement < 3 years old	Done / Ongoing / Not done	Transponder occupancy always ≤ 10%?  ☐ YES → go to Step 5 and choose any method ☐ NO → go to Step 5 and choose Periodic Airborne RF Measurement						
4	Analysis of surveillance coverage redundancy of ground based environment ≤ 20	Done / Ongoing / Not done	Surveillance coverage redundancy ≤ 20?  ☐ YES → go to Step 5 and choose any method ☐ NO → go to Step 5 and choose Periodic Airborne RF Measurement						
5	Transponder occupancy verification method		Method for VERIFICATION 1:  RF Model  Periodic Airborne RF Measurement						
6	Determination of point of measurement / simulation			Explanation what points have been chosen and how they have been chosen.					

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Step	Analysis	Status	Results				Source / Evidence / Justification
			VERIFICATION 1 Results:	≤ 10%	> 10% and < 20%	> 20%	
7	Results of VERIFICATION 1	Done / Ongoing / Not done	RF Model				
			Periodic analysis Airborne RF Measurement				
VERIFI	CATION 2 – SPI IR Article 6(1)						
1	Availability of RF measurement < 1 year old	YES/NO	☐ YES → go to Step 5 and c ☐ Periodic Ground ☐ Periodic Airborn ☐ NO → go to Step 2	RF Measurement Ref:			
2	Availability of RF measurement < 3 years old	YES/NO					RF Measurement Ref:
3	Analysis of aircraft transponder reply rates in RF measurement < 3 years old	Done / Ongoing / Not done	Maximum reply rate?				
4	Performs a preliminary ground or airborne RF recording analysis	Done / Ongoing / Not done	Go to Step 5 and report :  Periodic Ground RF Measurement Periodic Airborne RF Measurement			RF Measurement Ref:	

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Step	Analysis	Status	R		Source / Evidence / Justification				
			Method for VERIFICA						
	Aircraft transponder reply rates verification method		Theoretical Calculation	on					
			RF Model						
5			Periodic ground RF m	neasurements	5 <u></u>				
			Permanent ground R	F measureme	ents 🗌				
			Periodic Airborne RF	Measuremen	its 🗌				
6	Determination of point of measurement / simulation		Provide in table below the n	naximum Moo	de A/C reply r	bee bee	anation what n chosen and l n chosen.	points have how they have	
	Results of VERIFICATION 2	Done / Ongoing / Not done	VERIFICATION 2 Results for Mode A/C replies	< 150	≥ 150 and < 250	≥ 250 and < 450	≥ 450 and ≤ 500	> 500	
			Theoretical Calculation						
			RF Model						
			Periodic ground RF measurements						
			Permanent ground RF measurements						
7			Periodic Airborne RF Measurements						
			Provide in table below the maximum Mode S reply rate:						
			VERIFICATION 2 Results for Mode S replies	< 15	≥ 15 and < 25	≥ 25 and < 45	≥ 45 and ≤ 50	> 50	
			Theoretical Calculation						
			RF Model						
			Periodic ground RF measurements						
			Permanent ground RF measurements						

Step	Analysis	Status	R	esults				Source / Ev Justifica	
			Periodic Airborne RF Measurements				]		
			Provide in table below the maximum Mode S long reply rate:						
			VERIFICATION 2 Results for Mode S long replies	< 5	≥ 5 and < 8	≥8a <1		≥ 14 and ≤ 16	> 16
			Theoretical Calculation				]		
			RF Model				]		
			Periodic ground RF measurements				]		
			Permanent ground RF measurements				]		
			Periodic Airborne RF Measurements				]		
			Source / Evidence / Justification:  Source of pollution identified?  Identification of ground-based surveillance interrogator with bad configuration?						
VERIF	CATION 3 – SPI IR article 6(3)								
	Ground-based surveillance	Done for all	List of ground surveilland	ce interrogato	ors Com with				
	interrogators compliant with partially done /		• · ·						
		not done	• .			]			
VERIF	CATION 4 (Analysis of ground-b	pased surveillance	e interrogators configuration	on) – Optior	nal				
	Process of pre-transmission approval	In place / not in place					Proc	ess document	reference

Step	Analysis	Status	Result	Source / Evidence / Justification		
			List of ground surveillance	≤ 6 All-Call	> 6 All-Call	document / analysis reference
		Verified for all	interrogators	replies	replies	
	Theoretical number of triggered	interrogators /	• .			
	All-Call replies in the beam ≤ 6	partially / not verified	• .			
		not verified	• .			
VERIFI	CATION 5 (Aircraft transponder	· All-Call reply and	alysis during Verification 2) – O	ptional		
			List of ground surveillance	≤ 6 All-Call	> 6 All-Call	document / analysis reference
		Verified /	interrogators	replies	replies	·
	Ground-based surveillance	Partially /	• .			
	interrogators from own State	not verified	• .			
			• .			
			List of ground surveillance	≤ 6 All-Call	> 6 All-Call	document / analysis reference
		Verified / not verified	interrogators	replies	replies	
	Ground-based surveillance		• .			
	interrogators from other States		• .			
			• .			
Manag	gement and Support					
	Process to handle over-	In place /				Process document reference
	interrogations	not in place				
	Process to handle unexpected	In place /				Process document reference
	interferences	not in place				
		Nominated / not nominated	Name:			
	State Point(s) of contact	not nominated	Organisation: E-mail address:			
			Telephone number:			
		Nominated /	Name:			
	On a mate we Delint/a) of a subset	Partially /	Organisation:			
	Operators Point(s) of contact	Not nominated	E-mail address:			
			Telephone number:			

# Annex A. Abbreviations

ACAS Airborne Collision Avoidance System

ADS-B Air Dependent Surveillance-Broadcast

ANSP Air Navigation Service Provide
ASP Aeronautical Surveillance Panel

**AWACS** Airborne Warning and Control System

**CS** Constitution

DoC Declaration of Conformity

DoV Declaration of Verification

**DSU** Declaration of Suitability for Use **EASA** European Aviation Safety Agency

**EC** European Commission

**EDA** European Defence Agency

ELS Mode S Enhanced Surveillance

Mode S Elementary Surveillance

IC Interrogator Code

ICAO International Civil Aviation Organisation

ICAO EUR ICAO European
ICAO MID ICAO Middle East
II Interrogator Identifier

IFF Identification Friend / Foe

IRF Interrogation Repetition Frequency

ITU International Telecommunication Union

MICA Mode S Interrogator Code Allocation

MIP Mode Interlace Pattern

**MLAT** Multilateration

MTL Minimum Threshold Level

NM Network Manager

**NSA** National Supervisory Authority

**RED** Radio Equipment Directive (2014/53/EU)

RF Radio Frequency

**SARPs** Standards and Recommended Practices

SI Surveillance Identifier

SIEM SSR/IFF environment model
SISSIM SSR IFF System Simulator

**SPI IR** Surveillance Performance Interoperability Implementation Rule

**SSR** Secondary Surveillance Radar

TCAS Traffic Collision Avoidance System
TRD Test, Research and Development

**WAM** Wide Area Multilateration

## **Annex B. Definitions**

**Accuracy**: degree of conformity of the provided value of a data item with its actual value at the time when the data item is output from the surveillance chain.

**ADS-B** (Regulation (EC) No 1207/2011): automatic dependent surveillance — broadcast, a surveillance technique in which aircraft automatically provide, via a data link, data derived from onboard navigation and position-fixing systems.

**Availability** (Regulation (EC) No 1207/2011): degree to which a system or component is operational and accessible when required for use.

**Aircraft identification** (Regulation (EC) No 1207/2011): group of letters, figures or a combination thereof which is either identical to, or the coded equivalent of, the aircraft call sign to be used in air-to-ground communications, and which is used to identify the aircraft in ground-to-ground air traffic services communications.

**Cluster**: a set of Mode S interrogators connected with each other in the same network and using the same IC to share track information in order to allow aircraft acquisition already acquired by other stations in the same cluster.

**Dwell time**: duration that the target remains in the radar's beam during each scan.

**Eligible Interrogator Code** (Regulation (EC) No 262/2009): any code among the II codes and the SI codes, except:

- 1. II code 0;
- 2. the interrogator code(s) reserved for military entities, including intergovernmental organisations in particular North Atlantic Treaty Organisation (NATO) management and allocation:

**Extended squitter**: spontaneous periodic transmission of a 1090 MHz 112-bit Mode S signal format containing 56 bits of additional information (e.g. used for ADS-B, TIS-B and ADS-R).

**Harmful interference** (Regulation (EC) No 1207/2011): interference that prevents the achievement of the performance requirements.

**Interrogation Rate Frequency (IRF)**: number of interrogations of a specified type transmitted over a one-second period.

**Lockout** (Regulation (EC) No 262/2009): protocol that allows the suppression of Mode S all call replies from already acquired Mode S targets.

**Lockout Coverage**: Mode S interrogator configuration defining where and how to apply lockout to Mode S targets. The Lockout Coverage can be provided in different formats depending on Mode S interrogator capabilities: European Mode S Coverage Map ICD, lockout range per sector, unique lockout range.

Mode Interlace Pattern (MIP): sequence of interrogation periods that an interrogator is repeating.

**MLAT**: process of locating an object by accurately computing the time difference of arrival (TDOA) of a signal emitted from that object to three or more receivers.

Mode A/C Interrogation Recognition Probability or transponder availability (Mode A/C IRP): the probability of the aircraft recognising a Mode A/C interrogation in the presence of interference at 1030 MHz from other interrogators and from non-SSR equipment on the aircraft.

**Mode S**: cooperative surveillance technique for air traffic control, which enables the selective interrogation of aircraft and the extraction of air derived data through which new air traffic management functionalities, can be developed.

**Mode S All Call interrogations**: messages that are normally used by Mode S interrogators to acquire Mode S targets entering their area of coverage.

**Mode S EHS**: Use of downloaded flight parameters by ground systems in order to improve monitoring applications. It provides selected altitude, roll angle; true track angle and track angle rate, ground speed, magnetic heading, indicated airspeed, vertical rate and ACAS downlinked resolution advisories.

**Mode S ELS**: Use of downloaded aircraft identity, altitude, transponder capability report, SI code capability by ground systems for flight management.

**Mode S interrogator** (Regulation (EC) No 262/2009): a system composed of antenna and electronics, supporting addressing of individual aircraft through the Mode Select, known as Mode S.

**Mode S Operator** (adapted from Regulation (EC) No 262/2009): a person, organisation or enterprise operating or offering to operate a Mode S interrogator, including:

- (a) Air navigation service providers;
- (b) Mode S interrogators manufacturers;
- (c) Airport operators;
- (d) Military authorities;
- (e) Research establishments;
- (f) Any other entity entitled to operate a Mode S interrogator;

**Plot detection probability**: the probability that a specified target will be detected, a track initiated or updated.

**Power (visibility)**: power emitted by a radar to be visible by transponders.

Range lockout information: range within which a radar locks a transponder on its IC code.

**Reply decode probability**: the probability that a reply at a specified SSR mode from a specified target will be correctly decoded.

**Round trip probability**: the probability that a specified interrogation will be replied to and the reply correctly decoded.

**State aircraft** (Regulation (EC) No 1207/2011): any aircraft used for military, customs and police purposes.

**Squitter:** spontaneous periodic transmission by a Mode S transponder (nominally once per second) of a specified format, including the aircraft address, to permit passive acquisition.

**Surveillance data** (Regulation (EC) No 1207/2011): any data item, time stamped or not, within the surveillance system that pertains to:

- aircraft 2D position;
- aircraft vertical position;
- aircraft attitude;
- aircraft identity;
- 24-bit ICAO aircraft address;
- aircraft intent;
- aircraft velocity;
- aircraft acceleration

**Transponder occupancy**: a state of unavailability of the transponder from the time it detects an incoming signal that appears to cause some action or from the time of a self-initiated transmission, to the time that it is capable of replying to another interrogation.

**Transponder processing time**: time used by a transponder to receive an interrogation, process it, reply and recover or suppress.

**Surveillance data processing system** (Regulation (EC) No 1207/2011): system that processes all surveillance inputs received to form a best estimate of the current aircraft surveillance data.

# **Annex C. References**

- [RD 1] COMMISSION IMPLEMENTING REGULATION (EU) No 1207/2011 of 22 November 2011 laying down requirements for the performance and the interoperability of surveillance for the single European sky
- [RD 2] COMMISSION IMPLEMENTING REGULATION (EU) 2017/386 of 6 March 2017 amending Implementing Regulation (EU) No 1207/2011 laying down requirements for the performance and the interoperability of surveillance for the single European sky
- [RD 3] COMMISSION IMPLEMENTING REGULATION (EU) 2020/587 of 29 April 2020 amending Implementing Regulation (EU) No 1206/2011 laying down requirements on aircraft identification for surveillance for the single European sky and Implementing Regulation (EU) No 1207/2011 laying down requirements for the performance and the interoperability of surveillance for the single European sky
- [RD 4] Acceptable Means of Compliance and Guidance Material to Commission Implementing Regulation (EU) No 1207/2011

  Issue 1 18 August 2020
- [RD 5] Annex 10 to the Convention on International Civil Aviation
  Aeronautical Telecommunications
  Volume IV Surveillance and Collision Avoidance Systems
  4<sup>th</sup> and 5<sup>th</sup> Editions (see section 1.8)
- [RD 6] Guidance material on Mode S interrogation configuration to reduce 1030/1090 RF usage, SNI-WP3-Del3.5 v2.0, 16 May 2018
- [RD 7] RF Performance Report Avril 2017 Airborne Measurement v2.0, 17 May 2018
- [RD 8] Aeronautical Surveillance Manual, ICAO Doc 9924 Second Edition, 2017
- [RD 9] 1030/1090 Guidance Report Deliverable 15.01.06.D16
- [RD 10] ASP TSG WP14-31 Transponder Occupancy Measurements 2011 Northeast Corridor Flight Test

- [RD 11] EASA Report to the European Commission

  Detection losses in Central Europe on the 5<sup>th</sup> and 10<sup>th</sup> of June 2014

  Ed04 00
- [RD 12] European Mode S Station Functional Specification SUR/MODES/EMS/SPE-01 Edition 3.11 – 9 May 2005
- [RD 13] DIRECTIVE 2014/53/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 April 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment and repealing Directive 1999/5/EC
- [RD 14] COMMISSION IMPLEMENTING REGULATION (EU) 2019/123 of 24 January 2019 laying down detailed rules for the implementation of air traffic management (ATM) network functions and repealing Commission Regulation (EU) No 677/2011.
- [RD 15] Airborne Collision Avoidance System (ACAS) Manual ICAO Doc 9863 Second Edition 2012
- [RD 16] MINIMUM OPERATIONAL PERFORMANCE SPECIFICATION FOR SECONDARY SURVEILLANCE RADAR MODE S TRANSPONDERS

  ED-73E May 2011

# Annex D. Document update procedures

It is necessary to periodically check this EUROCONTROL Guideline for consistency with referenced material. In addition, the content of these guidelines can evolve following feedback from implementation projects and field experience.

The main objectives of a regular review are:

- a) to improve the quality of the guidance (e.g. clarity, testability, etc.);
- b) to verify that the level of detail published is adequate;
- c) to make all stakeholders including industry aware of the latest developments.

The update of these guidelines is expected to be initiated by stakeholders directly or through the CNS Team working arrangement (or its subgroups). Any stakeholder that wishes to request a change to these guidelines can submit a change request (CR) to the document editors (page 2) or the generic email address: <a href="mailto:standardisation@eurocontrol.int">standardisation@eurocontrol.int</a>.

The CR needs to provide following minimum elements:

- Originator information (name, Organisation, contact details)
- Guideline title, number and edition date
- Page, chapter, section (subsection) where the issue appears
- Description of the issue and reason for change
- Specific change proposal text (incl. potential alternatives, if any).

Main steps towards a revised version:

- EUROCONTROL will assess each CR and consult relevant working arrangements.
- The CR will be classified in terms of urgency and impact.
- A resolution proposal(s) will be prepared and, if needed, discussed with the originator.
- Agreed changes will be integrated into a revised version "Proposed Issue" including a summarised list of changes in the document record.
- The "Proposed Issue" will be consulted with relevant working arrangements.

Note: Identified errors which may cause potential problems when implementing, may be corrected directly via separate "Corrigendum".

# Annex E. Surveillance coverage redundancy of Mode S radar

A reference indication of the redundancy of surveillance coverage (i.e. number of overlapping surveillance coverage) considering operational Mode S radars (civil and military) at 30,000ft in the ICAO EUR region and the ICAO MID region is provided in the Figure 6 below. This reference indication is derived from the Mode S interrogator code allocation plan published at the end of the MICA Cycle 28 (effective date: 16 August 2018).

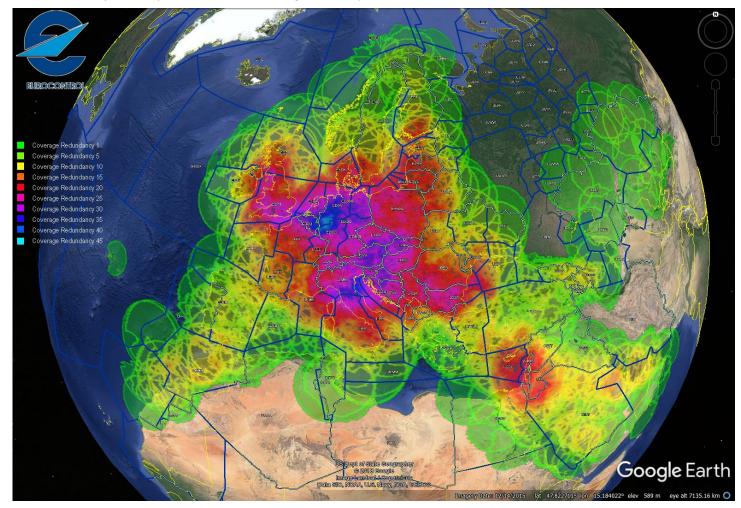


Figure 6 – Surveillance coverage redundancy of Mode S radar – MICA Cycle 28

For **VERIFICATION 1**, the States can use two different methods to evaluate the transponder occupancy. In the absence of airborne RF measurements, the method selection will depend on the number of overlapping ground-based surveillance interrogators. In order to clearly distinguish the regions where the redundancy of surveillance coverage is equal or lower than  $\underline{20}$ , and the regions where the redundancy of surveillance coverage is greater than  $\underline{20}$ , the Figure 7 below displays the redundancy of surveillance coverage of Mode S radars at 30,000ft using only two different colours.

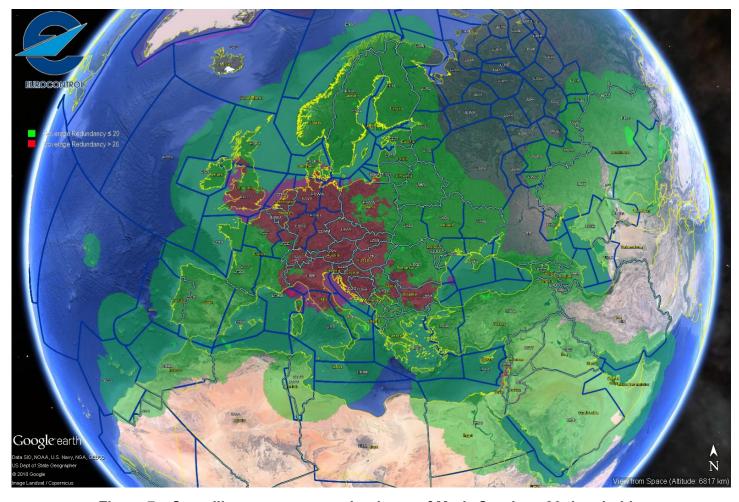


Figure 7 – Surveillance coverage redundancy of Mode S radar – 20 threshold.

The real radar visibility is used to compute the real surveillance coverage at 30000ft.

The colour code to represent the number of overlapping surveillance coverage (redundancy of surveillance coverage) is provided in the legend on the left part of the pictures above.

TRD (Test, Research and Development) Mode S radar, Mobile Mode S interrogators on II 00 and other ground surveillance interrogators (WAM, MLAT, SSR Mode A/C radar) are not taken into account in the figures above.

# Annex F. Background of SPI IR

SSR Mode A/C and Mode S radar interrogate aircraft transponders on the 1030 MHz RF band. Transponders reply on the 1090 MHz RF band. In addition, the 1030 and 1090 MHz RF bands are also used by other systems like ACAS, IFF military radars, ADS-B and WAM/MLAT.

SSR Mode A/C and Mode S radar, IFF military radars and WAM/MLAT are ground-based surveillance interrogators while ACAS and AWACS military radars are airborne interrogators. They all use the 1030 MHz RF band to interrogate aircraft transponders, which reply on the 1090 MHz RF band. ADS-B is using airborne long squitters spontaneously transmitted on the 1090 MHz RF band.

These transmitters access randomly the same 1030 and 1090 MHz frequency bands to transmit messages without any synchronisation between each other, comparable to a multiple access based on Aloha protocol principle. The multi-use of the RF bands may cause collision in the reception of interrogations and replies.

### Three issues have been identified:

- Transponder capability of reply:
  - Transponder occupancy: when receiving an interrogation, the transponder processes the message to verify if the interrogation elicits a reply or not. If so, the transponder prepares the reply and sends it. During this time of processing, the transponder is unable to reply to other interrogations. As a result, if the transponder receives too many interrogations, it may not be able reply to all of them, which may affect the performances of surveillance interrogators.
    - When a surveillance interrogator does not receive a reply to a selective interrogation, it generally re-interrogates the transponder, which increases the number of interrogations on 1030 MHz and the transponder occupancy.
  - Transponder capacity limit: when the number of interrogations eliciting a reply exceeds the transponder maximum capacity of reply, the transponder may not be able to reply, partly or completely, to new interrogations it receives.
- Garbling: if a large number of aircraft transponders are in a receiver coverage, the high number of replies leads to interference and garbling. The receiver faces difficulties to decode the replies.
  - Omni-directional antennas are more impacted by garbling than rotating antennas, which have a narrow beam.
- Interrogations collision: if the number of interrogations issued from different surveillance interrogators is excessive, interrogations arrive at the same time and the transponder will reply to only one of them.

### Some examples highlight these issues:

- Transponder capacity limit: loss of detection of some aircraft in June 2014 in central Europe. The analysis showed that aircraft were over interrogated; some transponders overheated and stopped replying. More information is provided in the EASA report [RD 11].
- Transponder capacity limit: Some transponders have implemented a limitation of their transmission when reaching the minimum reply rates specified in the ICAO Annex 10, Volume IV.
- Interrogations collision: A BDS swap happens when two surveillance interrogators send an interrogation to the same transponder, asking for two different BDS. If the interrogations

reach the transponder at the same time, the transponder will only reply to one of them. One of the two interrogators will then receive a wrong reply. The more interrogators, the larger the number of BDS swaps.

Several cases have been identified through measurements made on board a test aircraft. Per radar, there can be around 5 to 6 swaps per day, which decreases radars performance. The monitored number of BDS swap shows an increasing number of occurrences of such phenomenon in the core area of Europe.

 SESAR Simulation: This simulation conducted in SESAR Working Package 15.1.6 in 2011 was aimed to determine the congestion on the 1030/1090 MHz frequency bands in high RF interference environments.

Results (1030/1090 Guidance Report Deliverable, 15.01.06 D16 **[RD 9]**) show the 1030/1090 MHz frequencies are highly congested. According to the SESAR 15.1.6 study, the congestion seems to be at the limit of acceptability in core area of Europe and the performance of surveillance systems could degrade rapidly if it keeps increasing.

As a result, the general objective is to monitor the transmissions made on 1030/1090 MHz RF frequency bands in order to maintain the surveillance performance of the different systems at an acceptable level.

In particular, the following recommendations with high priority are provided in the EASA report to the European Commission about detection losses in Central Europe on the 5th and 10th of June 2014 [RD 11]:

- 1. States are reminded that Article 6 of SPI regulation (1207/2011 and amendments) clearly identifies their responsibility for spectrum protection at the latest by 5 February 2015. States should put in place required mechanisms to comply with it.
- 2. States should decrease the amount of interrogations in their airspace originating from ground systems (e.g. from SSRs, MSSRs, MLAT, WAM, test transmitters, military SSR/MSSR), so that each transponder is interrogated well below the rates required in the MOPS; Particular attention should be paid to tests or maintenance activities that use interrogators in the 1 030/1 090 MHz frequency;
- 3. States ensure that the use of the 1 030/1 090 MHz frequency band is monitored and recorded. This monitoring and recording shall not be limited to direct ground sensor observation, but shall also include observation of all the transmissions by a subset of aircraft in the air. The recordings shall be kept for at least 6 months to allow post event investigation;
- 4. States should ensure that each MLAT/WAM interrogator use a unique interrogator code and interrogations are kept to a minimum. The level of interrogations should be coordinated within the States and across boundaries;
- 5. Neighbouring States should collaborate particularly within the FABs, but ensuring also wider collaboration at the EU level, to make sure that recommendations numbers 1, 2, 3 and 4 are carried out in a consistent and harmonised way;
- 6. States should notify the Agency and the European commission of safety occurrences in a timely manner. The Agency should be provided with the relevant available data to facilitate the timely identification of the causes as well as the identification of potential measures to be taken;

# Annex G. TCAS replies from test aircraft

### G.1. TCAS replies measured in April 2017

The Figure 8 below provides a geographical representation of the <u>maximum number of TCAS replies</u> (<u>DF 0</u>) per second over a one-minute period transmitted by the test aircraft during a 2 days test flight in April 2017.

The white arrows show the flight trajectory on the first day:

- taking-off from Schiphol airport at 07:35 UTC and landing at Dubrovnik airport at 11:02 UTC
- taking-off from Dubrovnik airport at 11:59 UTC and landing at Schiphol airport at 15:50 UTC

The blue arrows show the flight trajectory on the second day:

taking-off from Schiphol airport at 08:42 UTC and landing at Schiphol airport at 12:44 UTC

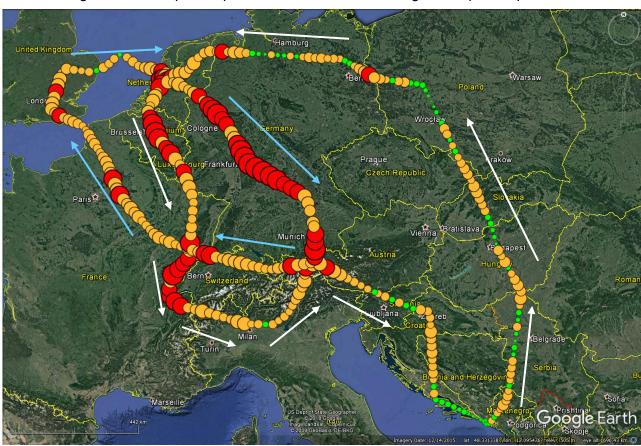


Figure 8 – Max number of TCAS replies in 2017 – map

The following thresholds are used for colours:

- Red: max number of TCAS replies (DF 0) per second > 10
- Orange: 5 < max number of TCAS replies (DF 0) per second ≤ 10
- Green: max number of TCAS replies (DF 0) per second ≤ 5

The maximum icon size corresponds to a maximum number of TCAS replies per second > 15.

The minimum icon size corresponds to a maximum number of TCAS replies per second < 1.

The picture above is extracted from [RD 7]. For more information, please refer to the report.

The Figure 9 below provides a time representation the <u>maximum number of TCAS replies (DF 0) per second over a one-minute period</u> transmitted by the test aircraft during the 2 days test flight in April 2017. The two arrows indicate the first and second day of test flight.

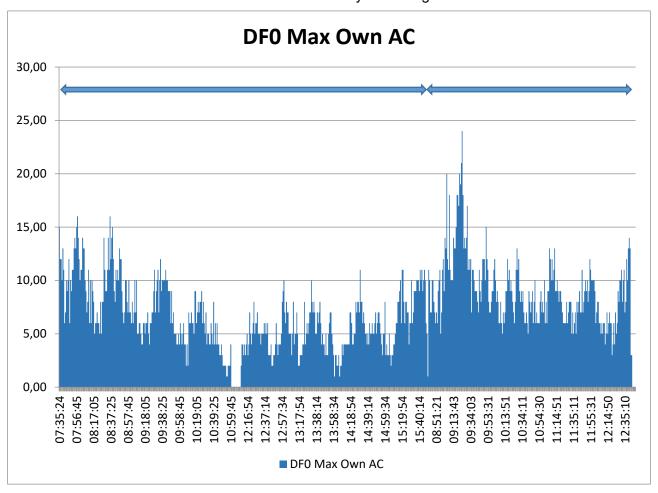


Figure 9 - Max number of TCAS replies in 2017 - graph

The pictures above show that the maximum number of TCAS replies (DF 0) per second exceeds 10 replies per second at several places in Europe, in general in the vicinity of large airports (up to 24 TCAS replies per second). The average value of the maximum number of TCAS replies per second over a one-minute period during the 2 days test flight in April 2017 is 6.2 TCAS replies (DF 0).

Considering the minimum reply rates capability of 50 Mode S replies per second specified in the ICAO Annex 10, Volume IV [RD 5], the pictures above enforce the need to consider TCAS replies in the assessment of **VERIFICATION 2**.

In the absence of RF measurements and simulations, it is recommended to consider that ACAS installations are able to generate at least 10 of 50 Mode S replies per second in the vicinity of large airports and 5 of 50 Mode S replies per second elsewhere.

In addition, the aircraft transponder occupancy due to TCAS activity may also be relatively high in the vicinity of airports, enforcing the need to consider TCAS activity in the assessment of **VERIFICATION 1**.

### G.2. TCAS replies measured in 2019

The Figure 10 below provides a geographical representation of the <u>maximum number of TCAS</u> replies (DF 0 and DF 16) per second over a one-minute period transmitted by a test aircraft during a one-day test flight in August 2019 and a two-day test flight in December 2019.

The test flight in August 2019 was

• taking-off from Schiphol airport at 10:30 UTC and landing at Schiphol airport at 14:35 UTC.

The 1st test flight in December 2019 was:

- taking-off from Prague airport at 08:10 UTC and landing at Helsinki airport at 11:34 UTC
- taking-off from Helsinki airport at 13:50 UTC and landing at Prague airport at 18:27 UTC The 2<sup>nd</sup> test flight in December 2019 was:
  - taking-off from Prague airport at 08:15 UTC and landing at Burgas airport at 11:16 UTC
  - taking-off from Burgas airport at 12:00 UTC and landing at Prague airport at 16:28 UTC

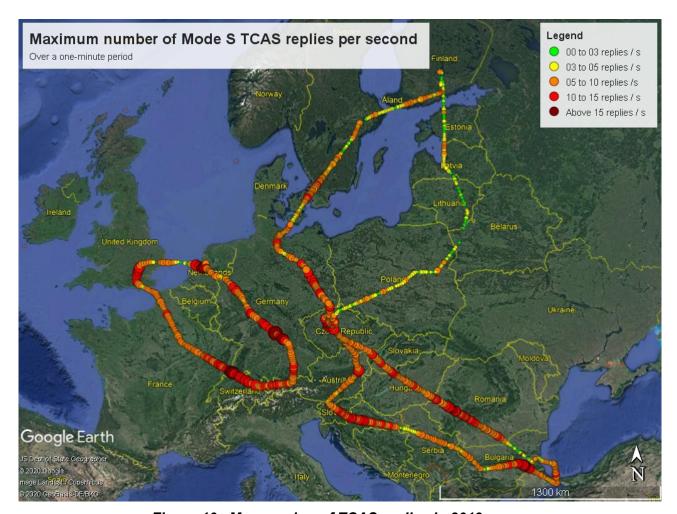


Figure 10 -Max number of TCAS replies in 2019 - map

The maximum icon size corresponds to a maximum number of TCAS replies per second > 15. The minimum icon size corresponds to a maximum number of TCAS replies per second < 2.

The above figure shows that the maximum number of TCAS replies (DF 0) per second exceeds 10 replies per second at several places in Europe, in general in the vicinity of large airports. It exceeds rarely 15 replies per second.

The average values of the maximum number of TCAS replies per second over a one-minute period recorded during the test flights are:

- 6.85 DF 0 and 2.25 DF 16 in August 2019
- 5.43 TCAS replies (DF 0 + DF 16) during the first flight in December 2019
- 7.60 TCAS replies (DF 0 + DF 16) during the second flight in December 2019

In the absence of RF measurements and simulations, it is recommended to consider that ACAS installations are able to generate at least 10 of 50 Mode S replies per second in the vicinity of large airports and 5 of 50 Mode S replies per second elsewhere, as indicated above.

# Annex H. Mode S replies from test aircraft measured in 2019

### H.1. Maximum number of Mode S replies per second

The Figure 11 below provides a geographical representation of the <u>maximum number of Mode S</u> <u>replies per second over a one-minute period</u> transmitted by a test aircraft during a one-day test flight in August 2019 and a two-day test flight in December 2019.

The maximum number of Mode S replies contains:

- All-Call replies (DF11) on II<>00 and on II=00 (including the short squitters: 1 short squitter per second)
- Short Mode S replies (DF4/5)
- Long Mode S replies (DF20/21)
- ACAS (DF00 and DF16)

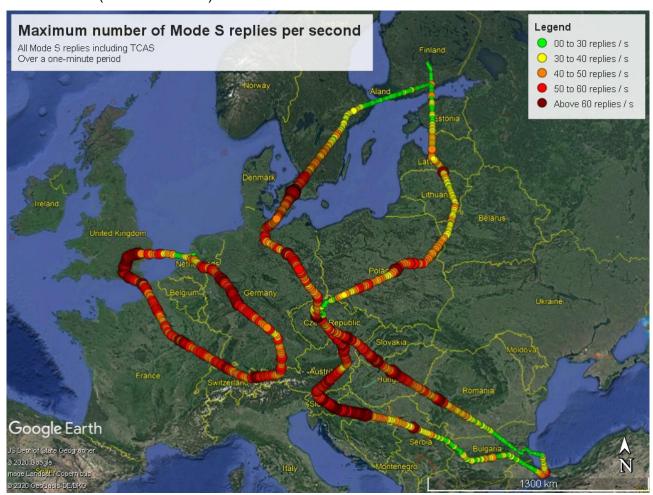


Figure 11 – Max number of Mode S replies in 2019

We can notice that the maximum number of Mode S replies per second of the test aircraft often exceeds the minimum transmission rates specified in the ICAO Annex 10 Volume IV (50 Mode S replies per second), except in northern Europe.

### H.2. Maximum number of Mode S replies per second without TCAS

The Figure 12 below provides a geographical representation of the <u>maximum number of Mode S</u> <u>replies per second without ACAS replies over a one-minute period</u> transmitted by a test aircraft during one day test flight in August 2019 and two days test flight in December 2019.

The maximum number of Mode S replies contains:

- All-Call replies (DF11) on II<>00 and on II=00 (including the short squitters: 1 short squitter
  per second in theory)
- Short Mode S replies (DF4/5)
- Long Mode S replies (DF20/21)

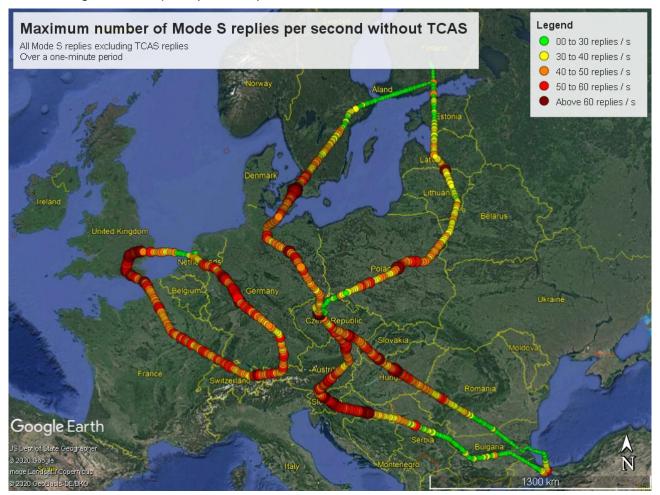


Figure 12 – Max number of Mode S replies without ACAS

We can notice that the situation is slightly better when ACAS replies are removed. However the maximum number of Mode S replies per second of the test aircraft still often exceeds the minimum transmission rates specified in the ICAO Annex 10 Volume IV (50 Mode S replies per second).

### H.3. Maximum number of Mode S long replies per second

The Figure 13 below provides a geographical representation of the <u>maximum number of Mode S</u> <u>long replies per second without ACAS replies over a one-minute period</u> transmitted by a test aircraft during a one-day test flight in August 2019 and a two-day test flight in December 2019.

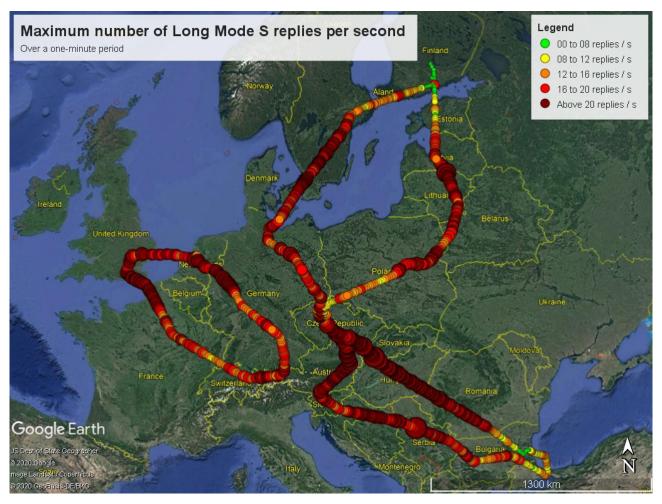


Figure 13 - Max number of Mode S long replies

We can notice that the maximum number of long Mode S replies of the test aircraft does very often exceed the minimum transmission rates specified in the ICAO Annex 10 Volume IV (16 long Mode S replies per second).

# Annex I. Transponder occupancy considerations

### I.1. Transponder occupancy due to replies

The purpose of this section is to compute the maximum transponder occupancy considering only the interrogations that trigger a reply and squitter transmissions. The maximum number of Mode AC and Mode S replies per second is taken into account (the minimum reply rates specified in the ICAO Annex 10, Volume IV):

- 500 Mode A/C replies: 250 Mode A replies and 250 Mode C replies
- 16 Mode S long replies
- 34 Mode S short replies (50 Mode S replies 16 Mode S long replies)
- 1 acquisition squitter (Mode S short message)
- 6.2 extended squitters (Mode S long message ADS-B)

The computation of transponder occupancy is done using standardised time and typical time. The standardised and typical occupancy values for different type of interrogations, eliciting a reply or not, are provided in the Appendix M of ICAO Doc 9924 **[RD 8]** and in the **Annex N**.

Reply type	Number of replies or transmissions	Standardised value (μs)	Standardised Transponder occupancy (ms)	Typical value (μs)	Typical Transponder occupancy (ms)
Mode A	250	157.55	39.39	48.55	12.14
Mode C	250	170.55	42.64	61.55	15.39
Mode S short	34	321.75	10.94	212.75	7.23
Mode S long	16	377.75	6.04	268.75	4.30
Acquisition squitter (short)	1	189	0.19	80	0.08
Extended squitter (long ADS-B)	6.2	245	1.52	136	0.84
TOTAL			100.72		39.98

Table 3 – Transponder occupancy due to maximum number of replies

The Table 3 above shows that the standardised transponder occupancy is equal to 10% when the transponder receives interrogations addressed to itself that trigger replies at the minimum reply rates specified in the ICAO Annex 10, Volume IV; and transmits squitters at the rate provided above. The typical transponder occupancy is much lower and is equal to 4%.

### I.2. Transponder occupancy close to large airports

The interrogations received on 1030 MHz and the replies on 1090 MHz recorded on board the test aircraft during the 2 days test flight in April 2017 are used to compute the transponder occupancy at proximity of large airport.

All interrogations and pulses received by a transponder, with a power level above its minimum triggering level, are detected and processed. ICAO Annex 10, Volume IV, paragraph 3.1.2.10.1 **[RD 5]** defines an MTL of –74 dBm ±3 dB. Please note that some interrogations may still be received and decoded at power level below the MTL, but with a lower probability.

It is not straightforward to determine the real MTL of the transponder of the test aircraft (–74 dBm ±3 dB). In addition, the RF recording system on-board the test aircraft has to be correctly calibrated to ensure that the power of received signal is correctly computed in dBm.

The computation of the transponder occupancy has been done at -74 dBm and -77 dBm in sections below. That means that interrogations received on 1030 MHz with a power level above -74 dBm and power level above -77 dBm are taken into account to compute the transponder occupancy. The replies of the test transponder on 1090 MHz are taken into account to compute the transponder occupancy.

The transponder occupancy is very sensitive to the MTL used for the analysis, as we will see in sections below.

### I.2.1. Transponder occupancy close to large Airport A (MTL = -74dBm)

The Figure 14 below provides the transponder occupancy per second over a one-minute period close to a large airport in European core area. The 1030/1090 MHz RF activity has been recorded on-board the test aircraft on Wednesday 12 April 2017 at 09:19:49 UTC, at 37100ft.

As recommended in Section 2.3.2.1, the MTL value used for the analysis is -74 dBm. All interrogations and pulses received by a transponder, with a power level above the MTL, are detected and processed.

The time in second is provided on the x-axis. The transponder occupancy in % of the time is provided on the y-axis.

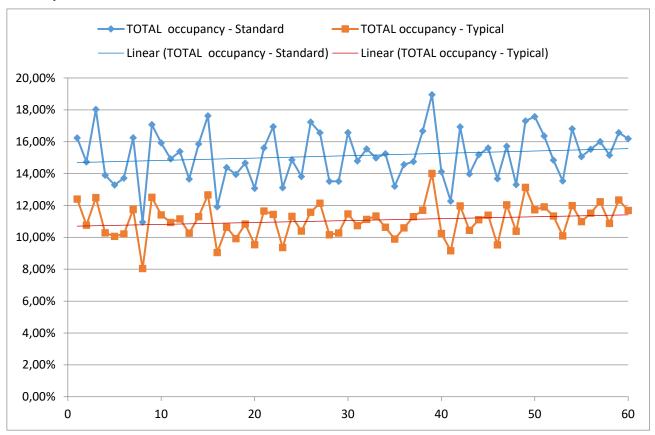


Figure 14 – Transponder occupancy per second close to Airport A (MTL = -74dBm)

The figure above shows that standardised transponder occupancy per second is lower than 20% (maximum transponder occupancy per second = 19%). The standardised transponder occupancy per second remains in general between 12% and 18%.

Note: Because the suppressor bus was not available for this recording flight, the occupancy due to suppressions from other avionic devices is not evaluated. Namely own aircraft DME transmissions are not accounted for (but are estimated below 0,1% occupancy) and own aircraft TCAS transmissions detected on 1030 MHz are evaluated as a received Mode S interrogation not followed by a reply.

The Table 4 below provides the average value of transponder occupancy over a one-minute period using standardised and typical values of occupancy. The transponder occupancy is provided by interrogation type, and in separate column whether the test aircraft transponder replies or not.

Transponder Occupancy per		Standardised		Typical		
category of message	Total	Reply	NO Reply	Total	Reply	NO Reply
Mode A/C	2.59%	2.59%		0.87%	0.87%	
Mode A/C Intermode	0.86%		0.86%	0.80%		0.80%
Mode A/C - SLS	0.19%		0.19%	0.16%		0.16%
Mode S All-Call	0.89%	0.69%	0.20%	0.61%	0.46%	0.15%
Mode S Roll-Call	1.18%	0.28%	0.90%	0.89%	0.19%	0.70%
Mode S Roll-Call on II00	1.18%	0.02%	1.16%	0.92%	0.01%	0.90%
Mode S - SLS	0.06%		0.06%	0.05%		0.05%
TCAS	2.90%	0.36%	2.53%	2.21%	0.24%	1.97%
Military	0.14%		0.14%	0.12%		0.12%
ADS-B (DF 17)	0.13%	0.13%		0.07%	0.07%	
Interference pulses	5.02%		5.02%	4.35%		4.35%
Total	15.13%	4.08%	11.05%	11.06%	1.85%	9.21%

Table 4 – Average value over 1 minute of transponder occupancy per interrogation type close to Airport A (MTL = -74dBm)

We can notice that the main contributors to the aircraft transponder occupancy are the interference pulses. That pulses are linked to the relatively high RF occupancy on 1030 MHz due to high density of surveillance sensors and aircraft transmitting on 1030 MHz.

The second contributors to the aircraft transponder occupancy are the interrogations from TCAS. In this case, the transponder is mainly occupied by interrogations that are addressed to other aircraft. The test aircraft is flying at high altitude (37100ft) at proximity of a large airport where most of aircraft are flying at low altitude. That is why it is not much interrogated by TCAS.

The third contributors are Mode A/C interrogations.

The forth contributors are Roll-Call interrogations (selective interrogations) from ground-based surveillance interrogators on II code = 0 and II code <> 0. The test aircraft is flying outside the surveillance volume of interest of the WAM. That is why it is almost not interrogated by the WAM.

The next contributors are the All-Call interrogations.

### I.2.2. Transponder occupancy close to large Airport A (MTL = -77dBm)

The Figure 15 below provides the transponder occupancy per second over a one-minute period close to a large airport in European core area. The 1030/1090 MHz RF activity has been recorded on-board the test aircraft at same position and same time as in previous section. The only difference is the MTL value used for the analysis. In this section, the MTL value used for the analysis is -77 dBm.

The time in second is provided on the x-axis. The transponder occupancy in % of the time is provided on the y-axis.

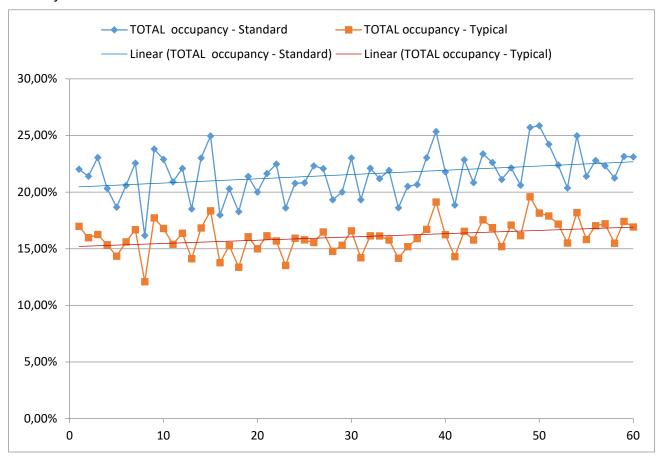


Figure 15 – Transponder occupancy per second close to Airport A (MTL = -77dBm)

The figure above shows that standardised transponder occupancy per second is higher than 20% most of the time when using a value of MTL = -77 dBm, whereas it is in general between 12% and 18% when using a value of MTL = -74dBm. The maximum transponder occupancy per second is equal to 25.9% when using a value of MTL = -77 dBm, whereas it is equal to 19% when using a value of MTL = -74 dBm.

The Table 5 below provides the average value of transponder occupancy over a one-minute period using standardised and typical values of occupancy. The transponder occupancy is provided by interrogation type, and in separate column whether the test aircraft transponder replies or not.

We can notice that the transponder occupancy due to interrogations eliciting a reply from the test aircraft are similar, 4.08% with MTL = -74 dBm and 4.92% with MTL = -77 dBm. The difference is mainly due to replies to Mode A/C interrogations.

On the contrary, the transponder occupancy due to interrogations not eliciting a reply is much higher when using MTL = -77 dBm, 11.05% with MTL = -74 dBm and 16.65% with MTL = -77 dBm. This difference is mainly due to the interference pulses (8.31% vs 5.02%) and TCAS interrogations (3.68% vs 2.53%).

Transponder Occupancy per		Standardised		Typical		
category of message	Total	Reply	NO Reply	Total	Reply	NO Reply
Mode A/C	3.43%	3.43%		1.15%	1.15%	
Mode A/C Intermode	1.12%		1.12%	1.03%		1.03%
Mode A/C - SLS	0.49%		0.49%	0.40%		0.40%
Mode S All-Call	0.92%	0.69%	0.23%	0.64%	0.46%	0.18%
Mode S Roll-Call	1.30%	0.27%	1.03%	0.99%	0.19%	0.80%
Mode S Roll-Call on II00	1.46%	0.03%	1.43%	1.14%	0.02%	1.12%
Mode S - SLS	0.12%		0.12%	0.11%		0.11%
TCAS	4.04%	0.36%	3.68%	3.10%	0.24%	2.86%
Military	0.24%		0.24%	0.21%		0.21%
ADS-B (DF17)	0.13%	0.13%		0.07%	0.07%	
Interference pulses	8.31%		8.31%	7.20%		7.20%
TOTAL	21.57%	4.92%	16.65%	16.06%	2.13%	13.92%

Table 5 – Average value over 1 minute of transponder occupancy per interrogation type close to Airport A (MTL = -77dBm)

### I.2.3. Comparison of transponder occupancy close to larger Airport A

### Comparison of Mode A/C interrogations and replies

A quality indicator (confidence) is computed for each Mode A/C interrogation received by the test aircraft. The table below provides the number of Mode A/C interrogations received by the test aircraft:

- with a confidence > 50% and with any confidence level,
- with a power level higher than -74 dBm and with a power level higher than -77 dBm, and
- the total number of Mode A/C replies from the test aircraft.

	Number of interrogations on 1030 at -74dBm	Number of interrogations on 1030 at -77dBm	Number of replies on 1090
P1 P3 Mode A (confidence > 50%)	4685	6180	
P1 P3 Mode C (confidence > 50%)	4769	6367	
P1 P3 Mode A (any confidence)	6231	10223	
P1 P3 Mode C (any confidence)	6363	10392	
P1 P3 Mode A/C			13182

Table 6 – Comparison of Mode A/C interrogations and replies

We can notice that the number of Mode A/C replies is higher than the number of Mode A and Mode C interrogations (any confidence) received at -74 dBm. That means that the MTL of aircraft may be higher than -74 dBm.

We can also notice that the number of Mode A/C replies is higher than the number of Mode A and Mode C interrogations received at -77 dBm considering a confidence > 50%, but lower than the number of Mode A and Mode C interrogations when considering any confidence. However, it is difficult to determine the MTL of the aircraft.

# <u>Comparison of Mode S selective interrogations from ground-based surveillance interrogators</u> and replies

The table below provides the number of Mode S selective interrogations addressed to the test aircraft and received with a power level higher than -74 dBm and with a power level higher than -77 dBm. It provides also the number of test aircraft replies.

	Number of interrogations on 1030 at -74dBm	Number of interrogations on 1030 at -77dBm	Number of replies on 1090
Mode S sel. addressed to own AC	472	478	
Mode S sel. addressed to own AC on II 00 triggering a short reply	40	52	
Mode S sel. addressed to own AC on II  00 triggering a long reply	0	0	
All Mode S sel. addressed to own AC (all IC)	512	530	
Mode-S selective Short Reply			281
Mode-S selective Long Reply			237
All Mode S selective replies			518

Table 7 – Comparison of Mode S selective interrogations from ground and replies

We can notice that the number of replies is higher than the number of interrogations received at -74 dBm. That means that the MTL of test aircraft may be higher than -74 dBm, even if messages with power level lower than the MTL may still be correctly decoded and replied.

Analysis of recordings showed that some messages with power level down to -76 dBm have been decoded by the test aircraft and replied, and almost half of interrogations between -74 and -77 have been correctly decoded and replied.

### Comparison of TCAS interrogations and replies

The table below provides the number of Mode S TCAS interrogations addressed to the test aircraft with power level higher than -74 dBm and power level higher than -77 dBm. It provides also the number of test aircraft replies.

	Number of interrogations on 1030 at -74dBm	Number of interrogations on 1030 at -77dBm	Number of replies on 1090
TCAS addressed to own	676	785	
TCAS Short Reply			669
TCAS Long Reply			7

All TCAS Replies			676
------------------	--	--	-----

Table 8 – Comparison of TCAS interrogations and replies

Even if the number of interrogations at -74dBm is equal to the number of replies, we can expect that some interrogations were not responded. That means that some interrogations with power level between -74 dBm and -77 dBm may have decoded and replied.

In conclusion, we can expect that the MTL of the test aircraft is around -74 dBm. The transponder occupancy calculation done for large airport B in next section will be limited to MTL = -74 dBm.

### I.2.4. Transponder occupancy close to large Airport B (MTL = - 74dBm)

The figure below provides the transponder occupancy per second over a one-minute period close to a large airport in west part of Europe. The 1030/1090 MHz RF activity has been recorded on-board the test aircraft on Wednesday 12 April 2017 at 13:57:32 UTC, at 36000ft.

The time in second is provided on the x-axis. The transponder occupancy in % of the time is provided on the y-axis.

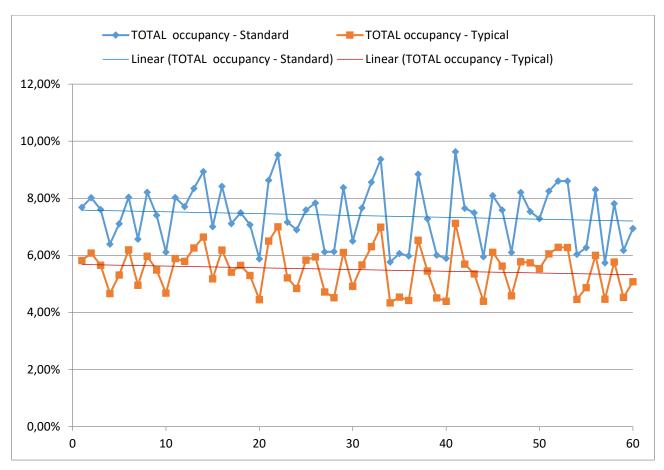


Figure 16 – Transponder occupancy per second close to Airport B

Note: Because the suppressor bus was not available for this recording flight, the occupancy due to suppressions from other avionic devices is not evaluated. Namely own aircraft DME transmissions are not accounted for (but are estimated below 0,1% occupancy) and own aircraft TCAS transmissions detected on 1030 MHz are evaluated as a received Mode S interrogation not followed by a reply.

The table below provides the average value of transponder occupancy over a one- minute period. The transponder occupancy is provided by interrogation type, and in separate column whether the test aircraft transponder replies or not.

Transponder Occupancy per	Standardised			Typical		
category of message	Total	Reply	NO Reply	Total	Reply	NO Reply
Mode A/C	0.81%	0.81%		0.27%	0.27%	
Mode A/C Intermode	0.34%		0.34%	0.31%		0.31%
Mode A/C - SLS	0.05%		0.05%	0.04%		0.04%
Mode S All-Call	0.77%	0.59%	0.18%	0.53%	0.39%	0.14%
Mode S Roll-Call	0.84%	0.41%	0.43%	0.62%	0.28%	0.34%
Mode S Roll-Call on II00	0.09%	0.00%	0.09%	0.07%	0.00%	0.07%
Mode S - SLS	0.01%		0.01%	0.01%		0.01%
TCAS	2.14%	0.15%	1.99%	1.65%	0.10%	1.55%
Military	0.07%		0.07%	0.06%		0.06%
ADS-B (DF17)	0.13%	0.13%		0.07%	0.07%	
Interference pulses	2.15%		2.15%	1.86%		1.86%
TOTAL	7.39%	2.09%	5.31%	5.50%	1.12%	4.39%

Table 9 – Average value over 1 minute of transponder occupancy per interrogation type close to Airport B

As in previous section, we can notice that the main contributors to the aircraft transponder occupancy are the interference pulses. That pulses are linked to the relatively high RF occupancy on 1030 MHz, due to high density of surveillance sensors and aircraft transmitting on 1030 MHz.

The second contributors to the aircraft transponder occupancy are the interrogations from TCAS. In this case, the transponder is mainly occupied by interrogations that are addressed to other aircraft. The aircraft is flying at high altitude (36000ft) at proximity of a large airport where most of aircraft are flying at low altitude. That is why it is not much interrogated by TCAS.

### I.3. Transponder occupancy from FAA Northeast flight test (April 2011)

The results presented in this section are extracted from a working paper, ASP TSG WP14-31 Transponder Occupancy Measurements 2011 Northeast Corridor Flight Test [RD 10], presented in the Aeronautical Surveillance Panel (ASP) – Technical Subgroup (TSG) meeting in January/February 2013.

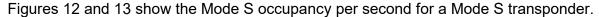
This working paper provided transponder occupancy measurements for the FAA Northeast flight test conducted in April 2011.

The approach under consideration is the addition of typical values for transponder occupancy as well as maximum occupancy based on transponders designed to the minimum performance requirements per current SARPs and MOPS requirements.

The WP includes calculations of transponder occupancy from the Northeast corridor flight test to provide insight into current transponder occupancy in high-density airspace.

Transponder sensitivity of the measurement system for this process is about -75 dBm. It should be noted that transponder sensitivity impacts occupancy results. The transponder occupancy was determined for both typical values and worst-case values (standardised values).

The figures below depicts the transponder occupancy per second for the flight test determined for a victim Mode S transponder. Mode S transponders have two components of occupancy, Mode S and ATCRBS.



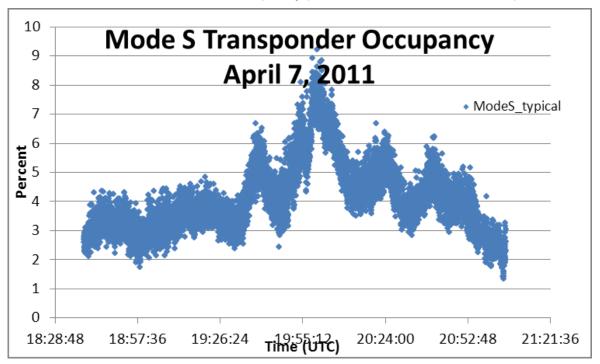


Figure 17 – Typical Mode S Transponder Mode S Occupancy

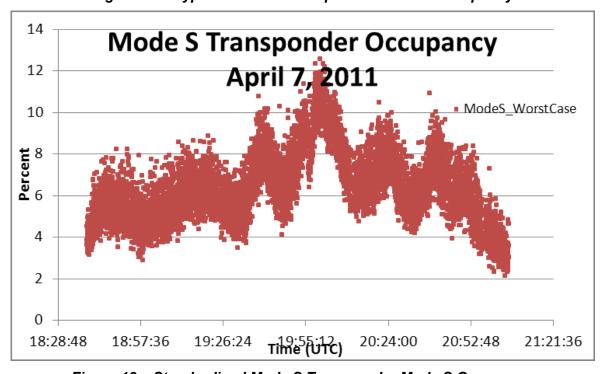
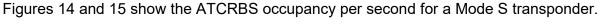


Figure 18 – Standardised Mode S Transponder Mode S Occupancy

The maximum transponder occupancy per second occurs when the flight test aircraft is located in the New York airport area. At this place, the maximum transponder occupancy due to Mode S per second is close to 12% using standardised values and close to 9% using typical values.



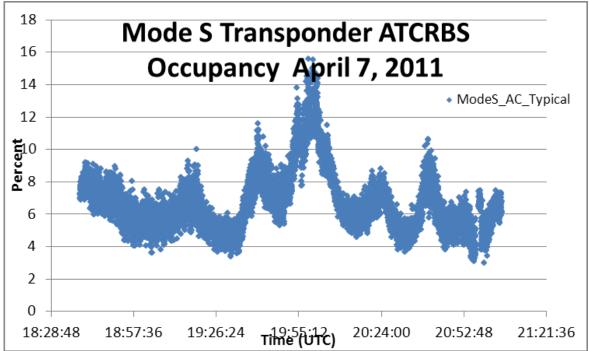


Figure 19 – Typical Mode S Transponder ATCRBS Occupancy

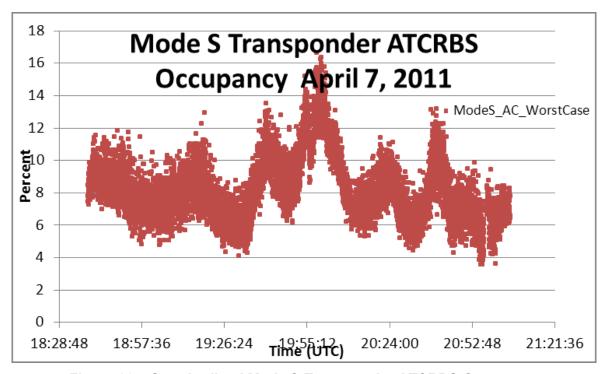


Figure 20 – Standardised Mode S Transponder ATCRBS Occupancy

The maximum transponder occupancy per second occurs when the flight test aircraft is located in the New York airport area. At this place, the maximum transponder occupancy due to Mode A/C per second is close to 17% using standardised values and close to 15% using typical values.

The global maximum transponder occupancy per second, considering Mode S and Mode A/C, occurs when the flight test aircraft is located in the New York airport area. At this place, the global maximum transponder occupancy per second, when considering as hypothesis that the maximum transponder occupancy due to Mode S happens at the same time as the maximum transponder occupancy due to Mode A/C, is close to 29% using standardised values and close to 24% using typical values. However, the values of the maximum transponder occupancy have been obtained by adding the maximum occupancy due to Mode S, to the maximum occupancy due to Mode A/C. The maximum occupancy due to Mode S and Mode A/C may not have happened at the same time, which means that the real maximum transponder occupancy may have been lower than the values provided above (29% and 24%).

# Annex J. Radar configuration assessment

Aim: Assess the radar configuration and MIP.

Mode S All-Call interrogations are used by Mode S radar to acquire Mode S aircraft. Once an aircraft is acquired, All-Call replies are useless. Aircraft that are lockout do no longer reply to Mode S All-Call interrogations. However, aircraft that are outside the lockout coverage will continue to receive these interrogations and will reply.

As recommended for **VERIFICATIONS 4** and **5**, the MIP of a Mode S radar is to be configured to generate no more than 6 All-Call replies per aircraft in a beam or period of 200ms on average when aircraft is not lockout as specified in section 3.1.2.11.1.1.2 of the ICAO Annex 10 Volume IV Amdt 89.

However, good practice would be to program the radar to operate with 4 Mode S All-Call replies per beam, as it is already the case for a large number of Mode S radars in Europe.

Mode S All-Call MIP should contain some interrogations with PR=1/2 or lower to facilitate the acquisition of aircraft in garbling situation and to reduce the number of triggered all call replies.

A first verification can be done using the MIP configured in the radar as shown in the example below. Assuming that 4 All-Call replies per aircraft are required in the beam, the table below provides the calculation to get the Mode S IRF (All-Call IRF) to use in a Mode S radar, considering that:

- MIP: S<sub>1/2</sub> A<sub>s</sub> / ... / S<sub>1/2</sub> C<sub>s</sub> / ...
  - All-Call probability of reply is set to  $\frac{1}{2}$  → 8 All-Call interrogations
- Radar range = 200NM
- Rotation period = 5s

number of periods	8		8 All-Call interrogations with PR=1/2 → 4 All-Call replies in average in the beam
rotation period (s)	5		
range (NM)	200		
SLS beam (Deg)	4.8		
beam dwell time (ms)		66.7	= 5000 (rotation period) / 360 * 4.8 (SLS beam)
Time between two successive All-Call periods (ms)		8.34	= 66.7 / 8

All-Call period (ms): 1/3 of time	0.33	2.78	
Roll-Call period (ms) 2/3 of time	0.67	5.56	
Range period All Call (NM)		225	=(3 x 10 <sup>8</sup> ) x (2.78 x 10 <sup>-3</sup> ) / 1852 / 2
IRF S or AC if combined (Hz)		120	= 1 / (8.34 x 10 <sup>-3</sup> )

Table 10 – Radar configuration verification

The computation above shows that using a Mode S IRF = 120Hz is sufficient to get 4 All-Call replies in the beam (8 All-Call interrogations with PR=1/2).

In that case, the interrogator triggers <sup>4</sup>/<sub>5</sub> All-Call reply (Mode S short reply) per second per aircraft.

Using a Mode S IRF = 120Hz is also sufficient to trigger 4 Mode A code replies and 4 Mode C code replies from aircraft Mode A/C transponder.

The detailed computed MIP is  $S_{1/2} A_s [2.78] / ... [5.56] / <math>S_{1/2} C_s [2.78] / ... [5.56]$ 

In the example above, the number of All-Call interrogations and replies, the rotation period and the range are fixed parameters, and the purpose of the computation is to provide the Mode S IRF value to program in the radar. The same type of calculation can be used the compute the value of the other parameters.

## Annex K. Method 2-1: Theoretical calculations

### K.1. Ground surveillance interrogations and transponder replies

**Aim**: Determining at a specific location, the number of interrogations an aircraft transponder will receive from ground-based surveillance interrogator and the number of replies it will send.

The number of Mode A/C replies, Mode S replies (sum of short and long replies) and Mode S long replies will be computed and compared to the minimum reply rates specified in the ICAO Annex 10 Volume IV.

### K.1.1. Mode A/C interrogations and replies

The number of Mode A/C radar decreases and the number of Mode S radar using Mixed Mode MIP (i.e. MIP including Mode A/C interrogations with no short P4) should be relatively low. Consequently, the number of Mode A/C replies from Mode S transponders should remain within the ICAO limits.

Mode A/C transponder aircraft generally flight at lower altitude and are generally interrogated by a lower number of interrogators.

An aircraft transponder will reply to Mode A/C interrogations from an interrogator if

- if it is in line of sight of the interrogator, and
- if the power of received interrogations exceeds its MTL.

The number of Mode A/C interrogations per second is provided by the calculation below:

$$Nbr\ interrogations\ per\ second = \frac{Dwell\ Time*Mode\ A/C\ IRF}{Rotation\ Period}$$

Where

$$\textit{Dwell Time} = \frac{\textit{Rotation Period} * \textit{Beam Width}}{360}$$

Then

$$Nbr\ interrogations\ per\ second = \frac{Beam\ Width*Mode\ A/C\ IRF}{360}$$

In order to simplify the computation of the number of Mode A/C replies, it is assumed that: Number of interrogations per second = Number of replies per second.

$$Nbr\ Mode\ A/C\ replies\ per\ second = \frac{Beam\ Width*Mode\ A/C\ IRF}{360}$$

### K.1.2. Mode S All-Call interrogations and replies

An aircraft transponder will reply to Mode S All-Call interrogations from a Mode S radar:

- if it is in line of sight of the interrogator,
- if the power of received interrogations exceeds its MTL, and
- if the aircraft transponder is not locked on the Mode S radar interrogator code.

If an aircraft is inside the lockout coverage of a Mode S radar, we will consider that the aircraft is locked on the interrogator code of the Mode S radar. In such a case, the aircraft will not reply to All-Call interrogations from this radar.

Using the same type of calculation, we can compute the number of All-Call interrogations and replies. The number of Mode S All-Call interrogations per second is provided by the calculation below:

$$Nbr\ interrogations\ per\ second = \frac{Dwell\ Time * Mode\ S\ IRF}{Rotation\ Period}$$

Where

$$\textit{Dwell Time} = \frac{\textit{Rotation Period} * \textit{Beam Width}}{360}$$

Then

$$Nbr\ interrogations\ per\ second = \frac{Beam\ Width * Mode\ S\ IRF}{360}$$

The number of All-Call replies depends on the probability of reply (PR) set in the All-Call interrogations:

Nbr replies per second = Nbr interrogations per second \* PR

Nbr replies per second = 
$$\frac{Beam\ Width * Mode\ S\ IRF}{360}$$
 \* PR

A MIP where the probability of reply is the same for all Mode S All-Call interrogations:  $S_{1/2} A_s I ... I S_{1/2} C_s I ...$ 

But the same probability of reply may not be applied to all Mode S All-Call interrogations, e.g.  $S_{1/2} A_s I \dots I S C_s I \dots$ 

In that case:

- the probability of reply of the first All-Call interrogations PR = 1/2
- the probability of reply of the second All-Call interrogations PR = 1, and
- the overall probability of reply in the beam is <sup>3</sup>/<sub>4</sub>.

### K.1.3. Mode S Selective interrogations and replies

An aircraft transponder will received selective interrogations if it is inside the surveillance coverage of a Mode S radar or inside the region of interest of WAM/MLAT system.

A Mode S ground interrogator may send one or several selective interrogations addressed to an aircraft in the beam (Mode S radar) or during the interrogation period (WAM/MLAT). A Mode S selective interrogation triggers a Mode S short reply or a Mode S long reply.

In this section, we will consider that the aircraft replies to all selective interrogations, and that the number of Mode S replies is equal to the number of Mode S interrogations.

The number of Mode S replies per second is computed as follow for Mode S radar and for WAM/MLAT systems:

Mode S radar:

$$Nbr\ of\ Mode\ S\ replies\ per\ sec = \frac{Nbr\ of\ Mode\ S\ interrogations\ in\ the\ beam}{Rotation\ Period}$$

WAM/MLAT:

$$Nbr\ of\ Mode\ S\ replies\ per\ sec = \frac{Nbr\ of\ Mode\ S\ interrogations\ per\ period}{Interrogation\ Period}$$

Mode S ELS radar sends selective interrogations to trigger in general 1 or 2 Mode S short replies in the beam to get the altitude of the aircraft (UF4) and the Mode A code (UF 5). It is not necessary to request the aircraft Mode A code every scan.

For example if the Mode A is requested every 5 scans:

$$Nbr\ of\ Mode\ S\ short\ replies\ per\ sec = \frac{1}{Rotation\ Period} + \frac{1}{Rotation\ Period\ *\ 5}$$

Mode S EHS radar send selective interrogations to trigger several Mode S long replies in the beam to extract the content of several BDS, e.g. 3 Mode S long replies per scan to extract the BDS 40, 50 and 60.

*Nbr of Mode S long replies per sec* = 
$$\frac{3}{Rotation\ Period}$$

Active WAM/MLAT systems send also selective interrogations to the aircraft, to trigger for example the aircraft altitude (short Mode S reply) every second and the content of a BDS (long Mode S replies) every 5 second.

Nbr of Mode S short replies per 
$$\sec = 1$$
  
Nbr of Mode S long replies per  $\sec = \frac{1}{5}$ 

### K.2. Advantages and limits

This method is based on simple calculations and basic assumptions.

However, computations that are more complicated may also be required:

- To compute the visibility of interrogators in the own State and in the neighbouring countries
  in order to determine in the line of sight of which interrogators the simulated aircraft is.
- To use the transmission power of radar and the free-space path loss in order to determine if
  interrogations from the radars in line of sight are above the transponder MTL of the simulated
  aircraft. The simulated aircraft transponder will only detect correctly and reply to the
  interrogations that are above its MTL.

The advantages and limits of the method are presented in Table 11.

	Advantages	Limits
SSR Mode A/C	<ul><li>Calculation of:</li><li>Transponder replies</li><li>Transponder occupancy</li></ul>	Following calculations may not be straightforward:  • radar real visibility  • power budget (free space path loss)
SSR Mode S	<ul> <li>Calculations of:</li> <li>All-Call and selective interrogations</li> <li>Mode S short and long transponder replies</li> <li>Transponder occupancy</li> </ul>	May be difficult to get radar characteristics, particularly from the military side.

	Advantages	Limits
		Transponder occupancy not accurate due to SLS and other aircraft that are selectively interrogated in the radar beam.
MLAT/WAM	<ul> <li>Calculations of:</li> <li>selective interrogations</li> <li>Mode S short and long transponder replies</li> <li>Transponder occupancy</li> </ul>	Difficult to estimate the surveillance coverage of WAM/MLAT systems.  May be difficult to get WAM/MLAT characteristics  Transponder occupancy not accurate
ACAS	Not covered	Not covered

Table 11 - Characteristics covered and uncovered by theoretical calculations

Since calculations can become very complex if too much data has to be determined, this method should be limited to the determination of:

- Number of interrogations a transponder will receive from Mode A/C radars, Mode S radars, WAM and MLAT systems;
- Number of replies the transponder will send to these radars;
- Transponder occupancy due to the received interrogations and replies only, independently
  of the airborne environment.

For any deeper and more complex calculations requiring aircraft environment, the method based on RF model or methods based on ground and airborne measurements should be applied.

## Annex L. RF Models

### L.1. Description

The main objective of RF simulation using a RF Model is to avoid systematic measurements on site and/or to extrapolate RF transmissions in a future or specific environment.

Different types of simulators exist:

- Statistical simulation: when aircraft are flying within interrogators coverage, they are considered to reply to a certain amount of interrogations. Simulation calculations are realised from this assumption, based on a mean of transmissions. It does not take into consideration peaks of traffic. SIEM (SSR/IFF environment model) Simulation<sup>10</sup> is an example of a model using a probabilistic simulation. SIEM is a software tool which can be used to plan the use of secondary radar frequencies to minimise harmful interference effects. TOPAS (Transponder Occupancy Analysis) is another example. TOPAS is a software tool which calculates the percentage of occupancy of Mode A/C and Mode S transponders using real traffic scenarios, depending on the position of the transponder, the distribution of the interrogators and the distribution of other Mode S transponders.
- Time-based simulation: this type of simulator takes into consideration the interrogators beam. During every period of time, interrogators are assumed to send interrogations in the beam direction. This simulator is a more realistic model. As time-related simulations, ESG Simulation<sup>11</sup> and EUROCONTROL RF Model<sup>12</sup> can be used as references.

### L.2. Calibration

Prior to use a RF Model, it is important to calibrate the model to ensure that the results of the simulation are relatively close to the reality. It is best to calibrate the model at least at two different places:

- at high altitude (e.g. 40000ft) at place where there is the maximum redundancy of ground-based surveillance interrogators to have a high number of interrogations from ground (the Annex E provides an example of the surveillance coverage redundancy of Mode S radar at 30000ft);
- at proximity of large airport at low altitude (e.g.15000ft) to have high aircraft density area and high ACAS activity;

The following information is required to perform a good calibration:

• 1030/1090 MHz RF measurement recorded on-board a test aircraft that will be used as reference. The results of the RF Model will be compared to that reference.

<sup>&</sup>lt;sup>10</sup> SIEM Simulation: A Simulation of the Interference Effects of Mode S Systems on the RF Environment and on the Surveillance Performance of Mode S and Mode A/C Ground Stations, DERA/LSB1(ATC)/SIEM/REP(MODE S)/6/C (March 2000)

<sup>&</sup>lt;sup>11</sup> ESG Simulation: SISSIM SSR-IFF System Simulator (Presentation, September 2002)

<sup>&</sup>lt;sup>12</sup> EUROCONTROL RF Model: *1090 Mode S FRUIT Model, User Manual*, (Helios Technology, September 2005)

- 1030 MHz RF measurement contains the interrogations from ground-based surveillance interrogators and air interrogators (TCAS) that are addressed to the test aircraft and to other aircrafts
- o 1090 MHz RF measurement contains the replies from the test aircraft
- The occupancy of the test aircraft can be computed using the suppression bus, or using interrogations on 1030 MHz and replies on 1090 MHz
- Surveillance data recordings (ASTERIX Cat. 48) used to build the RF Model air scenario. It
  is recommended to get a surveillance data recording at same place and at same time than
  the airborne RF recording in order to define in the RF Model an aircraft environment that is
  as clause as possible to the reality.
- The information of all ground-based surveillance interrogators to build the RF Model ground surveillance interrogators scenario. The ground scenario is to reflect, as close as possible, the real ground interrogator environment.

Most of the time the calibration will be done using a single day of RF measurement. That means that surveillance data recordings (ASTERIX Cat. 48) of the same day will be required, from countries (not necessary all) crossed by the test aircraft.

To calibrate the RF Model, it will be necessary to compare:

- the number of interrogations received by the simulated aircraft to the number of interrogations received by the test aircraft;
- the number of replies of the simulated aircraft to the number of replies of the test aircraft (Mode A/C replies, Mode S short and long replies per DF type);
- the transponder occupancy of the simulated aircraft to the transponder occupancy of the test aircraft.

# Annex M. Probability of detection using ground RF measurements

In Section 7.2.1 and Section 7.2.2, we have seen that it is difficult to decode aircraft replies in high traffic density area where the high number of replies may create a lot of garbling, particularly when an omni directional antenna is used to receive and record messages on 1090 MHz. Therefore, only replies from aircraft at short distance are correctly decoded by the ground RF measurement system in high traffic density area.

The aircraft density is particularly important at proximity of large airports. The figure below provides the simulated probability of detection at proximity of two large airports in European code area: Airport A in green and Airport B in blue.

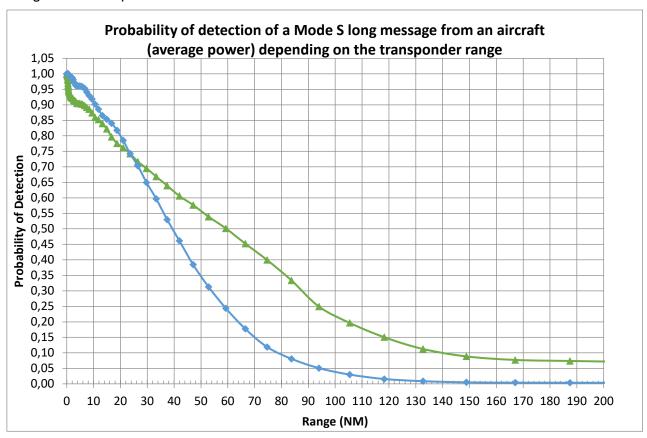


Figure 21 - Probability to decode Mode S long message vs Range

We can see that the probability of detection of a Mode S long message by an omni-directional antenna decreases rapidly with the range. At 30NM, less than 70% of Mode S long messages are correctly received and decoded by a ground receiver using an omni-directional antenna.

The probability of detection at Airport A decreases rapidly at very short range because of the high number of aircraft transmitting ADS-B messages on the ground.

No aircraft was recorded on the ground at Airport B (there was no aircraft on the ground in surveillance data, which does not mean that there was none in reality).

The probability of detection decreases more rapidly at Airport B than at Airport A because the aircraft density is higher at proximity of Airport B.

# **Annex N. Transponder occupancy times**

Occupancy Times for Currently Specified SARPs Maximum Mode A/C and Mode S rates (ICAO Doc 9924 Appendix M [RD 8])

Received Pulses		Total transponder occupancy time (μs) <sup>a,b</sup>			
		Mode A/C-only Transponder		Mode A/C/S Transponder	
		Standardised	Typical	Standardised	Typical
P <sub>1</sub> P <sub>3</sub>	Mode A	157.55	89.55	157.55	48.55
	Mode C	170.55	102.55	170.55	61.55
P <sub>1</sub> P <sub>3</sub> P <sub>4</sub> short	Mode A	157.55	89.55	27.4	25.3
	Mode C	170.55	102.55	40.4	38.4
P <sub>1</sub> P <sub>3</sub> P <sub>4</sub> long	Mode A	157.55	89.55	330.2	221.2
	Mode C	170.55	102.55	343.2	234.2
P <sub>1</sub> P <sub>2</sub>	Mode A/C	47	39 <sup>d</sup>	47	39 <sup>d</sup>
	Mode S			19.75°	17.75°
P <sub>1</sub> P <sub>2</sub> P <sub>5</sub> P <sub>6</sub>	_	47	39 <sup>d</sup>	19.75°	17.75°
P <sub>1</sub> P <sub>2</sub> P <sub>6,</sub> correctly addressed	short reply	47	39 <sup>d</sup>	321.75	212.75
	long reply			377.75	268.75
P <sub>1</sub> P <sub>2</sub> P <sub>6,</sub> not addressed	_	47	39 <sup>d</sup>	49.75	38.75
Squitter	short	_	_	189	80
	long	<u> </u>	_	245	136

### Notes:

Figure 22 – Occupancy Times for Currently Specified SARPs Maximum Mode A/C and Mode S rates

**Note:** ICAO is currently reassessing the above values. These guidelines will be reviewed once ICAO publishes an updated edition of ICAO Doc 9924 as these values are used for transponder occupancy computation.

a) Additional effects may occur due to reply rate limiting.

b) Military transponders may accept a second interrogation during the turnaround time of the first interrogation. The interleaving of interrogations can produce a lower occupancy for military transponders in comparison to civil transponders.

c) In this case the incoming RF signal extends beyond this time and/or other incoming signals will only be decoded if they are sufficiently above the receiver threshold set by the original signal.

d) Typical values were measured, thus adding a reference is not necessary.



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