Cost-Optimized Avionics System - Surveillance Solution with Radar for Small Aircraft Transportation Segment

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Abstract. In this paper is explained the need for cost-optimized SAT surveillance system and described one potential approach to the solution which provides a complete protection against traffic, terrain and obstacles at an affordable price. The second part of the paper focuses on the radar. The trade-off analyses of performance, frequency bands and antenna size are described here. The goal of this paper is to highlight the need for securing the frequency spectrum for airborne radars that is under strong pressure of telecommunication lobby.

1. Motivation
Per EASA statistics shown in Figure 1 below, the main cause of General Aviation (GA) fatal accidents is the loss of control during the flight. However, the next most often known causes are the controlled flight into terrain, followed by the low altitude operations. Significant surveillance-related reasons of the accidents, which can be addressed by a single dedicated system, are the collisions with obstacle during take-off and landing, and the mid-air collisions (MACs).

Figure 1. Risks areas in General Aviation [1]

The key prerequisite for any hazard prevention function is to be aware of the hazard, i.e., to be able to detect it. The primary mean to stay well clear from any hazard including other traffic during VFR operations is for the general-aviation pilot’s ‘See and Avoid’ capability. 'See and Avoid' method has, however, limited effectivity. Furthermore, the rapidly increasing amount of low-level airspace users (primarily drones) increases the risk of an MAC involving GA aircraft both due to higher traffic
density and small size of these vehicles which makes their visual detection very difficult. Thus, it implies that system being capable to provide complete protection against traffic, terrain and obstacles at an affordable price would be highly beneficial for the Small Air Transport (SAT) segment.

2. Candidate technologies

Surveillance means intended for SAT market can be divided into two main categories – means for cooperative surveillance and means for non-cooperative surveillance.

Cooperative surveillance technology is currently represented mainly by Air Traffic Control Radar Beacon System (ATCRBS) Transponder, historically the key enabler used for surveillance in commercial air transport, and Automatic Dependent Surveillance-Broadcast (ADS-B) Out mandated since January 2020 in USA, and since December 2020 in Europe. There is a number of already existing systems, like Airborne Collision Avoidance System (ACAS), or Traffic Advisory System (TAS), which provides the traffic awareness without the collision avoidance functionality. But generally, these standardized and certified avionics systems are very expensive for the SAT segment, thus equipping of the aircraft which are not under the mandate is not probable. Other standardized means, such as FLARM devices or other systems available in the UK under Electronic Conspicuity program, have unfortunately limited usability and interoperability. If we focus on terrain and obstacles, the Enhanced Ground Proximity Warning System (EGPWS) provides information and alert against potentially hazardous terrain to prevent a controlled flight into terrain. Equipping with the EGPWS is required for aircraft with MTOW above 5700 kg or capable to transport more than nine passengers, but versions intended for light turbine and piston aircraft are also available on the market. There is a combination of TAS and EGPWS called Multi-Hazard Awareness System providing traffic awareness and terrain warning, but it lacks the non-cooperative targets detection and requires high acquisition costs.

Non-cooperative and active systems are the primary way how to provide awareness and alerting against all types of threats. These systems can provide high performance, but generally suffer from weight, size, power consumption, and the cost requirements (SWAP-C). On the other side, this segment of sensors is quickly developing and brings new possibilities even for the SAT segment.

It seems that there is a clear operational need for systems providing integrated Detect and Avoid (DAA) functions to SAT pilots/users, and this need will become even stronger in the next years due to growing drones and Urban Air Mobility (UAM) market. It is evident that such a system must contain sensors suitable for detection of non-cooperative threats. Generally, the following sensors are considered: lidars, radars and cameras (infra-red, electro optical). While lidars provide long range and detection of all threats, but they suffer from performance degradation in poor meteorological conditions, the cameras provide great angular resolution and low power consumption, but their calibration and installation costs are quite high, and its use-case is quite narrow, limited by the weather conditions (night, rain, fog) and the environmental factors as lens drops or lens dust. However, properly designed radars seem to be able to achieve majority of the targeted performance requirements what provides the promising solution when combined with other sensors. More detailed review of radars is provided in the upcoming sections.

3. Proposed SURV system solution

As already indicated, the market currently lacks complex and affordable SAT-suitable surveillance solution capable to operate in all-weather conditions. Moreover, the need for such a system is increasing with the emerging increase of uncontrolled airspace users, especially in very low altitudes.
The proposed SURV system solution described in this paper aims at integration of the functionalities with adapted DAA alerting and avoidance functions capable to detect both cooperative and non-cooperative traffic, but also the terrain and obstacles, with the use of radar and database.

![Figure 2. High Level Architecture of SURV system solution](image)

In particular, the SURV system consists of an ADS-B In receiver for the detection of cooperative traffic, K-band radar for the detection of non-cooperative threats. Data from both are processed in the computing platform called DAA module. It hosts the algorithms for the traffic avoidance (ACAS) and terrain and obstacle avoidance including terrain and obstacle database. The DAA module also provides ADS-B data to the Compact Computing Platform (CCP), which is needed by Tactical Separation System (TSS). Finally, DAA module obtains ownership positional data from the NAV module through the CCP. Information to pilots are displayed using portable application.

The first simplified prototype of above-described system was realized under the Clean Sky 2 COAST programme. System was flight tested in June 2021 together with other technologies developed also by other partners of COAST project.

4. Radar Trade-Offs

In the aerospace industry, X-band radars, (operational frequency range 8-12 GHz), are primarily used in large passenger aircraft. The reason for the use of this particular frequency band is that it can provide detection range in order of hundreds of kilometers (depending on the transmit power and antenna aperture). X-band radars are used primarily as weather hazard sensors, however limited types of radars can be used for terrain mapping or target detections. Target detection and tracking functionality is required primarily for military aircraft. Although the X-band radars provide superior performance and quite broad operational scope, their SWAP-C parameters could be too demanding for the SAT segment.

Radars for non-cooperative surveillance are not widely used in General Aviation and Air transport segment. This is mainly due to the high cost and installation difficulties with the large antenna. Furthermore, the antenna requires additional free space under the radome for its mechanical steering. As the technology is evolving, new radar concepts are becoming feasible. Inspiration could be found in automotive industry with electronically steered antennas and continuous wave modulation. In the following sections we will be discussing the trade-offs that should clarify the main challenges and limitations for the surveillance radar design. The main focus is in the SAT segment but the presented
approaches could also be used for UAM or Drones. For other than SAT, usability must be considered, for instance, different size and performance criteria.

Two challenges should be addressed:
- Functional, connected to technology and use cases.
- Legislation, aiming at safety, spectrum access and certification.
This paper analyzes the first challenge and partially also the second one aiming at spectrum access.

4.1. Size vs. performance vs. cost
Basic trade-off should be performed to select an optimal radar for a specific use – in this paper we assumed Small Air Transport category. The main requirements and constrains are formulated in following bullets.
Radar should:
- Be of a small size to fit to limited SAT radome.
- Have sufficient performance like range and resolution.
- Be a cost efficient.
But:
- Smaller antenna means lower achievable performance.
- Better performance means higher cost and SWAP requirements.
These contradicting requirements and trade-offs are summarized and partially solved in following sections.

4.2. Frequency dependencies
The main parameter defining the radar could be identified even from the abbreviation RADAR which means Radio Detection and Ranging. Functionality of radar depends on the RADIO waves which is defined by the frequency and the corresponding wavelength. In this section C to Ka frequency band is considered, covering frequencies from 4 to 32 GHz.

The optimal frequency selection trade-off is between the achievable detection range and angular resolution due to the suitability for SAT aircraft category.
Achievable radar range is equal to radio signal energy received as an echo from the remote target, where the signal power is attenuated by atmosphere. Attenuation by atmosphere for different radio frequencies is described for example in [2]. After some simplification, it could be stated that the higher the frequency the more attenuation through the atmosphere.
Lower frequency is therefore preferred to achieve longer detection range since it has lower attenuation in the atmosphere. The graph (Figure 3) shows the dependency described by decreasing SAT suitability for higher frequencies due to atmospheric attenuation.

Let’s focus on the second actor in the trade-off – the angular resolution. Angular resolution (precision of object position detection) is defined by the beam width created by the antenna. Narrow beam is desired to achieve precise resolution hence, a larger antenna is needed to achieve a narrow beam. A larger antenna can also increase the gain and enables longer detection range but this will not be discussed here for simplicity.

The size of the antenna is equal to multiple or ratio of the operating radio signal wavelength. That means that the size of the antenna reflects the radio signal frequency, longer the wavelength the larger the antenna. For better imagination of this fact see Figure 4. It could be concluded that for SAT with limited installation space for the antenna there is a needed for a radar with higher operating frequency that enables high angular resolution and antenna gain with relatively smaller size when compared to lower frequency. That formulates the initial trade-off – for SAT is higher operating frequency beneficial due to smaller antenna size, but at the same time is lower frequency preferred due to smaller signal attenuation.

4.3. Trade-offs results
To narrow down candidate systems and frequencies, one parameter will be baselined. Selected was the beam width parameter that is required to be smaller than 10 degrees. This value was selected as an initial fixed point without deeper analyses and should be evaluated in following work. Assuming the planar array antenna, the sizes of antennas in respective frequency bands are calculated in Table 1. This table also answers the initial trade-off dilemma between the size and range, when considered the SAT DAA use case limitations. Maximal size of the antenna for SAT was defined as 12 inches (approx. 305 mm) and minimal range of DAA radar as 10 km. For more details about required DAA performance see [3].

| Band | Frequency | Antenna size in Inches | SAT Suitability note |
|------|-----------|------------------------|----------------------|
| C    | 4 GHz     | 20                     | No - too large antenna |
| X    | 9 GHz     | 10                     | Yes – size on limit   |
| Ku   | 13 GHz    | 7                      | Yes                  |
| Ku   | 15 GHz    | 6                      | Yes                  |
| K    | 24 GHz    | 4                      | Yes - limited range   |
| Ka   | 32 GHz    | 3                      | No – small range      |

These presented trade-offs formulate the approaches how to select optimal radar concept. Goal of this paper was not to present a winning variant with precise calculations, but rather introduce the questions and trade-offs necessary to be answered before the radar design is started.

5. Frequency challenge
Feasibility of the new radar concepts are not limited only by the technology capabilities, but also by the legislation. There are strict rules for radiating the electromagnetic energy especially in the radio frequency spectrum. Global harmonization is covered by the International Telecommunication Union (ITU) that is the United Nations specialized agency for information and communication technologies. Spectrum usage by Aeronautical applications is coordinated with another UN agency - International
Civil Aviation Organization (ICAO). New radar must fulfill technical requirements defined by global legislation with some local specifics valid for countries or regions. From legislation point of view the DAA airborne radar belongs to Aeronautical Radio Navigation Services (ARNS). Some frequencies are already allocated for radar as the primary application, but coexistence of new DAA radar with existing airborne weather radars and other applications must be considered. Short list of widely accepted frequencies is in Table 2. This table should be updated and extended in the future to enable evolution of safe SAT, UAM and Drones operations.

Table 2. Frequencies allocation for Airborne Radar [3], [4], [5]

| Band                  | Allocation to Airborne Radar |
|-----------------------|------------------------------|
| 8.75-8.850 MHz        | primary                      |
| 9.300-9.500 MHz       | primary                      |
| 13.250-13.400 GHz     | primary                      |
| 15.400-15.700 GHz     | primary                      |
| 24.450-24.650 GHz     | primary in some Regions      |
| 32.300-33.400 GHz     | primary                      |

Radio frequency spectrum becomes a rare commodity and even aeronautical frequency bands allocation is under a strong pressure from telecommunication industry. This is mainly due to 5G introduction and expansion of new satellite constellations providing worldwide coverage data connection. Therefore, it is important to highlight the needs for aeronautical frequencies suitable for surveillance radars for SAT, but also for UAM and drones. The proper forums to address these inquiries are for example EUROCAE for Europe and RTCA for USA.

6. Conclusion

The integration of new airspace users, especially those operating in low altitudes, is slowly progressing. Multiple initiatives are taking place to develop smart, automated, interoperable and sustainable traffic management solutions. It is however important to keep in mind, that these operations do not only need to be efficient, but safe in the first place. Even before new users arose, there was a strong need for affordable surveillance system solution providing complete protection against traffic, terrain and obstacles for SAT segment. Now, having drones and soon also UAM aircraft joining the operational environment of SAT, this need becomes even more emphasized and important.

This paper introduced the promising and affordable SAT solution which provides not only the situation awareness, but also collision avoidance capability. Significant benefits of the proposed system would be facilitated using radar, which is not widely used today due to its high cost and installation difficulties. New radar concepts using the state-of-the-art technology are however becoming more feasible and extensive usage is anticipated in multiple aircraft categories. Developed initial SURV system was flight tested in June 2021 and final tests of complete system with radar are planned in 2022.

One of the main outputs of the Radar concept definition and the trade-off considerations is the identification of the need for legislative push in order to highlight the issue with securing the portion of frequency spectrum for surveillance radars.
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