AIRSPACE TRAFFIC CONTROL

Modern Challenges and Technical Solutions

This article explains the basics of PSR, SSR and ADS-B as the main sensors used for Air Traffic Control. It touches upon their limitations and emerging challenges of the changing environment in which they operate. New trends and proven technical solutions are introduced.

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Air Traffic Control (ATC) and specifically FIR (Flight Information Region) management is the responsibility of each country to ensure the flight safety. In most countries this responsibility is shared between the National Air Navigation Services Providers (ANSPs) and the Air Force (AF), with the respective roles varying from country to country.

The main technical means used for ATC are the following:

- **The Primary Surveillance Radar (PSR)**. PSR is the 'classic' radar that does not require the 'cooperation' of the target aircraft for detection and tracking.

- **The Secondary Surveillance Radar (SSR)**, which requires the 'cooperation' of the aircraft, as the SSR simply activates with its transmissions a special device aboard the aircraft, called Transponder, which in turn sends coded messages related to the flight back to the SSR (identification number, flight altitude, etc.)

- **ADS-B (Automatic Dependent Surveillance - Broadcast)**, which is the most recent addition, is a system where the aircraft automatically transmits the flight data from its transponder to the ground without requiring activation. However, in this case these messages can be received and decoded by anyone with a suitable receiver, not just the ANSPs.

Usually, all PSR stations have a co-located SSR (Combined PSR/SSR), but there are also stations with SSR only.

In this article we will focus on the radar systems used by ANSPs. Military users use more complex and specialized radar systems which additionally incorporate Electronic Counter-Counter Measures (ECCM) systems for times of conflict, as well as other capabilities such as e.g. ballistic missile detection and tracking, anti-aircraft missile guidance etc.

Primary Surveillance Radar | PSR

The specifications of PSRs that are Certified for ATC usage are defined by International and National aviation regulatory authorities (ICAO, EUROCONTROL for Europe, FAA for USA, CAA and MAA for UK, etc.).

They are divided into two major categories according to their mission: Airport Surveillance Radars (ASRs) and En-route radars

Airport Surveillance Radars (ASRs)

The mission of ASRs, also referred as Terminal Approach or Terminal Area Radars (TARs), is to monitor inbound and outbound traffic at the airports. For this purpose, they are installed either within the airport grounds or on adjacent elevated positions (e.g. hills). Their range is typically 60 NM (Nautical Miles) and they are almost always Combined, i.e. co-located with SSRs.

ASRs are usually 2D, meaning that they only provide the target's bearing and range, not its height information. That is obtained by the co-located SSR through a coded message from the target's onboard transponder.

Most of the ASRs operate on S-Band frequencies (2700-2900 MHz), on a single or a pair of fixed frequencies allocated by the country's Spectrum Management Agency. ASRs are often 'full frequency diversity systems', meaning that they can change frequency pulse-to-pulse for the purpose of improving the detection. Depending on the user's requirements in terms of system availability they have one channel or two channels where the second one is at 'hot stand-by'. That ensures higher than 99% availability in case of failure, with the critical failure elements being limited to the antenna rotation assembly, cabling and waveguides.

ASRs usually incorporate a Weather Processor, which provides the 'general picture' of the weather conditions of the area (e.g. rainfall intensity levels) for advisory purposes only and not for forecasting purposes for which high-resolution information from the specialized weather radars is required.

En-route radars

Their mission is to monitor air traffic along the air-routes of the FIR: from the entry points of the FIR to the exit points (for traversing traffic) and to/from the terminal areas of the airports. They are usually installed at elevated positions with a range of up to 200 NM and are almost always Combined, i.e. co-located with SSRs of similar range.

They usually operate on a single or a pair of frequencies in the L-Band (1215-1400 MHz) which is assigned to them, they are also usually 2D and in this case the aircraft altitude is obtained from the co-located SSR. In some countries ANSPs do not have their own En-Route PSRs and receive their respective traffic information in the FIR from the military air surveillance radars.

PSR challenges

The main challenges that PSRs face in the modern operational environment can be summarized as follows:

- Interference to their ultra-sensitive receivers from the ever-expanding 4G/5G mobile communication networks operating in adjacent L-Band and S-Band frequencies. For example, the presence of a 4G base station whose transmitter is malfunctioning (e.g. producing spurious emissions) is sufficient to cause problems (saturation, sensitivity degradation, etc.) in the reception of a ASR located hundreds of metres away.

- The creation false targets by wind farms becoming more prevalent and larger in size. The rotating blades of wind turbines exhibit spectral doppler characteristics similar to the aircraft's, allowing them to pass through the PSR processing filters to appear as real aircraft, thus complicating the work of air traffic controllers.

- The increasing use of drones for commercial or amateur applications. Drones do not carry transponders to be tracked cooperatively by SSR or via ADS-B. They generally have a much smaller Radar Cross Section (RCS) and different spectral Doppler characteristics than the normal aerial targets which PSRs are designed and configured to detect. As a result, drone flights (especially near airports) cannot be effectively tracked by existing ASRs.

- The existing threat of using aircraft as a means for terrorist activities/hijackings with disabled transponders (Renegade case) or even the use of drones for malicious activities. These prospects make imperative and necessary to increase the capabilities of PSRs to autonomously (non-cooperatively) monitor air traffic without the assistance of SSR or ADS-B.

Addressing the challenges

To address the above challenges, technical solutions are being developed along the following lines, either as new radar systems or as upgrades/modernisation of existing ones:

- New Signal Processors based on modern FPGA (Field Programmable Gated Array) technology and high-speed processors achieve through sophisticated algorithms a higher resolution in the target velocity processing range (doppler) and a more efficient filtering of false targets, especially those from wind farms or electromagnetic interference. Such cases are the 16-point MTD filters, the Median filter and the Vertical Clutter Canceller (VCC) patented algorithm that are used in Intersoft Electronics' Next Generation Signal Processor (NGSP®), as shown in **Figure 1**.

- Several radar manufacturers have started to enhance their PSRs performance with the ability to determine the height of targets (3-Dimension – 3D) in order to decouple from the SSR dependence. Height information from PSRs increases the rejection efficiency of false targets and in addition provides a significant operational advantage as it is possible to calculate the height of targets with a non-functional/malfunctioning transponder or without a transponder (e.g. drones). In line with this trend, the IE's NGSP® introduces the 3D processing feature even to legacy PSRs when it is installed as part of a modernization program.

- A 'positive' side-effect of the rapid development of 4G/5G network technology is the competitive development of a multitude of components in the L and S frequency bands, resulting in a steep drop in their prices. This fact has now made it possible to develop and manufacture non-rotating Active Electronic Scanning Array (AESA) antennas in the L and S frequency bands for civilian PSR radars (eg ASRs) at an affordable cost to ANSPs. To date radars with AESA-type antennas have exclusively been used at very high-cost military applications. The use of non-rotating AESA-type antennas in combination with advanced signal processors, like NGSP®, can provide a solution to the above challenges as PSRs can now acquire 'special' operating rates that are currently found only in military radars: e.g. multiple simultaneous beams, possibility of detecting and tracking (tracking) suspicious targets without Transponder, etc. Such non-rotating antennas are being developed and tested by Intersoft Electronics and will soon appear in the market, as shown in **Figure 2**.

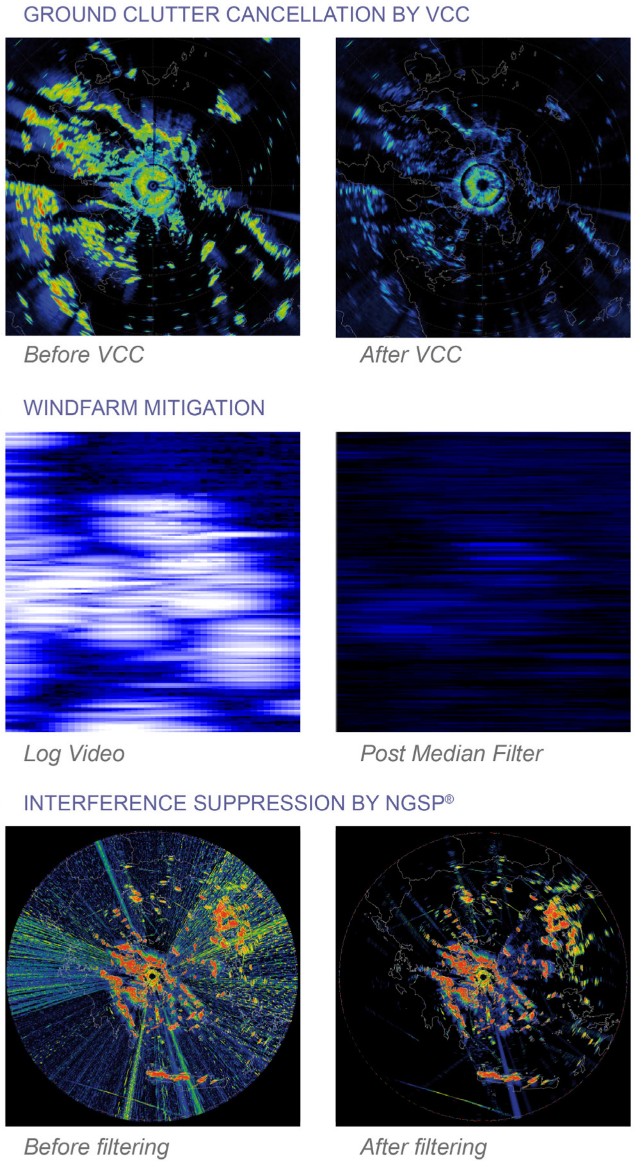

Figure 1 | *Advanced PSR signal processing functions of Intersoft Electronics' NGSP®*
Source: Intersoft Electronics NV

NGSP® includes the patented Vertical Clutter Cancellation (VCC), which reduces clutter while maintaining the sensitivity on targets. It removes ground clutter and mitigates the unstable clutter caused by windfarms.
NGSP® also offers protection against interference such as from 4G/5G and other high frequency applications. ECCM options are available for the military.

Figure 2 | *Prototype of Intersoft Electronics' L-IESA® L-Band non-rotating antenna*
Source: Intersoft Electronics NV

Secondary Surveillance Radar | SSR

As with PSRs and SSRs, their specifications are clearly defined by aviation regulatory authorities.

SSR Description

SSRs are technically simpler systems than PSRs, with low acquisition and maintenance costs and in most cases share the rotation infrastructure of co-located PSRs. This means that the SSR antennas are installed on top of the PSR antennas so that they use the same rotator, as shown in **Figure 3**. In addition, the accuracy and fidelity of the information provided by the SSR is superior to the PSR's due to the sensor/target cooperation in process of detection and tracking.

All SSRs operate at two fixed frequencies:

- 1030 MHz for the 'question': Transmission from the SSR to the aircraft (UPLINK) and
- 1090 MHz for the 'response': The aircraft's Transponder transmission to the SSR (DOWNLINK).

The distance of the target aircraft is determined by the time that elapses between the transmission of the 'question' and the reception of the Transponder's 'response', while the azimuth is determined by the position (angle) of the rotating antenna at the moment of receiving the 'answer'. The content of the 'response' includes additional details of the flight (flight data), such as the barometric height (Flight Level), identification code, etc.

The detection range of an SSR varies between 100 NM and 250 NM. They are often co-located with ASR or En-route PSR, while there are also stand-alone En-route type SSR installations, as shown in **Figure 4**.

For the above reasons (simplicity, accuracy, reliability, low cost), two decades ago the SSRs were supposed to become the basic and later the sole ATC system which ANSPs would use to control the traffic in the FIR and ensure the flight safety. The rationale was that civilian aircraft are by definition 'cooperative' targets and it does not make sense to invest in high-cost PSRs. This view was revised after the tragic events of September 11, 2001.

SSR challenges

The major challenge that SSR systems are facing in the modern era is the saturation due to the ever increasing traffic density especially around the major international airports (Hubs) such as Frankfurt, New York, Dubai, Hong-Kong etc.

The saturation occurs because the operation of all SSRs is carried out exclusively on a pair of frequencies (1030 MHz and 1090 MHz). Consequently, in cases of high aircraft density in an area, the information (flight data) transmitted by their transponders (all at 1090 MHz) overlap and cannot be correctly decoded by the SSR stations on the ground (effects known as FRUIT and Garbling).

Figure 3 | *S-Band PSR antenna (ASR) with co-located SSR antenna mounted on top*
Source: Intersoft Electronics NV

Figure 4 | *Standalone En-route SSR antenna installation (without co-located PSR)*
Source: Intersoft Electronics NV

Addressing the Challenges

To address the problem of saturation, the special Mode-S (Selective) of SSR has been developed which foresees the scheduled selective activation of transponders of specific aircraft instead of the indiscrete activation in the past. Thus, Mode-S has now become the dominant mode of operation for ANSP SSRs. However, even Mode-S, in cases of very high traffic density, reaches the limits of saturation. In USA in particular, in an effort to decongest the 1090 MHz frequency, the FAA has licensed the use of the alternative frequency 978 MHz for light aircraft (General aviation) transponders for flights below 18,000 feet (UAT: Universal Access Transceiver system).

ADS-B system

The ADS-B system was developed in parallel with the introduction of GPS receivers for aviation use, which provide the exact position and speed (velocity vector) of the aircraft, which are then encoded in messages and transmitted in every direction (Broadcast). With regards to the technical means, it requires the installation on the aircraft of a new type of transponder, which now transmits the messages containing the flight data automatically at regular intervals (usually every 1 sec). It is essentially the 'aviation' counterpart of the 'maritime' AIS (Automatic Identification System) and the 'air picture' resulting from the flight data received by the ADS-B stations on the ground is available in real time to the public via websites and apps.

As far as ANSPs are concerned, the main advantage of ADS-B is the very low cost of the equipment required as they no longer need the complex and maintenance-intensive infrastructure of a rotating antenna, but instead: a lightweight omni-type antenna, a small electronic receiver board and decoding software on a PC. The cost of a certified ADS-B station for use by ANSPs with a range of around 100-200 NM is in the order of a few thousand euros.

At the same time, 'amateur' ADS-B receivers (in the form of USB sticks) are available in the market at very low cost, while the decoding software is available free of charge on the internet. Note that all modern ANSP SSR systems can, in addition to Mode-S messages, also receive and decode ADS-B messages without additional equipment.

ADS-B challenges

The major challenge of ADS-B is the same as that of SSR, namely the over-usage and saturation of the 1090 MHz frequency. The continuous transmission (every 1 sec) of ADS-B messages on the unique frequency of 1090 MHz by all aircraft further aggravates the saturation effect which is already being addressed by selective activation of transponders via Mode-S of the SSR.

From an operational point of view, the simplicity of ADS-B is also its 'Achilles' heel': just as someone with a laptop, a receiver on a USB stick and a small antenna can receive the image of the airspace within a radius of several NM, in the same way he can with a small transmitter create thousands of virtual aircraft and cause congestion/confusion in the ATC system, as there is no encryption of any kind. This is why, despite its irrefutable usefulness and flexibility, ADS-B will remain as an 'advisory' ATC medium.

CONCLUSIONS

- The PSRs will remain the main ATC equipment and will address the modern challenges by borrowing technological capabilities currently found only in military radars: countering interference from mobile communications networks using sophisticated digital filters, applying advanced processing algorithms for rejecting false targets from wind farms, tracking suspicious targets with low RCS and speed, such as drones, using AESA-type non-rotating antennas etc.

- SSRs with Mode-S will remain the main complementary ATC medium, as the high fidelity of the information they provide in terms of identification and accurate tracking of flights is essential to the safe regulation of air traffic. Saturation phenomena, where they occur, will continue to be addressed, to the degree possible, by 'intelligent' algorithms of Selective Interrogations of Transponders.

- ADS-B systems will remain the main 'advisory' tool for air traffic situational awareness. However, due to their vulnerability to malicious interference, they cannot be considered as reliable means for controlling air traffic.

- The periodic maintenance, proper adjustment, and continuous monitoring of the performance of the above ATC technical means is an obligation of ANSPs and is a prerequisite for the accuracy and reliability of the Air Traffic data, based on which air traffic is regulated and flight safety is ensured.

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