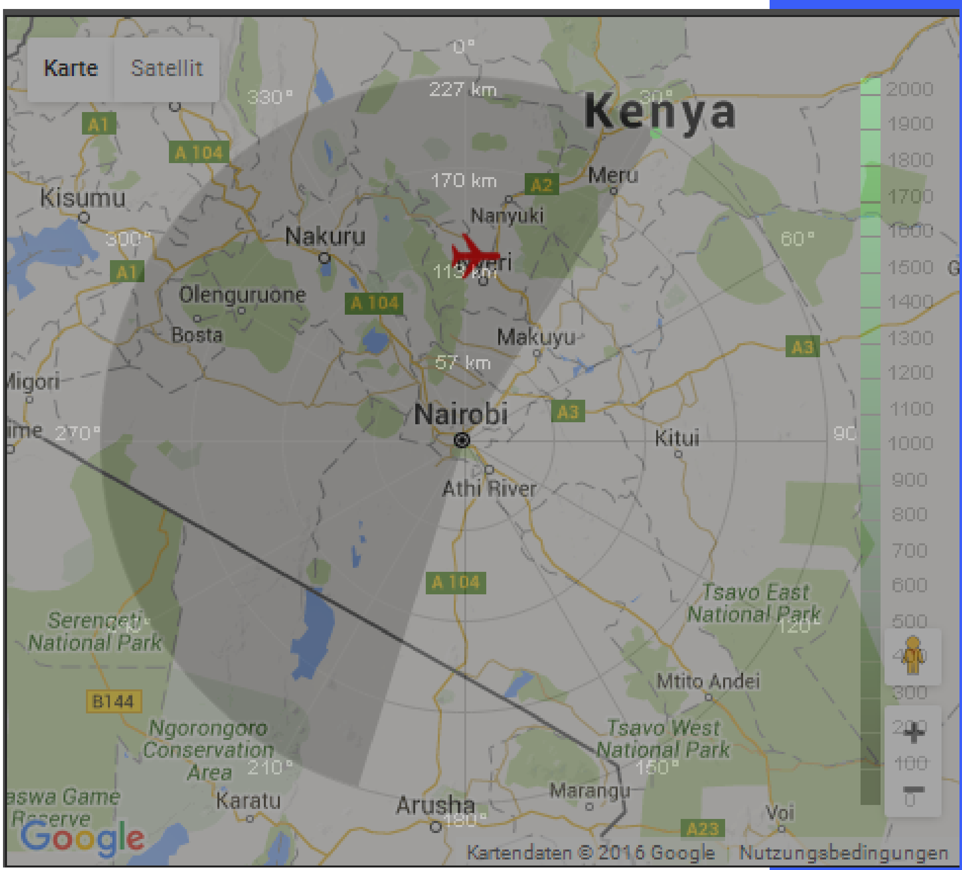
ADS-B Live
Training Exercise Manual



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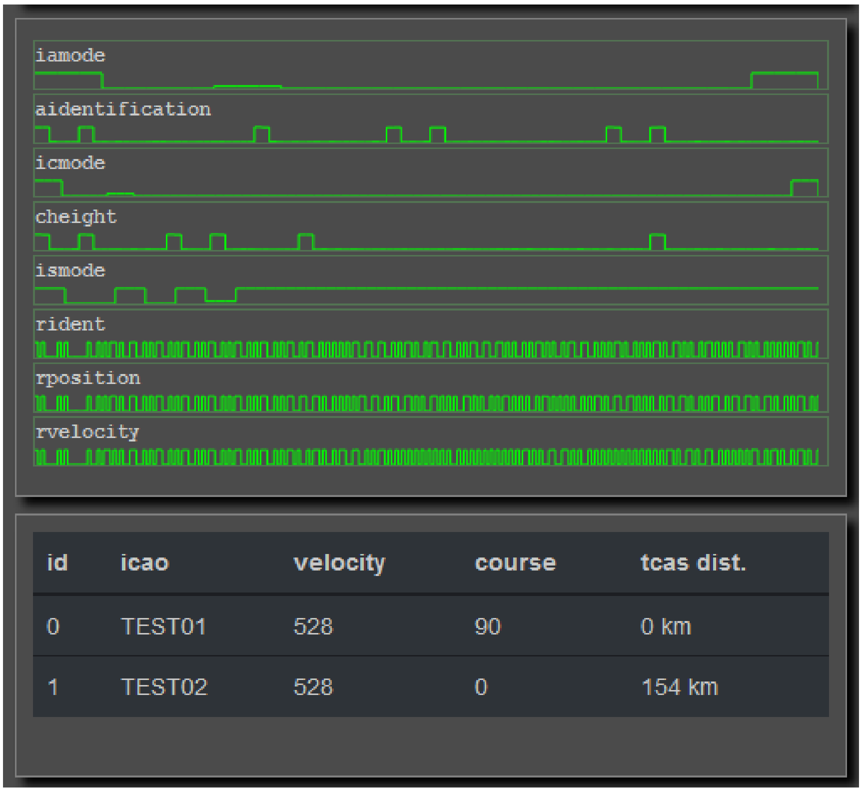
1 Secondary Surveillance Radars

A Secondary surveillance radar (SSR) is a radar system used in air traffic control (ATC), that not only detects and measures the position of aircraft i.e. range and bearing, but also requests additional information from the aircraft itself such as its identity and altitude. Unlike primary radar systems that measure only the range and bearing of targets by detecting reflected radio signals, SSR relies on targets equipped with a radar transponder which reply to each interrogation signal by transmitting a response containing encoded data. SSR is based on the military identification friend or foe (IFF) technology originally developed during World War II. Therefore the two systems are still compatible. Mode A/C, Mode S, and ADS-B are complementory modern methods of secondary surveillance.



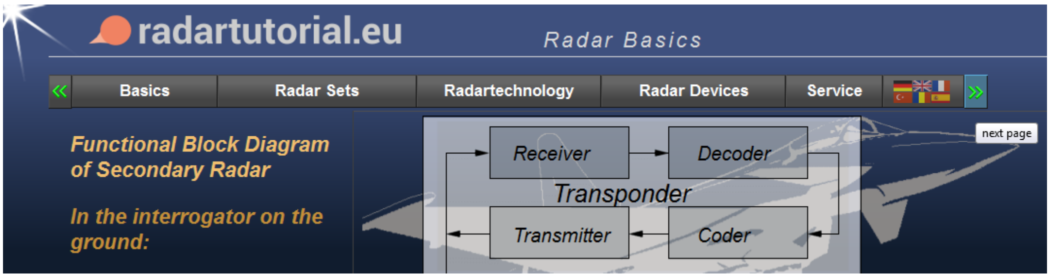
SSR lives on alternations of interrogations (the requests from the air traffic surveillance towers) and the replies by the aircrafts. It visualizes these interrogations and replies as binary signals as well as interpreted messages.

This ADS-B live radar allows to train ADS-B technology, but it also includes Mode A/C and Mode S downlinks. The radar allows to train those in Mode S, A and C. Applied in self-learning mode and experiment settings, it comprehend concept and implication, to apply secondary surveillance modes, to analyze signals and their implications and to discuss or assess measurement outcomes.

Technically this radar only measures the ADS-B downlink. However it "reverse-engineers" suitable interrogations (uplinks) to the monitored ADS-B responses.

For a detailed introduction into SSR refer to the RadarTutorial.eu.

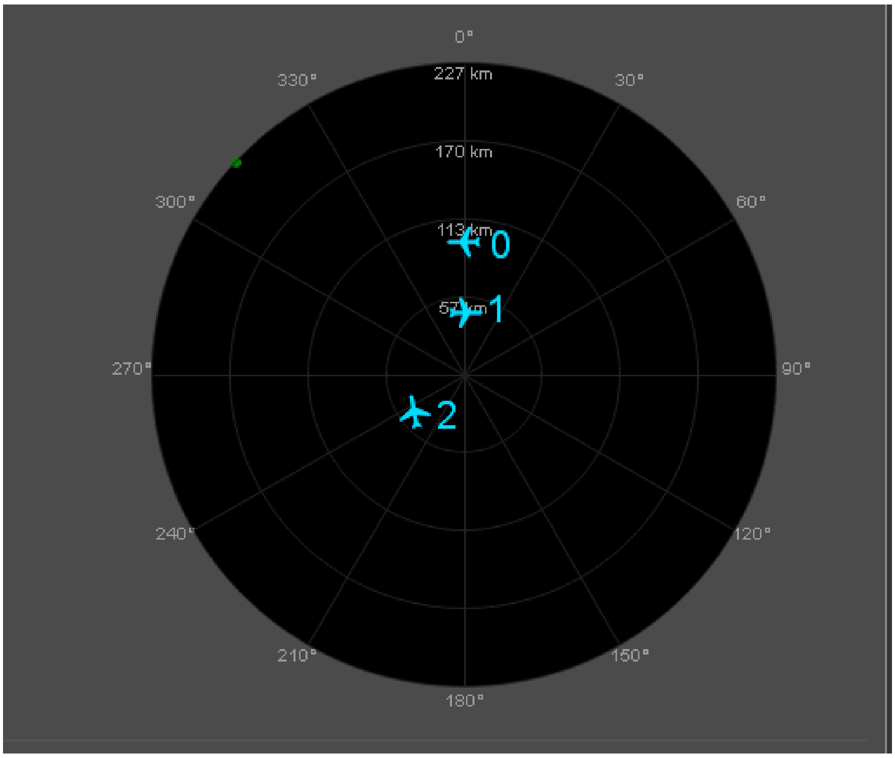
Best follow the didactic learning path on SSR by following the **>>** on the top right side.



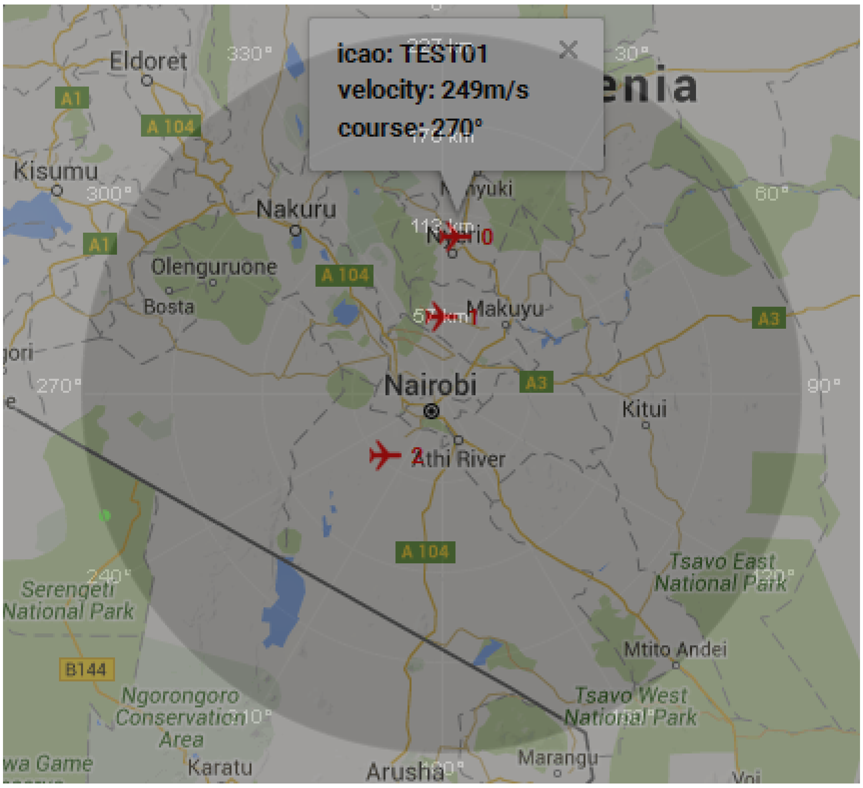
For detailed introductions into Mode S and Mode A/C, please refer to the corresponding chapters in the RadarTutorial.eu .

2 Experimenting with the SSR Simulator

You should be able to observe an airspace situation similar to this one PPI view



Test the PPI with map representation. You can read out the aircraft's ICAO number, velocity and course on mouse over.


icao: TEST01
velocity: 249m/s
course: 270°
Eldoret
Kisumu
Nakuru
Olenguruone
Bosta
Makuyu
Nairobi
Kitui
Athi River
Tsavo East
National Park
Mtito Andei
Tsavo West
National Park
Serengeti
National Park
Ngorongoro
Conservation
Area
Karatu
Arusha
Marangu
A1
A 104
A3
B144
330°
30°
300°
60°
270°
90°
240°
0
1
2

2.1 Theoretical Information on Mode A, C and S in the context of air traffic control

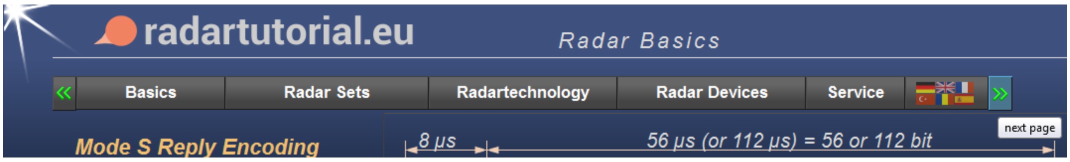
Performance Indicators:

- Learners will be able to understand and describe the basics of SSR Mode A, C and S.

Procedure:

In order to conduct the subsequent experiments, you need to have an understanding of the concepts of Mode A, C and S. Please read the introduction into SSR and SSR Encoding as online resource in our partner portal:

- For a detailed introduction into SSR refer to the RadarTutorial.eu.
- Follow the learning path on SSR Encoding by following the >> on the top right side.



A mode S interrogation comprises two 0.8 µs wide pulses, which are interpreted by a mode A & C transponder as coming from an antenna sidelobe and therefore a reply is not required. The following long P6 pulse is phase modulated with the first phase reversal, after 1.25 µs, synchronizing the transponder's phase detector. Subsequent phase reversals indicate a data bit of 1, with no phase reversal indicating a bit of value 0. This form of modulation provides some resistance to corruption by a chance overlapping pulse from another ground interrogator. The interrogation may be short with P6 = 16.125 µs, mainly used to obtain a position update, or long, P6 = 30.25 µs, if an additional 56 data bits are included. The final 24 bits contain both the parity and address of the aircraft. On receiving an interrogation, an aircraft will decode the data and calculate the parity. If the remainder is not the address of the aircraft then either the interrogation was not intended for it or it was corrupted. In either case it will not reply. If the ground station was expecting a reply and did not receive one then it will re-interrogate.

The aircraft reply consists of a preamble of four pulses spaced so that they cannot be erroneously formed from overlapping mode A or C replies. The remaining pulses contain data using pulse position amplitude modulation. Each 1 µs interval is divided into two parts. If a 0.5 µs pulse occupies the first half and there is no pulse in the second half then a binary 1 is indicated. If it is the other way round then it represents a binary 0. In effect the data is transmitted twice, the second time in inverted form. This format is very resistant to error due to a garbling reply from another aircraft. To cause a hard error one pulse has to be cancelled and a second pulse inserted in the other half of the bit period. Much more likely is that both halves are confused and the decoded bit is flagged as "low confidence".

The reply also has parity and address in the final 24 bits. The ground station tracks the aircraft and uses the predicted position to indicate the range and bearing of the aircraft so it can interrogate again and get an update of its position. If it is expecting a reply and if it receives one then it checks the remainder from the parity check against the address of the expected aircraft. If it is not the same then either it is the wrong aircraft and a re-interrogation is necessary, or the reply has been corrupted by interference by being garbled by another reply. The parity system has the power to correct errors as long as they do not exceed 24 µs, which embraces the duration of a mode A or C reply, the most expected source of interference in the early days of Mode S. The pulses in the reply have individual monopulse angle measurements available, and in some implementations also signal strength measurements, which can indicate bits that are inconsistent with the majority of the other bits, thereby indicating possible corruption. A test is made by inverting the state of some or all of these bits (a 0 changed to a 1 or vice versa) and if the parity check now succeeds the changes are made permanent and the reply accepted.

Mode S operates on the principle that interrogations are directed to a specific aircraft using that aircraft's unique address. This results in a single reply with aircraft range determined by the time taken to receive the reply and monopulse providing an accurate bearing measurement. In order to interrogate an aircraft its address must be known. To meet this requirement the ground interrogator also broadcasts All-Call interrogations.

Mode S plays an important role. Its downlink formats are required for a variety of tasks. In the following exercises, this simulator takes a particular look at

- The DF17 format which is used to communicate the ADS-B dataset
- The DF0 and DF16 format, required to provide information on collision avoidance.

Automatic Dependent Surveillance – Broadcast (ADS–B) is a cooperative surveillance technology in which an aircraft determines its position via satellite navigation and periodically broadcasts it, enabling it to be tracked. The information can be received by air traffic control ground stations as a replacement for secondary radar. It can also be received by other aircraft to provide situational awareness and allow self-separation.

ADS–B is "automatic" in that it requires no pilot or external input. It is "dependent" in that it depends on data from the aircraft's navigation system.

ADS-B information is communicated through the DF17 downlink format.

For details see the online resources in our partner portal: Downlink Broadcast

SSR uses the Manchester Code which is nicely described in this video

2.2 Capturing and Interpreting ADS-B

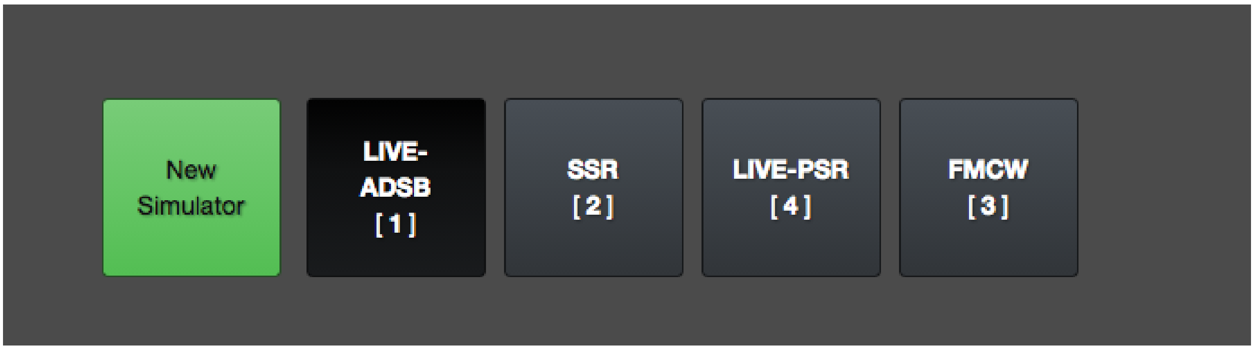
Performance Indicators:

- Learners will be able to break down and interpret major ADS-B data.
- Learners will understand and be able to interpret Manchester Code.

Set up and Experimental Procedure:

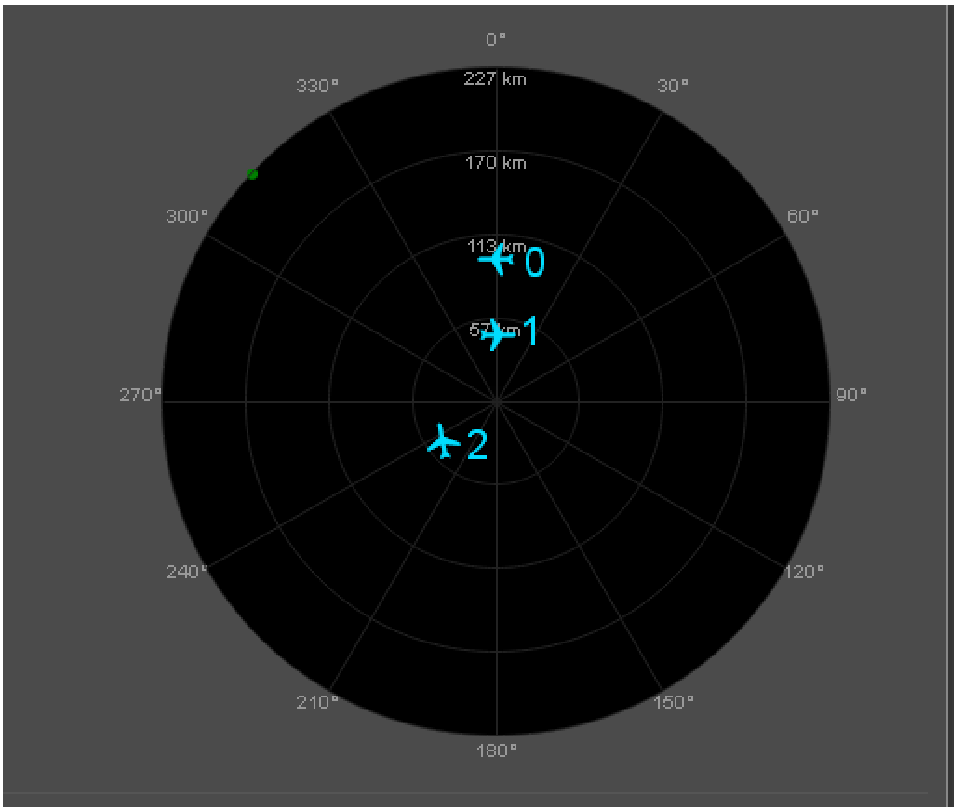
Building on the knowledge from the subsection "Theoretical Information on Mode A, C and S in the context of air traffic control", you will now do experiments focusing on ADS-B information.

Switch to the ADS-B live radar in the selection GUI



You will see the representation of a Controller Work Position including the Plan Position Indicator PPI, the pulse diagram, the ICAO table. A-Scope and B-scope will not provide any data, as this is a real secondary radar representation.

Now look at the PPI. You will see a screen similar to this one:

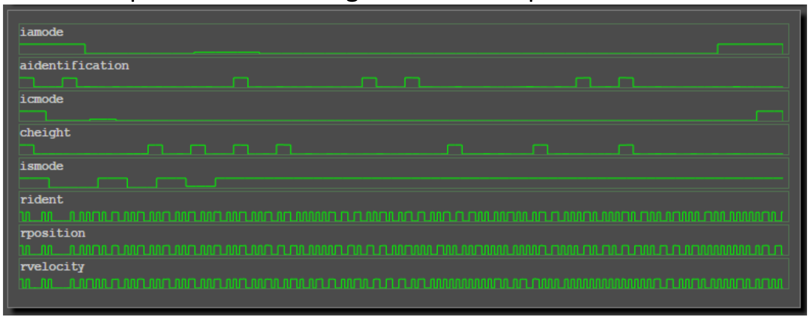


In this training experiment manual, we use the dummy ICAO flight numbers. You will see realistic ones.

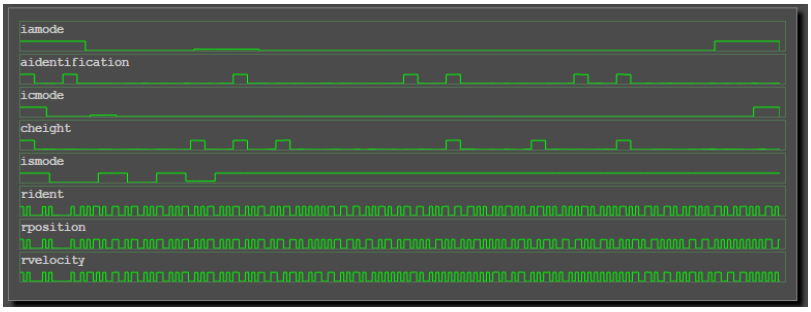
You will capture the ADS-b signals for the separate aircrafts

Aircraft No

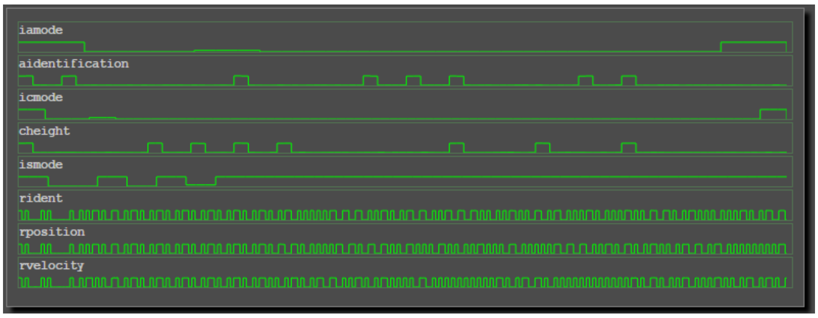
0



1

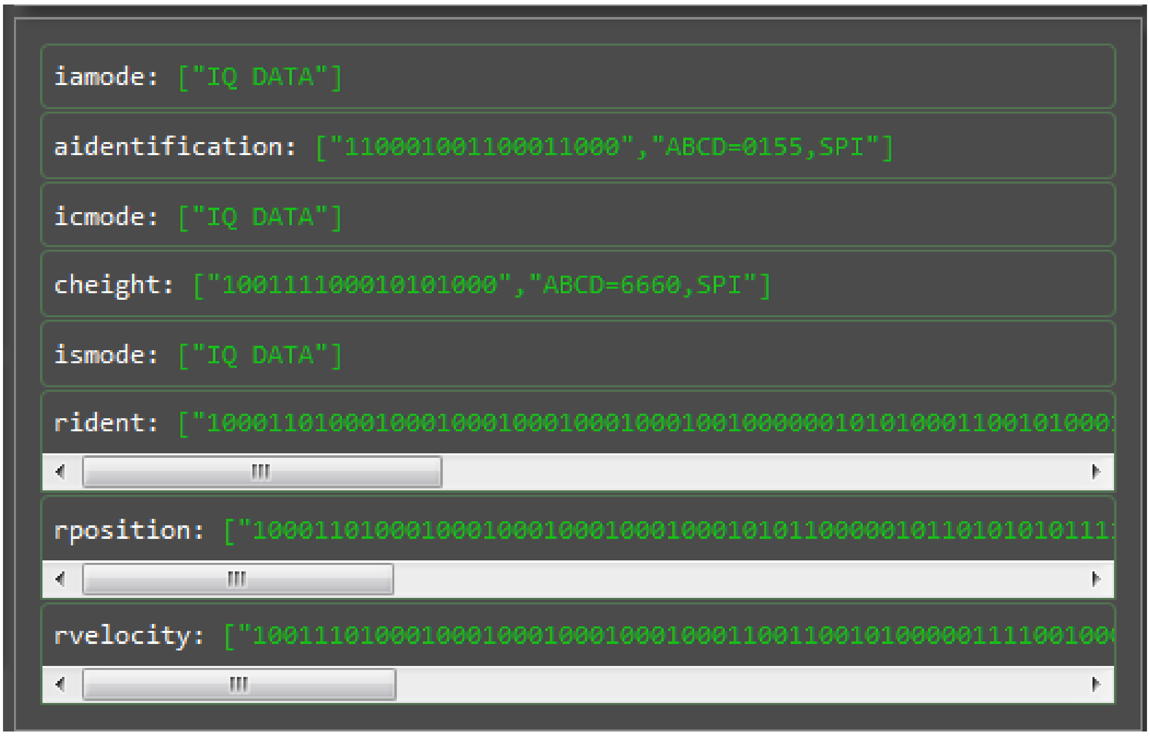


2



Now select some easy parameters of the easy parameters from the ICAO table under the impulse diagram (e.g. course, height), take the values and try to develop the corresponding impulse diagram based on the Manchester Code.

Compare the results and verify their correctness in the bottom table, presenting the detailed communicated data in binary mode.



2.3 Side lobes suppression

Performance Indicators:

- Learners will be able to describe the process of sidelobe suppression, as well as the reasons for doing that.
- Learners will identify suppressed sidelobes in the impulse diagram.

Additional theory, Set up and Experimental Procedure:

In antenna engineering, side lobes or sidelobes are the lobes (local maxima) of the far field radiation pattern that are not the main lobe.

The radiation pattern of most antennas shows a pattern of "lobes" at various angles, directions where the radiated signal strength reaches a maximum, separated by "nulls", angles at which the radiated signal strength falls to zero. In a directional antenna in which the objective is to emit the radio waves in one direction, the lobe in that direction has a larger field strength than the others; this is the "main lobe". The other lobes are called "side lobes", and usually represent unwanted radiation in undesired directions. The side lobe in the opposite direction (180°) from the main lobe is called the "back lobe". In transmitting antennas, excessive side lobe radiation wastes energy and may cause interference to other equipment. Classified information may be picked up by unintended receivers. In receiving antennas, side lobes may pick up interfering signals, and increase the noise level in the receiver.

The power density in the side lobes is generally much less than that in the main beam. It is generally desirable to minimize the sidelobe level (SLL), which is measured in decibels relative to the peak of the main beam. The main lobe and side lobes occur for both conditions of transmit, and for receive.

The signal (1) from the omnidirectional antenna is less that signal from directed antenna (2). This means that the captured aircraft flies in the main-lobe of the monopulse radar. Other segments of the signal originating from other aircrafts, which are not flying in the main-lobe, will not be processed as long as the radar antenna isn't directed to them.

Find the sidelobes in the impulse diagram, describe their suppression and the technical reasons behind. What would happen, if side-lobes were not suppressed? What would be the consequences?

2.4 UF and DF

Performance Indicators:

- Learners will be able to describe and explain uplink and downlink formats
- Learners will be able to name different uplink and downlink formats
- Learners will be able to categorize the release versions over time and explain and evaluate the improvements that were coming with each improvement.

Additional theory, Set up and Experimental Procedure:

Starting in 2009, the ICAO defined an "extended squitter" mode of operation; it supplements the requirements contained in ICAO Annex 10, Volumes III and IV.

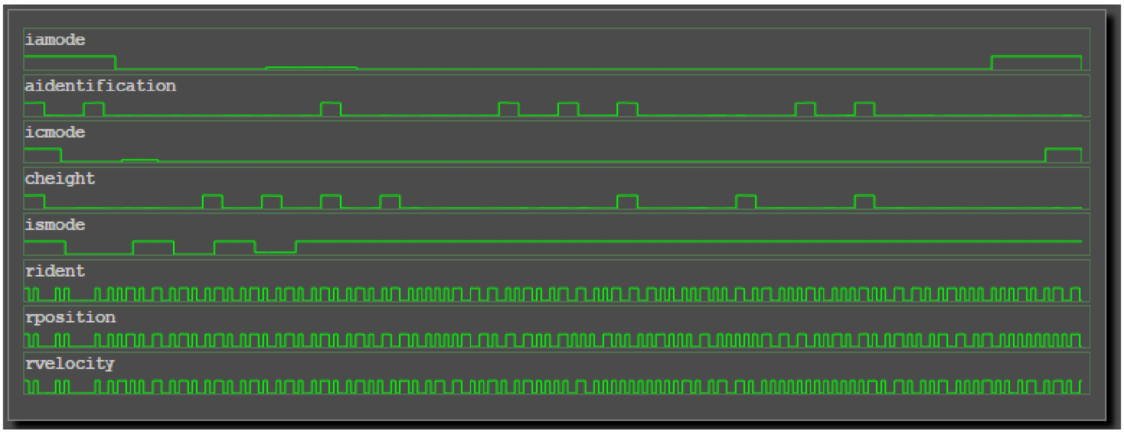
In the Mode S secondary surveillance radar system, 'squitter' is a term used to describe messages that are unsolicited downlink transmissions from an automatic dependent surveillance-broadcast (ADS-B) Mode S transponder system. Mode S transponders transmit acquisition squitter (unsolicited downlink transmissions) to permit passive acquisition by interrogators with broad antenna beams, where active acquisition may be hindered by all-call synchronous garble. Examples of such interrogators are an airborne collision avoidance system and an airport surface system.

The first edition specified earlier versions of extended squitter messages:

- **Version 0:** Extends Mode S to deal with basic ADS-B exchanges, to add traffic information broadcast (TIS-B) format information, as well as uplink and downlink broadcast protocol information.
- **Version 1:** Better describes surveillance accuracy and integrity information (navigation accuracy category, navigation integrity category, surveillance integrity level), and additional parameters for TIS-B and ADS-B rebroadcast.
- **Version 2:** The second edition introduced yet a new version of extended squitter formats and protocols to:
    - enhance integrity and accuracy reporting
    - add a number of additional parameters to support identified operational needs for the use of ADS-B not covered by Version 1 (including capabilities to support airport surface applications)
    - modify several parameters, and remove a number of parameters, which are no longer required to support ADS-B applications

Now look at the different commands in the impulse diagram again.

- iamode, icmode, ismode – are Uplink interrogation signals for modes a, c and i;
- The remainder are downlink replies,
- The last three are DF17 replies



The following three subsections allow you to dive deeper into

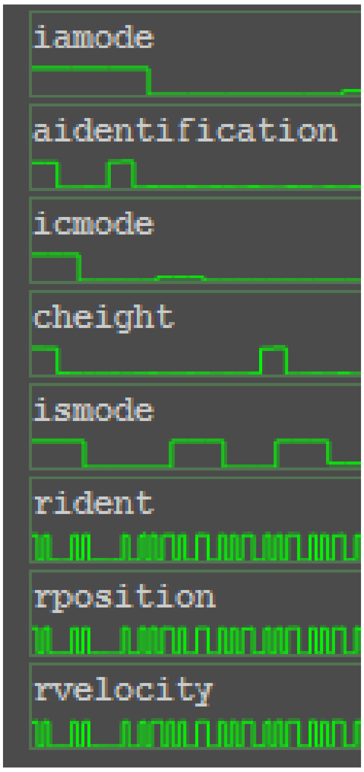
- Interrogations in Mode A, C and S
- Replies in Mode A and C
- Replies in Mode S including ADS-B

Study the different modes, recognize the differences, describe them and present a synthesis of all: what is the overall contribution that the Modes A/C respectively S could not bring alone. What are the advantages of the complete picture.

2.4.1 Interrogation in Mode A, C and S

Modern SSR systems operate with Mode A, C and Mode S signals.

The table always show the data related to the aircraft that was covered the most recent by the radar.



The parameters:

- Interrogation in Mode A: *iamode*
- Interrogation in Mode C: *icmode*
- Interrogation in Mode S: *ismode*

Interrogation is done by uplink signals send from the Air Traffic Control station to the aircraft

Read more on uplink signals at RadarTutorial.eu. and for Mode S.

2.4.2 Replies in Mode A and C

The table provides a selection of responses.

The parameters:

- Aircraft Identification: *aidentitication*
- Aircraft Altitude in Mode C: *cheight*

Read more on the reply message / downlink signals read at RadarTutorial.eu.

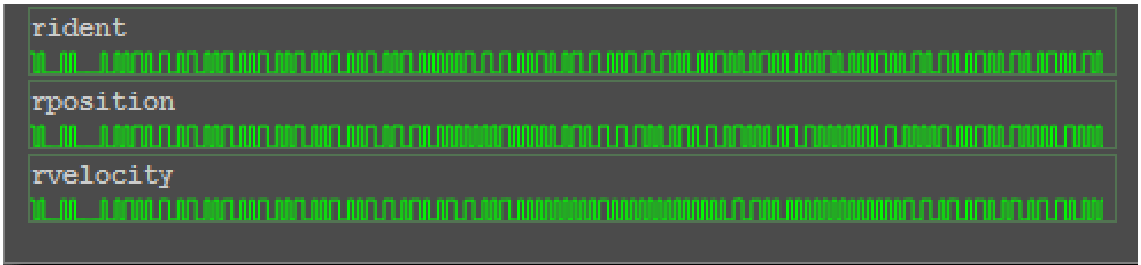
2.4.3 Replies in Mode S / ADS-B

The table shows 3 parameters from the downlink format DF17.

DF17 is an important segment. It is part of the reply message block in Mode S and it carries the ADS-B data.

- Aircraft identification number (ICAO number): *ident*
- Aircraft position: *rposition*
- Aircraft velocity: *rvelocity*

As position and velocity are vectors, the course of the aircraft can be derived easily.



id	icao	velocity	course	tcas dist.
0	TEST01	528	90	0 km
1	TEST02	528	0	178 km