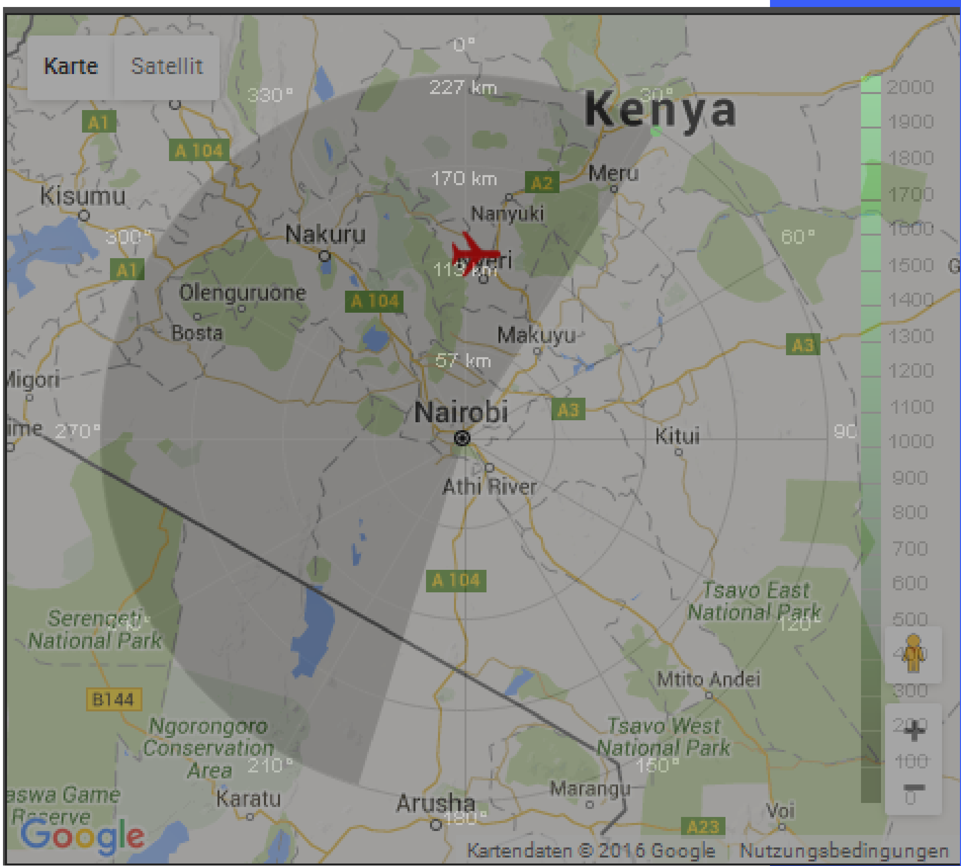
SSR Simulator



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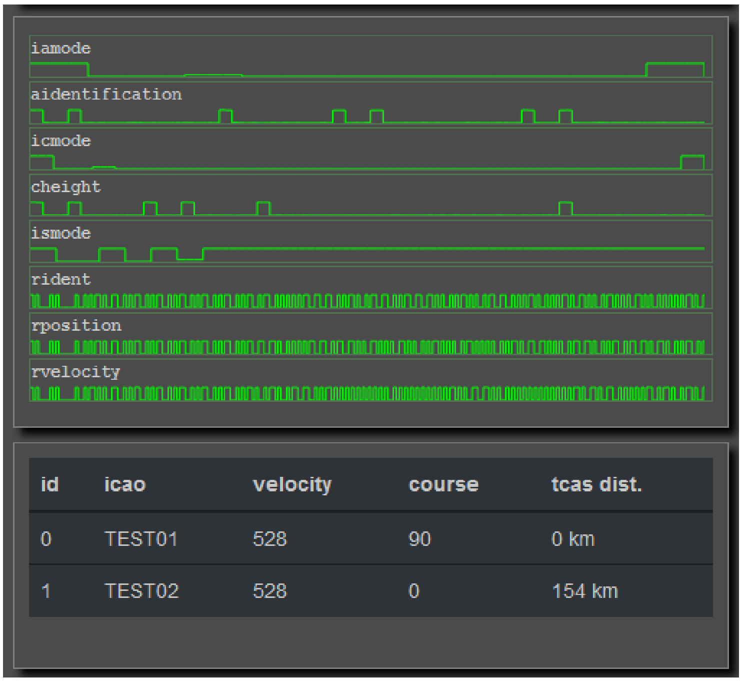
SkyRadar Modular Radar Simulator PSR (Pulse)

1 Secondary Surveillance Radars

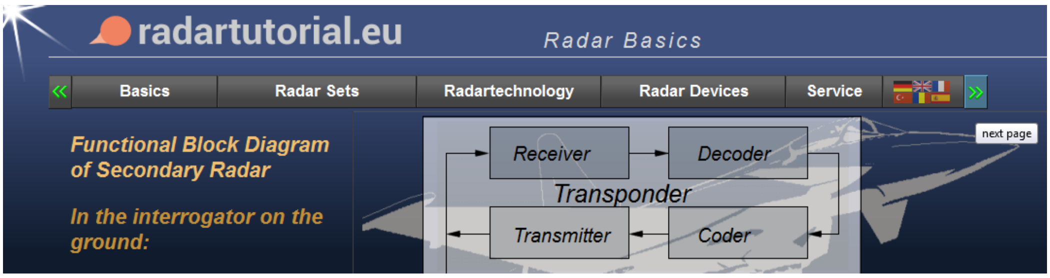
A Secondary surveillance radar (SSR) is a radar system used in air traffic control (ATC), that not only detects and measures the position of aircraft i.e. range and bearing, but also requests additional information from the aircraft itself such as its identity and altitude. Unlike primary radar systems 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, TCAS and ADS-B are similar 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. This simulator allows to understand and train those in Mode S, A and C. It visualizes these interrogations and replies as binary signals as well as interpreted messages.



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.

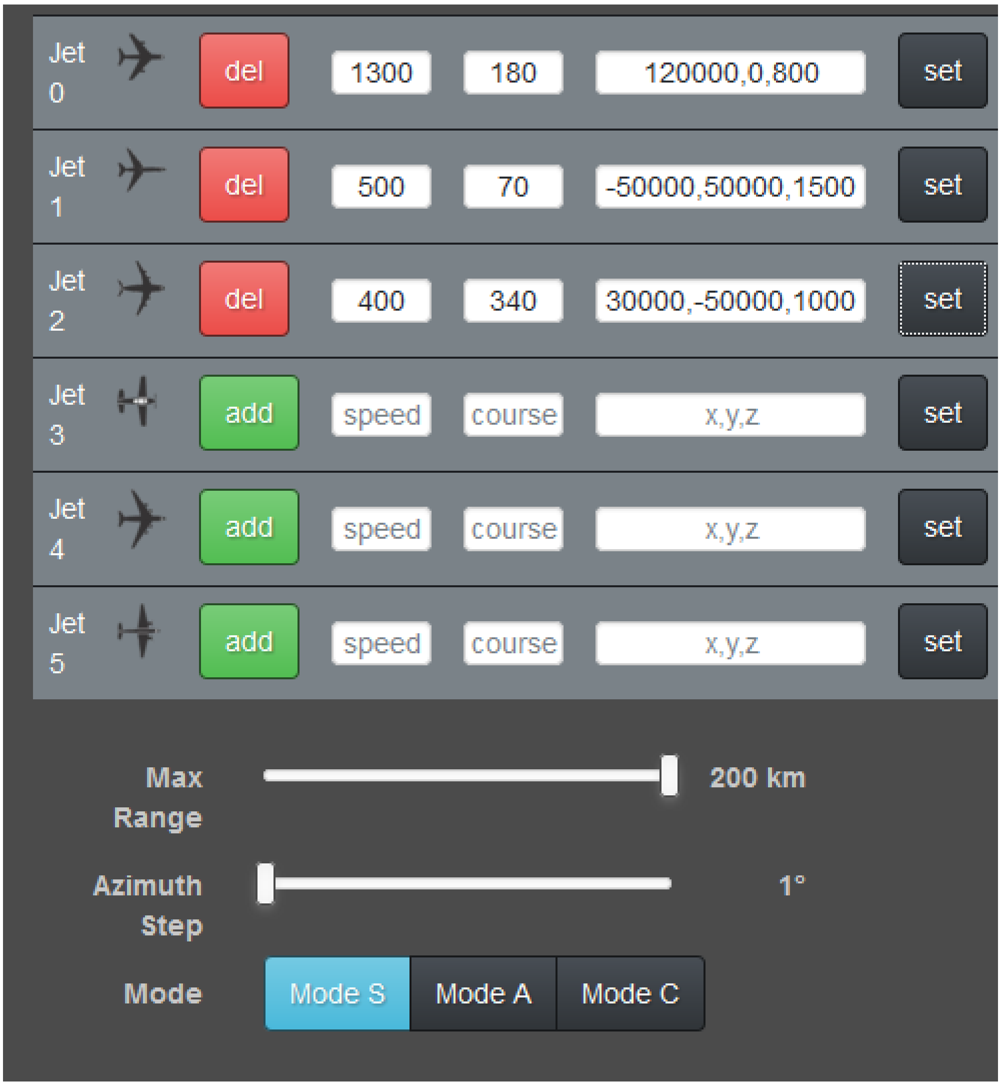


2 Basic functionality

Like all SkyRadar simulators, the SSR is conceived for role plays. A pseudo pilot position (PPP) can set the airspace and position aircrafts in the sky. You can set

- Speed in m/s (default: 250 m/s)
- Course in ° (default: 270°, meaning from right to left)
- Position – for this you can set the vector in m [x-axis (vertical), y-axis (horizontal), flight height].
- (100000,0,1000), would position the aircraft on the x-axis at 100 km
- (50000,0,1500), would position the aircraft on the y-axis at 50 km and 1500 m altitude.
- (-30000,-40000,1000) would position the aircraft in the bottom left quarter of the PPI.

You can choose between Mode S, Mode A and Mode C.



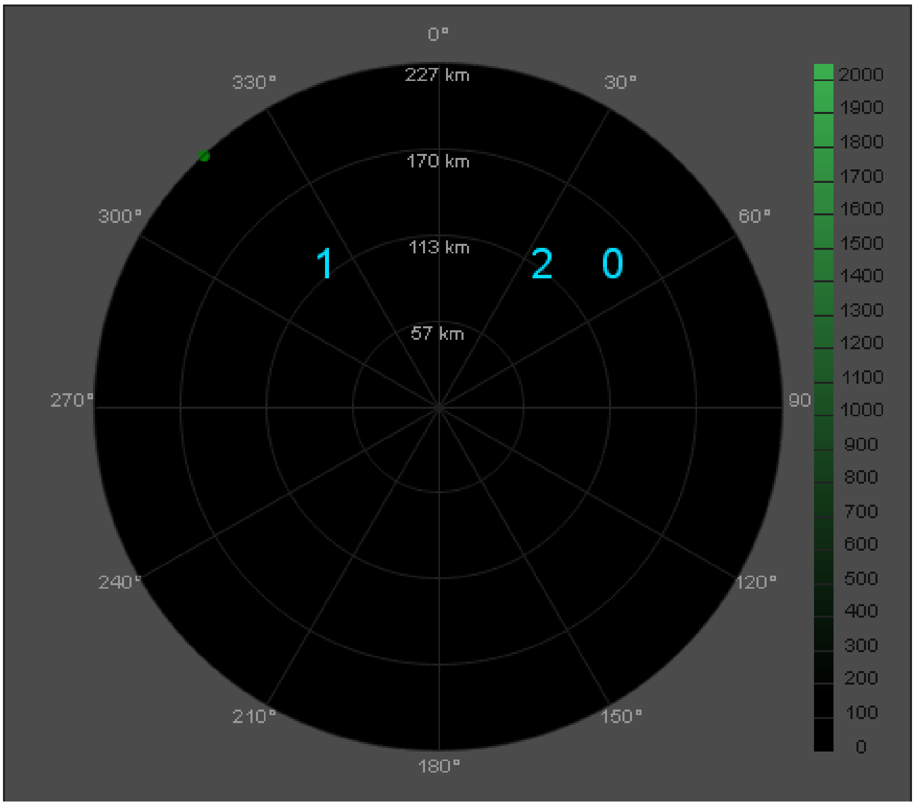
For detailed introductions into Mode S and Mode A/C, please refer to the corresponding chapters in the RadarTutorial.eu .

3 Experimenting with the SSR Simulator

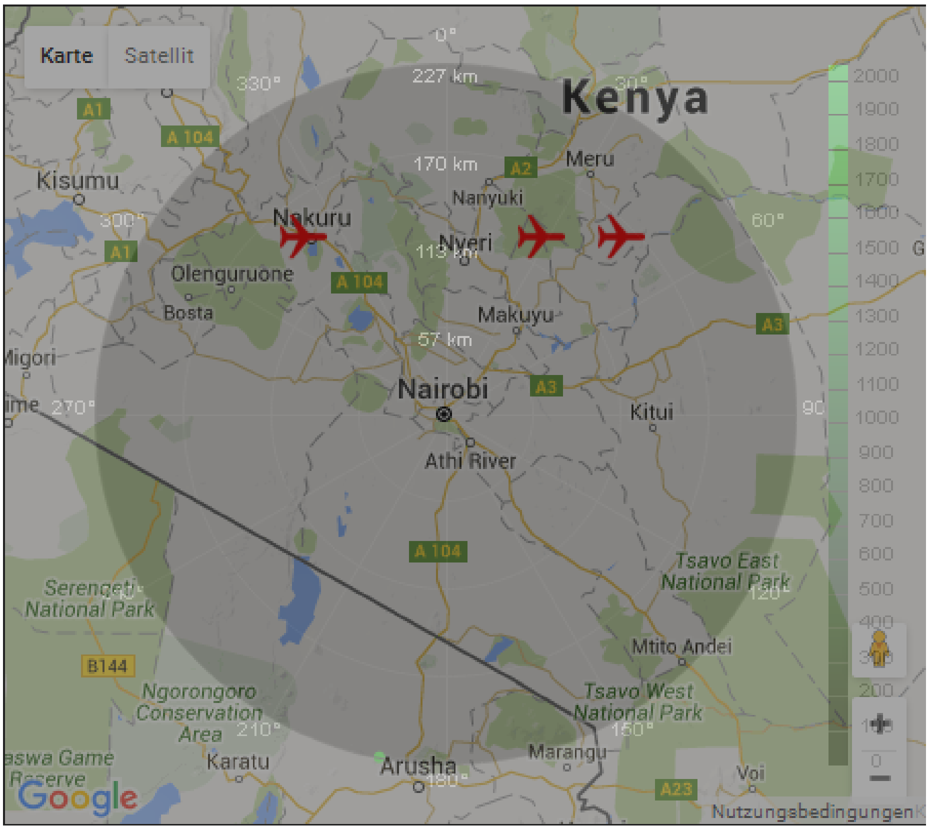
3.1 Monitoring Aircrafts in the SSR Simulator

Let us set the airspace in the PPP:

We can observe current flying situation in a pure PPI view



Or with map representation



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".

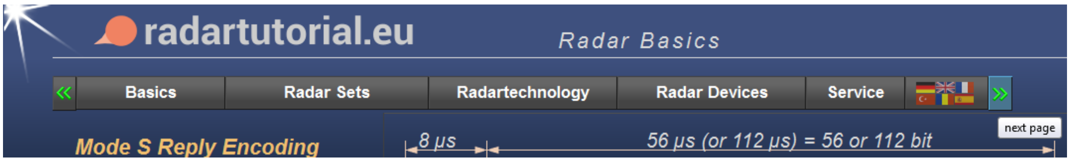
The reply also has parity and address in the final 24 bits. The ground station tracks the aircraft and uses the predicted position to indicate the range and bearing of the aircraft so it can interrogate again and get an update of its position. If it is expecting a reply and if it receives one then it 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. 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.

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



3.2 Capturing and Interpreting ADS-B

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.

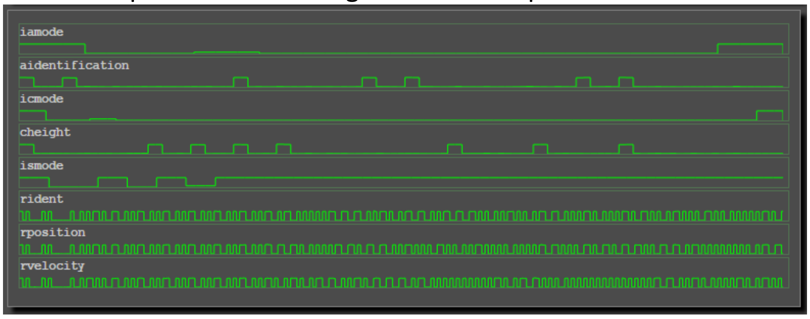
ADS-B information is communicated through the DF17 downlink format.

For details see [Downlink Broadcast]

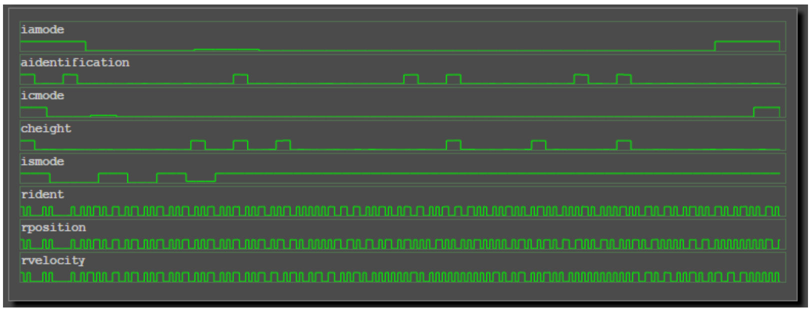
Also we capture the ADS-b signals for the separate aircrafts

Aircraft No

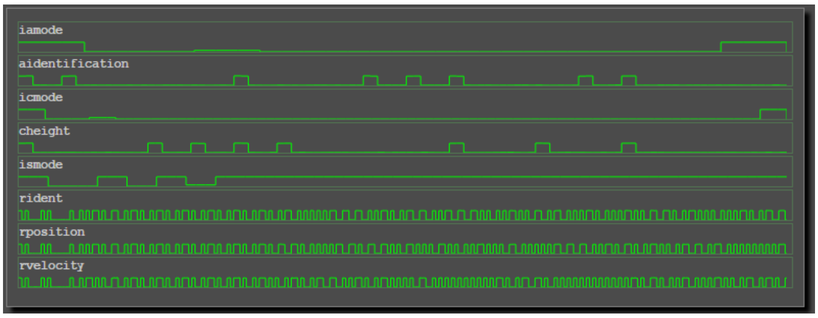
0



1



2

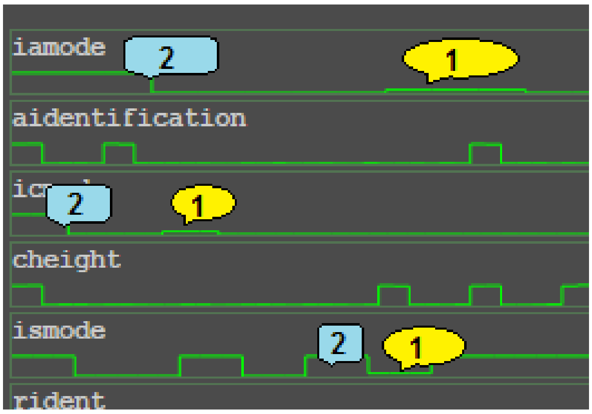


3.3 Side lobes suppression

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

3.4 UF and DF

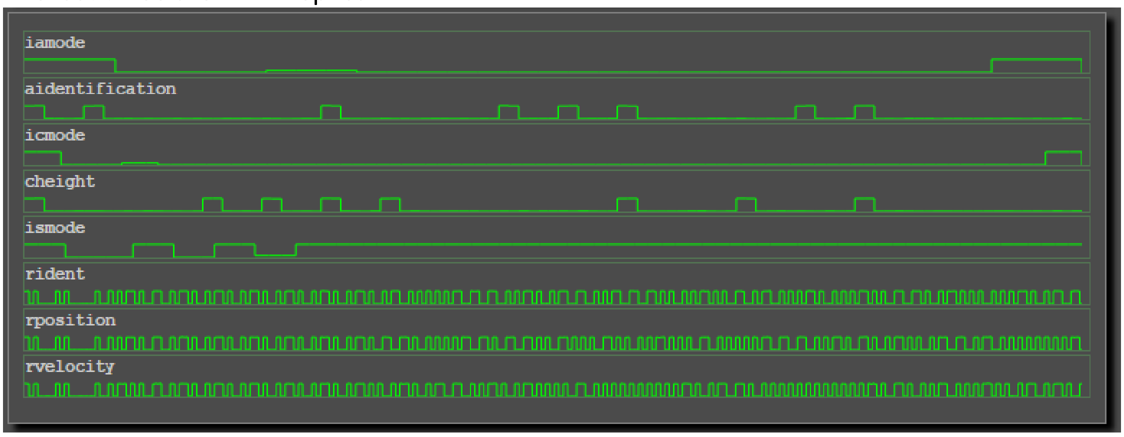
Starting in 2009, the ICAO defined an "extended squitter" mode of operation; it supplements the requirements contained in ICAO Annex 10, Volumes III and IV.

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

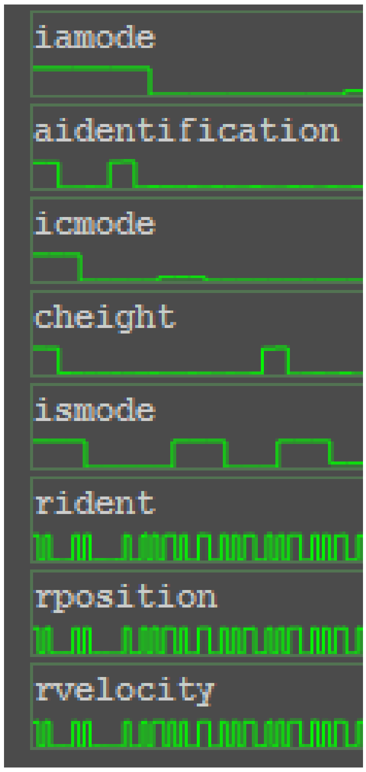
iamode, icmode, ismode – are Uplink interrogation signals for modes a, c and i;
The remainder are downlink replies,
The last three are DF17 replies



3.4.1 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.

3.4.2 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.

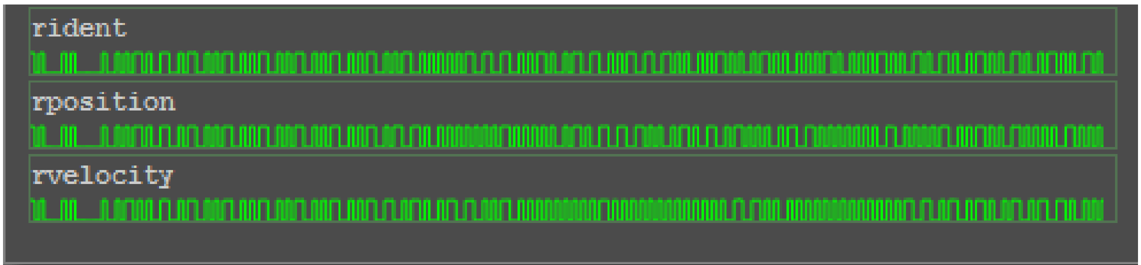
3.4.3 Replies in Mode S / ADS-B

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

Additional downlink parameters of DF0 and DF16 will be discussed in the section on collision avoidance.

3.5 Collision Avoidance

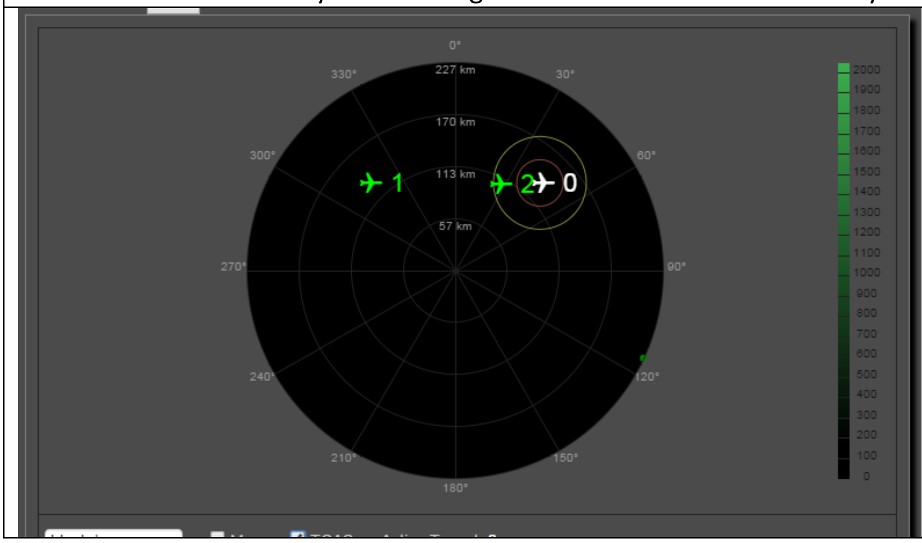
An airborne collision avoidance system (ACAS) is a type of Ground Collision Avoidance Technology (GCAT) that operates independently of ground-based equipment and air traffic control in warning pilots of the presence of other aircraft that may present a threat of collision. If the risk of collision is imminent, the system indicates a maneuver that will reduce the risk of collision. ACAS standards and recommended practices are mainly defined in annex 10, volume IV, of the Convention on International Civil Aviation.

A distinction is increasingly being made between ACAS and ASAS (airborne separation assurance system). ACAS is being used to describe short-range systems intended to prevent actual metal-on-metal collisions. In contrast, ASAS is being used to describe longer-range systems used to maintain standard en route separation between aircraft (5 nm {9.25 km} horizontal /1000' {305 m} vertical). As of 2009, the only implementations that meets the ACAS II standards set by ICAO are Versions 7.0 and 7.1 of TCAS I.

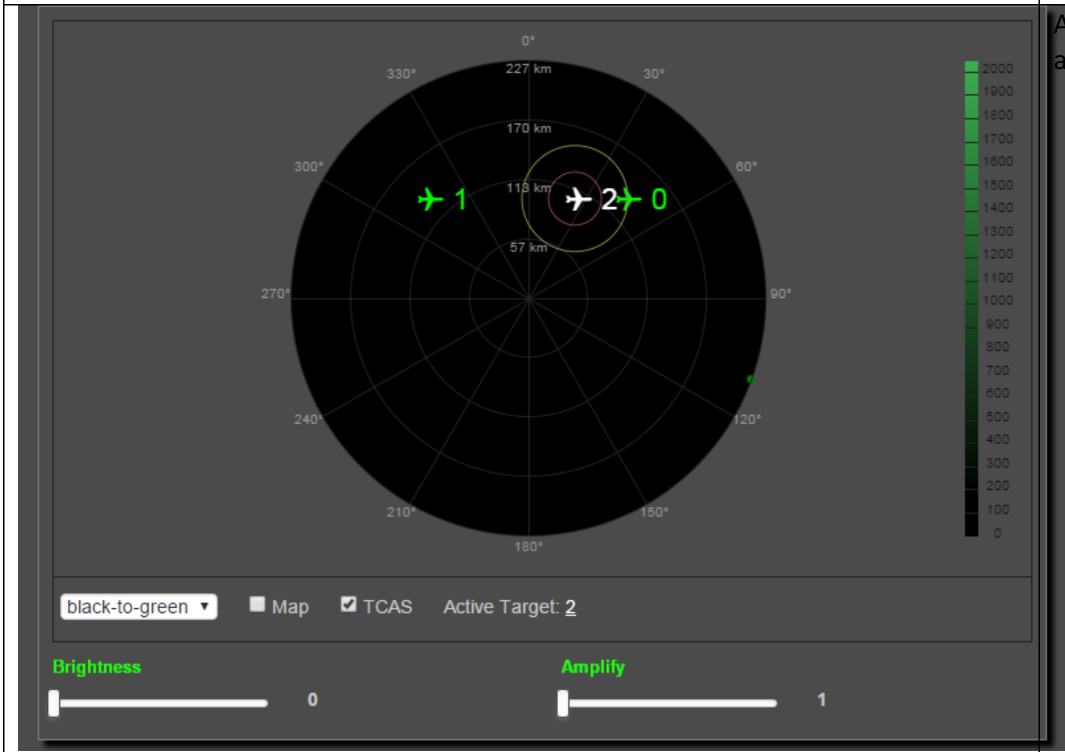
Technically, ACAS and ASAS make use of the ADS-B data block. The term ACAS is nowadays used for the short air-to-air (DF0) and ASAS for the long-distance or long-air-to-air (DF16) collision avoidance system.

Following the definition by EuroControl, TCAS (Traffic Alert and Collision Avoidance System) is a specific implementation of the ACAS (Airborne Collision Avoidance System) concept. TCAS II version 7.0 and 7.1 are currently the only available equipment that is fully compliant with the ACAS II Standards and Recommended Practices (SARPs). ACAS II provides "Resolution Advisories" (RA's) in the vertical sense (direction) telling the pilot how to regulate or adjust his vertical speed so as to avoid a collision. TCAS II Minimum Operational Performance Specification (MOPS) have been published by RTCA (DO-185B) and EUROCAE (ED-143).

The TCAS implementation in this simulator makes use of DF16.

TCAS it is aircraft based system and it gives situation which differ for any aircraft	For example
	For aircraft 0 – distance for closest 50 km, for other -199 km

id	icao	velocity	course	tcas dist.
0	ICAO111111	681	0155	0 km
1	ICAO222222	515	0255	199 km
2	ICAO333333	637	0355	50 km



And situation for aircraft 2

id	icao	velocity	course	tcas dist.
0	ICAO111111	681	0155	50 km
1	ICAO222222	515	0255	150 km
2	ICAO333333	637	0355	0 km

3.5.1 A deeper look at TCAS

A traffic collision avoidance system or traffic alert and collision avoidance system is an aircraft collision avoidance system designed to reduce the incidence of mid-air collisions between aircraft. It monitors the airspace around an aircraft for other aircraft equipped with a corresponding active transponder, independent of air traffic control, and warns pilots of the presence of other transponder-equipped aircraft which may present a threat of mid-air collision (MAC). It is a type of airborne collision avoidance system mandated by the International Civil Aviation Organization to be fitted to all aircraft with a maximum take-off mass (MTOM) of over 5,700 kg (12,600 lb) or authorized to carry more than 19 passengers. CFR 14, Ch I, part 135 requires that TCAS I is installed for aircraft with 10-30 passengers and TCAS II for aircraft with more than 30 passengers.

ACAS / TCAS is based on secondary surveillance radar (SSR) transponder signals, and operates independently of ground-based equipment to provide advice to the pilot on potential conflicting aircraft.

In modern glass cockpit aircraft, the TCAS display may be integrated in the Navigation Display (ND) or Electronic Horizontal Situation Indicator (EHSI); in older glass cockpit aircraft and those with mechanical instrumentation, such an integrated TCAS display may replace the mechanical Vertical Speed Indicator (which indicates the rate with which the aircraft is descending or climbing).

TCAS involves communication between all aircraft equipped with an appropriate transponder (provided the transponder is enabled and set up properly). Each TCAS-equipped aircraft interrogates all other aircraft in a determined range about their position (via the 1.03 GHz radio frequency), and all other aircraft reply to other interrogations (via 1.09 GHz). This interrogation-and-response cycle may occur several times per second.

The TCAS system builds a three dimensional map of aircraft in the airspace, incorporating their range (garnered from the interrogation and response round trip time), altitude (as reported by the interrogated aircraft), and bearing (by the directional antenna from the response). Then, by extrapolating current range and altitude difference to anticipated future values, it determines if a potential collision threat exists.

TCAS and its variants are only able to interact with aircraft that have a correctly operating mode C or mode S transponder. A unique 24-bit identifier is assigned to each aircraft that has a mode S transponder.

The next step beyond identifying potential collisions is automatically negotiating a mutual avoidance manoeuver (currently, manoeuvers are restricted to changes in altitude and modification of climb/sink rates) between the two (or more) conflicting aircraft. These avoidance manoeuvers are communicated to the flight crew by a cockpit display and by synthesized voice instructions.[1][2]

A protected volume of airspace surrounds each TCAS equipped aircraft. The size of the protected volume depends on the altitude, speed, and heading of the aircraft involved in the encounter. The illustration below gives an example of a typical TCAS protection volume.

3.5.2 STCA, MSAW, APM and APW

The ground based security complements to the airborne systems are

- STCA: Short Term Conflict Alert
- MSAW: Minimum Safety Altitude Warning
- APM: Approach Path Monitoring
- APW: Area Proximity Warning

3.5.3 Differences between the ground-borne STCA and air-borne TCAS

STCA and TCAS were developed independently by different organizations. Whilst TCAS was and is subject to rigorous standardization and certification, STCA was not. TCAS and STCA should also be compatible with one another, to ensure that they complement each other rather than interfere however some incompatibilities do exist today. In this article we explore those incompatibilities, what causes them and how the associated risks they create might be mitigated.

The independent operation of STCA and TCAS is an important characteristic. It provides redundancy and minimizes single points of failure, but at the same time it results in differences that in turn cause some incompatibilities (see table). These incompatibilities mean that the combined behavior of STCA and TCAS is not always predictable and well understood.

	STCA	TCAS
Performance	Ground-based surveillance has a 5 to 10 second update rate and good azimuth resolution	TCAS surveillance function has a 1 second update rate and poor azimuth resolution
Operation	STCA detects imminent or actual (significant) loss of minimum separation but provides no resolution advice	TCAS assumes collision and provides resolution advice to ensure sufficient vertical separation at the Closest Point of Approach (CPA)
Predictability	STCA is not standardised but optimised for the operational environment to varying degrees	TCAS is fully standardised
Communication	Complete by providing instructions subject to read-back/hear-back	Limited (pilot reporting not always possible in a timely manner)
Effectiveness	Only when the controller immediately assesses the situation, issues an appropriate instruction to the pilot and the pilot follows the instruction	Only when pilot promptly and correctly follows the Resolution Advisory (RA)

Source: SkyBrary.aero

3.5.4 STCA, MSAW, APM and APW

The ground based security complements to the airborne systems are

- STCA: Short Term Conflict Alert (some comparison to TCAS)
- MSAW: Minimum Safety Altitude Warning
- APM: Approach Path Monitoring
- APW: Area Proximity Warning

3.6 SAP, CAP and DBS

Eurocontrol keeps on enhancing ADS-B functionality. Mode S technology, in particular the extended squitter, and ADS-B introduces new functionalities that enable the exchange of additional information between ground and airborne systems. Modern communication protocols permit a more efficient utilisation of the available bandwidth, allowing regular transmission of attitude data as well as data showing selections made by the flight crew (with regards to the level for the time being).

Such technologies are capable of providing a number of flight parameters to an ATS ground system, in response to interrogation or by broadcasting. Overall, up to 36 possible parameters have been identified that are clustered in groupings. A limited number was defined to support operational and technical needs for ATS. Out of these, those indicating the aircraft's current state and short term intent parameters are considered to bring operational benefits. In the simplest form, those benefiting directly to the controller became known as Controller Access Parameters (CAPs). CAPs are to be presented to controllers, at their working positions, with the aim to increase their controller awareness and reduce, to the extent possible, the volume of air-ground voice communications.

The group of parameters designed to improve the overall ATS system performance is known as System Access Parameters (SAPs). SAPs are expected to improve, inter alia, the tracking systems (track initialization and early recognition of flight maneuvers) and safety net systems such as STCA and MSAW (see chapter on collision avoidance).

SAP/CAP provide information that is enhanced for the ease of use by the controllers. The simulator uses SAP/CAP data as like speed, course, height, etc. They are mathematically coded into strings like "*EW-1*681,NS0*0*". In fact they come binary coded as "10101010010101010…" in Manchester coding.

The raw data window in the FreeScopes software allows to see this code directly. The following image shows

SAP/CAP parameters that available on simulation (highlighted by yellow) and identification for searching in DBS register (highlighted in green)

```
Identification/emergency in A-mode
["110001001100011000", "ABCD=0155,SPI"]

Height in C-mode
["101100001010111000", "ABCD=1724,SPI"]

Identification in S-mode DF17:TC4
["10001101000100010001000100010001001000000101010001100101000101011100011100101000011000011011100111101110000001 10",
"DF17,5,ICAO111111,TC4,,\"TEST01\",CRC24"]

Position in S-mode DF17:TC11
["1000110100010001000100010001000101011000101011010111011111010100010100000011110110011010100110011110101011010111",
"DF17,5,ICAO111111,TC11,,10241.159,#1,-0.2603,37.9881,CRC24"]

Velocity and course in S-mode DF17:TC19
["10011101000100010001000100010001100110010100011010101001000000000000110010111100000000000000001010001100000110011 1", "DF17,5,ICAO111111,TC19,ST1,EW-
1*681,NS0*0,1,VR-1*6016,CRC24"]
```