RADIOLOCATION

Secondary Surveillance RADAR (SSR)

Air Traffic Control Radar Beacon System (ATCRBS)

Jordi Mateu – Jordi Berenguer

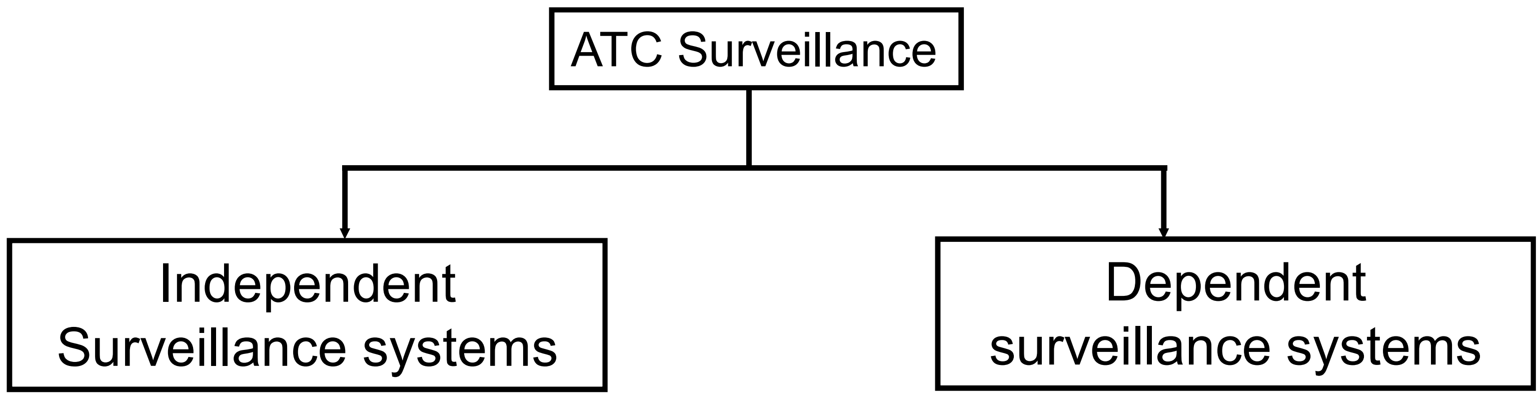
Course Contents

SSR

WORKING PRINCIPLES OF SECONDARY SURVEILLANCE RADAR

J. Mateu - J. Berenguer

Surveillance systems

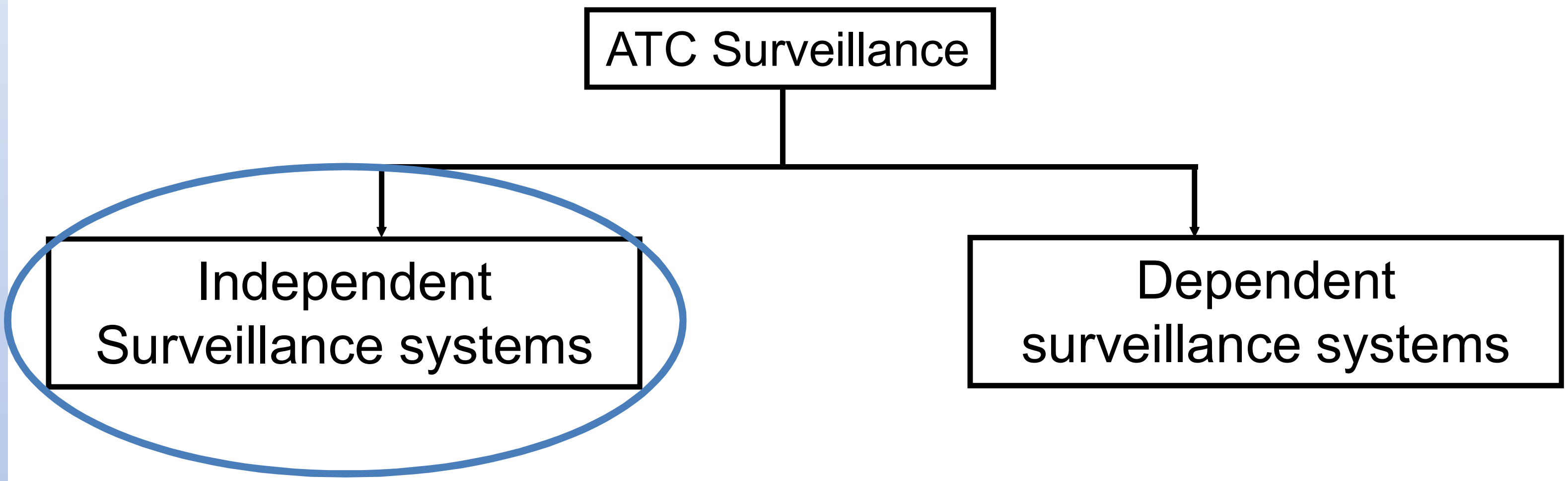


Independent Surveillance Systems: The aircraft position is obtained from **ground** equipment, **with** or **without** the aircraft collaboration.

Dependent surveillance systems: The aircraft position is obtained from on-board equipment and are transmitted to ground stations.

Overview

Surveillance systems



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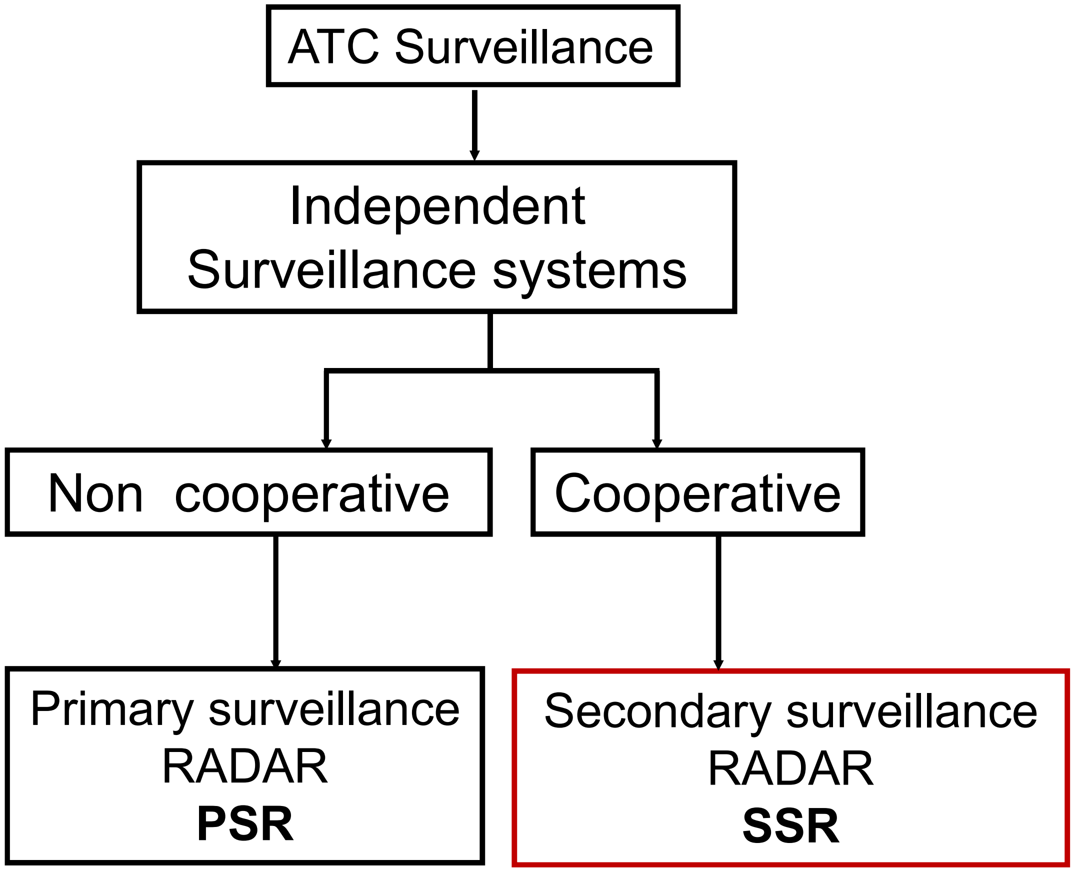
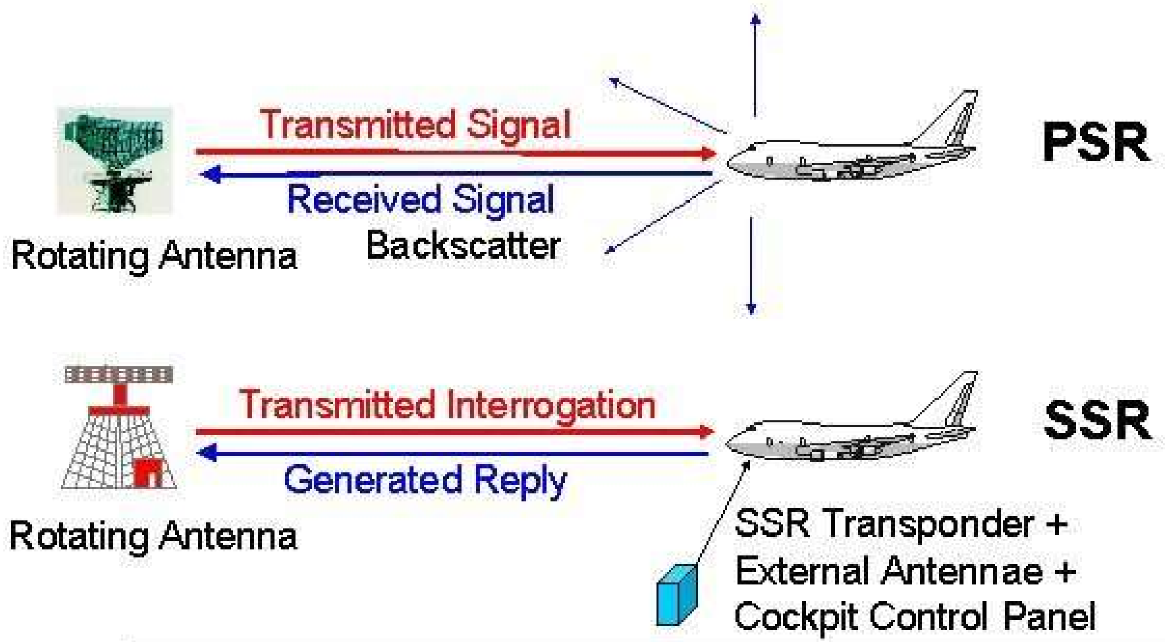


ATCRBS

- ATCRBS, the Air Traffic Control Radar Beacon System, is a secondary surveillance radar system developed for use within the air traffic control system for more precise position reporting of planes.
- It is used in conjunction with the primary radar, which is used to determine the presence of planes in the airspace.
- ATCRBS supplements this positional information with positive identification and altitude information, allowing controllers to track each plane more precisely and efficiently.
- Developed in 1956, ATCRBS was the first air route surveillance radar system developed and purchased for the purposes of air traffic control.
- The technology was based closely on that of the military's IFF (Identification Friend or Foe) system.

Working Principle of SSR

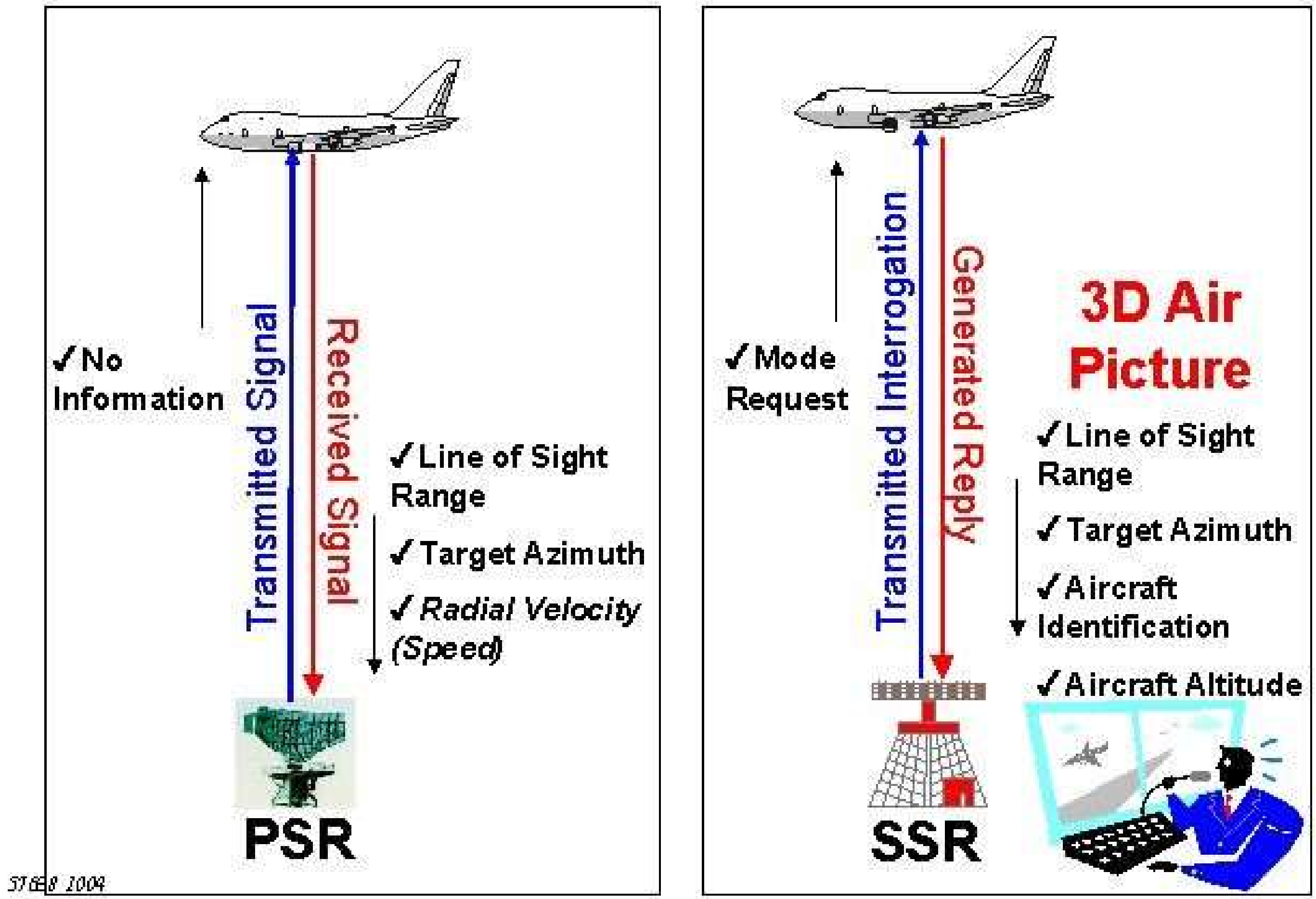
PSR and SSR



Non co-operative versus co-operative Independent Surveillance

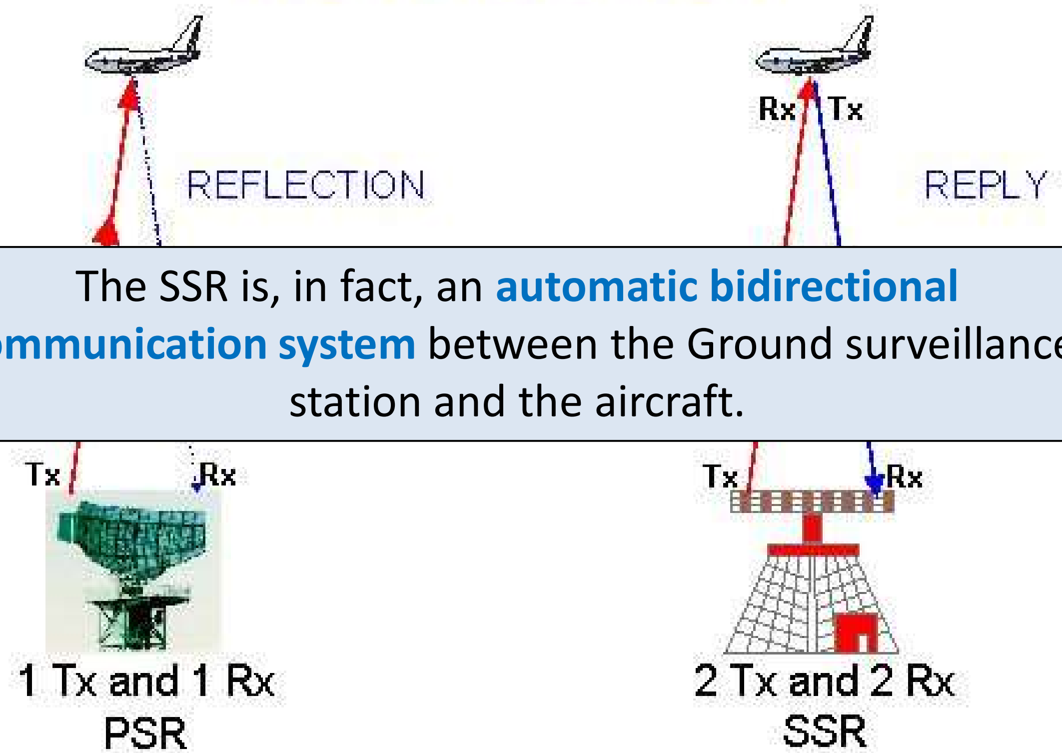
Working Principle of SSR

PSR and SSR



Working Principle of SSR

PSR and SSR



The SSR is, in fact, an **automatic bidirectional communication system** between the Ground surveillance station and the aircraft.

SSR “round trip” requires 2 successful transmissions and 2 successful receptions BUT each transmission require less power

Working Principle of SSR

- Primary surveillance radar (PSR) detects and measures the position of an aircraft.

- Secondary surveillance radar (SSR) requests additional information from the aircraft such as identity and altitude.

- It relies on the aircraft being equipped with a transponder that automatically replies to an interrogation signal.

Working Principle of SSR

PSR	SSR
Detects everything	Detects only Co-operating Targets
Sees “clutter”	No Clutter
High Transmitting Power	Conventional Transmission Power
Needs Sensitive Receiver *(the received signal depends of the target RCS)*	Bidirectional communications system. *(Good SNR in both senses)*
Tracking is more difficult	More unambiguous tracking
Blind to Height	**Extracts Altitude**
Blind to Identity	**Extracts Identity**

Working Principle of SSR

PRIMARY SURVEILLANCE RADAR (PSR)	SECONDARY SURVEILLANCE RADAR (SSR)
• Defined by the radar equation. $$P_r = \frac{P_t G_T \sigma A_{effR}}{(4\pi)^3 \boldsymbol{R^4}}$$ • The received power is proportional to $\boldsymbol{R^4}$	• Defined by the transmission equation. $$P_r = \frac{P_t G_T A_{effR}}{4\pi \boldsymbol{R^2}}$$ • The received power is proportional to $\boldsymbol{R^2}$

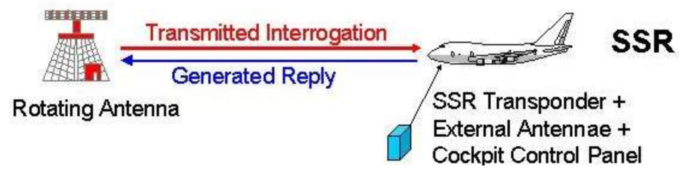
PSR and SSR differ in many ways:

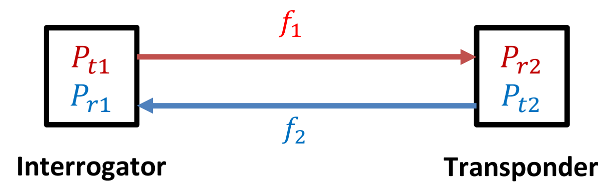
- Transmission frequencies differ
- Different antennas used (ground and air)
- Bidirectional communication system

UPLINK –DOWNLINK

SSR Uplink Range:

The range to which the transponder can go before it ceases to reply to 90% of the interrogations.



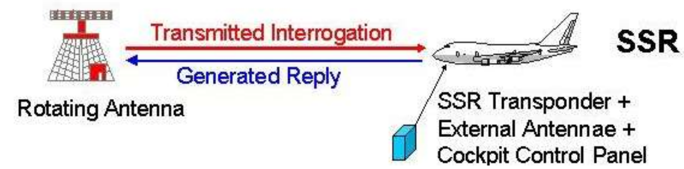


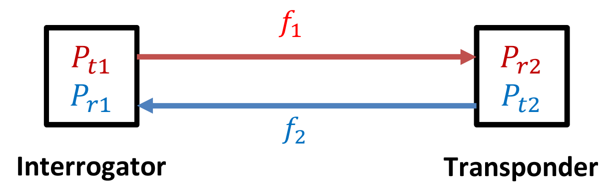
$$R_{t,max}^2 = \frac{P_{t1} G_T A_{effR}}{4\pi P_{r2,min}} = \frac{P_{t1}}{P_{r,2\ min}} G_T G_R \left(\frac{\lambda_1}{4\pi}\right)^2$$

$P_{r2,min}$ is the minimum power the on board transponder can receive.

UPLINK –DOWNLINK

SSR Down-link Range:
The range to which the transponder can be taken before its reply pulses cease to be detected by the interrogation station.



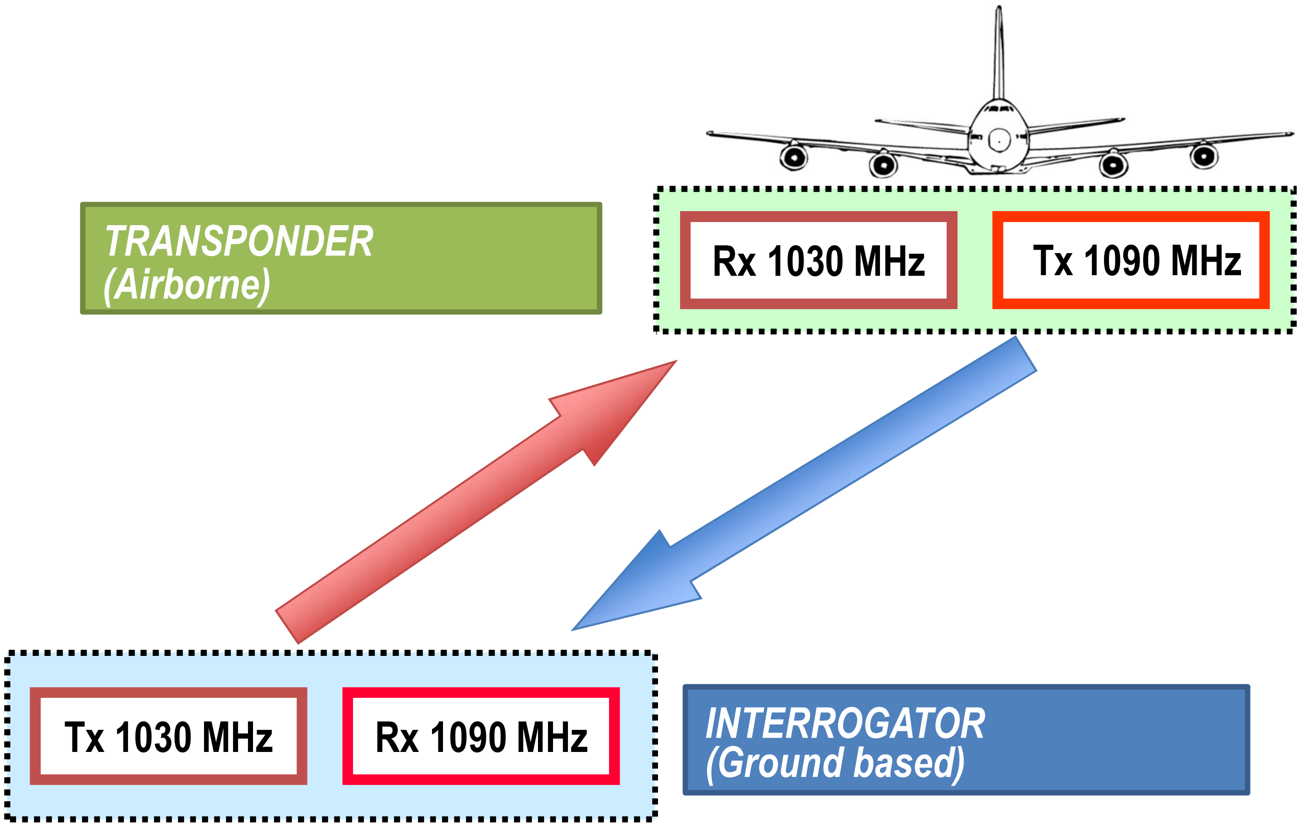


$$R_{i,max}^2 = \frac{P_{t2} G_T A_{effR}}{4\pi P_{r1,min}} = \frac{P_{t2}}{P_{r1,min}} G_T G_R \left(\frac{\lambda_2}{4\pi}\right)^2$$

$P_{r1,min}$ *is the minimum power the interrogation station can receive.*

Frequencies SSR

An Interrogator on the ground, transmits a signal on 1030Mhz requesting information from all transponders in range. A transponder is a device on the aircraft which replies to interrogations on 1090Mhz.



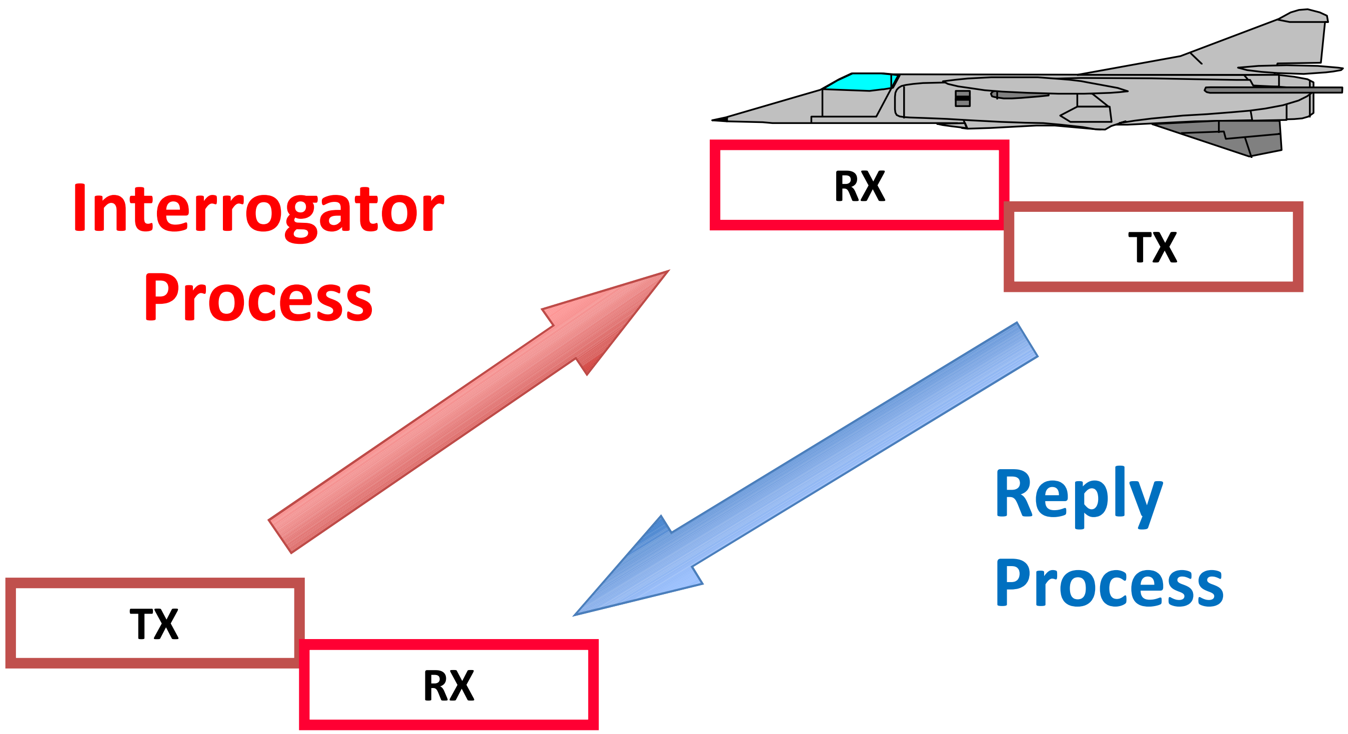
SSR CODE MANAGEMENT

J. Mateu - J. Berenguer

SSR Code Management: Coding System

Communicating **information** consists of the transmission and reception of pulses.

The method is divided into two processes:



SSR Code Management: Coding System

Only two modes are used in civil aviation:

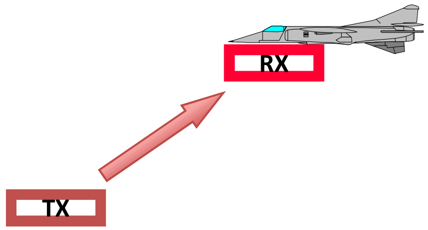
Mode A for identification

Mode C for automatic pressure altitude information

(Modes B and D - research and development)

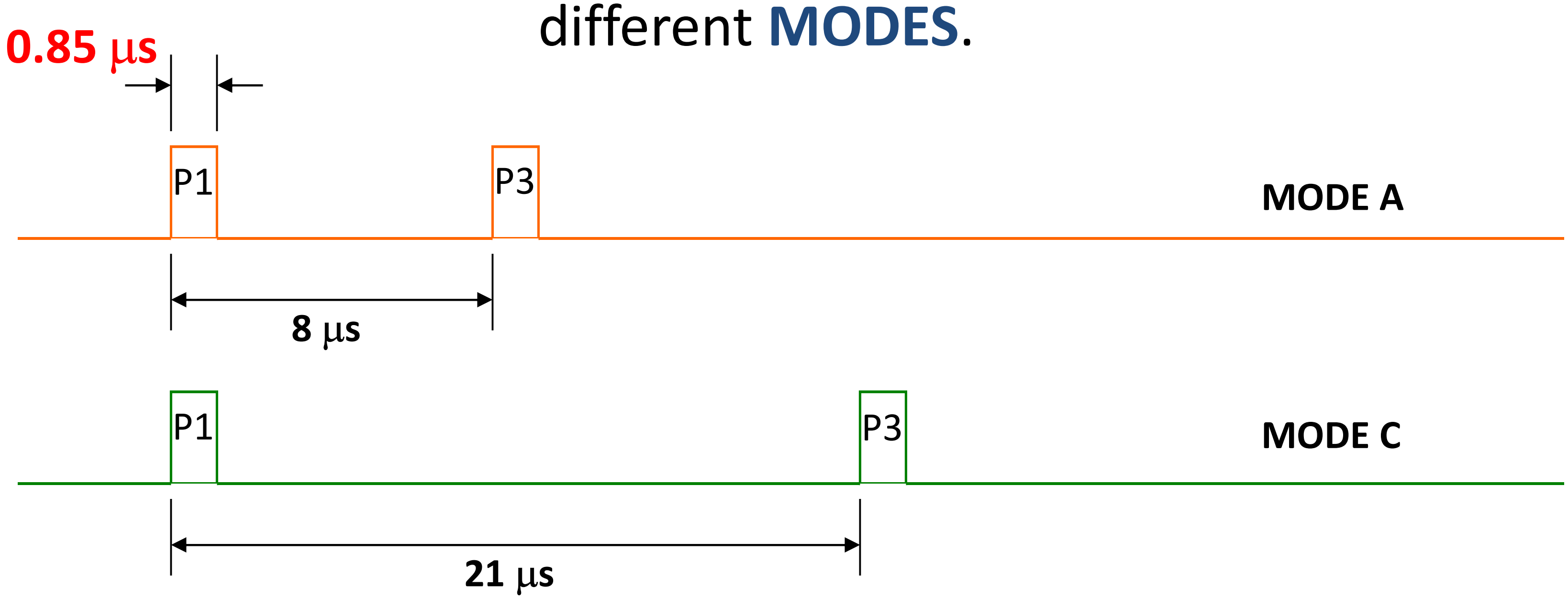
The ground interrogator and the airborne transponder must be **set to the same mode** in order that the exchange of information may take place.

SSR Code Management: Interrogator process



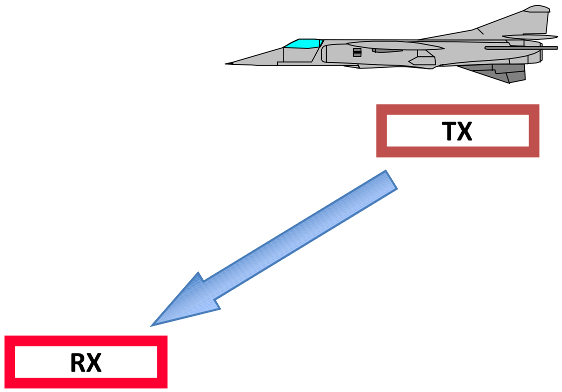
Two pulses with a known spacing are transmitted from the interrogator.

The ground-based interrogations comprise pairs of pulses in different **MODES**.



The interrogator, consists of a pair of pulses of **0,85µs** long.

SSR Code Management: Reply process



The aircraft transponder recognizes the **time spacing** between the two pulses.

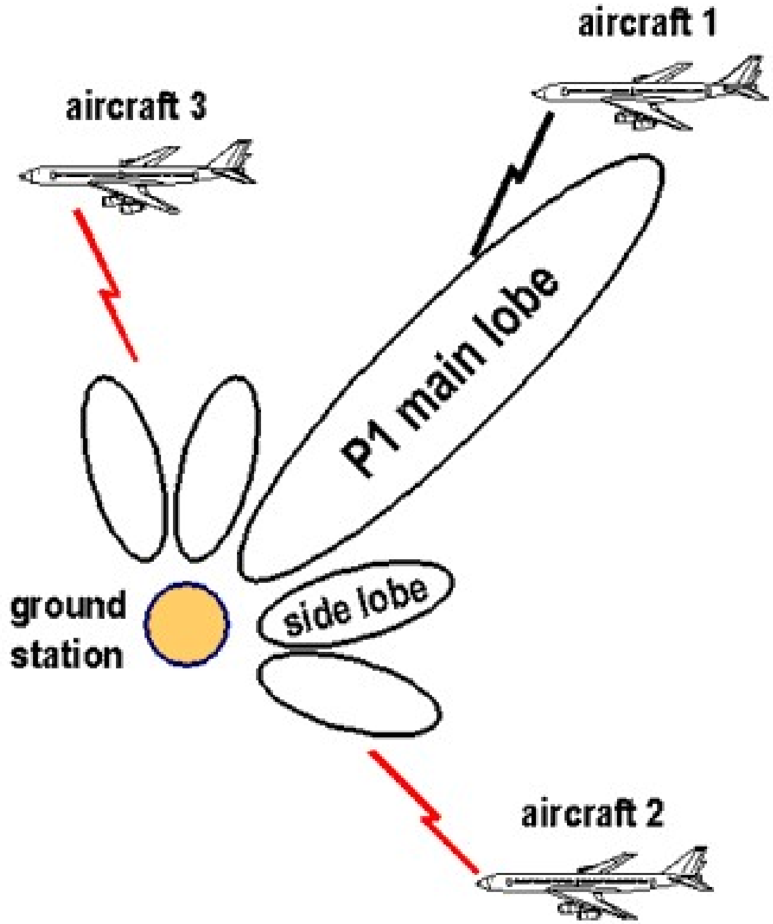
The transponder reply, consists of a train of pulses each of which is **0,45μs** long.

SSR

INTERROGATOR SIDE LOBE SUPPRESSION

J. Mateu - J. Berenguer

SSR Antenna Side Lobes



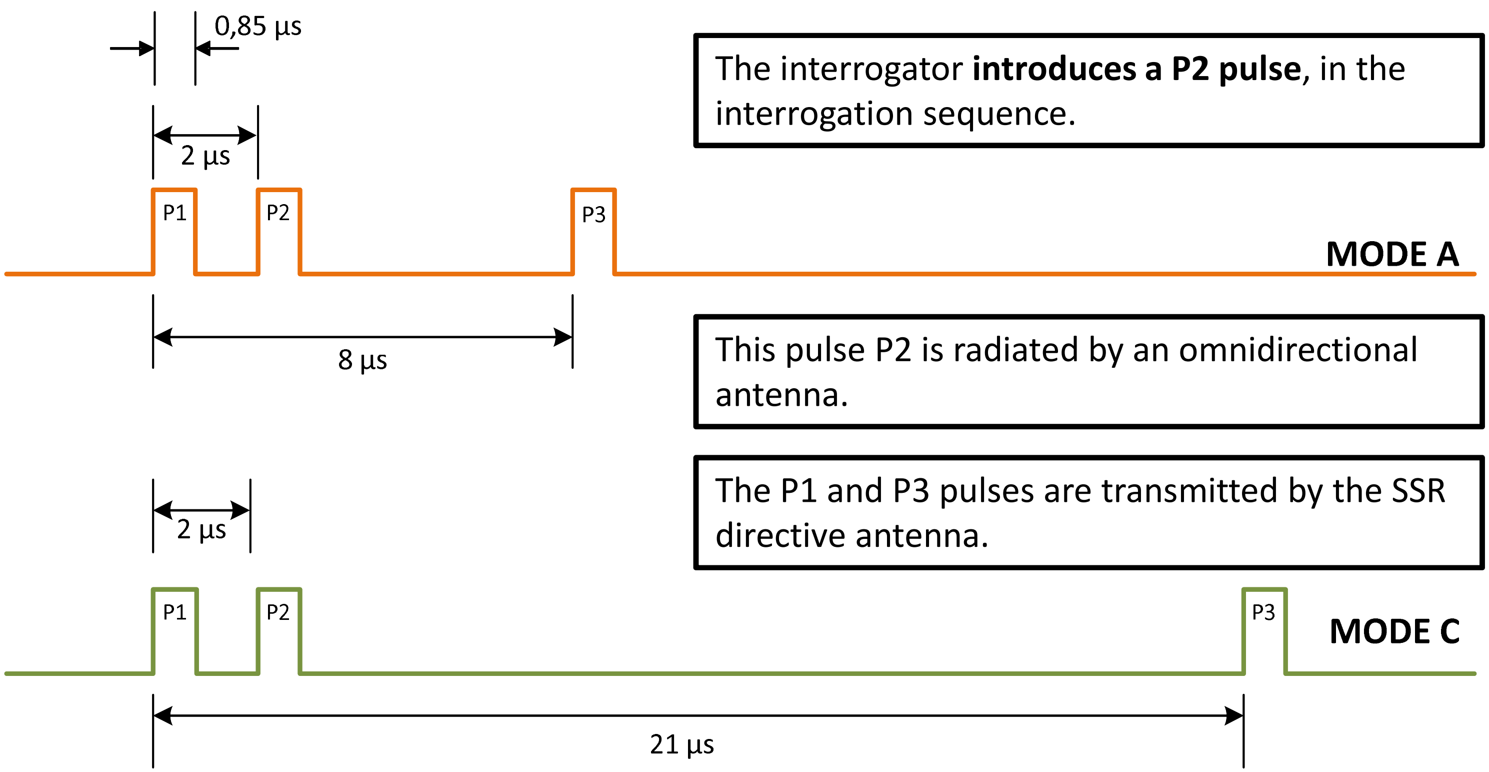
Interrogator Side Lobe suppression

This characteristic is used **to prevent replies** to interrogations received **via the side lobes of the interrogator antenna**, and to prevent Mode A/C transponders from replying to Mode S interrogations.

The interrogator **introduces a P2 pulse**, in the interrogation sequence.

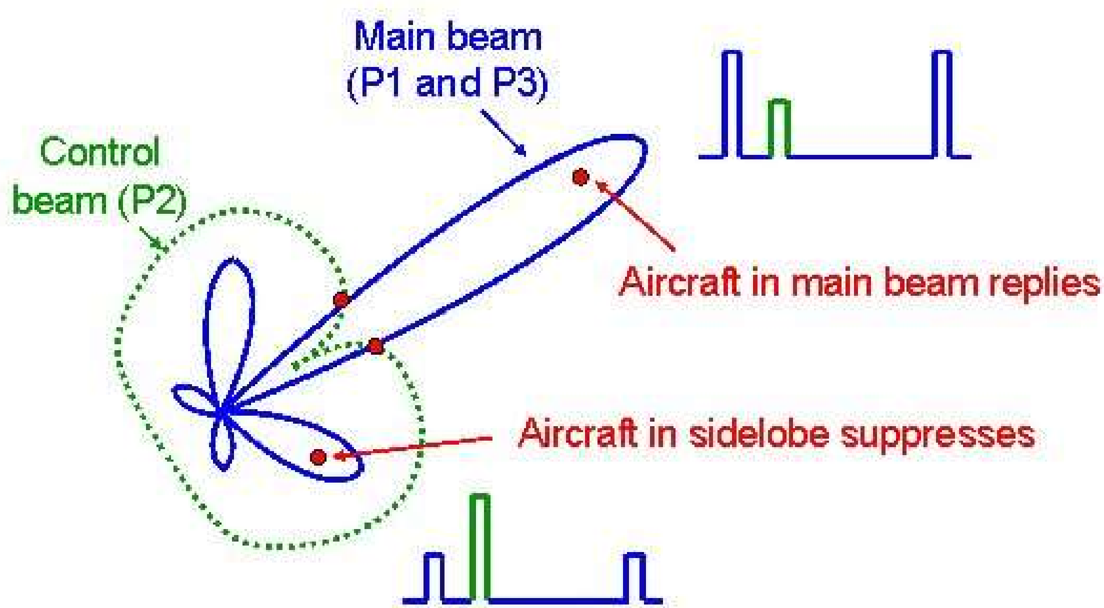
This pulse P2 is radiated by an omnidirectional antenna.

The P1 and P3 pulses are transmitted by the SSR directive antenna.



SSR Code Management: Interrogator process

Interrogator Side Lobe Suppression (2)



HD213_1010

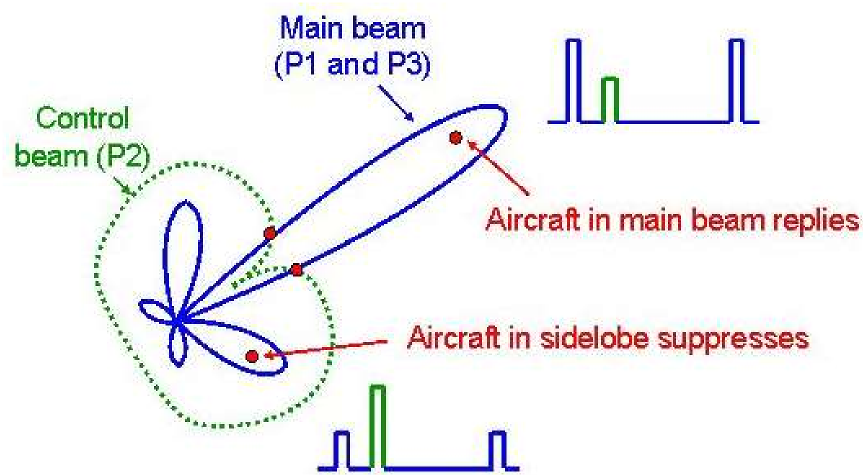
Interrogator Side Lobe suppression

This characteristic is used **to prevent replies** to interrogations received **via the side lobes of the interrogator antenna**, and to prevent Mode A/C transponders from replying to Mode S interrogations.

The **radiated amplitude** of ***P*2** at the antenna of the transponder shall be:

- **equal to or greater than the radiated amplitude of *P*1 from the side-lobe** transmissions of the antenna radiating *P*1;
- **And at a level lower than 9 dB below the radiated amplitude of *P*1**, within the desired arc of interrogation.

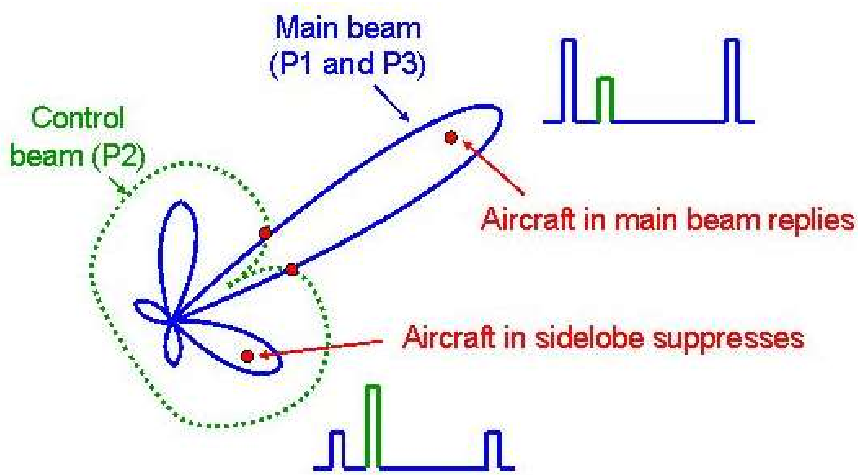
Within the desired beam width of the directional interrogation (main lobe), **the radiated amplitude of *P*3 shall be within 1 dB of the radiated amplitude of *P*1**.



Interrogator Side Lobe suppression

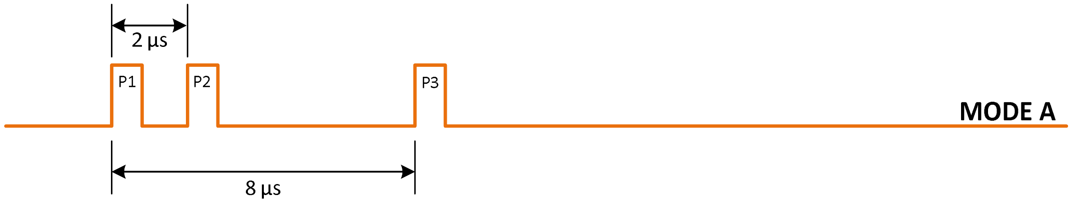
This characteristic is used **to prevent replies** to interrogations received **via the side lobes of the interrogator antenna**, and to prevent Mode A/C transponders from replying to Mode S interrogations.

- The transponder shall be **suppressed** when the **received amplitude of *P2*** is **equal to, or in excess of**, the **received amplitude of *P1*** and spaced 2.0 plus or minus 0.15 microseconds.
- The detection of *P*3 is not required as a prerequisite for initiation of suppression action.
- The transponder **suppression** shall be for a **period of 35 plus or minus 10 microseconds**.
- The suppression shall be **capable of being reinitiated** for the full duration within 2 microseconds after the end of any suppression period.

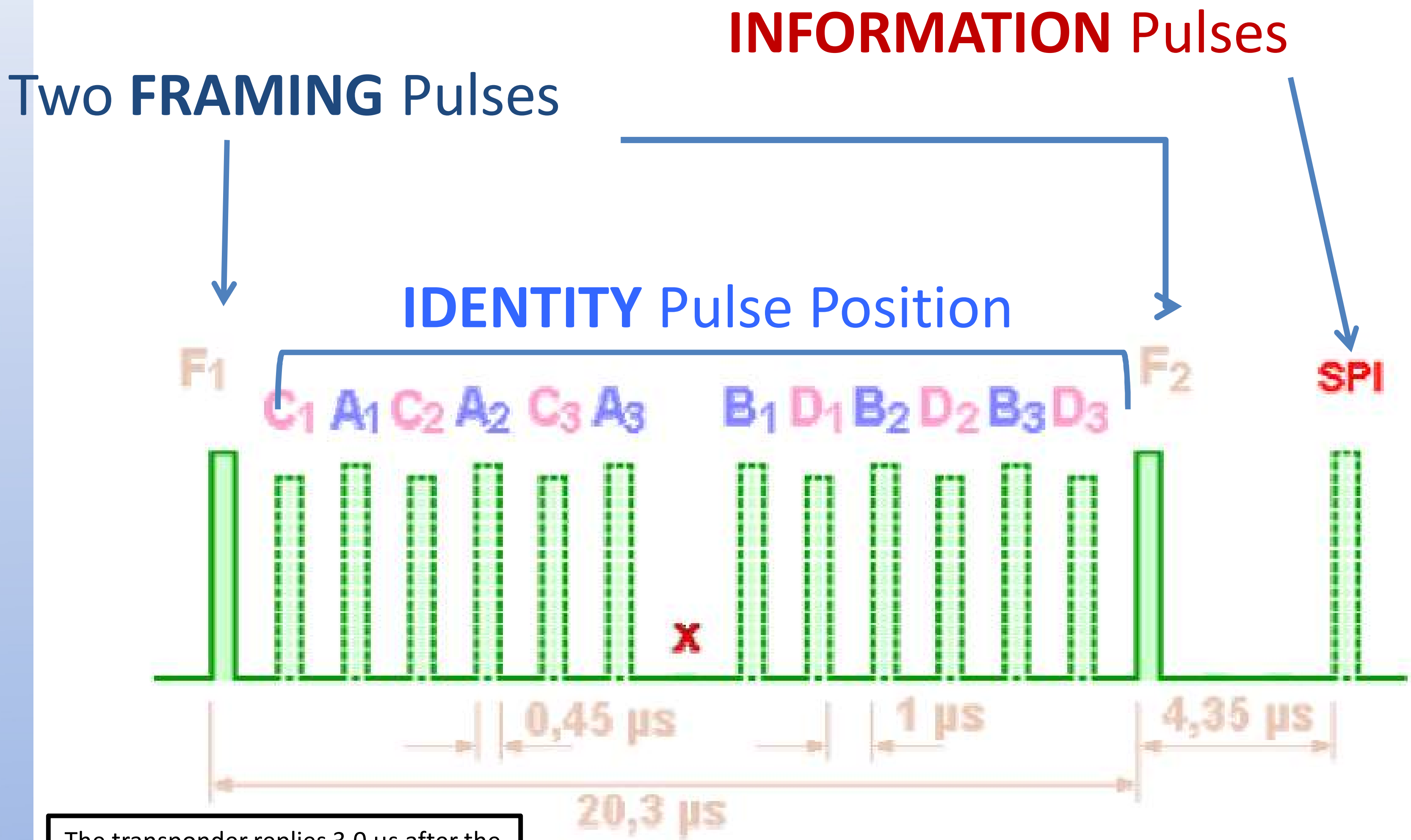


SSR CODE MANAGEMENT

MODE A: IDENTITY

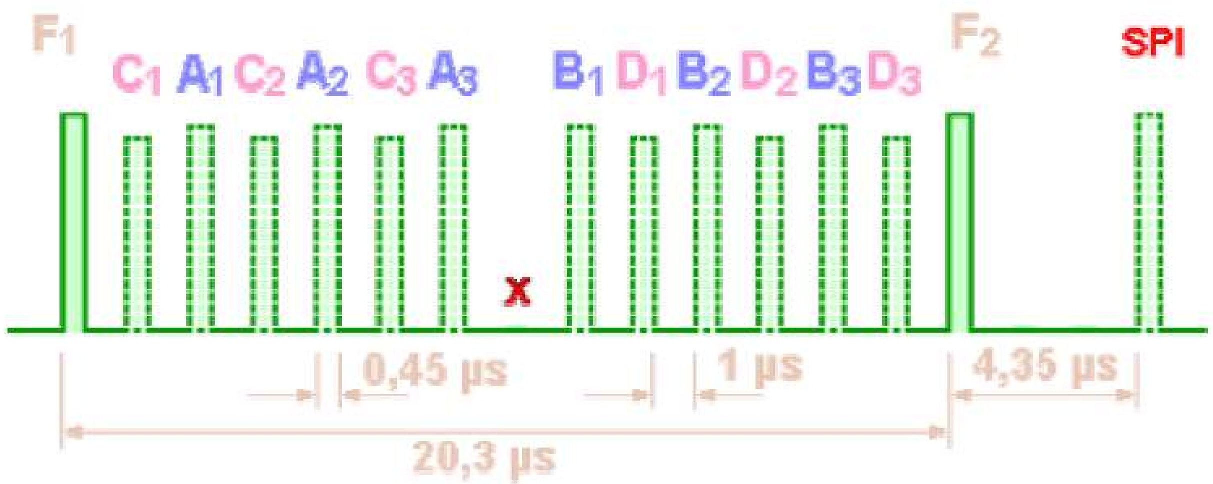


SSR Code Management: Reply process



The transponder replies 3,0 μs after the reception of P3.

SSR Code Management: Reply process



- **F1** and **F2** always present.
- A, B, C, D coded in **octal format.**
- **SPI**, additional pulse only reply if the pilot is explicitly requested by the ACTO.

SSR Code Management: Reply process

A binary bit, that is a 0 or a 1, is used to represent data.

How many decimal numbers can be represented by three binary bits?

3 Binary Bits	Decimal
0 0 0 =	0
0 0 1 =	1
0 1 0 =	2
0 1 1 =	3
1 0 0 =	4
1 0 1 =	5
1 1 0 =	6
1 1 1 =	7

There are no other combinations of the 3 binary bits - hence only decimal 0 to 7 can be represented by 3 binary bits.

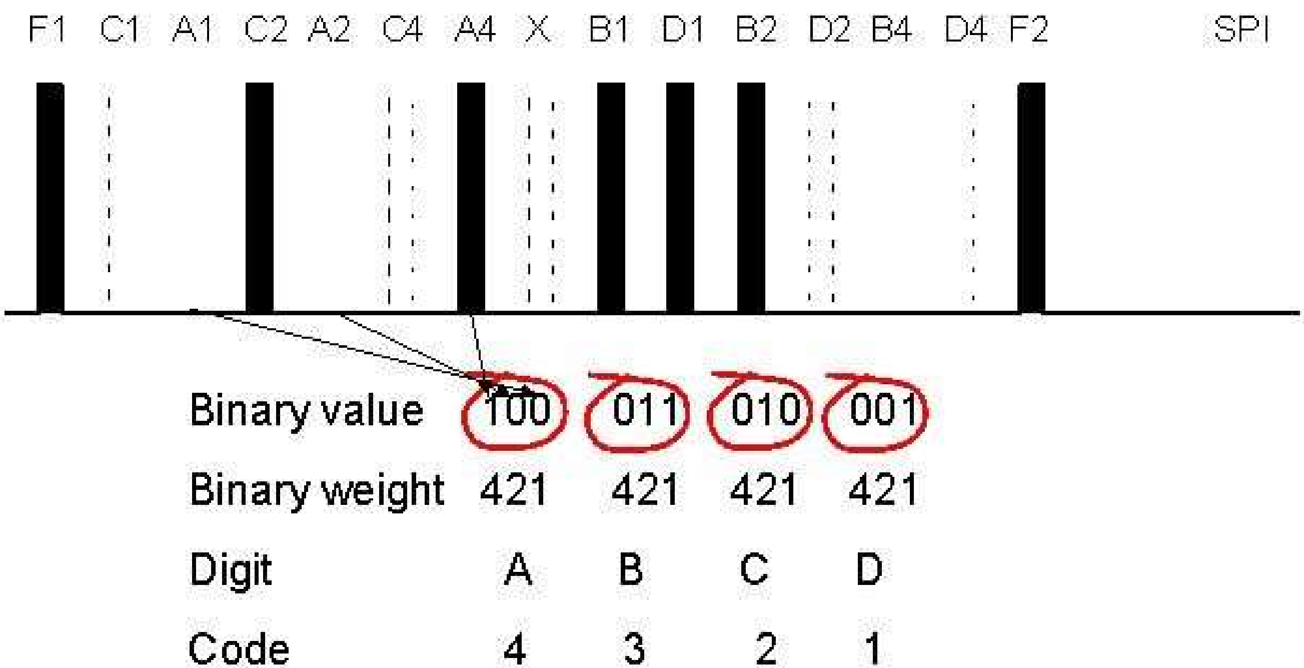
That is why there are no squawk codes containing the decimal numbers 8 and 9.

SSR Code Management: Reply process

Squawk code 4321 can be represented by combinations of 3 binary bits as:

1 0 0   0 1 1   0 1 0   0 0 1

These are the 12 information pulses



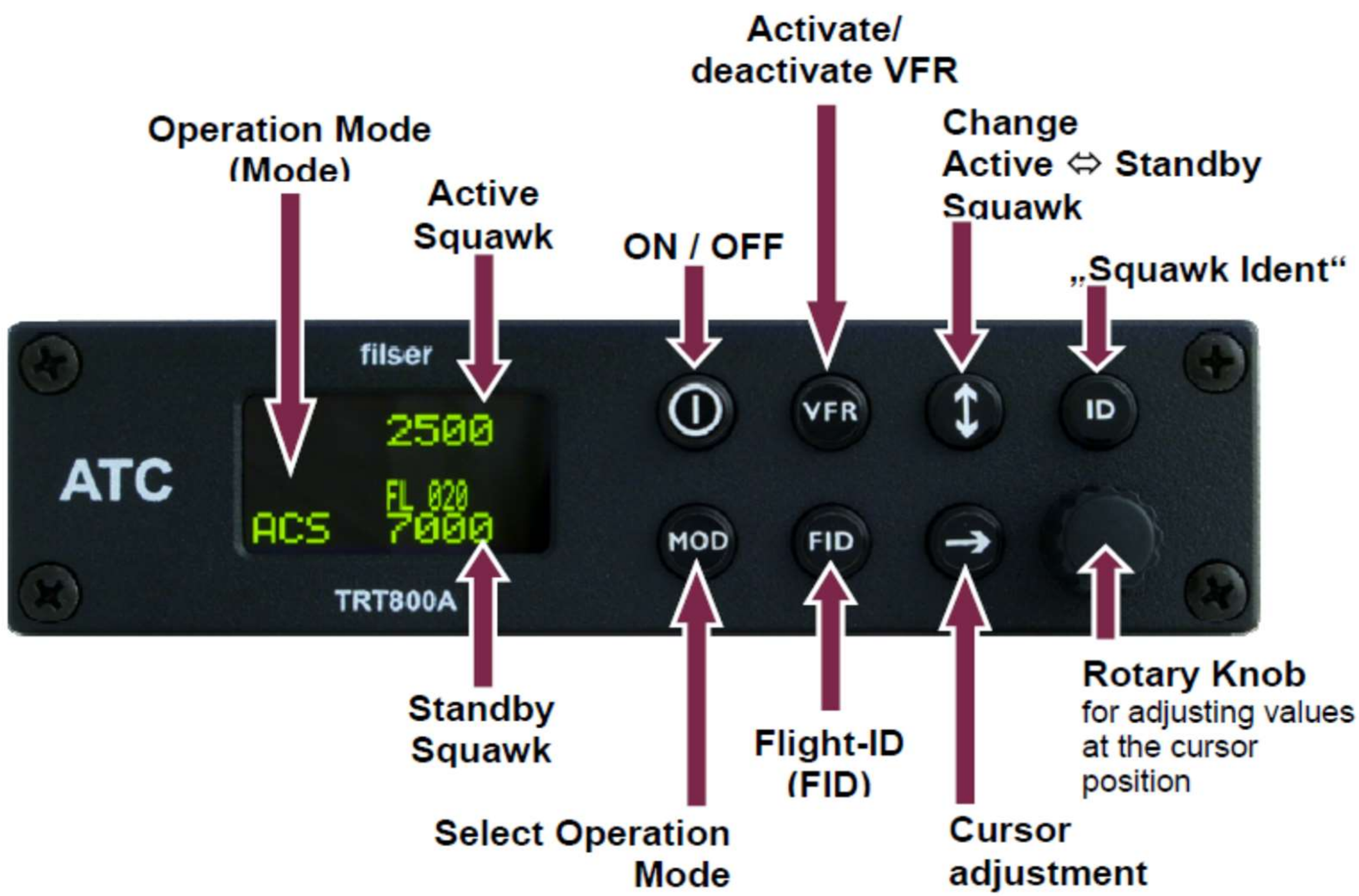
SSR Code Management: Reply process

Therefore, the number of possible combinations is $2^{12} = 4096$.

Hence there are 4096 discrete squawk codes.

LIMITATION

(Overcome with Mode S)


Activate/
deactivate VFR
Operation Mode
(Mode)
Active
Squawk
ON / OFF
Change
Active ⇔ Standby
Squawk
„Squawk Ident“
filser
ATC
2500
FL 020
ACS
7000
TRT800A
VFR
ID
MOD
FID
Standby
Squawk
Select Operation
Mode
Flight-ID
(FID)
Cursor
adjustment
Rotary Knob
for adjusting values
at the cursor
position

SSR Code Management: Reply process

Certain special codes have been agreed internationally to indicate some emergency situations:

Code 7700 - Aircraft emergency;
Code 7600 - Radio communication failure;
Code 7500 - Hijack or other act of violence;
Code 0030 - FIR Lost;
Code 0000 - Reserved as a general purpose code;
code 2000 - Aircraft without instructions from ATC to operate the transponder

SSR Code Management: Reply process

DISCRETE CODE - A code that is assigned to only one aircraft within a particular area of airspace.

NON-DISCRETE CODE - A code that may be assigned, concurrently, to more than one aircraft within a particular area of airspace.

All codes ending in **two zeros** are designated **non-discrete**. All other codes are designated discrete, unless otherwise specified.

Ex: Code 1400 - VFR flights above 12,500 feet.

SSR MODE-A CODE MANAGEMENT

THE ORCAM SYSTEM

J. Mateu - J. Berenguer

SSR Code Management: Code Allocation

ORCAM: Originating **R**egion **C**ode **A**ssignment **M**ethod

- Is a system developed by Eurocontrol and endorsed by ICAO.
- Since there are insufficient code blocks to develop a world-wide system, it has been necessary to group certain countries together into **PARTICIPATING AREAS (PA).**
- The ICAO **EUR region** is divided into **five PA**.
- ORCAM is designed to **reduce RTF (radiotelephony)** and **cockpit workload** by allocating an SSR code which will be retained by the aircraft from take off to touchdown.
- This will help controllers in forward planning, particularly in areas of **overlapping radar cover** and assist in implementation of **radar data processing and data exchange programs**.

SSR Code Management: Code Allocation

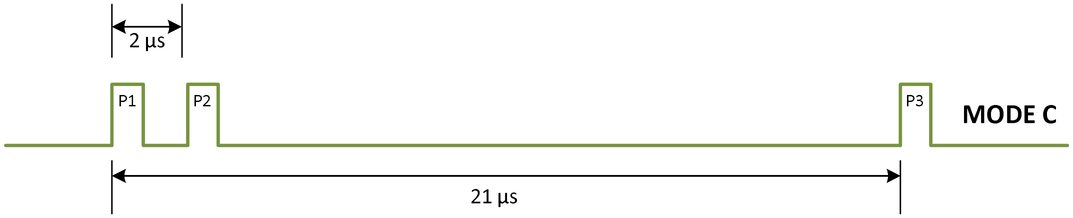
- Each ATCC (Air Traffic Control Center) is allotted two blocks of codes, one for internal flights (Domestic) and the other for international flights (ORCAM).

- The ATCC with jurisdiction over the airspace first entered by an aircraft (Originating Region) will assign a discrete code from one of the allotted blocks.

- The code will depend on the destination of the flight, either Domestic or ORCAM, and will be retained by the aircraft throughout its flight in the PA (Participating Areas).

SSR CODE MANAGEMENT

MODE C: ALTITUDE



SSR Code Management: **Transmission of Altitude**

- Aircraft altitude information is the response to an interrogation in **Mode C**.
- The altitude information is transmitted in the form of a response **pulse train** to the ground station.
- This is decoded into a numerical form and provides a direct indication of the vertical position of the aircraft.
- To exclude operational errors during the transmission of vertical position data, reference is solely made to the standard ICAO atmosphere pressure setting of **1013,2 hPa**.
- The process is entirely automatic, the only crew function being a selection of "**ALT ON**" on the transponder control panel.
- Thus, no matter what pressure setting has been selected on the altimeter, the vertical position of an aircraft in response to a Mode C interrogation is always given as a **Flight Level**.

SSR Code Management: **Transmission of Altitude**

- The altimeter altitude data are sent to an analog-digital converter that automatically encodes it in **increments/decrements of 100 feet** ranging between +126.750 to -1.000 feet, with an uncertainty of ± 50 ft.
- Only 1278 different combinations (from the 4096 available) are needed.
- The aircraft altimeters generally have greater accuracy and resolution.
- Although the aircraft altimeters have a greater accuracy and resolution than 100 ft, this kind of encoding is sufficiently accurate to be displayed in the label associated with the plane and presented to the controller, but it's not accurate to specify the vertical rate.

RANGE	PULSE POSITIONS (0 or 1 in a pulse position denotes absence or presence of a pulse, respectively)										
Increments (Feet)	D_2	D_4	A_1	A_2	A_4	B_1	B_2	B_4	C_1	C_2	C_4
88 250 to 88 350	1	1	1	0	1	0	1	0	1	0	0
88 350 to 88 450	1	1	1	0	1	0	1	0	1	1	0
88 450 to 88 550	1	1	1	0	1	0	1	0	0	1	0
88 550 to 88 650	1	1	1	0	1	0	1	0	0	1	1
88 650 to 88 750	1	1	1	0	1	0	1	0	0	0	1

SSR CODE MANAGEMENT

ACTIVE AND AUTOMATIC DECODING OF INFORMATION ON A RADAR DISPLAY

J. Mateu - J. Berenguer

ACTIVE DECODING

This provides a numerical display in answer to questions such as

“Who are you?”

or

“What is your altitude?”

Active decoding requires the individual interrogation of radar responses on the radar display.

SSR Code Management: Decoding

- A control stick or rolling ball is used to position a synthetic marker or symbol. The marker or symbol is overlaid on the target to be actively decoded.

- A light pen/gun is placed manually over the response to be actively decoded. An optical system and photo-electric detector transform the pulse of light into a trigger pulse for the active decoder.

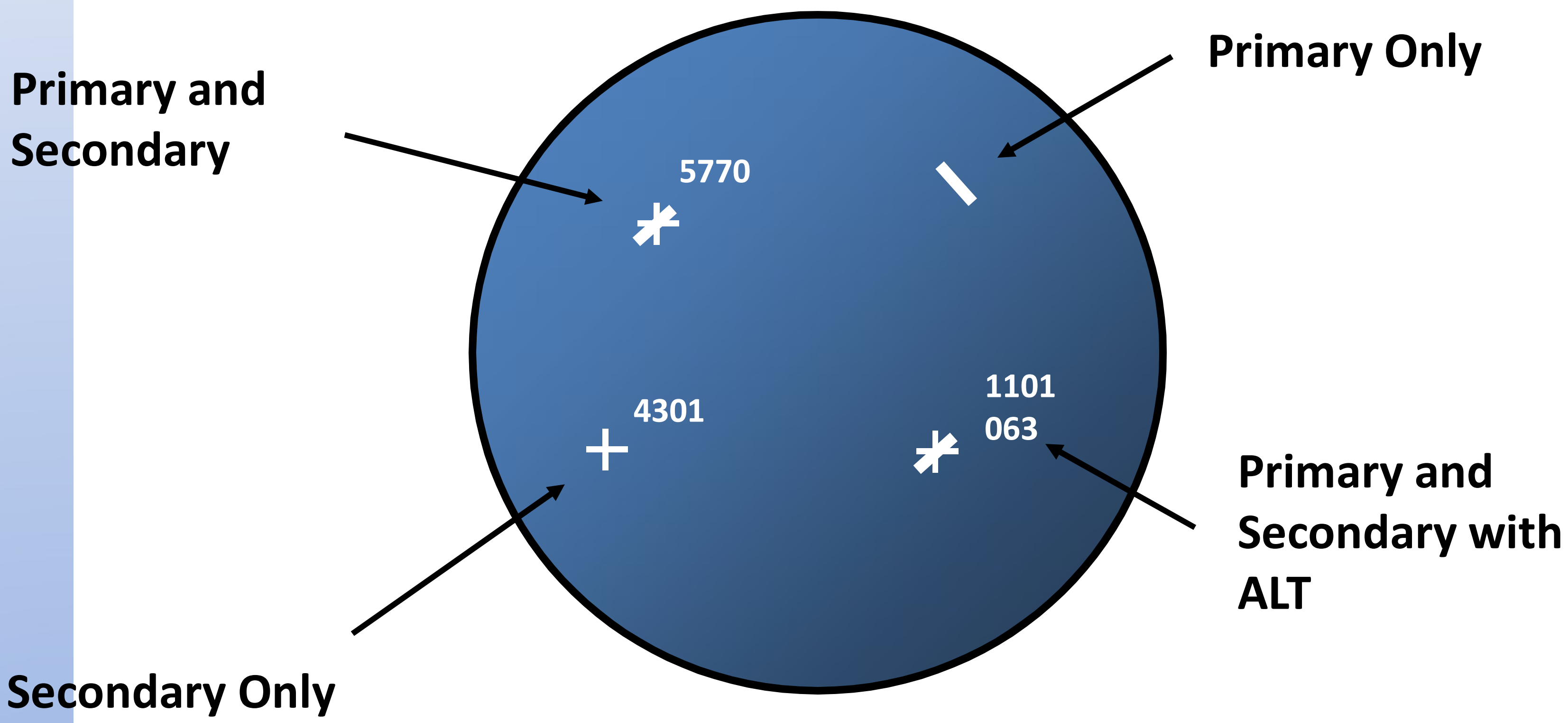
- The actively decoded information is normally displayed on a separate indicator adjacent to the radar console.

AUTOMATIC DECODING

Generally associated with automatic radar data processing. Information may be displayed on scan converted or synthetic radar displays.

Using Interscan/Intertrace techniques, SSR information may be presented in alphanumeric form on conventional CRTs, either in conjunction with primary radar or independently.

AUTOMATIC DECODING



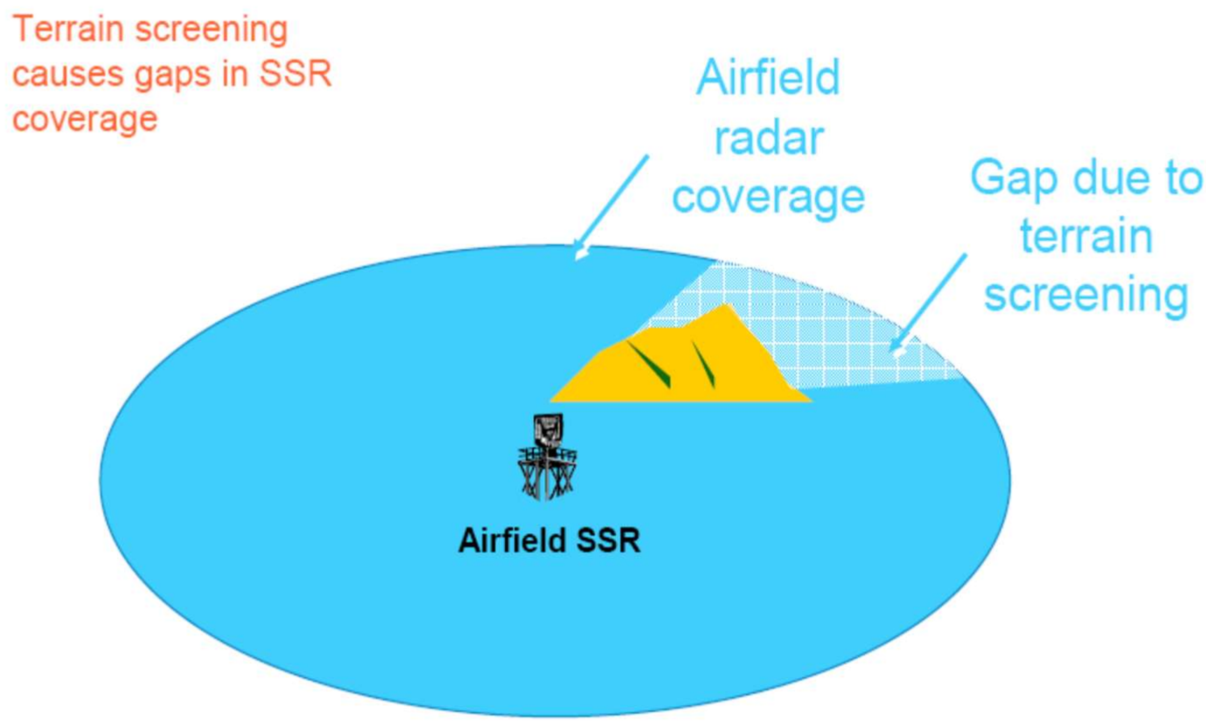
EFFECTS ON ANTENNA SHADOWING ON SSR OPERATION

J. Mateu - J. Berenguer

Antenna Shadowing

Transponder Antenna Shadowing

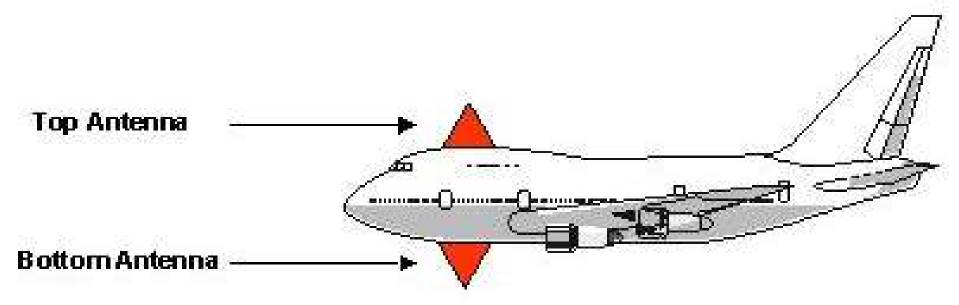
SSR operates on a line of sight basis and if a nearer target or object is obscuring a far target, it will not reply. This principle is known as antenna shadowing. When the aircraft turns, the SSR antenna may be shadowed by other parts of the airframe. This is less so nowadays for civil aircraft with both top and bottom antennas.



SSR Transponder Antennas

If the aircraft has only one antenna it is at the bottom of the aircraft.

If aircraft are equipped with two antennas **(DIVERSITY)**, one on top and one at the bottom, the antenna choice for squitter messages is under control of the **Squitter Antenna Selection (SAS).**



The reply is transmitted by just one antenna, usually that which as received a greater power level of the interrogation signal.

In the absence of SAS the default antenna choice is the top antenna. Mode S interrogations/replies are working in diversity.

SSR Transponder Antennas

OVERVIEW OF THE ANTENNA CHOICES

	ICAO		MOPS		ARINC	
Aircraft on the Ground	Inter-rogation	Squitter	Inter-rogation	Squitter	Inter-rogation	Squitter
Transponder + antenna diversity	**Diversity**	**SAS or Top**	**Div**	**SAS or Top**	**Diversity**	**Top**
Transponder with single antenna	**Bottom**	**Bottom**	**Bottom**	**Bottom**	**Bottom**	**Bottom**
ES/NT device	**Diversity**	**Top**	***TBD***	***TBD***	***TBD***	***TBD***

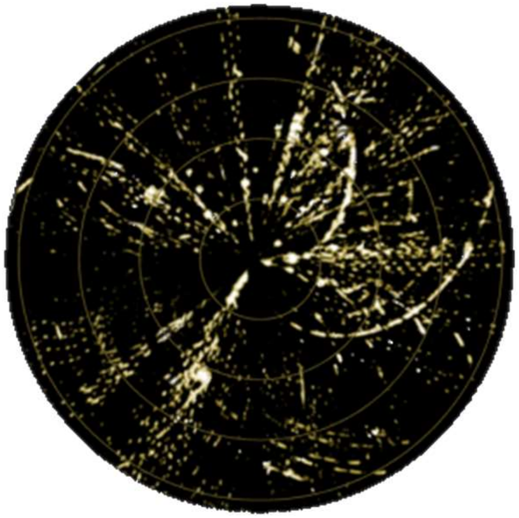
Diversity = replies following the antenna diversity protocol
Bottom = Bottom antenna
Top = Top antenna
SAS = Squitter Antenna Selection

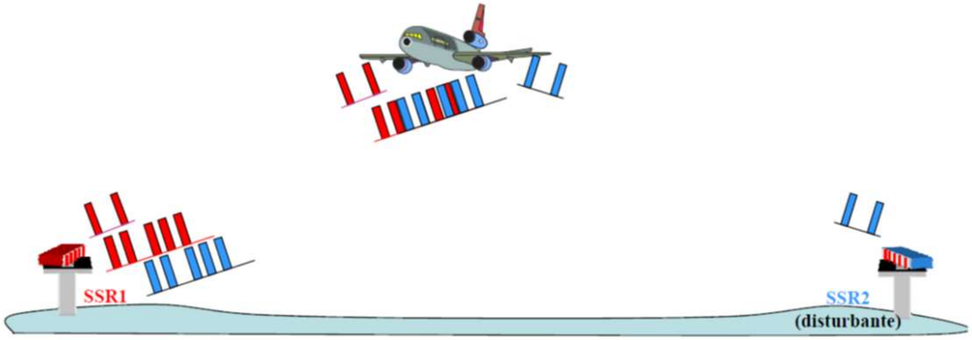
ES/NT= Enhanced Surveillance for Non Transponder

LIMITATION OF SSR

FRUIT

- Since all aircraft reply on the same frequency of 1090 MHz, a ground station will also receive aircraft replies originating from responses to other ground stations.
- These unwanted replies are known as **FRUIT** (**F**alse **R**eplies **U**nsynchronized with **I**nterrogator **T**ransmissions or alternatively **F**alse **R**eplies **U**nsynchronized **I**n **T**ime)
- These are removed by using a **defruiter.**
- Several successive fruit replies could combine and appear to indicate an aircraft which does not exist. As air transport expands and more aircraft occupy the airspace, the amount of fruit generated will also increase.



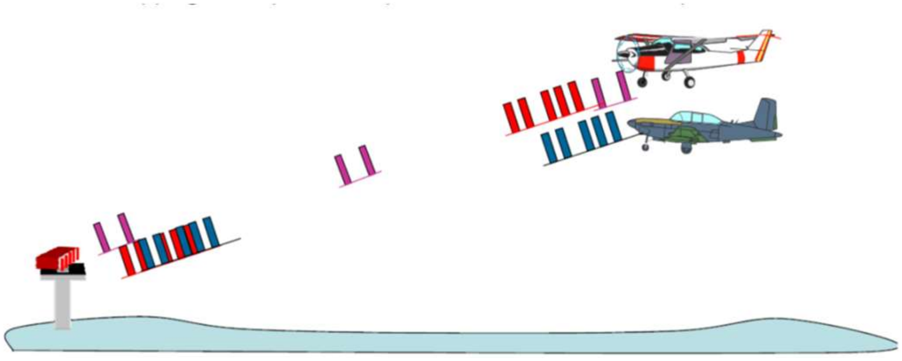


Limitations of SSR

Unwanted Responses

GARBLING

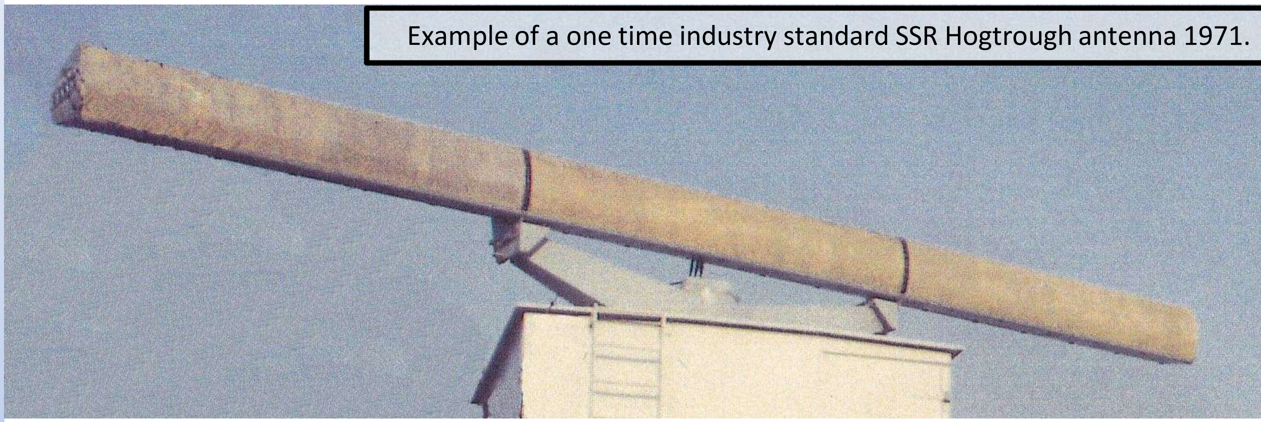
- Fruit replies can overlap with wanted replies at a ground receiver, thus causing errors in extracting the included data.
- A solution is to increase the interrogation rate so as to receive more replies, in the hope that some would be clear of interference.
- The process is self-defeating as increasing the reply rate only increases the interference to other users and vice versa.



Synchronous garble

- If two aircraft paths cross within about two miles slant range from the ground interrogator, **their replies will overlap** and the interference caused will make their detection difficult.
- Typically the controller will lose the longer range, and later to reply, aircraft just when the former may be most interested in monitoring them closely.

SSR Antennas



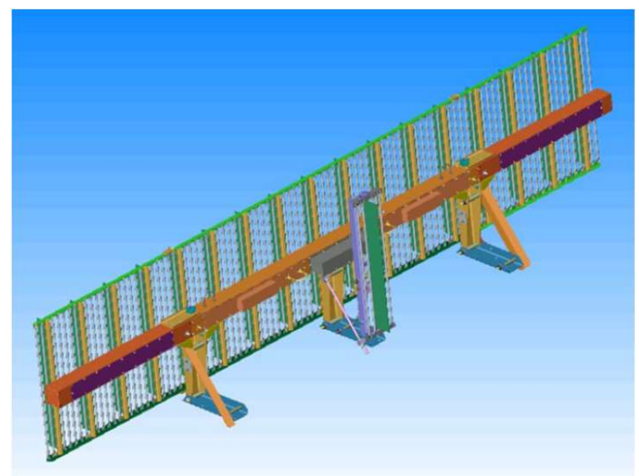
Example of a one time industry standard SSR Hogtrough antenna 1971.

- Various antenna architectures have been used in SSR systems. Early systems used a so-called “Hogtrough” antenna typically about 4 metres in horizontal aperture and 0.5 meters in vertical aperture.

- This resulted in a large vertical beamwidth resulting in heavy ground reflections and resulting inaccuracies.

- Recent designs use a Large Vertical Aperture antenna with a 1.6 meters vertical aperture and resulting narrower vertical beamwidth. This necessitated a vertical array of dipoles suitably fed to produce the desired shape. A five-foot vertical dimension was found to be optimum and this has become the international standard

- SSR antennas are often co-mounted with primary RADAR.



SSR Antennas

SSR Interrogator Antenna Types

Hog Trough
(now outdated)

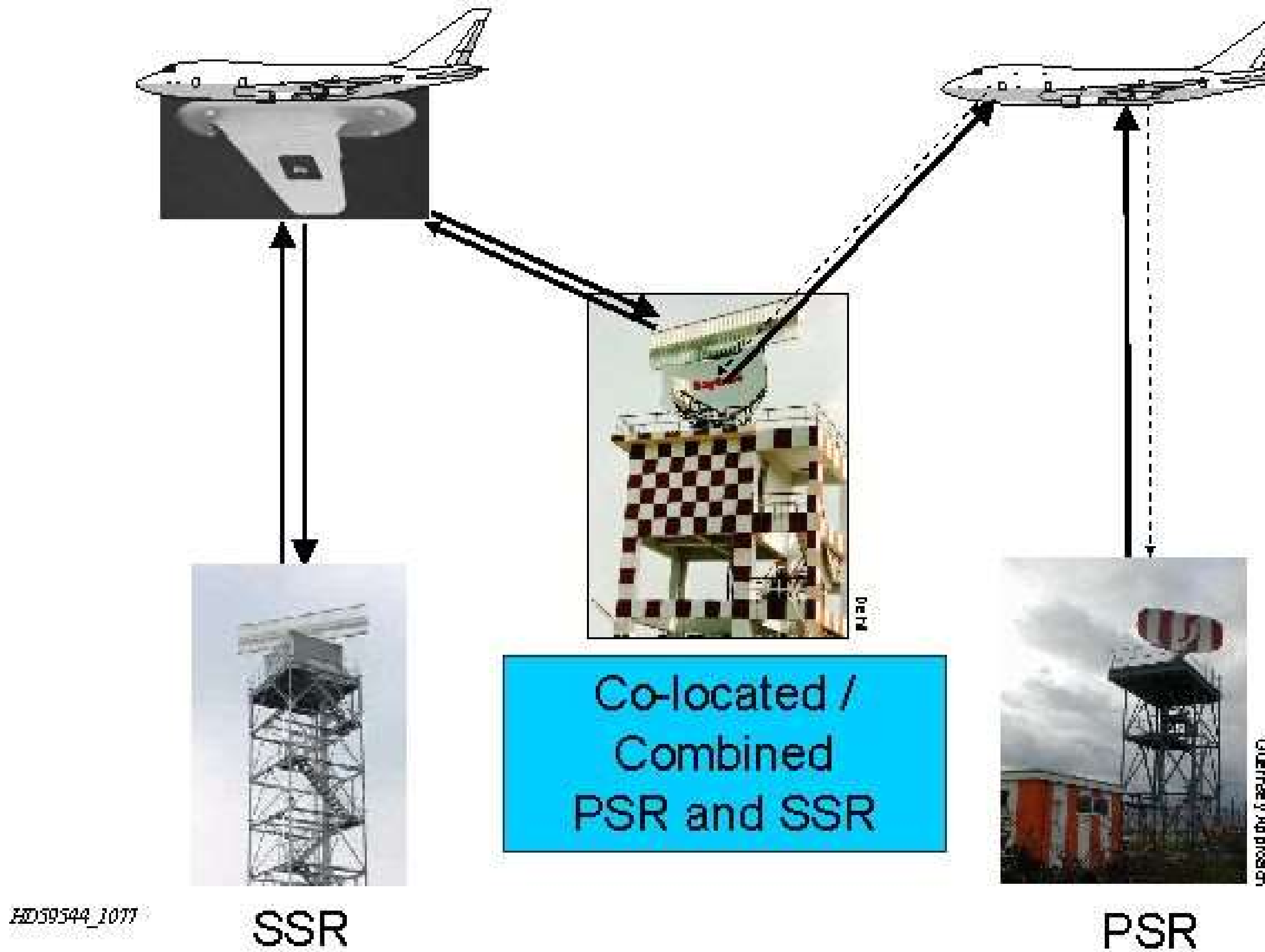
Flat Plate
Antenna

Planar Array

HD59544_1078

SSR Antennas

Radar Antennae



MONOPULSE TECHNIQUES FOR SSR

- Without requiring modification of system design, the use of monopulse techniques in the ground receiver can considerably improve the azimuth accuracy, and consequently, the effects of synchronous garbling can be greatly reduced.

- Since fewer replies are needed to ensure decoding and satisfactory position measurement, the techniques permit a reduction in the pulse repetition frequency of ground interrogators.

- Saturation of the SSR system due to traffic increases, therefore, may be postponed.

ELDIS®

Monopulse Secondary Surveillance Radar

with Mode S capability

Monopulse Secondary Surveillance Radar, developed by ELDIS Pardubice, s.r.o., is a fully modular system, which meets recommendations of ICAO standards.

Secondary Surveillance Radar Modular System

Basic configuration of the autonomous secondary radar fully comply with standard MARK X and allows extension according to increasing needs of the customer. Individual modules of the equipment can be used either in

channels, and mechanical dimensions.

Each antenna of ASSR series has a main beam (SUM).

The ASSR-20 antenna has DIF and BACK beams that are integrated in a SLS beam.

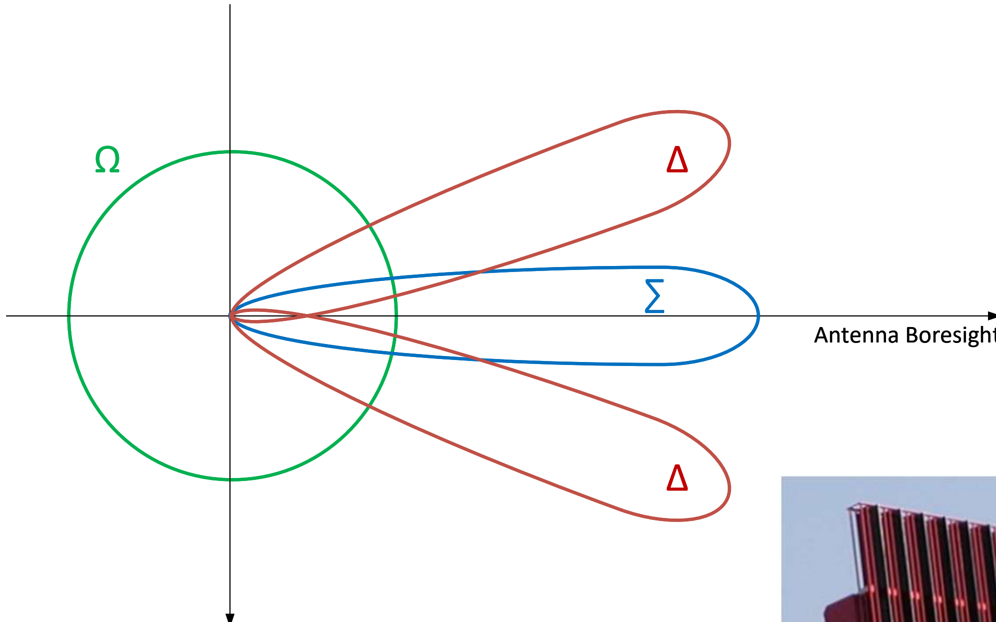
The ASSR-35LVA antenna has a separate DIF beam and this beam together with SUM beam serve to monopulse measurement of target azimuth. This antenna also has beams OMEGA and BACK. The SLS beam is created by integration of OMEGA and BACK beams at this antenna.

The unit comprises following functional parts:

- Two-channel transmitter
- Three- channel receiver
- Extractor

Frequency band		1030 & 1090 MHz
Antenna gain	ASSR-20 ASSR-35 LVA	>20 dBi >27 dBi
Mode		1; 2; 3/A; C; Mode S level 2
Input peak power of the transmitter		min. 62 dBm
Supply		3×230/400 V±10 %
Resistance from wind in operation / out of operation		30/50 m/sec
Operating temperature range (outdoor parts of the equipment)		-50 °C to +50 °C
Operating temperature range (indoor parts of the equipment)		-10 °C to +50 °C
Range		from 0,5 to 256 NM
Antenna revolution		from 4,5 to 15 1/min
Antenna beamwidth in a horizontal plane (ASSR-20)		2,2° at -3 dB level 4,2° at -10 dB level
Sensitivity for SNR 10dB [dBm]		min. -83
Dynamic range [dB]		min. 70
Altitude resolution (mode C)		100 feet
Altitude resolution v all-call mode C/S		25 feet
Range accuracy [m]		±27 r.m.s.
Targets processing capacity [1/sec]		min. 125
Azimuth accuracy [°]		±0,1°
Output data format		ASTERIX Category 34, 48

MONOPULSE TECHNIQUES FOR SSR



- Sum diagram (Σ), similar to a conventional SSR antenna diagram.
- Difference diagram (Δ), has a null at the antenna edge.
- Omnidirectional diagram (Ω), useful for the emission of P2 pulse.

MONOPULSE SSR

4.3 Monopulse SSR

- **4.3.1** SSR equipment installed in order to fulfil the radar surveillance requirements of this Standard or to replace existing equipment shall be of the monopulse type.
- **4.3.2 Recommendation** *New Monopulse SSR (MSSR) systems should be capable of upgrading to Mode S enhanced surveillance functions.*

NOTE - The requirements for Mode S enhanced surveillance functions of a MSSR system are developed in the frame of the Eurocontrol programme " Initial Implementation of Mode S Enhanced Surveillance".

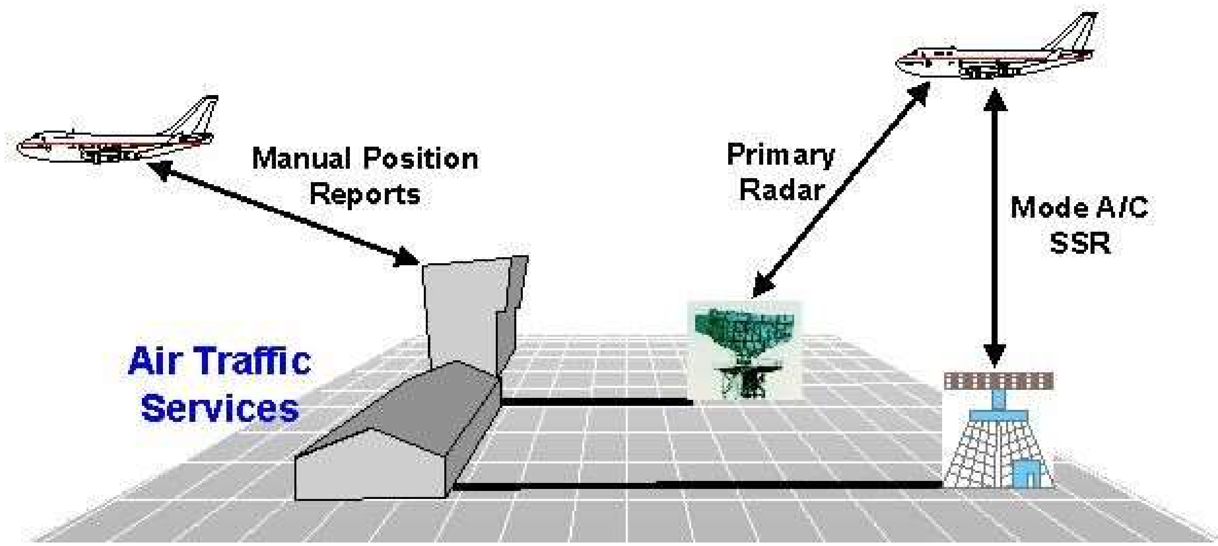
EUROCONTROL STANDARD DOCUMENT FOR RADAR SURVEILLANCE IN EN-ROUTE AIRSPACE AND MAJOR TERMINAL AREAS.
SUR.ET1.ST01.1000-STD-01-01

PSR AND SSR WITH AUTOMATED SYSTEMS

J. Mateu - J. Berenguer

PSR and SSR with automated systems

Surveillance systems: **Current environment**



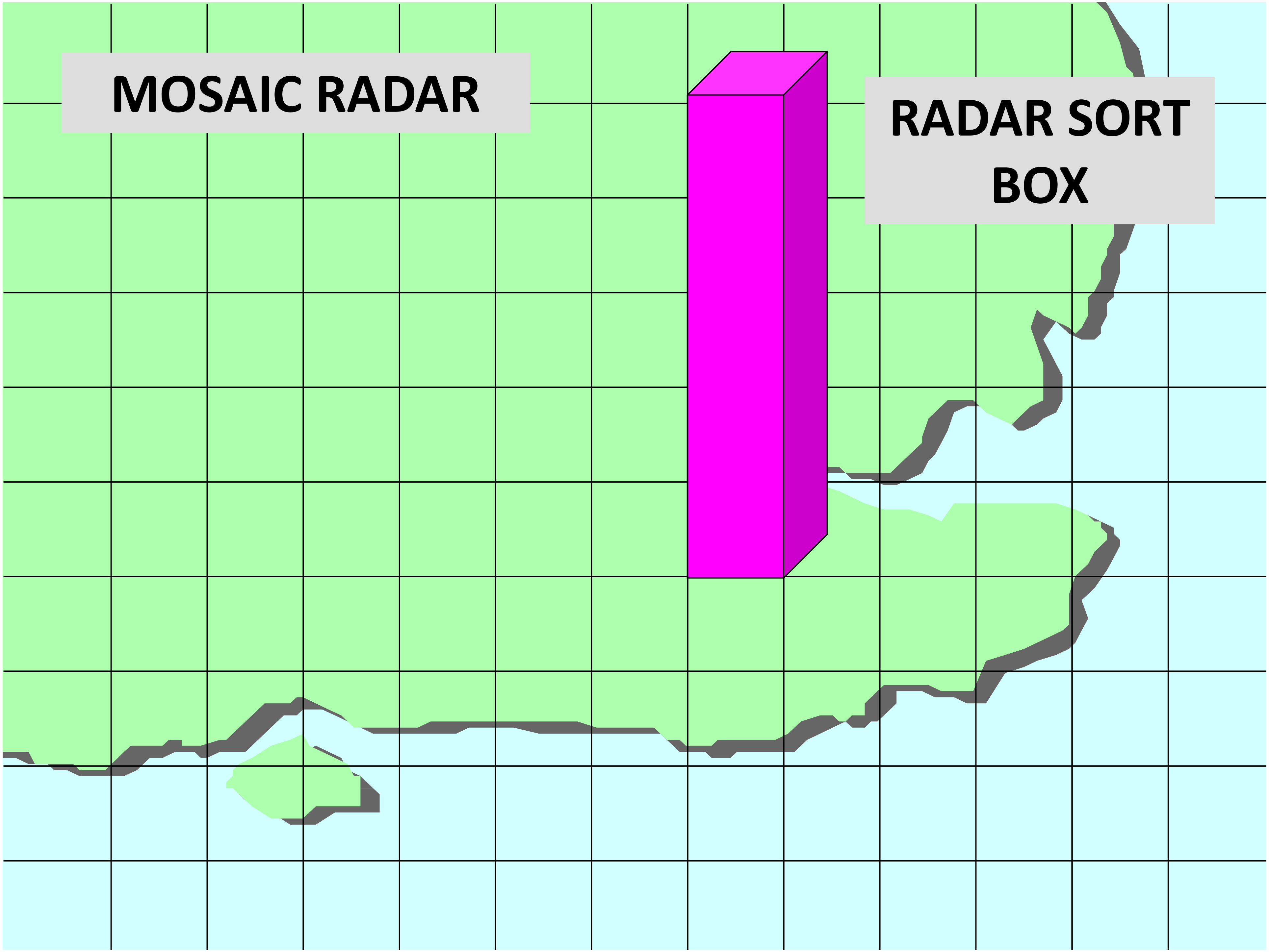
The current surveillance environment is comparatively basic compared to future scenarios

Multi Radar Processing

- Gaps in radar coverage can be reduced or eliminated if information from a variety of sources can be presented on one display.

- Digitised radar data from all achievable radar is correlated and a composite (mosaic) picture covering the whole airspace is constructed.

- To achieve this the airspace is divided into a grid of squares 16 NMI by 16 NMI forming columns of air from the ground upwards.

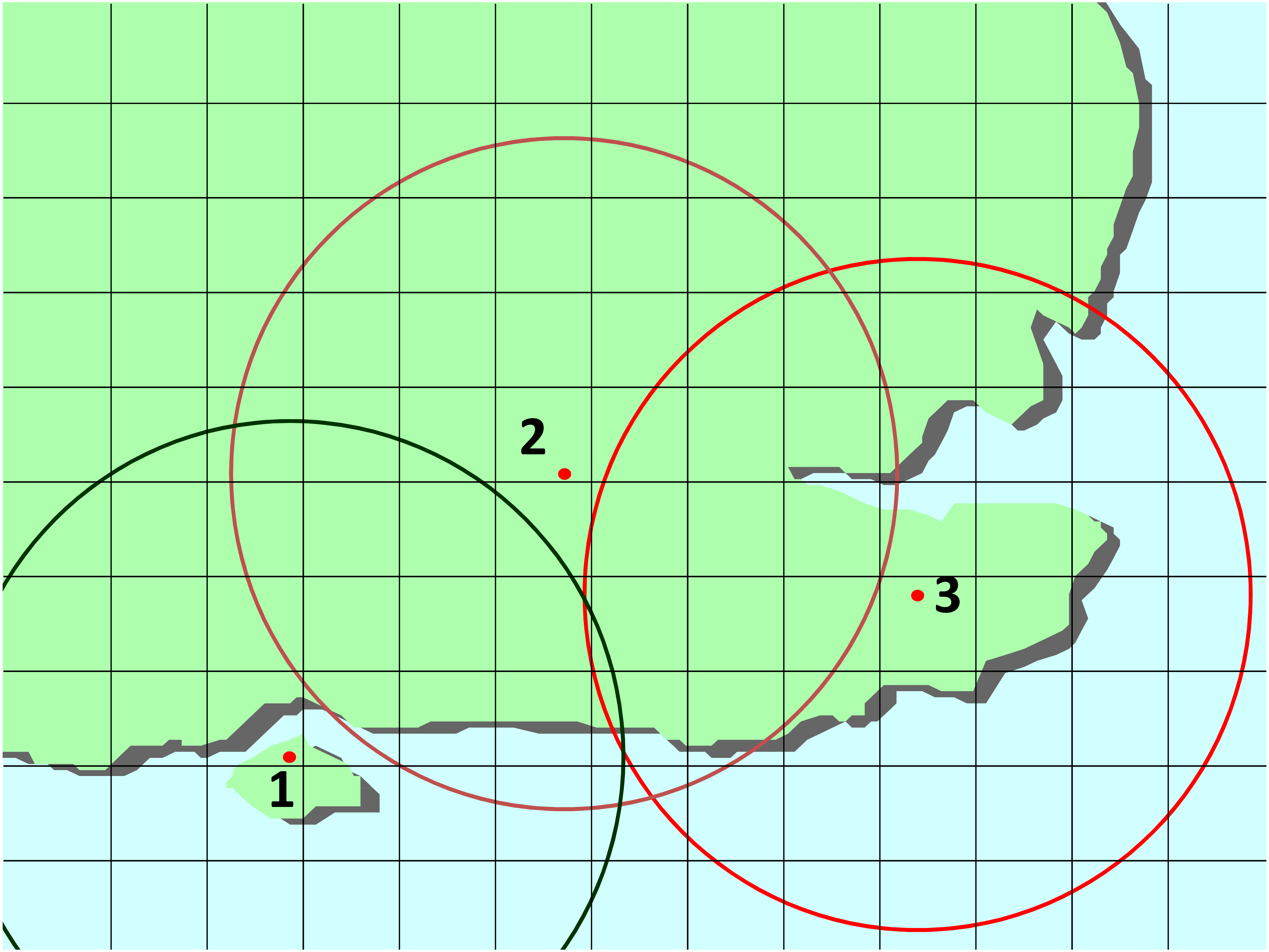

MOSAIC RADAR
RADAR SORT BOX

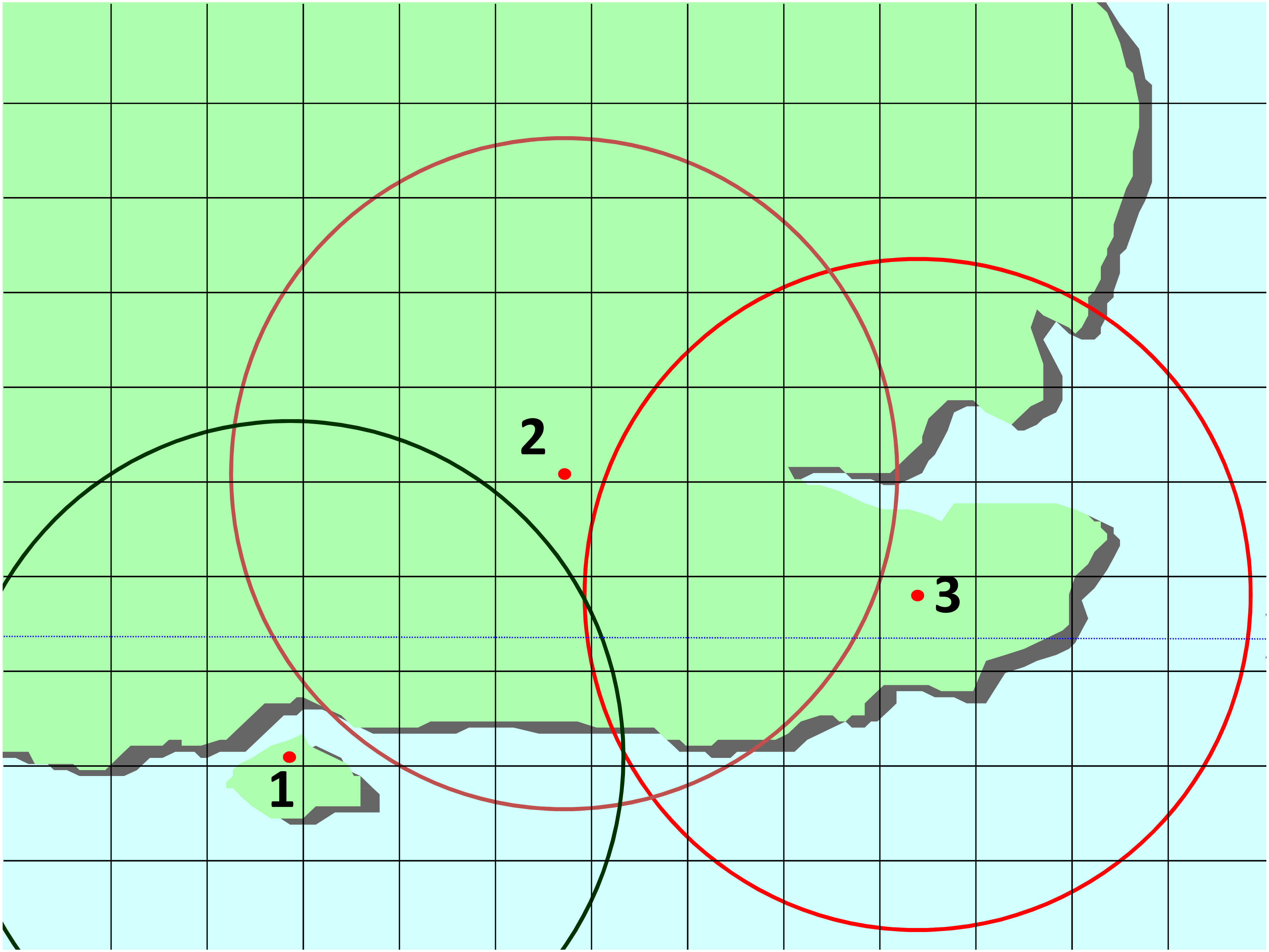
Multi Radar Processing

•Each radar sort box may have up to four radar systems allocated to it depending on the number of systems which can provide a service.

•The radar giving the best cover is nominated the 'preferred', the next best, the 'supplementary' and the remainder form a reserve.

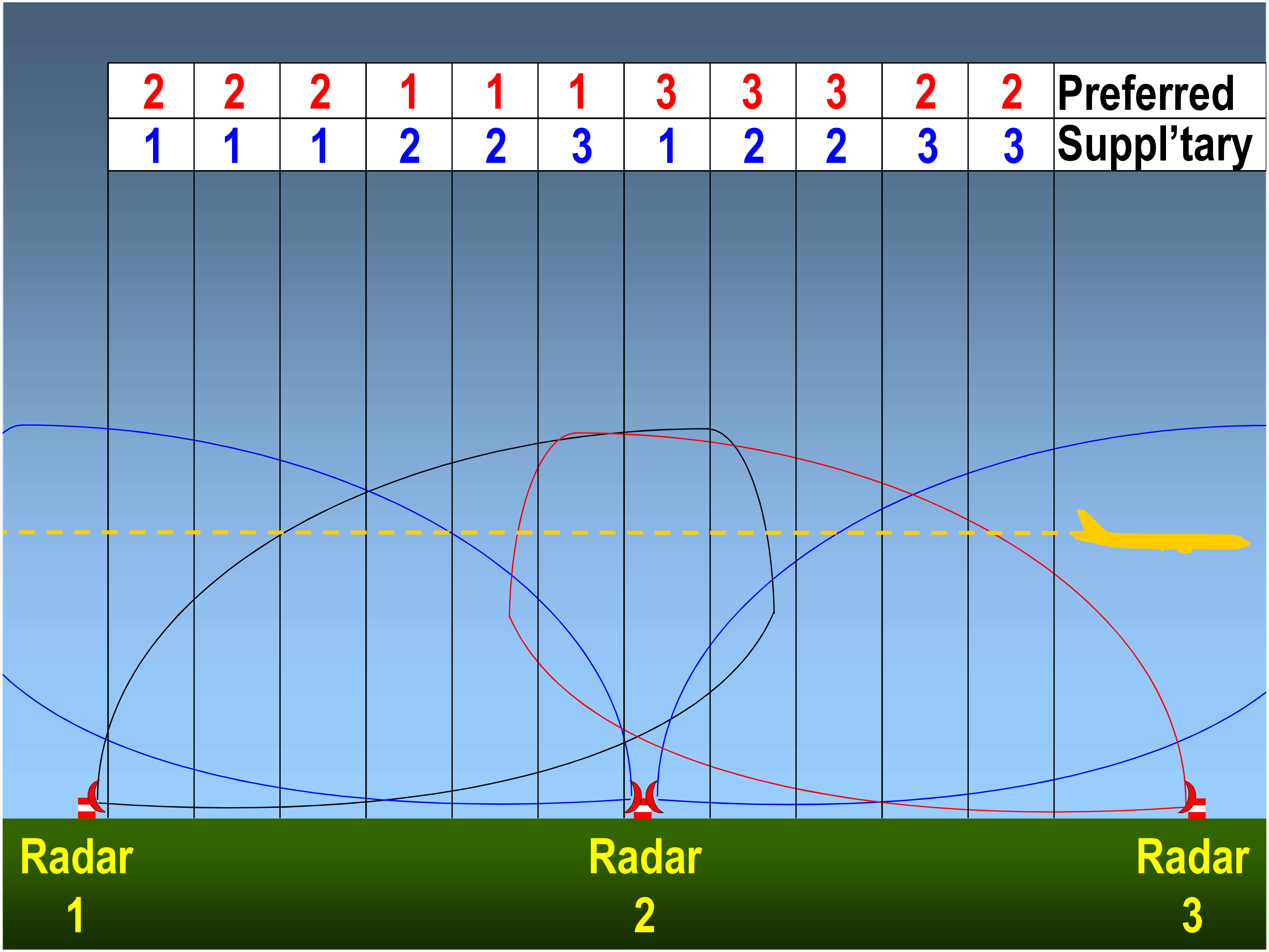
•Should the 'preferred radar' fail, the 'supplementary radar' can be upgraded either manually or automatically to 'preferred' and a reserve upgraded to 'supplementary'.


2
3
1



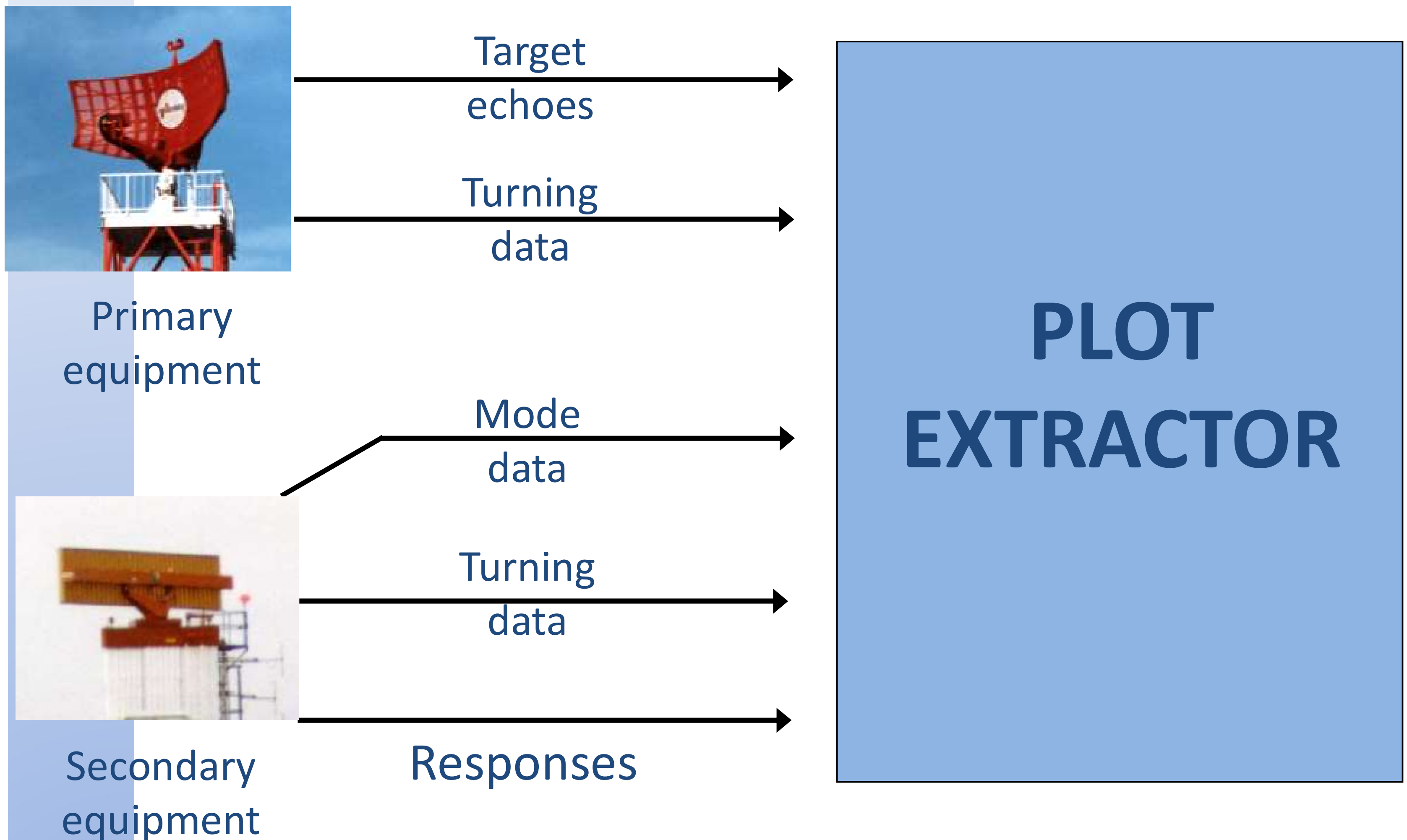
2
3
1

Or in side view......



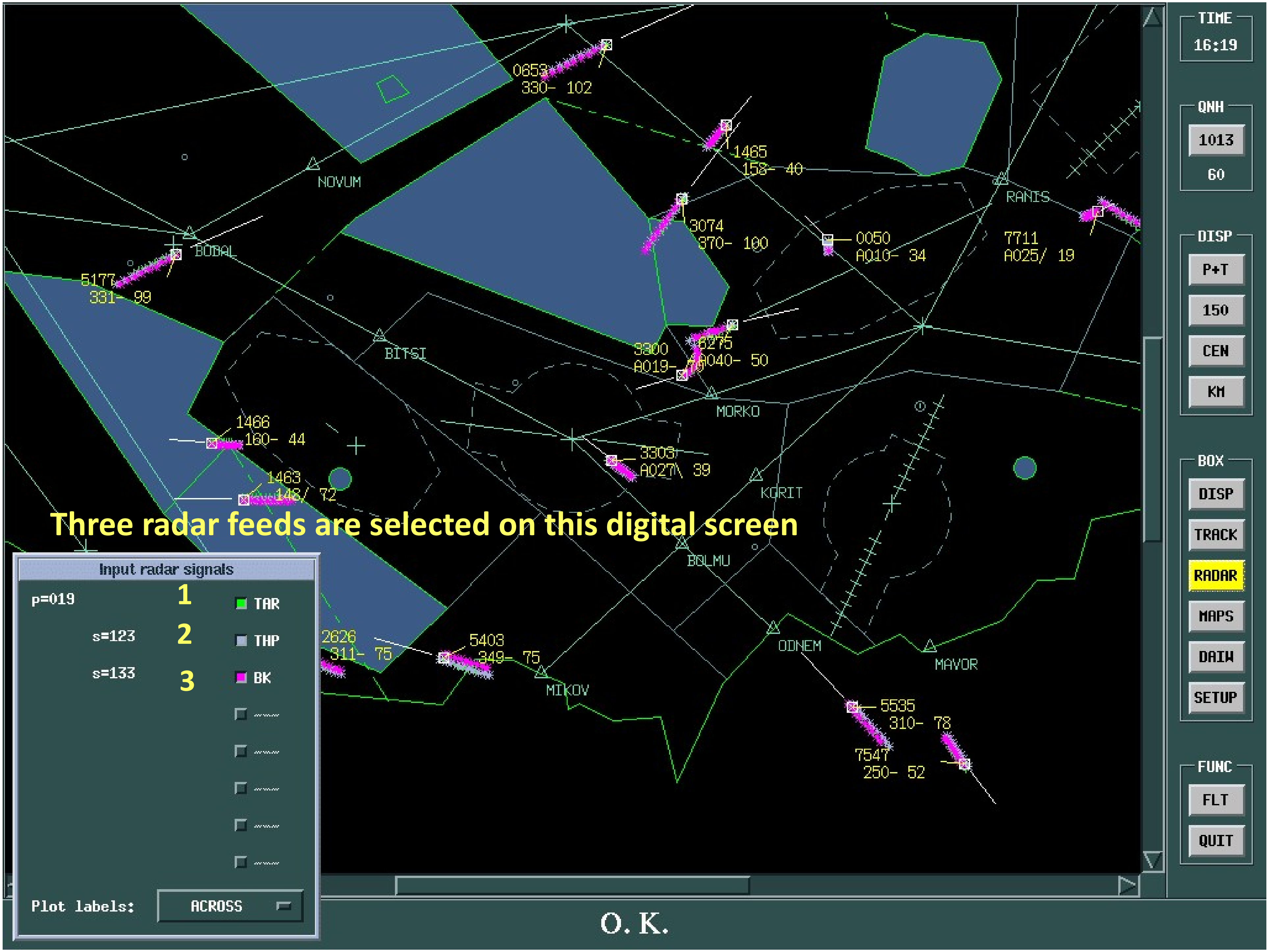
2 2 2 1 1 1 3 3 3 2 2 Preferred
1 1 1 2 2 3 1 2 2 3 3 Suppl'tary
Radar 1
Radar 2
Radar 3

Digital signal processing from Multi Radar sites



Digital signal processing from Multi Radar sites

- Decides validity of targets
- Calculates correct azimuth and range data.
- Decides if target is primary only, secondary only or combined
- Correlates code data in both identity and height modes.
- Checks for emergency, radio fail, SPI indications, etc.
- Produces one complete target report per aircraft per aerial revolution and outputs this in digital form.
- Produces synchronisation messages.
- Produces north mark messages.



Three radar feeds are selected on this digital screen
Input radar signals
p=019
s=123
s=133
1
2
3
TAR
THP
BK
Plot labels:
ACROSS
O. K.
TIME
16:19
QNH
1013
60
DISP
P+T
150
CEN
KM
BOX
DISP
TRACK
RADAR
MAPS
DAIW
SETUP
FUNC
FLT
QUIT
NOVUM
BODAL
BITSI
MORKO
KORIT
BOLMU
ODNEM
MAVOR
MIKOV
RANIS
0653
330- 102
1465
158- 40
3074
370- 100
0050
A010- 34
7711
A025/ 19
5177
331- 99
3300
A019-
6275
A040- 50
1466
160- 44
1463
148/ 72
3303
A027\ 39
2626
311- 75
5403
349- 75
5535
310- 78
7547
250- 52

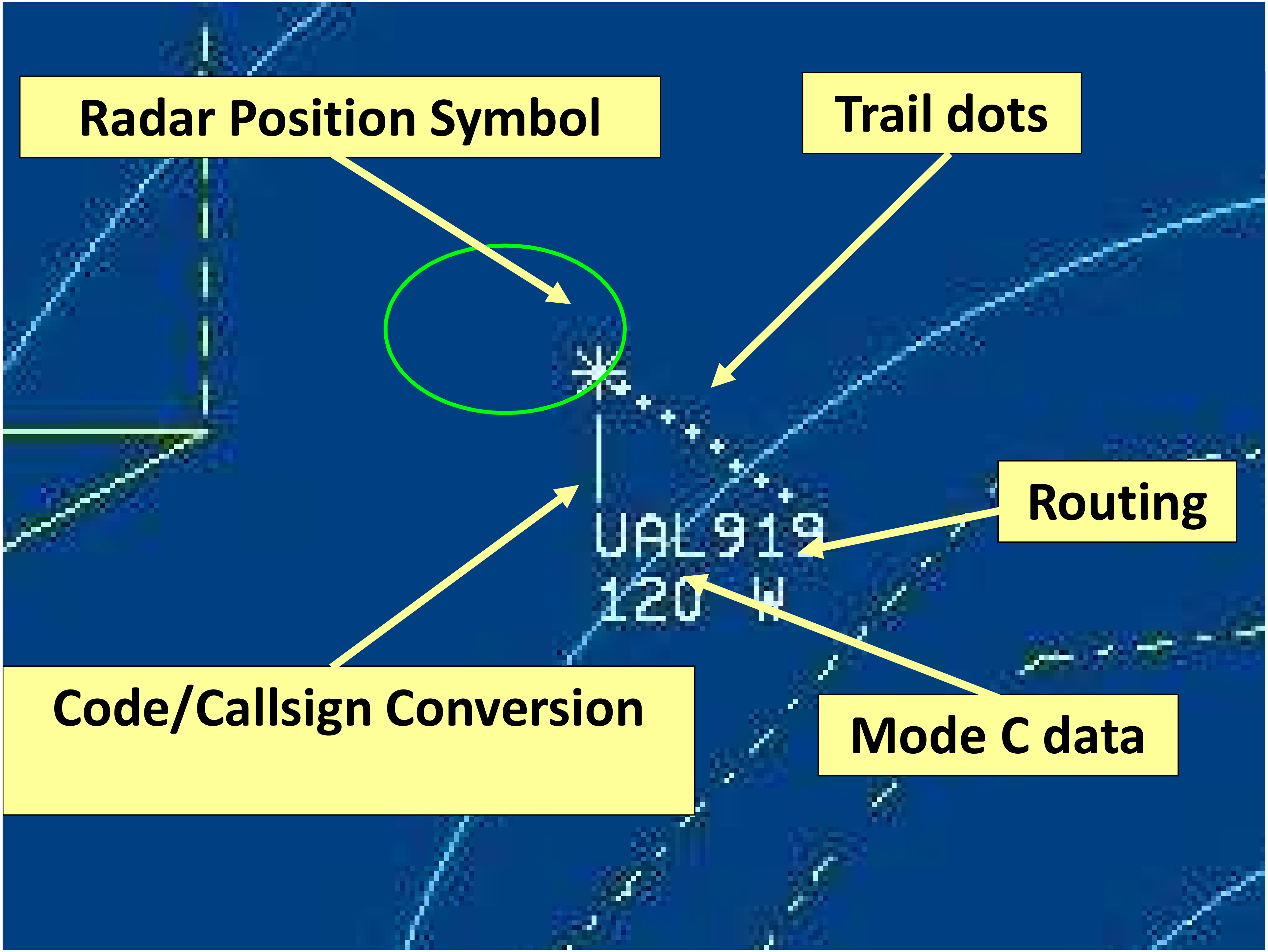
Signal Processing

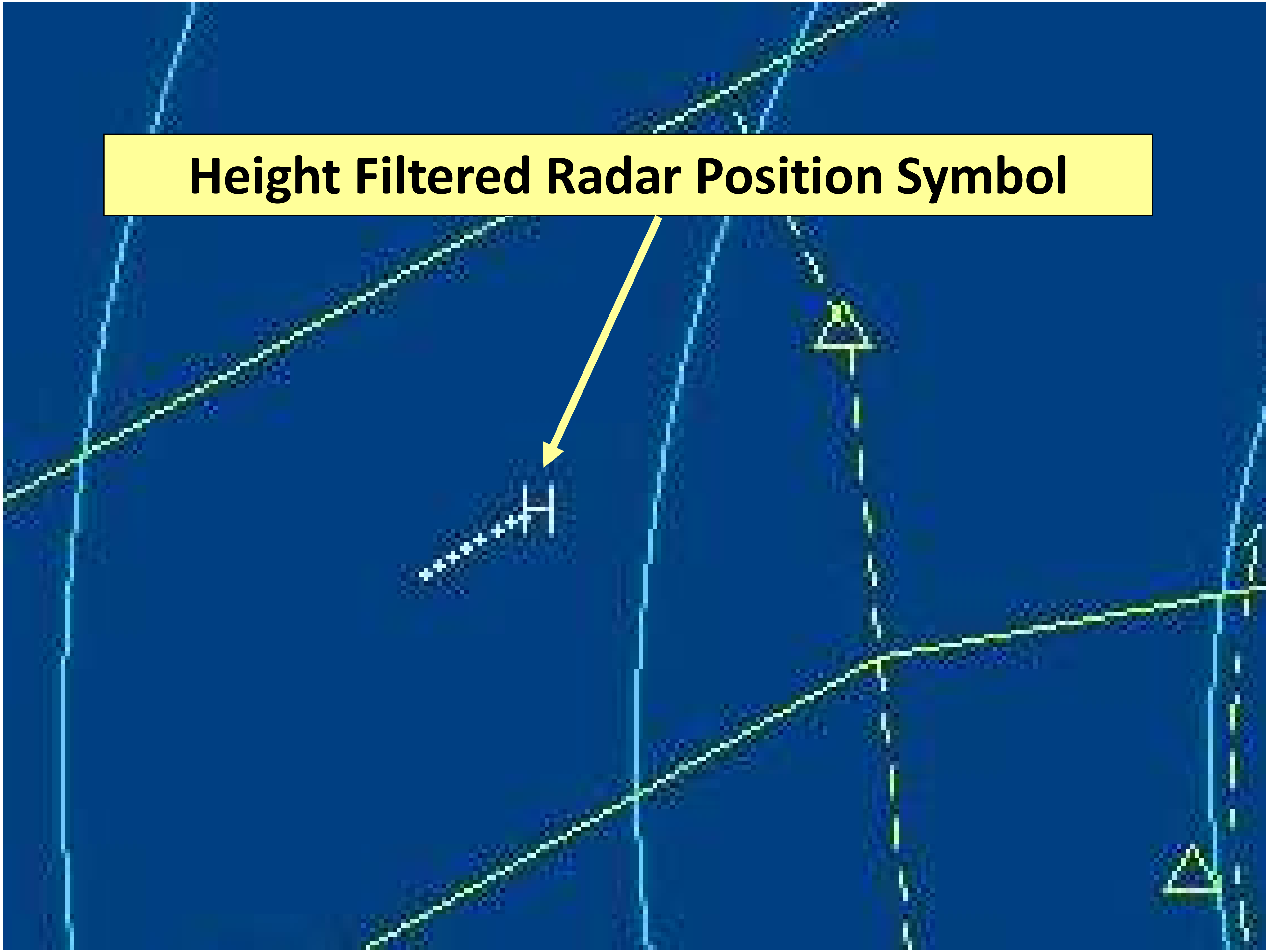
- Data from the flight plan database can be processed with the radar signal data enabling useful information to be presented on the radar display:

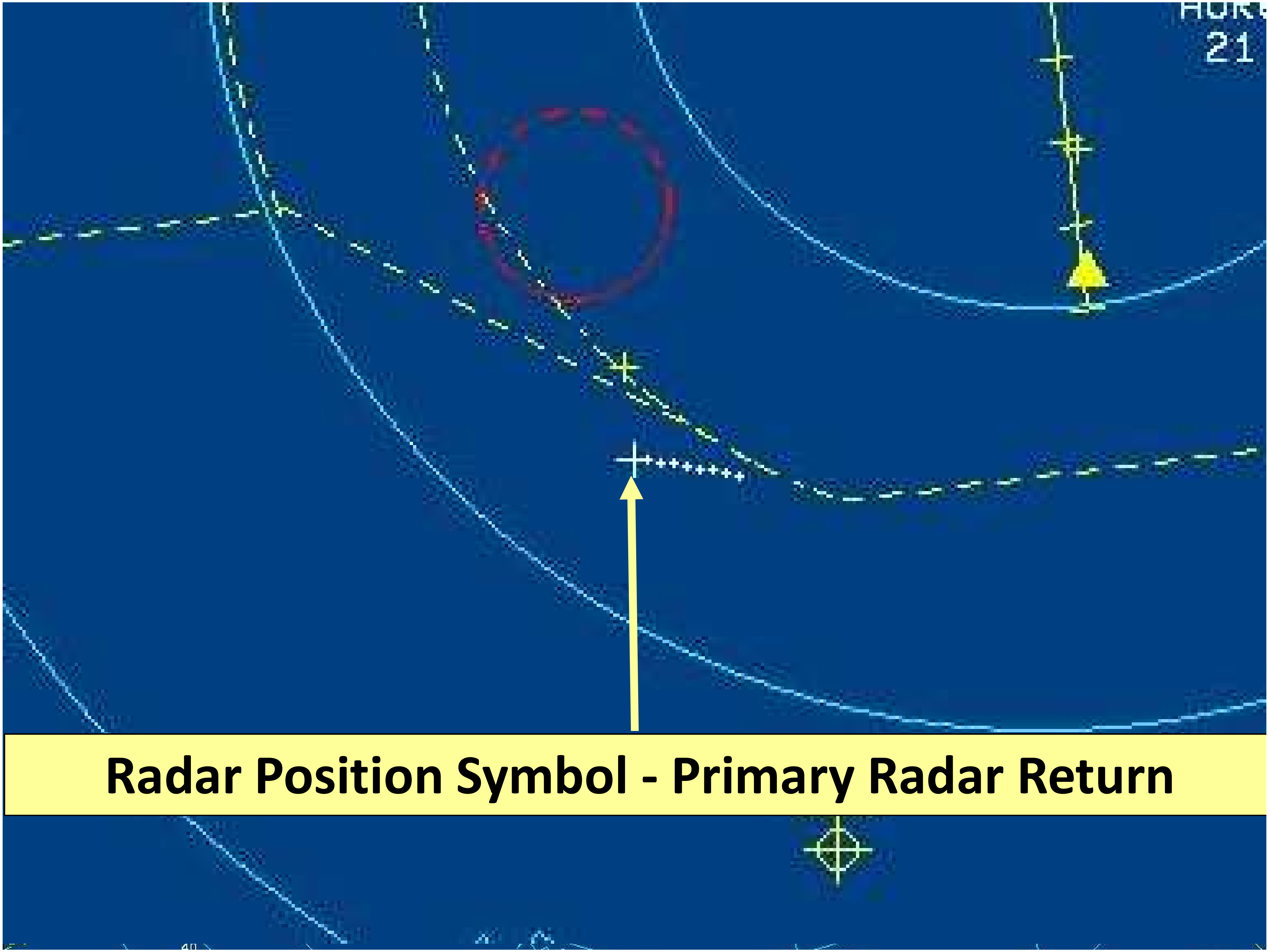
  - Conversion of Mode A squawk code to aircraft **callsign**.
  - Aircraft destination included in the radar response label.

- By examining the past movement of radar returns the signal processor can calculate and display the **ground speed** of an aircraft.

- Also, the progress of flights can be displayed as **trail dots**, and predictions of the future position of the aircraft can also be displayed.


Radar Position Symbol
Trail dots
Routing
UAL919
120 W
Mode C data
Code/Callsign Conversion


Height Filtered Radar Position Symbol


21
Radar Position Symbol - Primary Radar Return

Display of information: Video Map

Includes:

- Significant Points - Nav. Aids, Holding Points, Etc.
- Final Approach Tracks With Ranges
- Airspace Restrictions
- Controlled Airspace Boundaries
- Coastlines & Rivers
- Fir & National Boundaries
- Latitude & Longitude
- DF Bearing Lines
- Electronic Range & Bearing Marker (ERBM).
- Electronic Cursor
- Symbols
- Alphanumerics

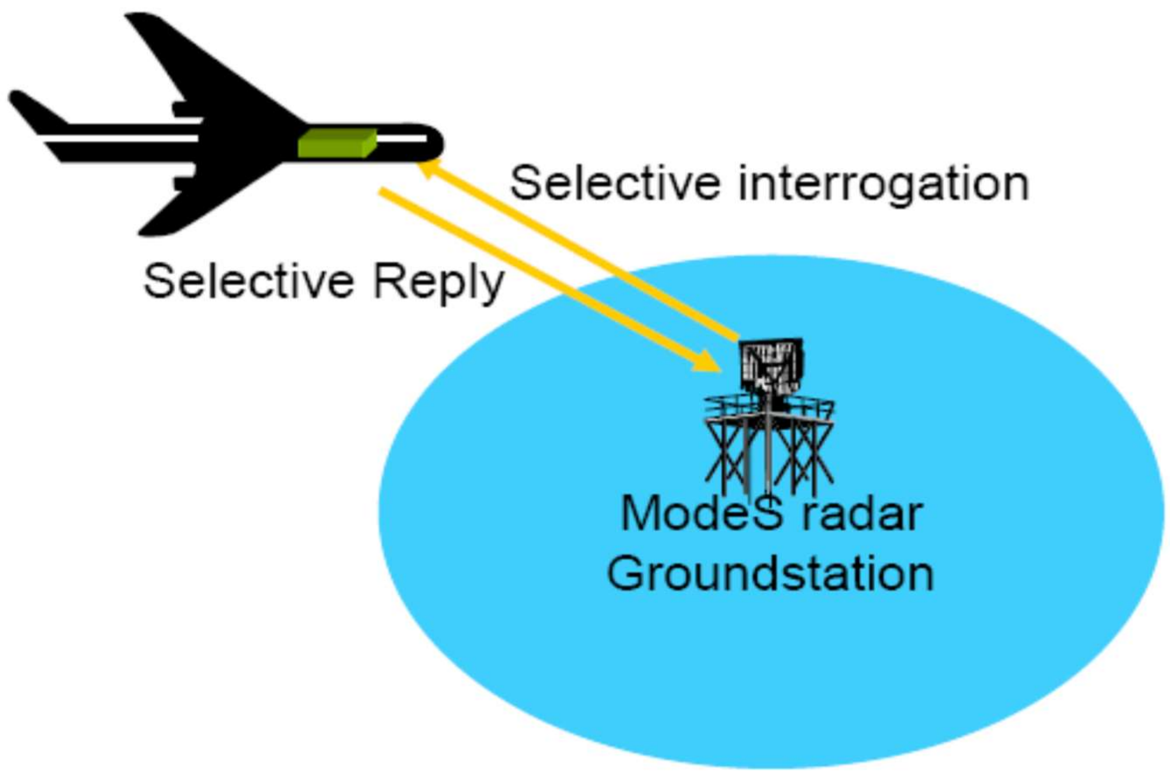
SSR

MODE S
SELECTIVE INTERROGATION

J. Mateu - J. Berenguer

Overview: What is available

Mode S Secondary Surveillance Radar



Principals of Mode S

Mode S

The limitations of the present SSR system produces a requirement for an individual interrogation system; i.e. individual aircraft are interrogated when required, this will overcome the problems of **fruiting and garbling**.

This requires a system of discrete codes for each aircraft which, at present, is not available with **4096 codes**.

What is Mode S?

Definition

Mode S (Select), which has been standardised by ICAO for many years, is a co-operative surveillance technique for air traffic control.

It employs ground based sensors and airborne transponders. Mode S operates in the same Radio Frequency (1030-1090 MHz) band as conventional SSR systems.

How does Mode S Work?

- **Each Mode S equipped aircraft is assigned a unique address code**. Using this discrete addressing system, Mode S compatible with ground radar installations are able to selectively interrogate a specific aircraft via its ICAO address code *(24 bits, provides 16.777.216 addresses)*, even in high-density situations.
- This significantly improves the ability of ATC to monitor and direct the aircraft, as well as the others around it.
- Sizeable unallocated blocks of codes have been reserved for different ICAO regions and over 3 million codes are as yet unallocated to any State or region.

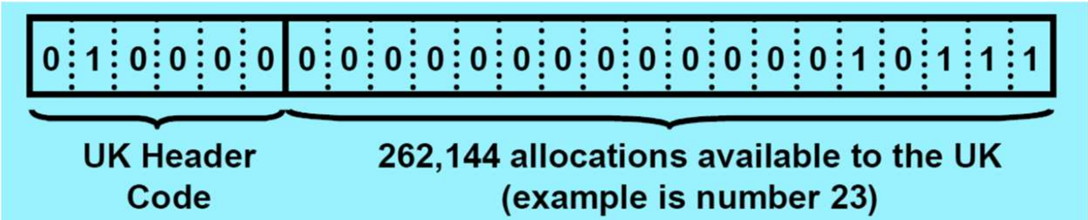


Figure 1. ICAO Aircraft Address

- Figure 1 illustrates an example of a code that would have been allocated by the UK. If the first 6 bits of the address are 010000 then this signifies that the aircraft is registered in the UK.
- The remaining 18 bits comprise 262,144 codes that can be allocated by the UK in whatever manner they choose.
- The length of the header block, and hence codes, varies by State. For example, Austria has a 9-bit header block which means that it has just 32,768 codes available to allocate.

Benefits of Selective Interrogation

- Using this unique ICAO code, interrogations can be directed to a particular aircraft, and individual replies **unambiguously** identified.
- All exchanges are protected against transmission errors using powerful error detection techniques.
- Mode S **reduces interference in identity and level reporting**, an important consideration in today's increasingly crowded ATC environment.
- The use of selective addressing of aircraft offers technical advantages over conventional secondary surveillance radar, such as reducing **FRUIT and garble,** hence providing higher integrity radar tracks.
- Mode S also offers a **data link facility**, which will be used to enhance safety, improved aircraft **surveillance and reporting accuracy,** by providing **Downlink Aircraft Parameters (DAPS)** such as aircraft speed, magnetic heading and level to Air Traffic Controllers and their systems, and:
  - Level coded in 25 ft increments.
  - Indication whether aircraft is airborne or on the ground.
  - Aircraft Identification **(call sign** or **registration mark)** used for Elementary Surveillance, in order to have a direct correlation with the ground flight plan.

SSR Mode S Attributes

a) The selective address capability **eliminates garbling situations** which may occur in high traffic density areas and will enhance the general reliability of SSR information.

b) The **coding of altitude data in 25-foot increments** improves the ability of ground systems to monitor and predict the movement of aircraft in the vertical plane.

c) The data link capability, associated with transponder Level 2 and above, **permits the ground system to acquire automatically aircraft call signs**, thus overcoming the problems connected with SSR code allocation and assignment, code/call sign correlation, radar identification and transfer procedures.

d) The data link capability also permits the ground system **to acquire automatically certain airborne data** which improve the ground tracking of aircraft, thus ensuring that the required level of safety is maintained when improved radar separation minima can be used.

e) Electronic scanning techniques **may permit the renewal rate of information** on each aircraft to be **selectively adapted** according to ATC needs.

SSR Ground Stations Requirements

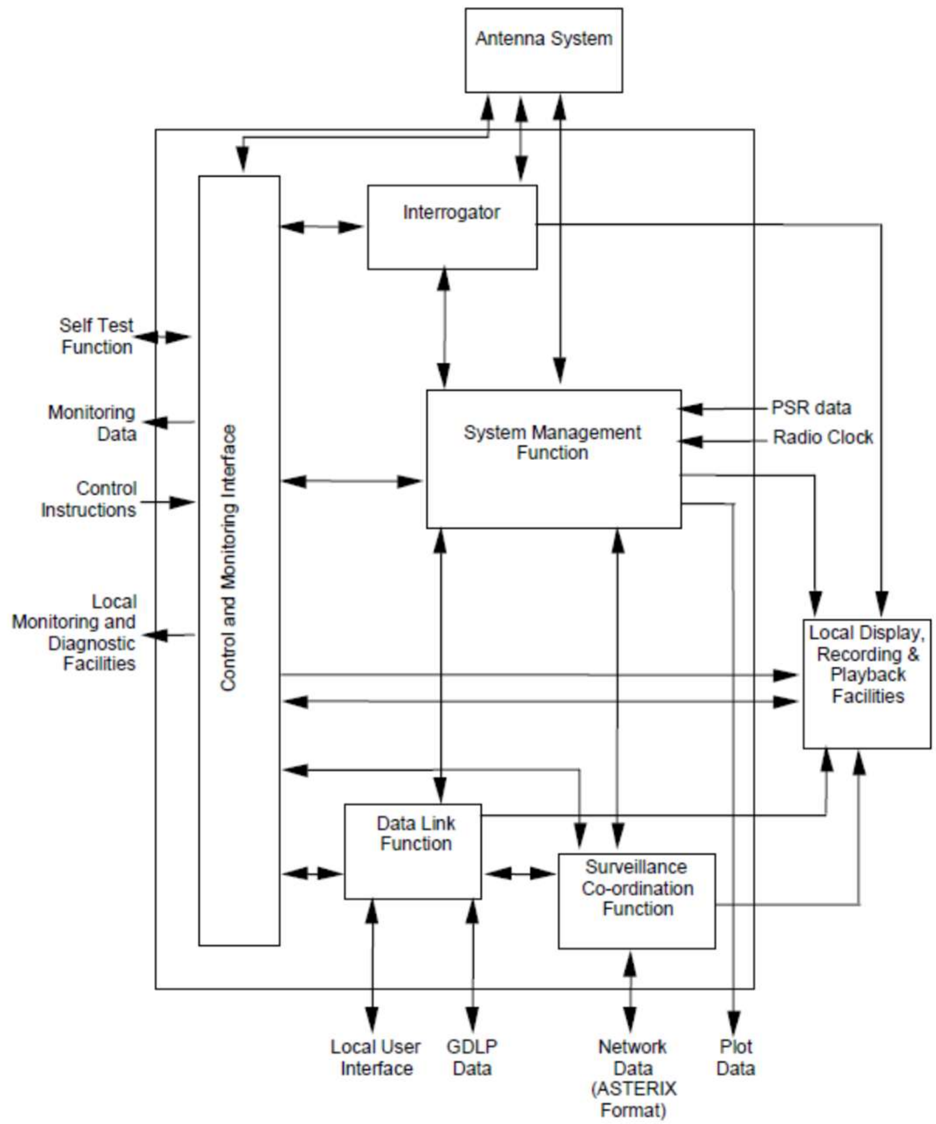
- Interrogation, detection and acquisition of **Mode S, 3/A and C** to comply:
  - (i) Mode 3/A,C,S All-Call interrogation;
  - (ii) Mode A/C only All-Call;
  - (iii) Mode S only All-Call.
- **Addressed surveillance** and standard length communication transactions which include:
  - (i) Surveillance, altitude request;
  - (ii) Comm A altitude request;
  - (iii) Surveillance identity request;
  - (iv) Comm A identity request;
  - (v) Surveillance altitude reply;
  - (vi) Comm B altitude reply;
  - (vii) Surveillance identity reply;
  - (viii) Comm B identity reply;
  - (ix) Lockout protocols;
  - (x) Basic data protocols including:
    - Flight status;
    - Capability reporting.
  - (xi) Standard length communication protocols:
    - Comm A
    - Comm A broadcast
    - Ground initiated Comm B
    - Air initiated Comm B
    - Comm B broadcast
    - Enhanced Comm-B protocol for Level 5 transponders.

- **Extended length communication** transactions as defined in [Ref.1.], including:
  - (i) Comm C
  - (ii) Comm D
  - (iii) Multisite uplink ELM protocol
  - (iv) Non selective uplink ELM
  - (v) Multisite downlink ELM protocol
  - (vi) Non selective downlink ELM
  - (vii) Enhanced ELM protocol for Level 5 transponders
- **Aircraft Identification Protocol** including:
  - (i) Aircraft identification reporting
  - (ii) Aircraft capability reporting
  - (iii) Change of aircraft identification
- **Data link function** including:
  - (i) Frame processing;
  - (ii) Mode S specific services processing.

SSR Ground Stations Functional Overview

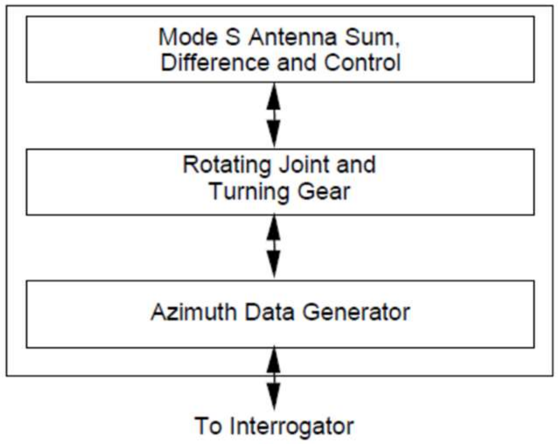
Radar Coverage

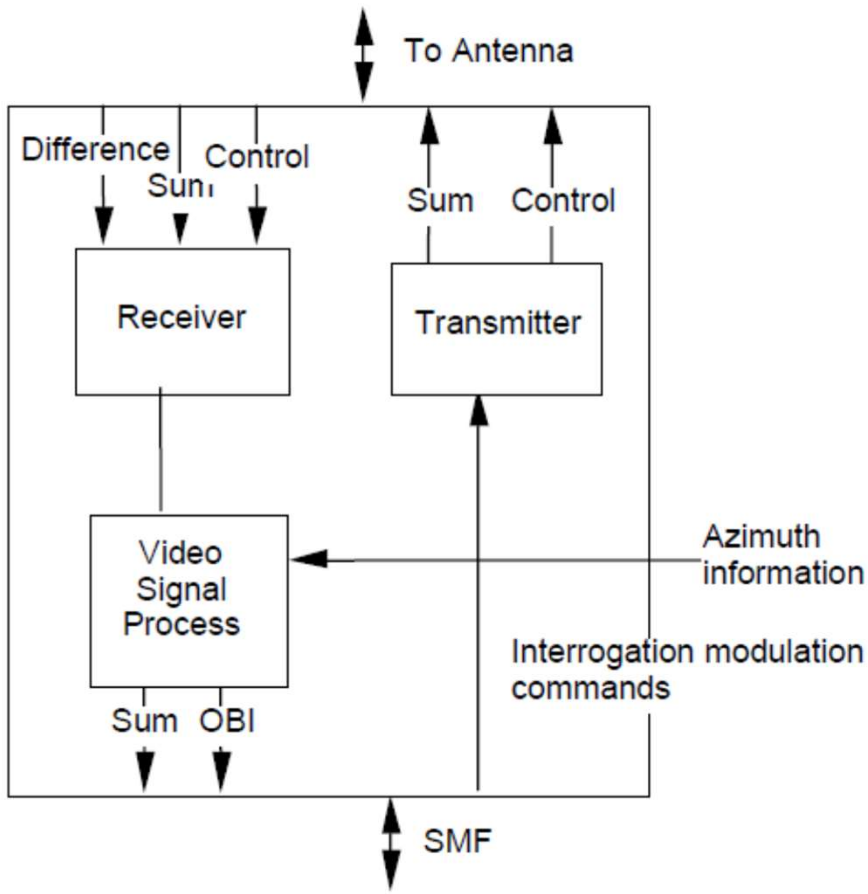
- The Mode S Radar shall provide continuous, gap-free cover through 360° of azimuth and over a range of 0.5 NM to at least 256 NM.
- The upper limit of cover shall be at least 66,000 ft.
- It is expected that, due to site conditions and earth curvature the lower limit of coverage shall not be horizontal all the way to 256 NM.



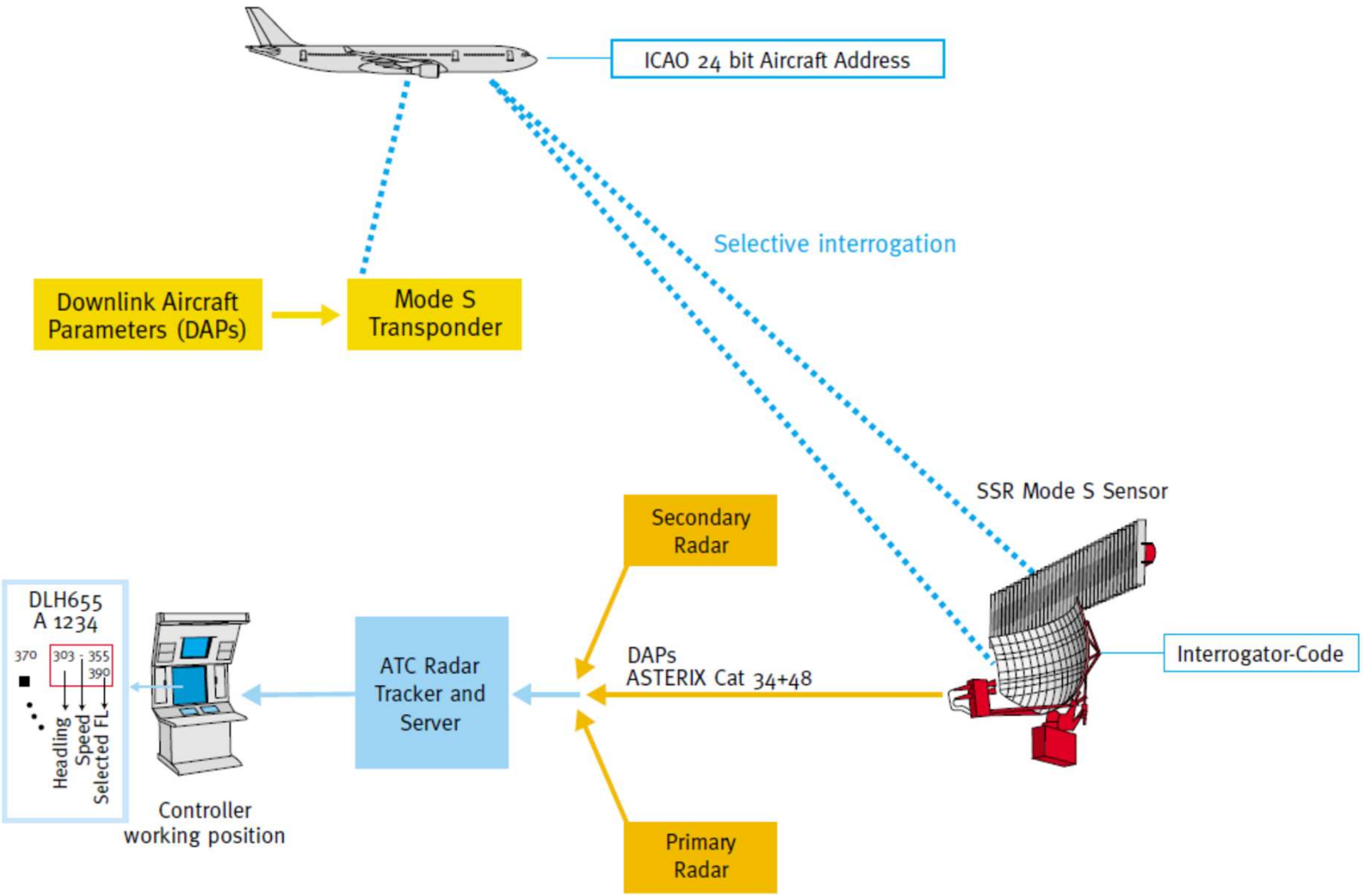
EUROCONTROL: European Mode S Station Functional Specification SUR.ET2.ST03.3114-SPC-01-00

SSR Ground Station Antenna



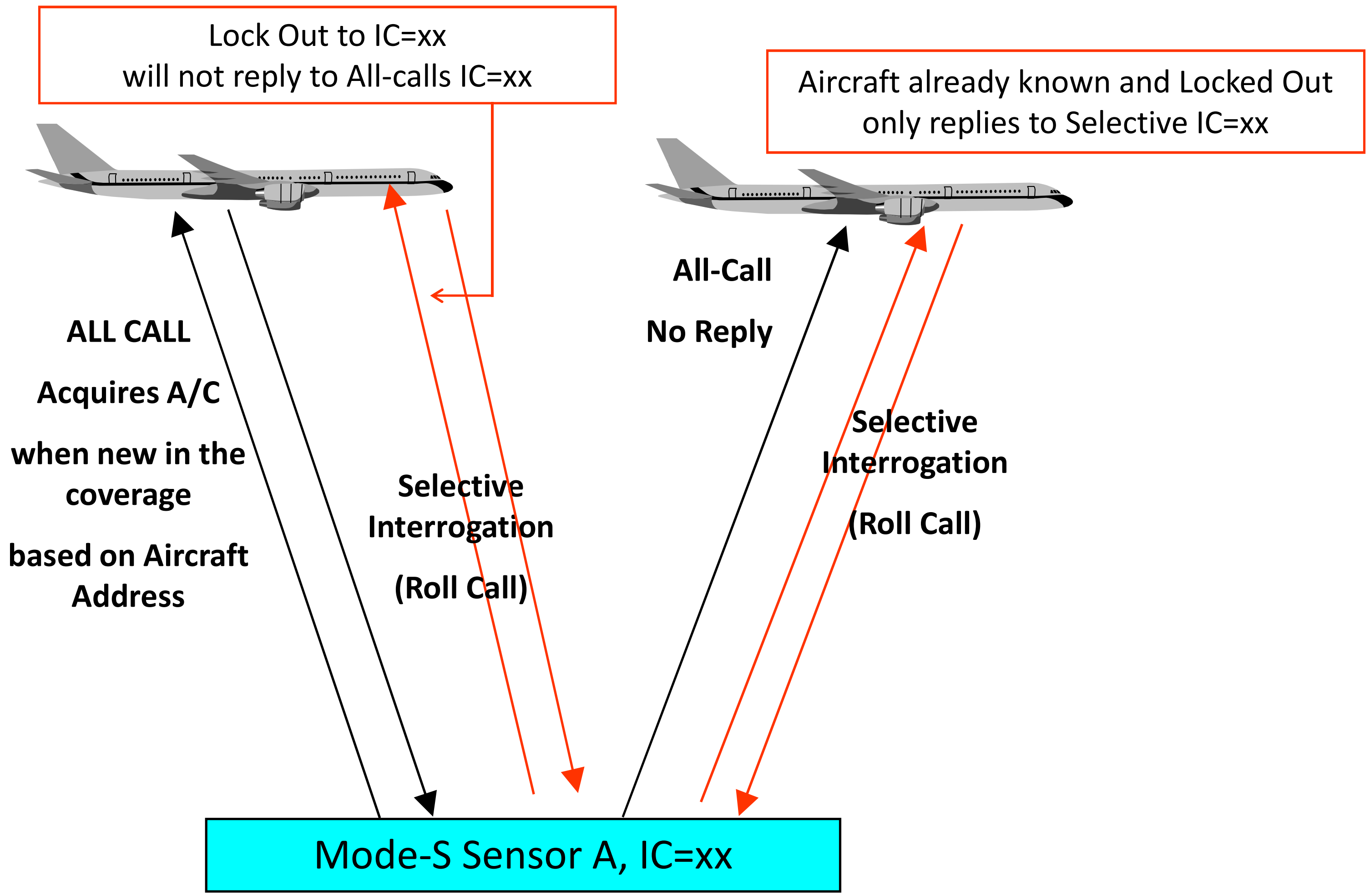


How does MODE-S work?



How does MODE-S work?

Mode-S Selective Interrogation Principle



SSR Mode S Interrogation types

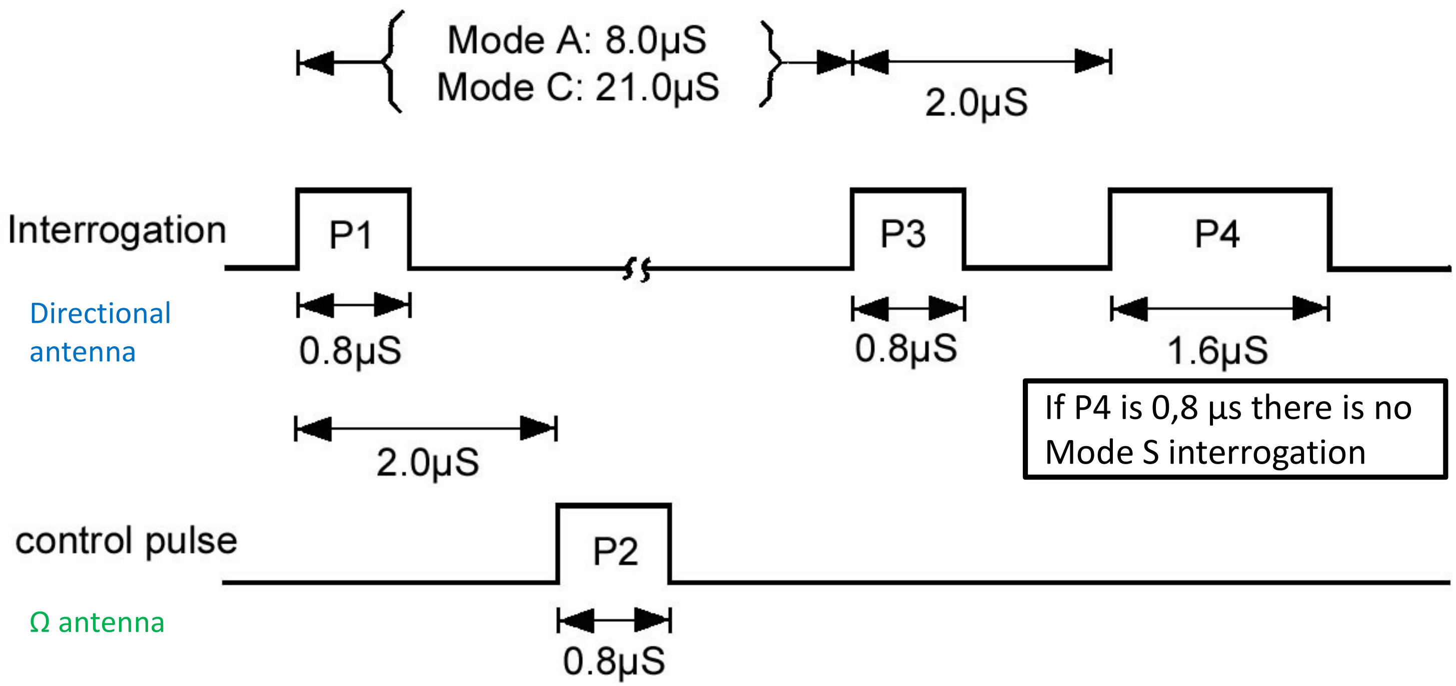
- **ATCRBS all call:**
  - This interrogation consists of P1, P3 and a **0.8 µs P4 pulse**.
  - P2 SLS is transmitted as normal.
  - All ATCRBS transponders reply with the 4096 identification code for mode A interrogations and altitude data for mode C.
  - **Mode S transponders do not reply** on this interrogation.

- **ATCRBS/mode S all call:**
  - This interrogation is identical to the former except **P4 is 1.6 µs long**.
  - **ATCRBS transponders reply with the 4096 code or altitude data** as per the ATCRBS all call.
  - **Mode S transponders reply with a special code**, which contains the identity and the aircraft's discrete address.

- **Mode S discrete interrogation:**
  - This interrogation is directed at a specific mode S transponder-equipped aircraft.
  - The interrogation consists of P1, P2 and P6. P2 is transmitted via the directional antenna and hence is the same amplitude as P1 and P3.
  - This effectively **suppresses ATCRBS transponders from replying**.
  - **P6 is actually a DPSK data block** that contains either a **56-bit or 112-bit** message.
  - The DPSK modulation produces a **spread-spectrum signal**, which has **immunity to interference**.

Interrogation types

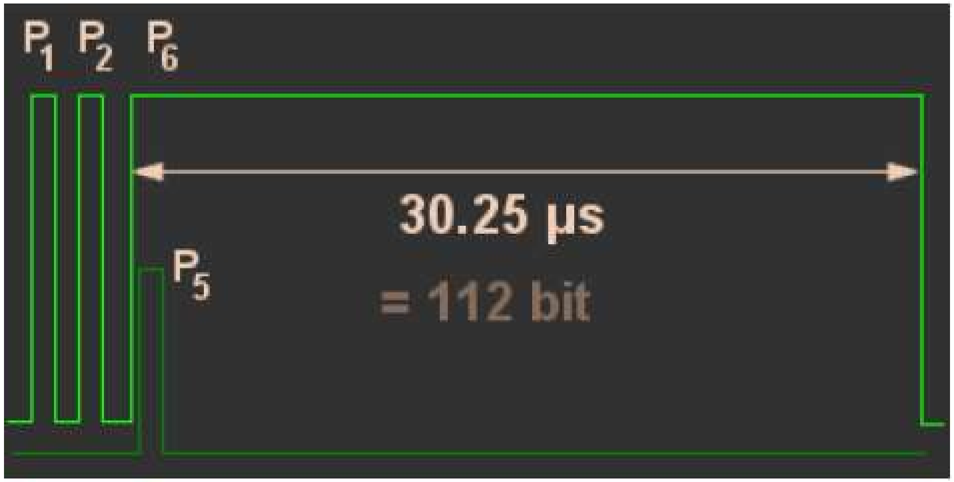
Up-link (Ground/aircraft)



Mode S interrogation, **ATCRBS all call**

How does MODE-S work?

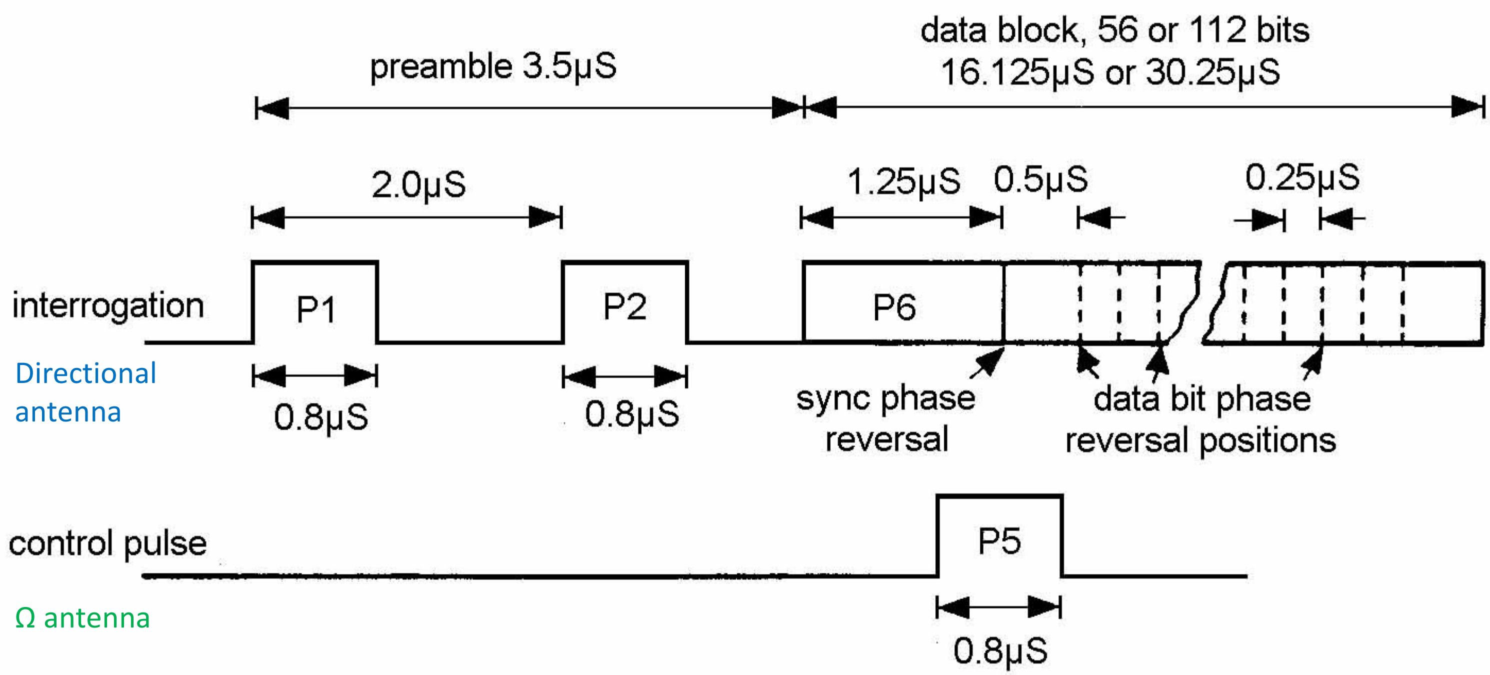
Up-link (Ground/aircraft)



- P1, P2 Check the compatibility
- P6 – Modulates the interrogation
- The interrogation happens about 50 Hz PRF.
- Frequency: 1030 MHz
- Modulation: Differential Phase-Shift Keying (DPSK)
- Data rate: 4 Mbps

Interrogation types

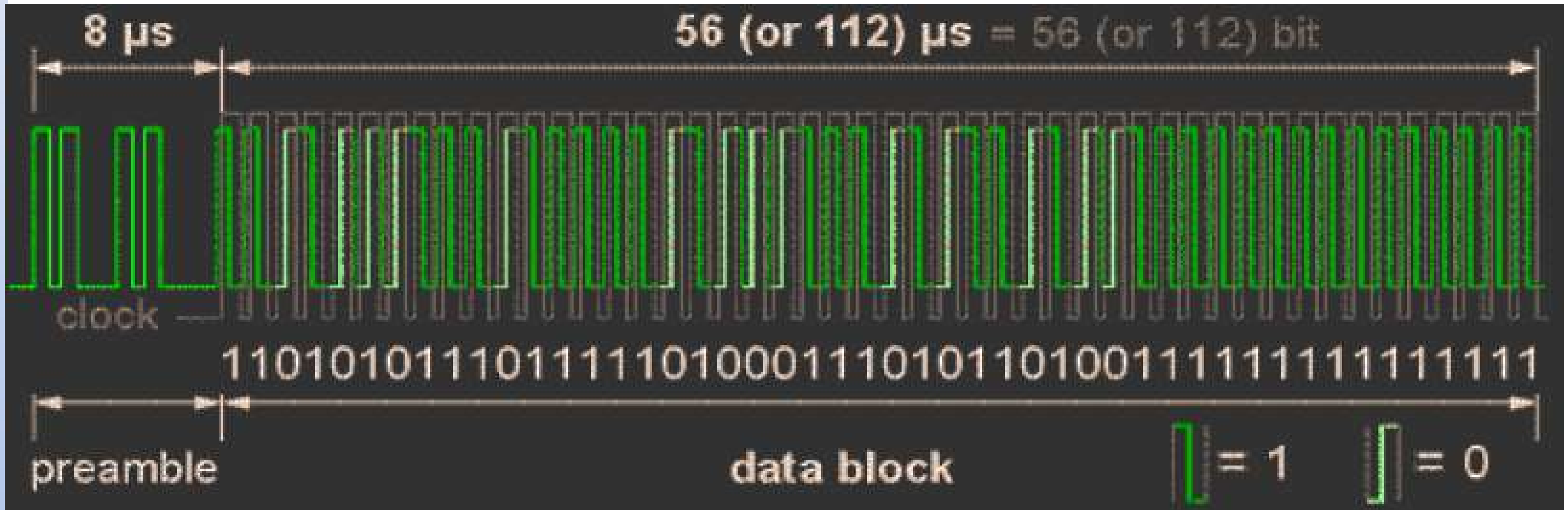
Up-link (Ground/aircraft)



Mode S interrogation, short and long.

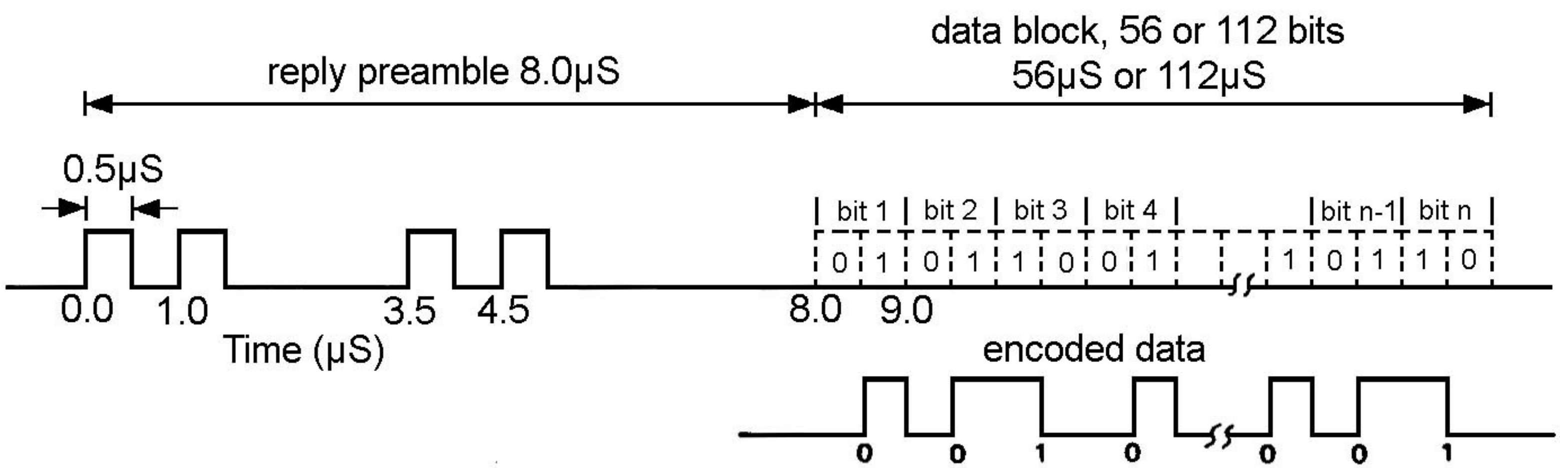
How does MODE-S work?

Down-link (aircraft/Ground)



- The reply is returned 128 µs after reception.
- The reply is transmitted on 1090 MHz and uses a 56-bit or 112-bit PPM transmission.
- Spacing between pulses 1 µs
- Synchronization + information
- Frequency: 1090 MHz
- Modulation: Pulse Position (PPM)
- Data Rate: 1 Mbps

Reply Format



- The reply is returned 128 µs after reception.
- The reply is transmitted on 1090 MHz and uses a 56-bit or 112-bit PPM transmission.
- Spacing between pulses 1 µs
- Synchronization + information
- Frequency: 1090 MHz
- Modulation: Pulse Position (PPM)
- Data Rate: 1 Mbps

How does MODE-S work?

Elementary Surveillance (ELS)	**Enhanced Surveillance (EHS)**
• Range • Azimuth • Height • AA code • Flight plan • Current state (errors, emergencies)	• **ELS** • Real time information: – Air Speed – Ground Speed – Magnetic Heading – Roll Angle – Selected Altitude – Track Angle Rate – True Track Angle – Vertical Rate

What are the Requirements?

- Aircraft Operators will be required to equip their aircraft with Mode S airborne equipment that supports Mode S Elementary Surveillance functionality.
- This includes Mode S transponders compliant with ICAO Standards and Recommended Practices (SARPS) and with the capability to downlink aircraft identification directly to the ground ATC system.
- Mode S Elementary Surveillance has already been introduced in European airspace. Initially for IFR (Instrumental Flight Rules) traffic, but eventually will cover VFR (Visual Flight Rules) traffic as well.

What will you See?

Radar Screen

For many years, controllers have been provided with identity (Mode A) and level (Mode C) information down linked via a transponder, supported by data processing and display functions.

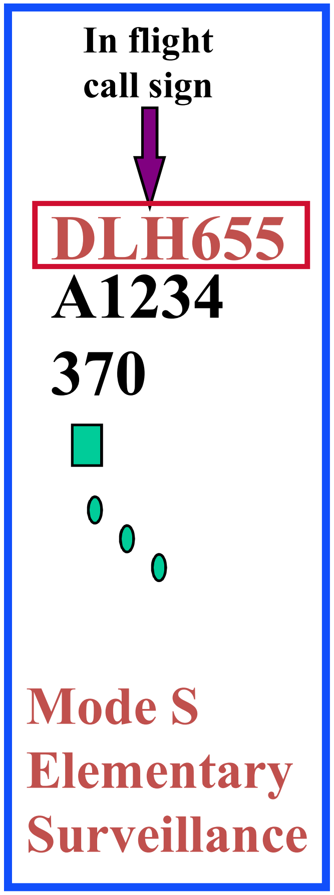
With the introduction of **Mode S Elementary Surveillance**, there will be an additional feature added to the track symbols on the radar screen. Besides being able to see Mode-A and C, **there is also the possibility to downlink the call sign used in flight**.

With this feature, **a controller can co-ordinate with an adjacent centre** without referring to Mode-A codes.

During daily operations, most of the time first identification of an aircraft will take place on takeoff. If the aircraft carries the necessary equipment, a non-unique code will be issued at start up.

What will you See?

The Downlink Aircraft parameters will provide the controller with:



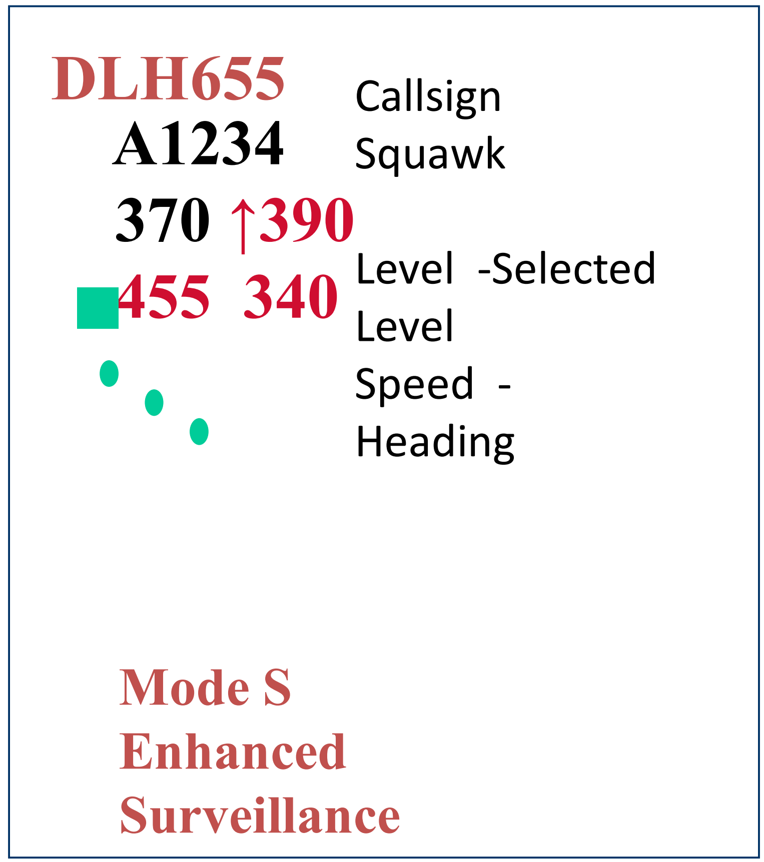
Elementary Surveillance: Position + Identification + Level

J. Mateu - J. Berenguer

What will you See?

The Downlink Aircraft parameters will provide the controller with:

Enhanced Surveillance:
Heading + Speed +
Selected Level



Aircraft Identification

- The aircraft identification is inserted by the pilot through the appropriate control panel, either FMS (Flight Management System) or ATC.
- With the Mode S data link, the aircraft identification (e.g. KLM511, AFR2177) as used in Item 7 of the ICAO flight plan is directly reported to the controller display.
- When no flight plan is filed, the aircraft registration (e.g. EIAKO) is reported.
- In case the pilot sets an erroneous aircraft identification, the air traffic controller will ask the pilot to re-enter it using the appropriate phraseology.

Mode S vs. SSR Performance

SSR Performance	Mode S Performance
• Probability of Detection 97% • Probability of Identification 98% • 400-450 Targets	• Probability of Detection 99% • Probability of Identification 100% • 900+ Targets • Full resolution of targets in close proximity

Perfomance SSR comparison

	Standard SSR	Monopulse SSR	Mode S
Replies per scan	20–30	4–8	1
Range accuracy	230 m rms	13 m rms	7 m rms
Bearing accuracy	0,08° rms	0,04° rms	0,04° rms
Height resolution	100 ft (30 m)	100 ft	25 ft (7,6 m)
Garble resistance	Poor	good	Best
Data capacity (uplink)	0	0	56–1.280 bits *
Data capacity (downlink)	23 bits = 12 bits/Mode A (4096) + 11 bits/Mode C (1278)	23 bits = 12 bits/Mode A (4096) + 11 bits/Mode C (1278)	56–1.280 bits *
Identity permutations	4.096	4.096	16 million

"SURVEILLANCE IN THE MODE S ERA"
M. C. Stevens.
IEE Colloquium on UK Air Traffic Control Systems in the 1990s

** Note.— Four categories of Mode S replies may be transmitted in response to Mode S interrogations:*
a) Mode S all-call replies (Downlink Format) (DF) = 11 bits);
b) surveillance and standard-length communications replies (DF = 4, 5, 20 and 21 bits);
c) extended length communications replies (DF = 24 bits); and
d) air-air surveillance replies (DF = 0 and 16 bits).

ICAO Annex 10 — Aeronautical Telecommunications. Volume IV — Surveillance and Collision Avoidance Systems

Summary of Mode S interrogations or uplink formats

Format No.	UF								
0	00000	3	RL:1	4	AQ:1	DS:8	10	AP:24	.... Short air-air surveillance (ACAS)
1	00001	27 or 83						AP:24	... Reserved
2	00010	27 or 83						AP:24	... Reserved
3	00011	27 or 83						AP:24	... Reserved
4	00100	PC:3	RR:5	DI:3	SD:16			AP:24	.... Surveillance, altitude request
5	00101	PC:3	RR:5	DI:3	SD:16			AP:24	.... Surveillance, identify request
6	00110	27 or 83						AP:24	... Reserved
7	00111	27 or 83						AP:24	... Reserved
8	01000	27 or 83						AP:24	... Reserved
9	01001	27 or 83						AP:24	... Reserved
10	01010	27 or 83						AP:24	... Reserved
11	01011	PR:4	IC:4	CL:3	16			AP:24	.... Mode S only all-call
12	01100	27 or 83						AP:24	... Reserved
13	01101	27 or 83						AP:24	... Reserved
14	01110	27 or 83						AP:24	... Reserved
15	01111	27 or 83						AP:24	... Reserved
16	10000	3	RL:1	4	AQ:1	18	MU:56	AP:24	.... Long air-air surveillance (ACAS)
17	10001	27 or 83						AP:24	... Reserved
18	10010	27 or 83						AP:24	... Reserved
19	10011	27 or 83						AP:24	... Reserved for military use
20	10100	PC:3	RR:5	DI:3	SD:16	MA:56		AP:24	.... Comm-A, altitude request
21	10101	PC:3	RR:5	DI:3	SD:16	MA:56		AP:24	.... Comm-A, identify request
22	10110	27 or 83						AP:24	... Reserved for military use
23	10111	27 or 83						AP:24	... Reserved
24	11	RC:2	NC:4	MC:80				AP:24	.... Comm-C (ELM)

NOTES:

1. XX:M denotes a field designated “XX” which is assigned M bits.
2. N denotes unassigned coding space with N available bits. These shall be coded as ZEROs for transmission.
3. For uplink formats (UF) 0 to 23 the format number corresponds to the binary code in the first five bits of the interrogation. Format number 24 is defined as the format beginning with “11” in the first two bit positions while the following three bits vary with the interrogation content.
4. All formats are shown for completeness, although a number of them are unused. Those formats for which no application is presently defined remain undefined in length. Depending on future assignment they may be short (56 bits) or long (112 bits) formats. Specific formats associated with Mode S capability levels are described in later paragraphs.
5. The PC, RR, DI and SD fields do not apply to a Comm-A broadcast interrogation.

Summary of Mode S reply or downlink formats

Format No.	DF										
0	00000	VS:1	CC:1	1	SL:3	2	RI:4	2	AC:13	AP:24	.... Short air-air surveillance (ACAS)
1	00001	27 or 83								P:24	... Reserved
2	00010	27 or 83								P:24	... Reserved
3	00011	27 or 83								P:24	... Reserved
4	00100	FS:3	DR:5	UM:6	AC:13					AP:24	.... Surveillance, altitude reply
5	00101	FS:3	DR:5	UM:6	ID:13					AP:24	.... Surveillance, identify reply
6	00110	27 or 83								P:24	... Reserved
7	00111	27 or 83								P:24	... Reserved
8	01000	27 or 83								P:24	... Reserved
9	01001	27 or 83								P:24	... Reserved
10	01010	27 or 83								P:24	... Reserved
11	01011	CA:3	AA:24							PI:24	.... All-call reply
12	01100	27 or 83								P:24	... Reserved
13	01101	27 or 83								P:24	... Reserved
14	01110	27 or 83								P:24	... Reserved
15	01111	27 or 83								P:24	... Reserved
16	10000	VS:1	2	SL:3	2	RI:4	2	AC:13	MV:56	AP:24	.... Long air-air surveillance (ACAS)
17	10001	CA:3	AA:24	ME:56						PI:24	... Extended squitter
18	10010	CF:3	AA:24	ME:56						PI:24	... Extended squitter/non transponder
19	10011	AF:3	104								... Military extended squitter
20	10100	FS:3	DR:5	UM:6	AC:13	MB:56				AP:24 / DP:24	.... Comm-B, altitude reply .... (see Note 5)
21	10101	FS:3	DR:5	UM:6	ID:13	MB:56				AP:24 / DP:24	.... Comm-B, identify reply .... (see Note 5)
22	10110	27 or 83								P:24	... Reserved for military use
23	10111	27 or 83								P:24	... Reserved
24	11	1	KE:1	ND:4	MD:80					AP:24	.... Comm-D (ELM)

NOTES:

1. XX:M denotes a field designated "XX" which is assigned M bits.
   P:24 denotes a 24-bit field reserved for parity information.
1. N denotes unassigned coding space with N available bits. These shall be coded as ZEROs for transmission.
2. For downlink formats (DF) 0 to 23 the format number corresponds to the binary code in the first five bits of the reply. Format number 24 is defined as the format beginning with "11" in the first two bit positions while the following three bits may vary with the reply content.
3. All formats are shown for completeness, although a number of them are unused. Those formats for which no application is presently defined remain undefined in length. Depending on future assignment they may be short (56 bits) or long (112 bits) formats.

WIDE AREA MULTILATERATION SYSTEMS

J. Mateu - J. Berenguer

What is Multilateration

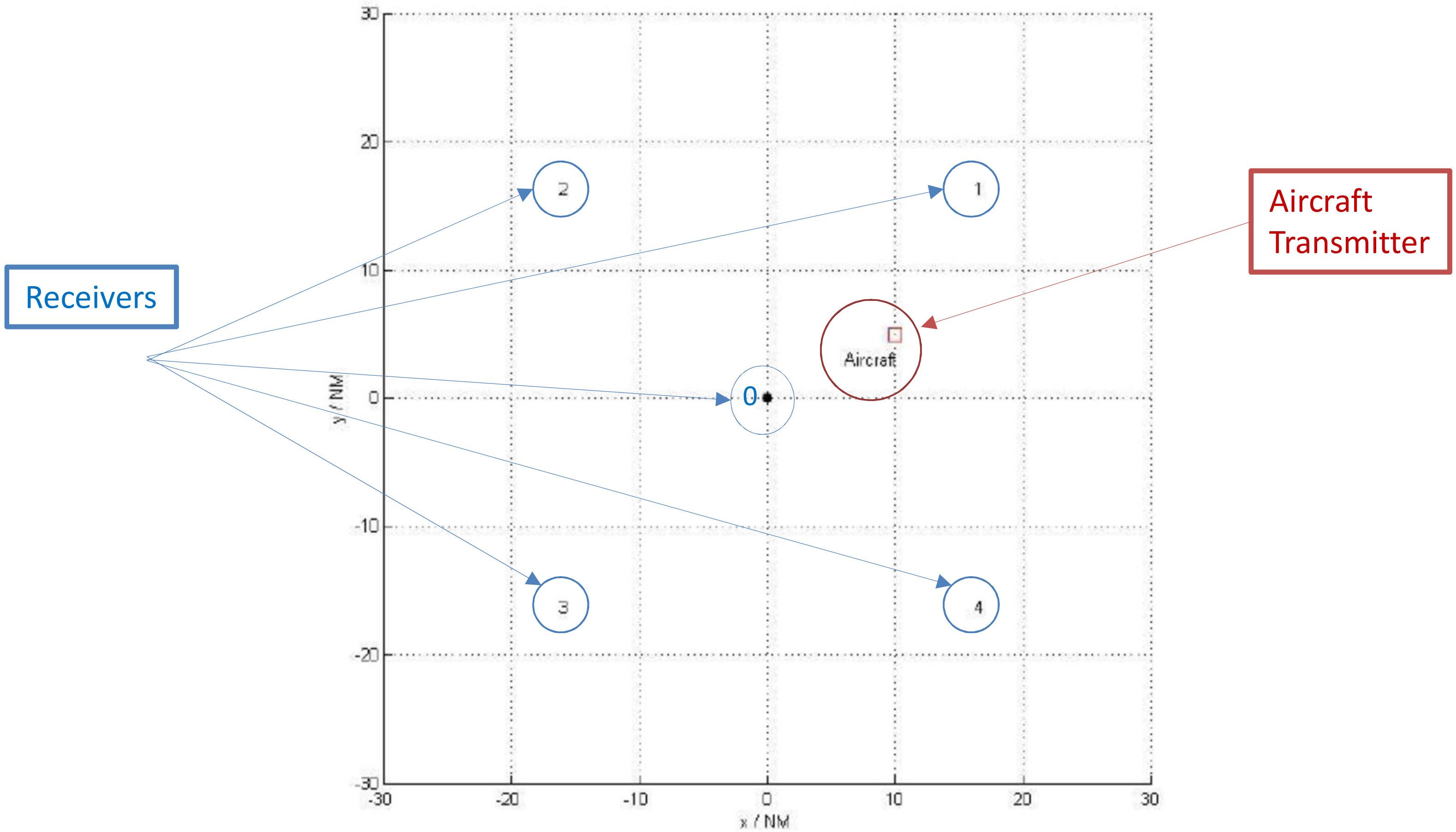
- A **multilateration** system consists of a **number of antennas receiving a signal from an aircraft** and a **central processing unit** calculating the aircraft's position from **the time difference of arrival (TDOA)** of the signal at the different antennas.

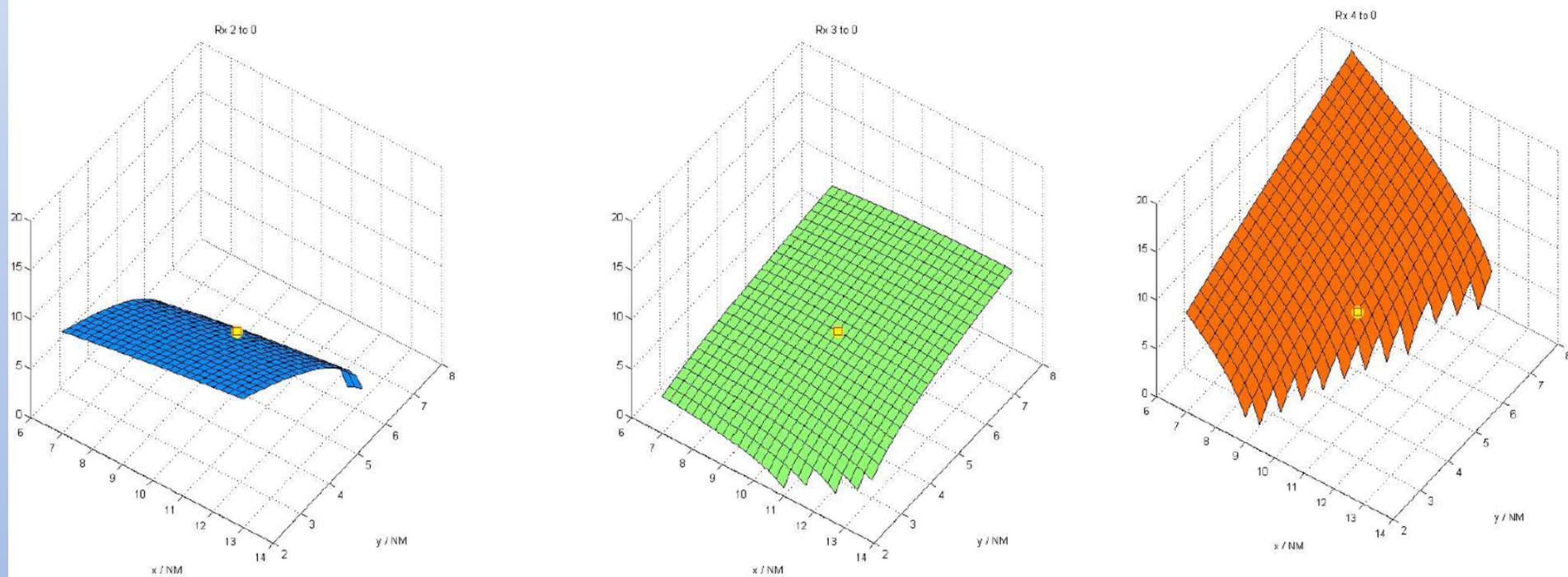
- The **TDOA between two antennas** corresponds, mathematically speaking, with a **hyperboloid** (in 3D) on which the aircraft is located.

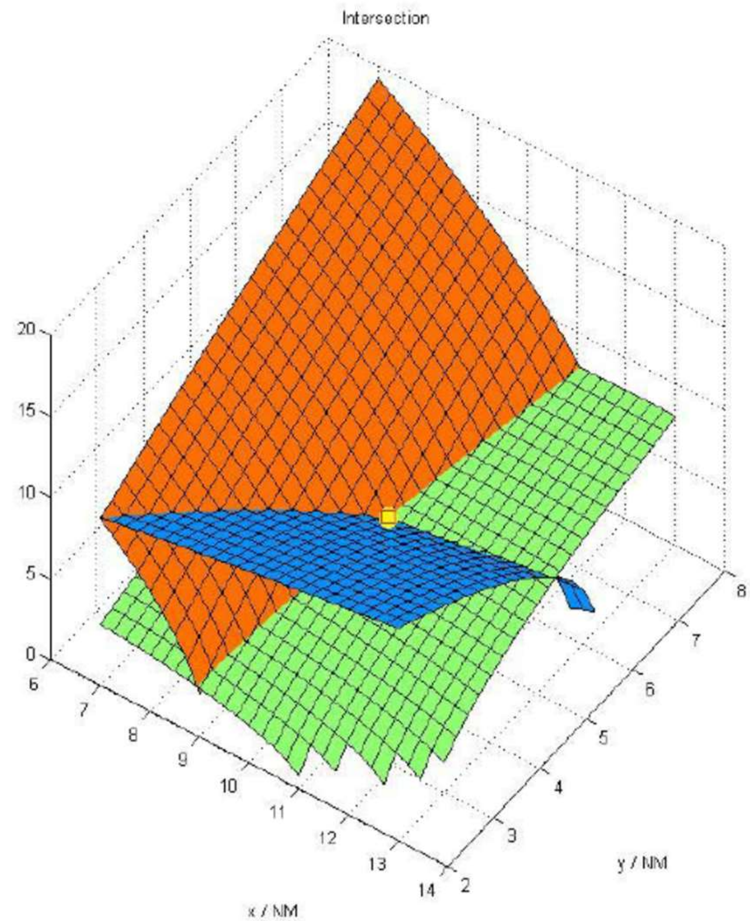
- When **four antennas** detect the aircraft's signal, it is possible to estimate the 3D-position of the aircraft by calculating the **intersection of the resulting hyperbolas**.

- **When only three antennas are available**, a 3D-position **cannot be estimated directly**, but if the **target altitude is known** from another source (e.g. from Mode C or in an SMGCS environment) **then the target position can be calculated**. This is usually referred to as a 2D solution. It should be noted that the use of barometric altitude (Mode C) can lead to a less accurate position estimate of the target, since barometric altitude can differ significantly from geometric height.

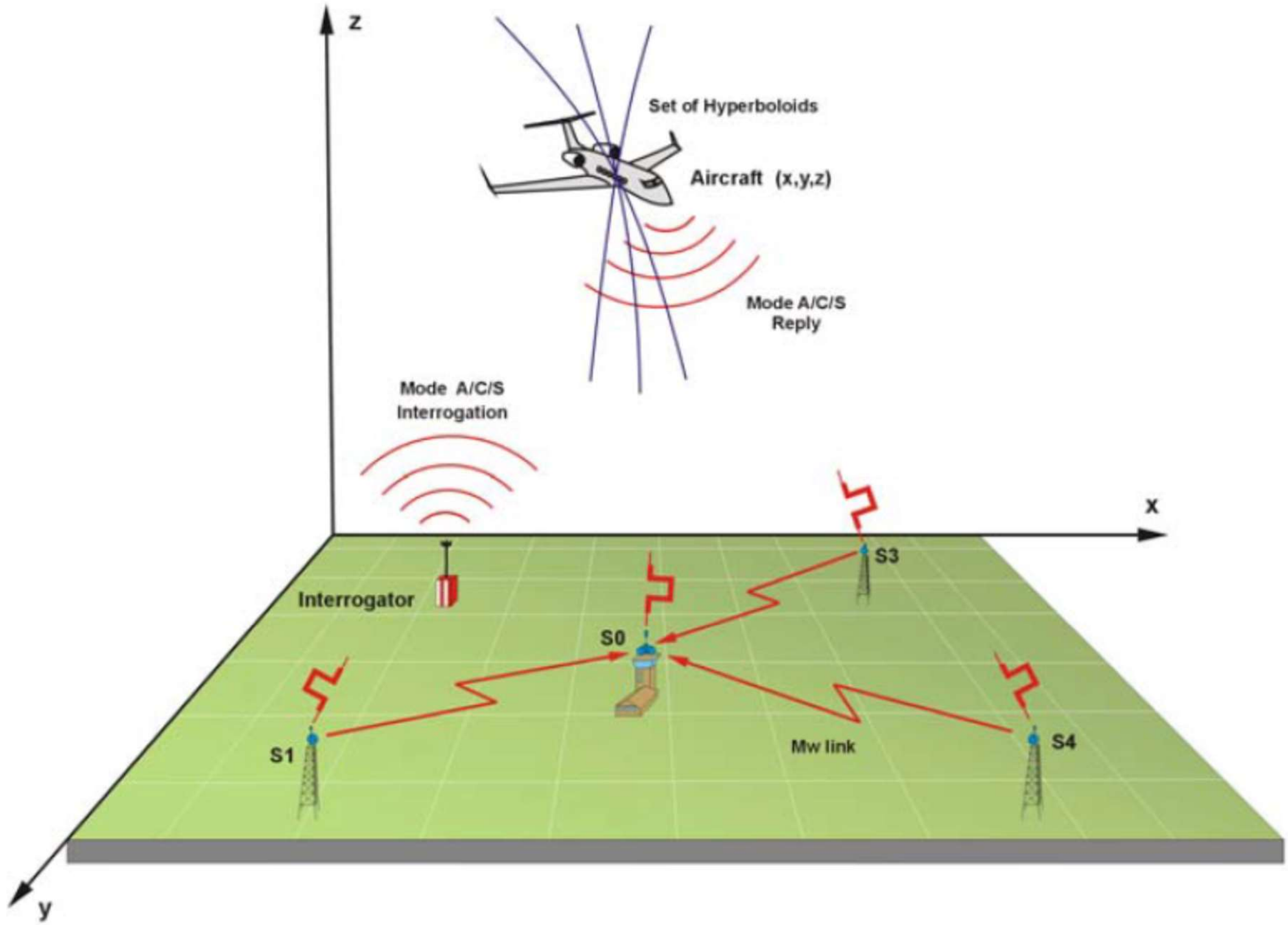
- **With more than four antennas**, the extra information can be used to either **verify the correctness of the other measurements** or to calculate an **average** position from all measurements which should have an overall **smaller error**.


Receivers
Aircraft
Transmitter
Aircraft
0
1
2
3
4
y / NM
x / NM
30
20
10
0
-10
-20
-30
-30
-20
-10
0
10
20
30


Rx 2 to 0
x / NM
y / NM
Rx 3 to 0
x / NM
y / NM
Rx 4 to 0
x / NM
y / NM


Intersection
20
15
10
5
0
6
7
8
9
10
11
12
13
14
x / NM
2
3
4
5
6
7
8
y / NM

Similar to a GPS receiver system


z
Set of Hyperboloids
Aircraft (x,y,z)
Mode A/C/S
Reply
Mode A/C/S
Interrogation
x
S3
Interrogator
S0
S1
Mw link
S4
y

Types of MLAT Systems

- **Passive:**
  - Consists only of receivers
  - It is dependent on other sources to trigger a transmission from an aircraft.
  - The update rate will depend on other surveillance sources.
  - No transmission frequency license is required for the installation and use of the system.
  - There is no increase in the number of interrogations or replies caused by the system.
  - Suitable for:
    - Busy areas with a high volume of ACAS (Aircraft Collision Avoidance System) equipped traffic
    - Areas with existing MSSR surveillance infrastructure
    - Areas where Mode S use is mandatory
- **Active:**
  - Has one or more transmitting antenna in order to interrogate.
  - It is not dependent on other sources to trigger a transmission from an aircraft.
  - Can provide a high update rate if required.
  - is much simpler than an MSSR interrogator.
    - A rotating antenna is not required.
    - An omni-directional or sectored antenna is used.
    - The power level of the interrogation can be limited to provide a shorter range than for equivalent MSSR surveillance.
  - A short range interrogator can be used to acquire low level aircraft on approach that fall below the coverage of existing MSSR systems, or in terminal area surveillance.
  - Directional antennas are another method of excluding certain areas.

MLAT Systems based in SSR Transponders

- An SSR receiver in an MLAT system might have a problem to distinguish between a Mode A and a Mode C reply.
- A **limitation** of the SSR antenna signal is the **line-of-sight visibility** that is **required** between the transponder and the ground receiver.
  - When the path is obscured by e.g. a building, the signal strength will degrade very strongly.
- The **maximum range** of an SSR signal is about **250 NM** (depending on the sensitivity of the receiver), but especially in regions with high density traffic interference problems may limit the useful range.

- **Mode S Squitter**:
  - An aircraft equipped with a Mode S transponder emits a signal, called **Acquisition Squitter**, approximately **once per second**.
  - The acquisition squitter consists of a **Mode S All-call reply** containing the **24-bit technical address** of the aircraft.
  - The high update rate makes them very useful for a passive MLAT system.

- **Mode S Extended Squitter**
  - Is agreed to be the first global Datalink for international commercial flight.
  - It makes use of the Mode S transponder to emit periodically, with a **frequency** up to about **6 Hz**, the **aircraft's 24-bit technical address** accompanied by either **aircraft state information or callsign**.
  - Just as with Acquisition Squitter, the high update rate is ideal for a passive MLAT system.

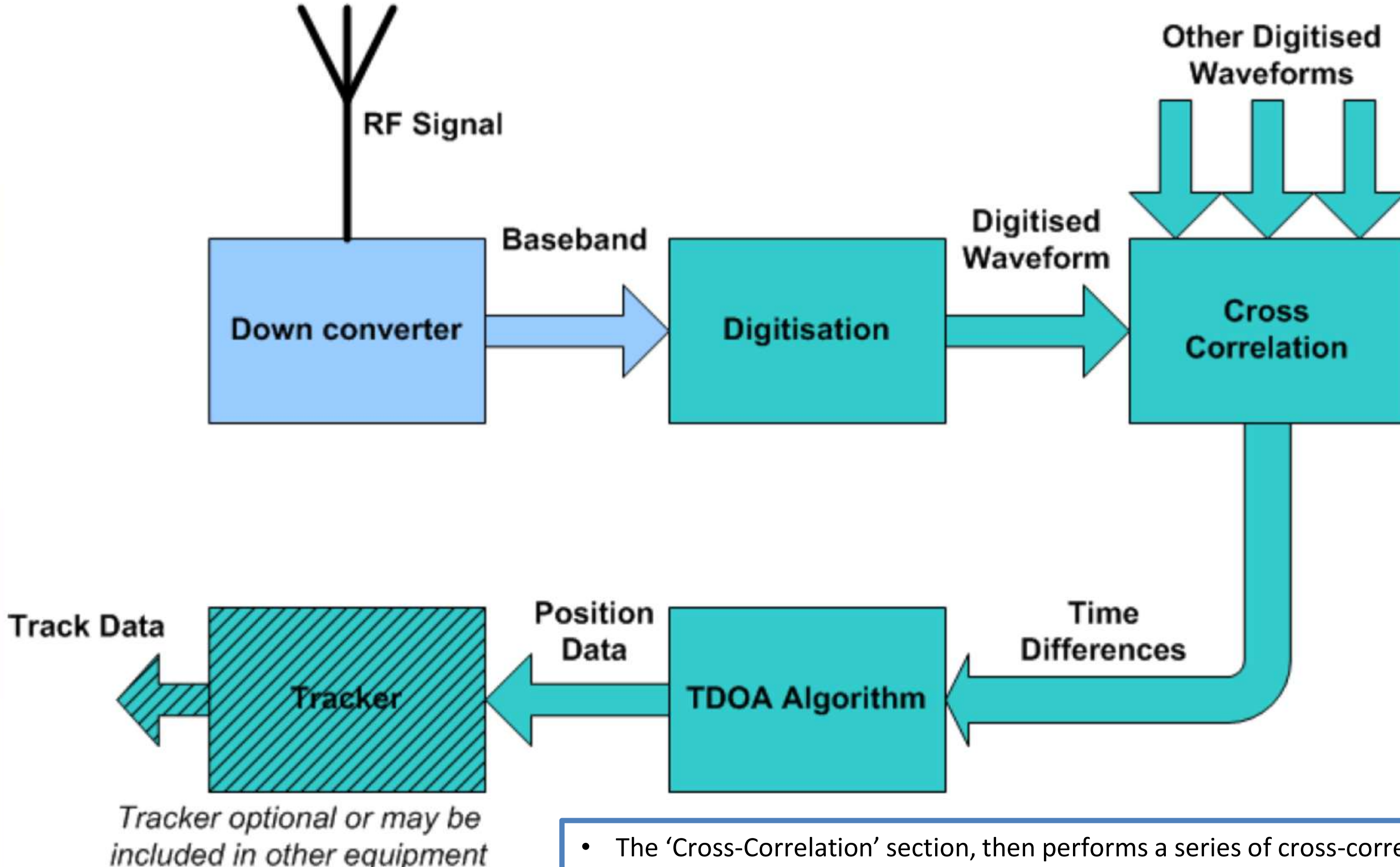
Measurement system

- It consists of a system able to:
  - Calculate the Time Difference of Arrival (TDOA): The difference in relative time that a transponder signal from the same aircraft (or ground vehicle) is received at different receivers.
  - Synchronize all the receivers.

- Systems of TDOA calculation:
  - Cross Correlation Data Flow
  - TOA *(Time of Arrival)* System

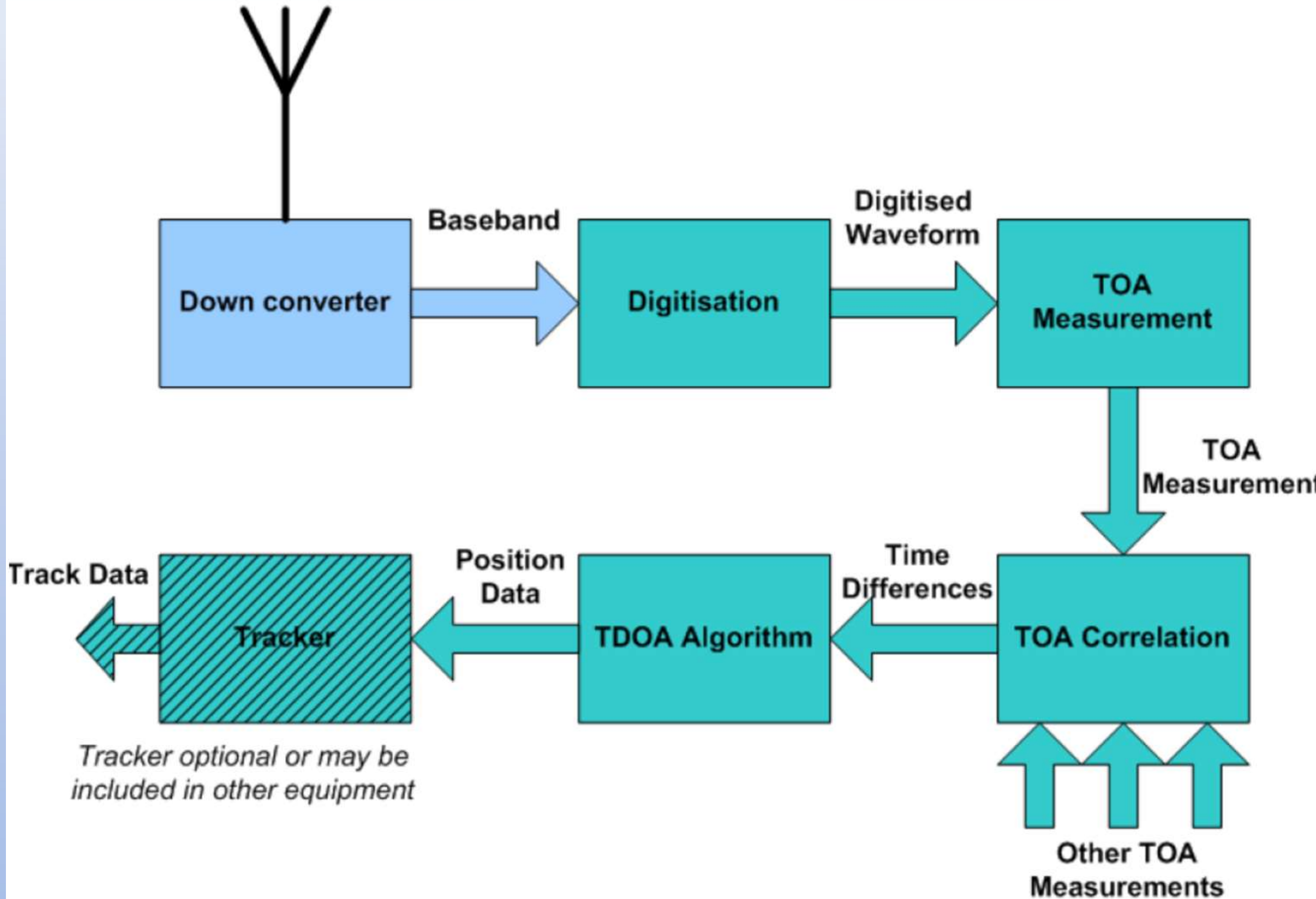
- Synchronization methods
  - Common clock systems
  - Distributed clock systems
    - Transponder Synchronized Systems
    - GNSS Synchronized Systems
      - Standalone GNSS Synchronization.
      - Common View GNSS Synchronization.

TDOA: Cross Correlation Data Flow



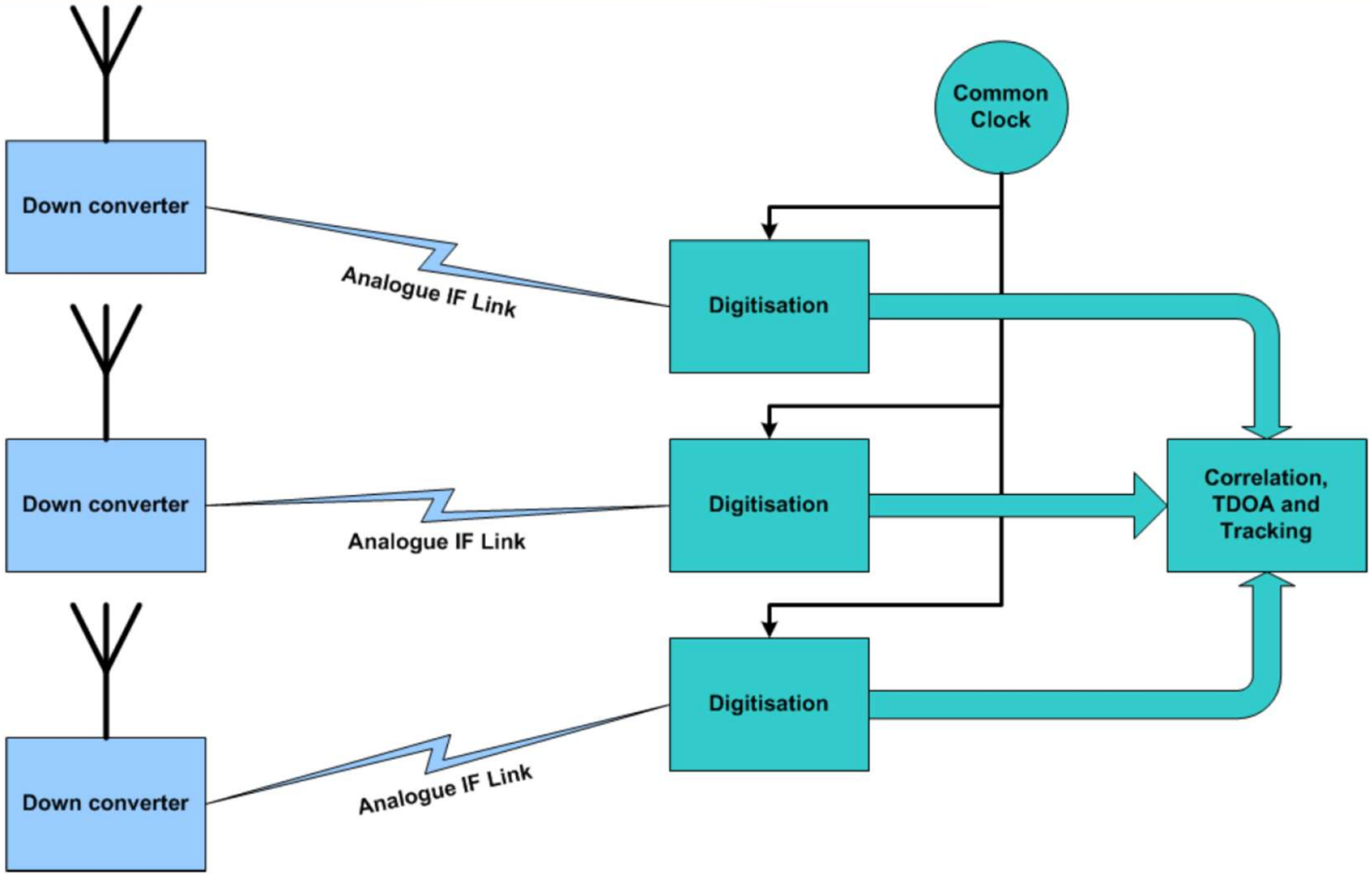
- The 'Cross-Correlation' section, then performs a series of cross-correlations of the digitized data for pairs of sites.
- Assuming that the same signal is present in the signal from both sites, this operation results in a TDOA value between the given pair of sites.
- The accuracy of this process is influenced by the type of signal digitized and multipath amongst other factors.

TDOA: TOA Data Flow



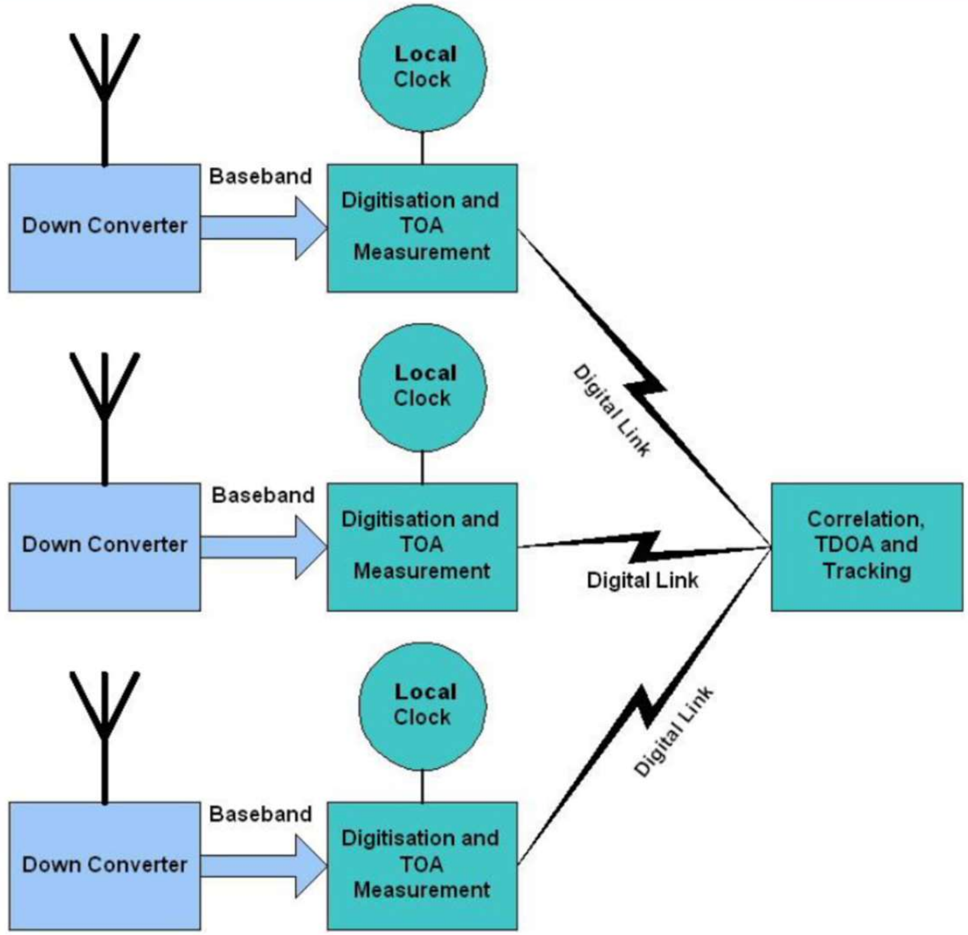
- A TOA system will now calculate the signals' time of arrival local to the receiver.
- Additionally, the SSR codes within the waveform are typically identified and extracted at this stage to aid correlation.
- Having calculated a series of TOAs for each receiver, these must now be correlated to associate a group of TOA values calculated for a given aircraft transmission.
- Having performed this correlation or grouping, the TDOA values may be calculated

SYNCHRO: COMMON CLOCK SYSTEM



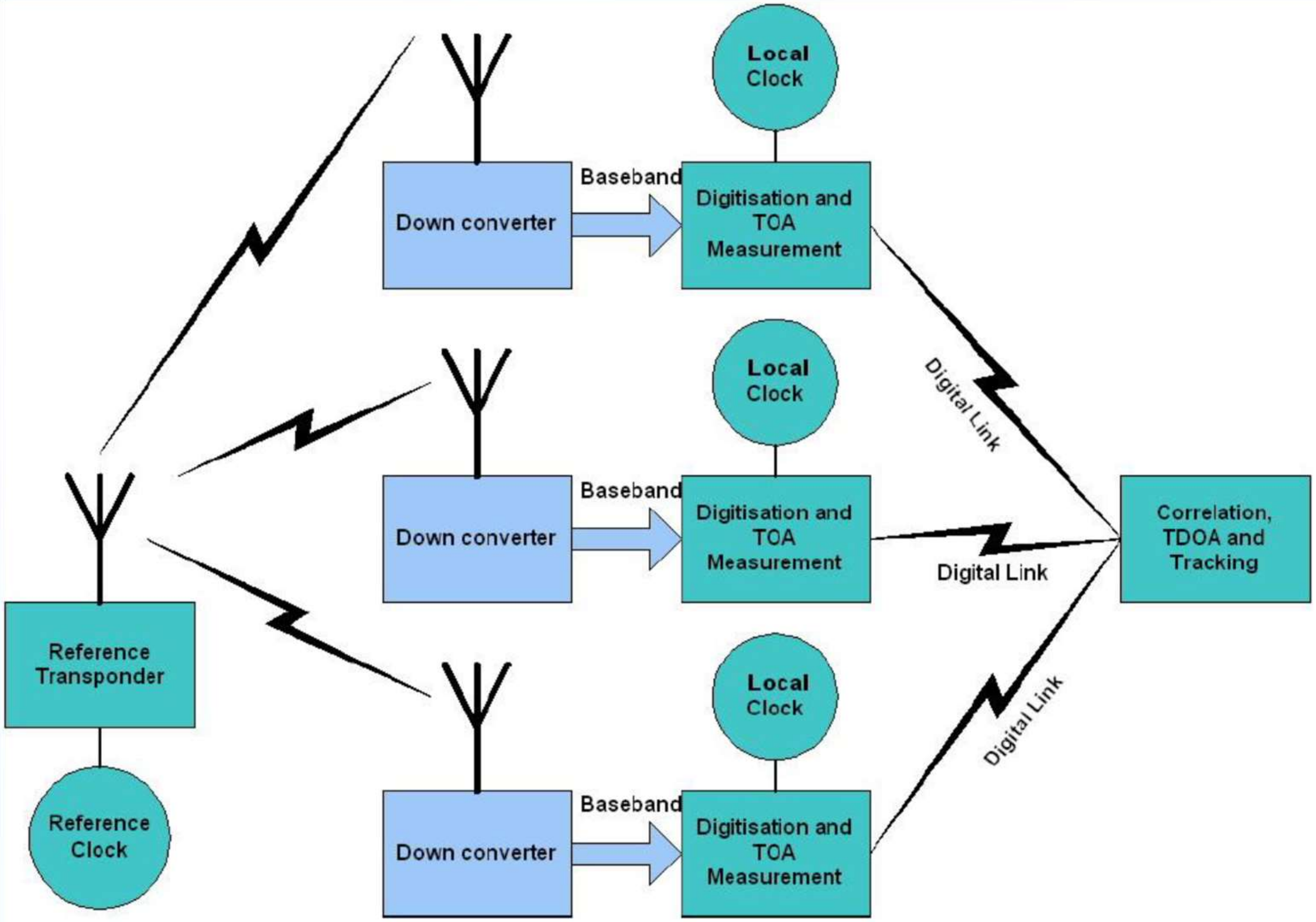
- Common clock systems use a simple receiver with most of the complexity at the central processing site.
- The IF signal is transmitted from each receiver to a central site over a custom analogue link.
- The signal delay between the antenna and the multilateration processor puts stringent requirements on the type and range of the link.
- The location of the multilateration processor must typically be at the centre of the system to minimize communication link distances.

SYNCHRO: DISTRIBUTED CLOCK SYSTEM



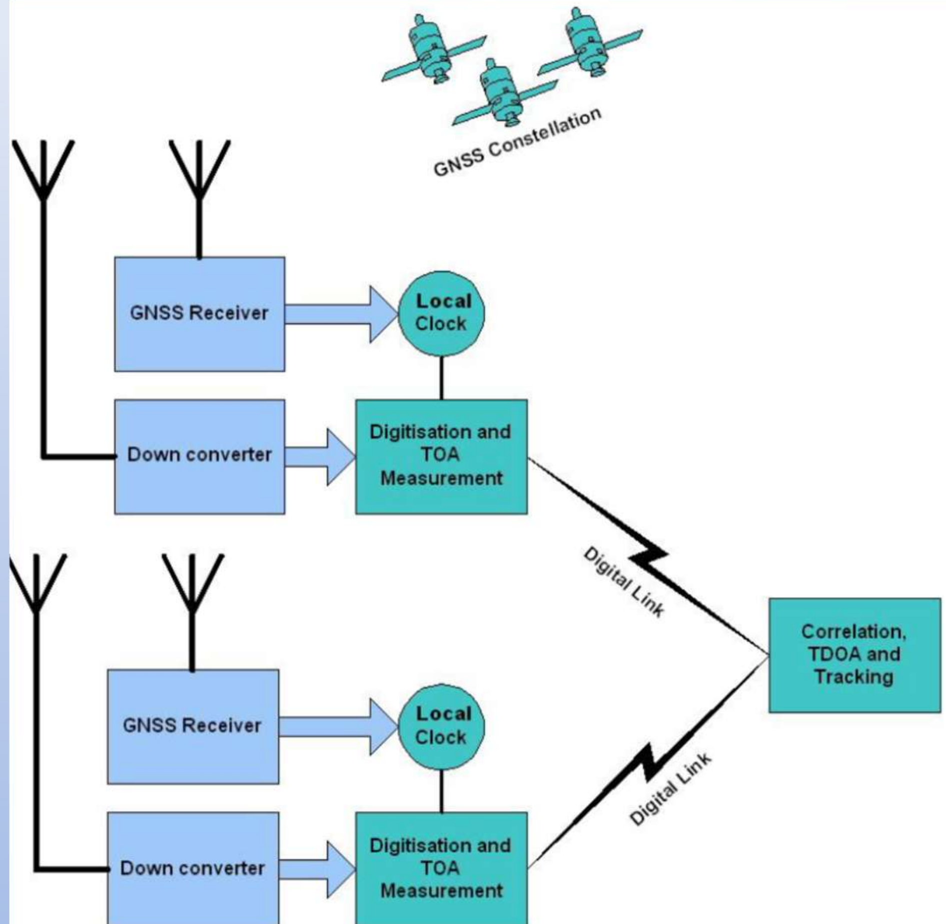
- Any digital data link can be used and the link latency is not critical.
- A mechanism must be used to synchronize the clocks at the local sites.

SYNCHRO: Transponder Synchronized Systems



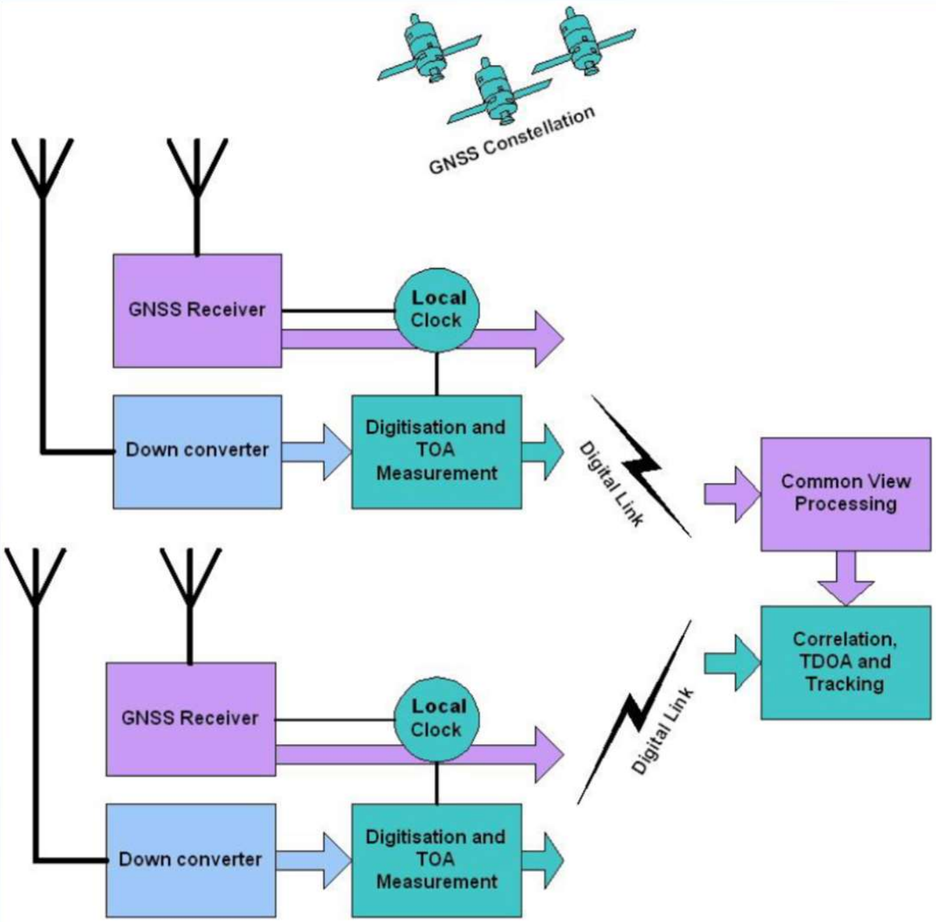
- Uses a transmission from a reference transponder to tie up the clocks at each of the receiver sites.
- The reference timing signal and the aircraft's SSR transmission pass through the same analogue receive chain.
- This means that common delays cancel out the delay bias caused by the analogue components.

SYNCHRO: Standalone GNSS Synchronized System



- An external common timing reference such as a Global Navigation Satellite System (GNSS) can be used to provide a common timing reference for each of the receivers.
- The Galileo constellation, provides high precision atomic clocks, suitable for this application.
- It is possible to synchronize the receivers to within 10-20ns by using a GPS disciplined oscillator at each site.
- GNSS synchronized systems are much easier to site than common clock and transponder systems as they do not need tall towers for synchronization and any digital data link can be used.

SYNCHRO: Common View GNSS Synchronized System



- For situations where the standalone GNSS synchronization between receivers is not accurate enough.
- Uses GNSS satellites that are in view of all the receivers and calculated differential data.
- This allows a large amount of the errors sources to be removed as they are common between signals.
- Sub-nanosecond accuracies can be achieved using this technique.
- The calculated synchronisation data may either by applied directly to the TOA data at each receiver, or to the TOA data upon arrival at the central site.

MLAT Synchronization Characteristics

	Accuracy*	Baseline	Link Choice	Mast	Line of Sight
Common clock	Medium	Medium	Microwave Optical Fiber	High Low	Yes No
Transponder Sync	Medium	Medium	Any	High	Yes
Standard GNSS	Low	Any	Any	Low	No
Common View GNSS	High	Large	Any	Low	No

*Accuracy may be approximately defined as:
- Low – worse than around 10-20 ns
- Medium – between 2-5 ns and 10-20 ns
- High – better than 2-5 ns