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CAUC training – Surveillance – SB508
Surveillance systems
Tianjin, November 2016

Teacher : Marc FRAYARD - ENAC

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Personal presentation

- ENAC
  - Science and Engineering for Air Navigation
    - CNS-ATM Systems Division
      - Surveillance, ATM Systems, ATM Monitoring Systems

- Marc FRAYARD
  - Trainings for engineers, ATSEP, ATCO, technicians, …
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问路总比迷路好。

Wèn lù zǒng bǐ mílù hǎo

« Better to ask the way than go astray »

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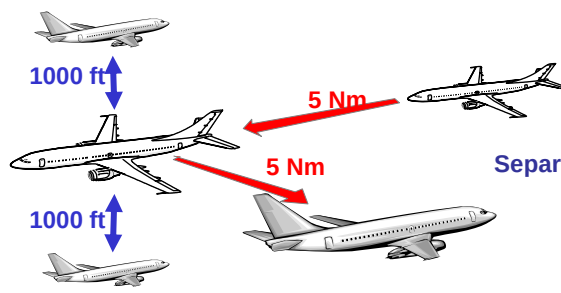
Surveillance Concepts

Be able to :

Detect an aircraft



Separate the aircraft

Getting the parameters of the aircraft

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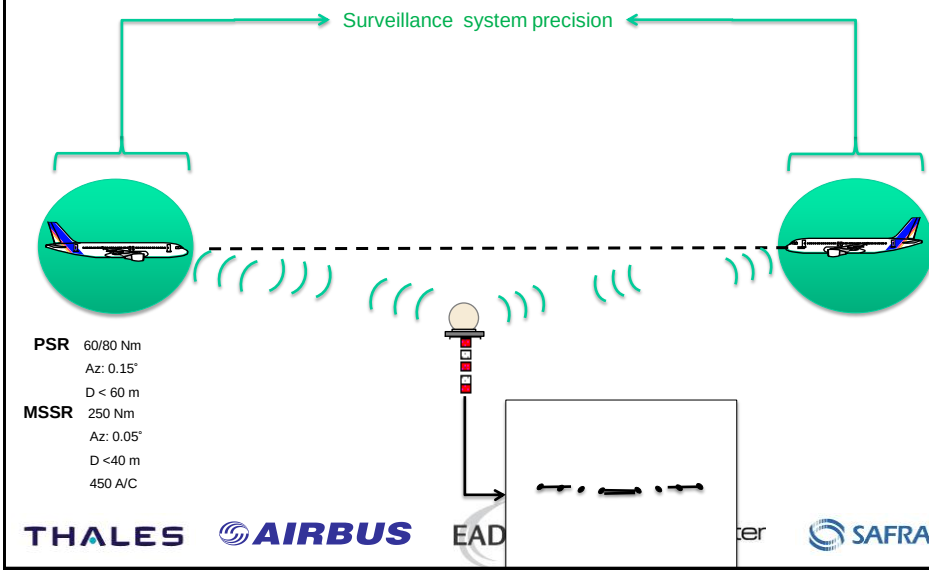

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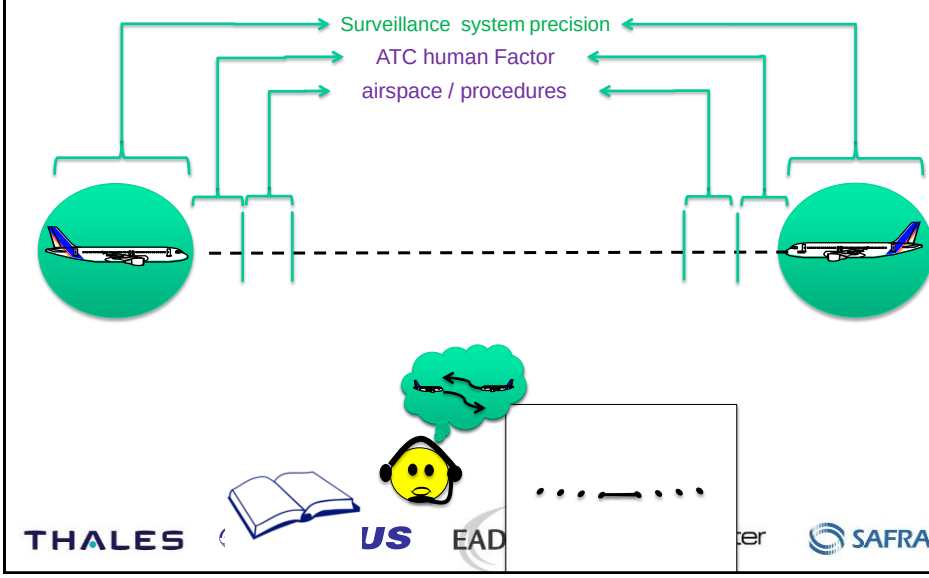

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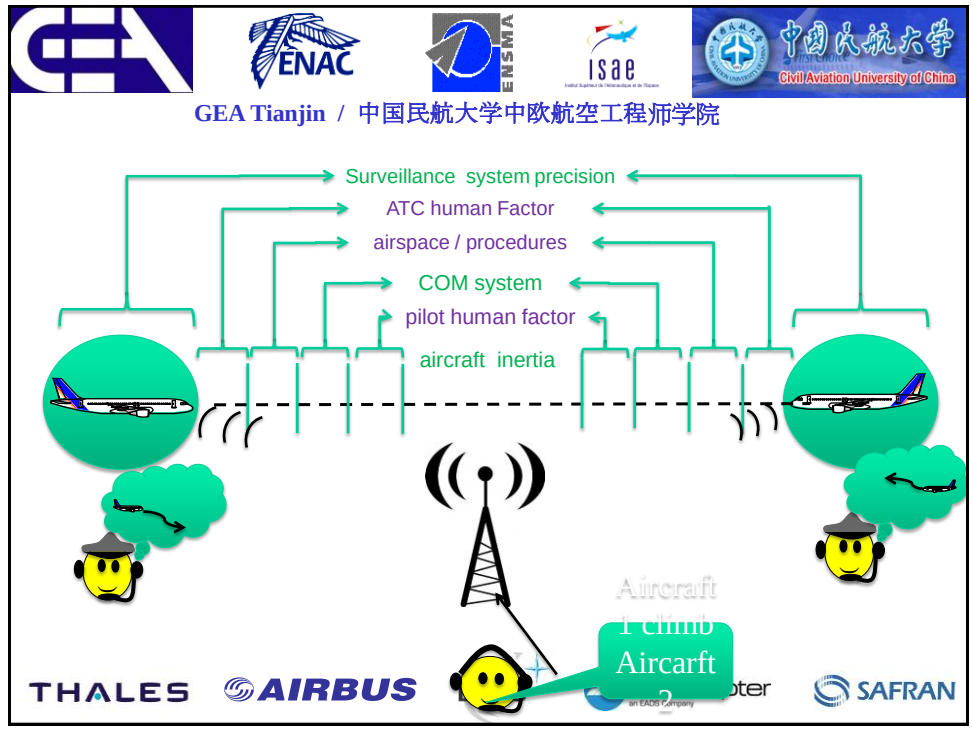
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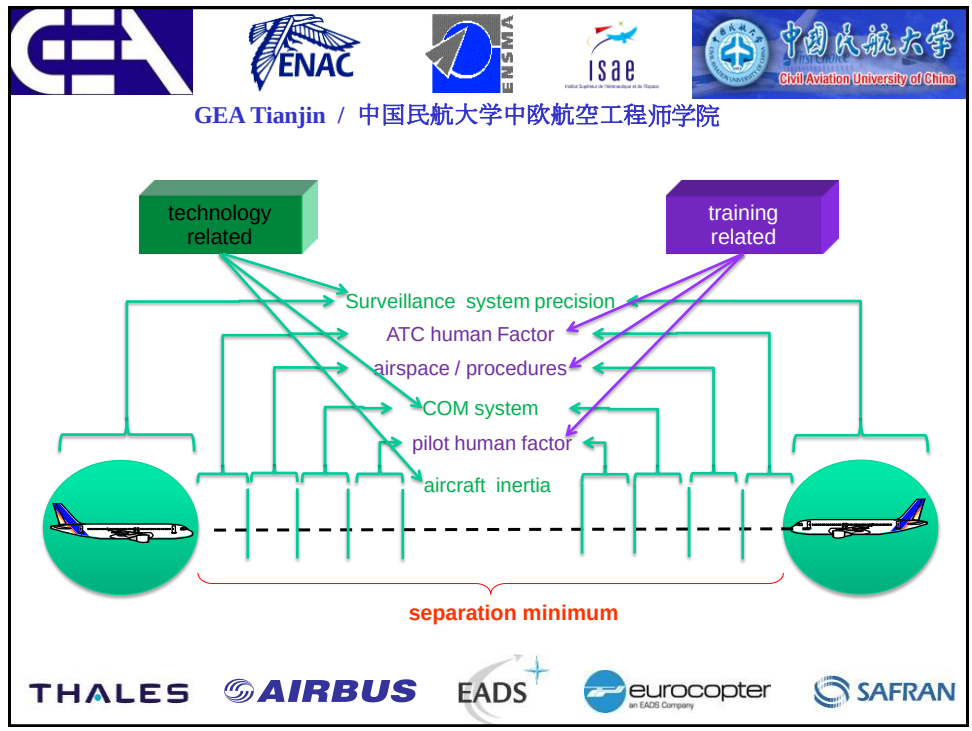
Surveillance system precision
ATC human Factor
airspace / procedures
COM system
pilot human factor
aircraft inertia
Aircraft
T climb
Aircarft
2
THALES
AIRBUS
SAFRAN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technology related
training related
Surveillance system precision
ATC human Factor
airspace / procedures
COM system
pilot human factor
aircraft inertia
separation minimum
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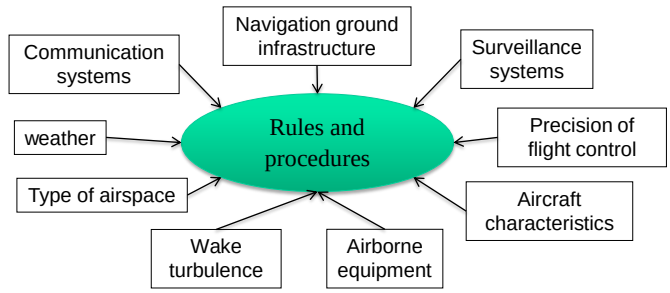
EADS
eurocopter
SAFRAN

Separation minimum



Development of separation minima is complex

But Rule of application very simple for control

Do not give authorisations that lead to manoeuvres which would reduce the separation between two aircraft to a distance lower than the minimum applicable distance in the considered conditions.

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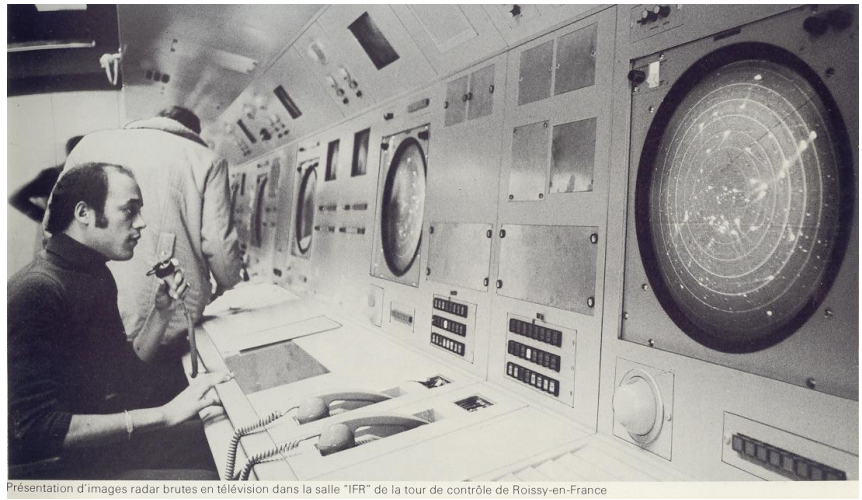
Salle de contrôle du CCR Sud-Est : le système plotting permet de déterminer la position de tous les avions circulant au-dessus d'une zone.



Présentation d'images radar brutes en télévision dans la salle "IFR" de la tour de contrôle de Roissy-en-France

How can we achieve that

- By a measurement
  - A Ground equipment detects and localizes **all** the targets of interest for ATC
- By data communication
  - The aircraft are able to determine their position and transmit it using some data link

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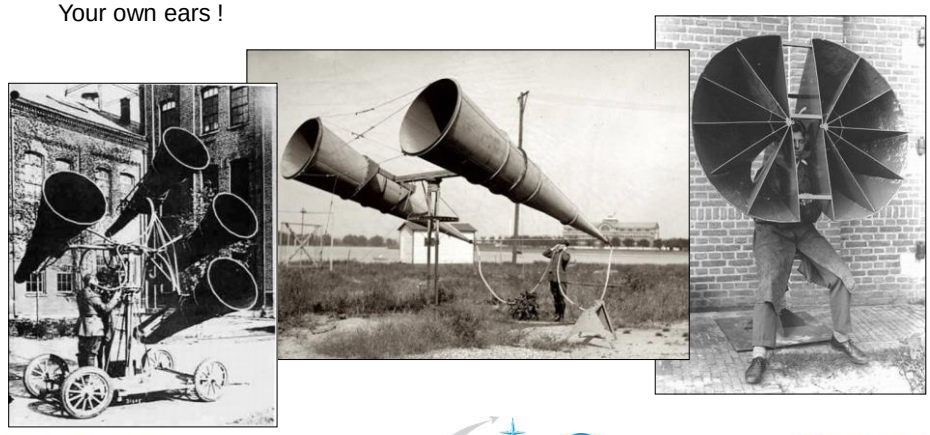
What type of sensor

Your own ears !



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What type of sensor

Or with your own eyes

Plane in Beijing airport

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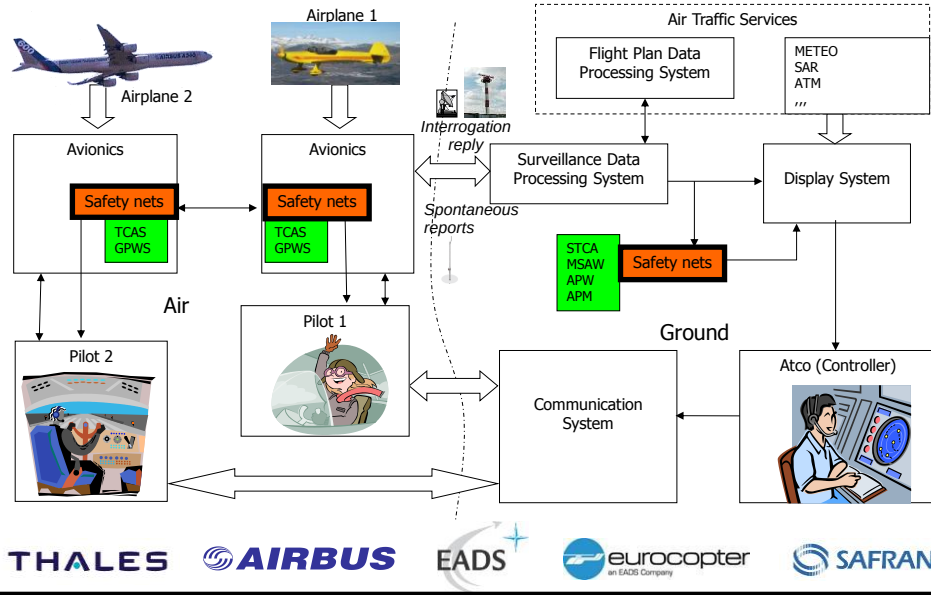

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RADARS

Radar principles

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Radars are extremely complicated systems !

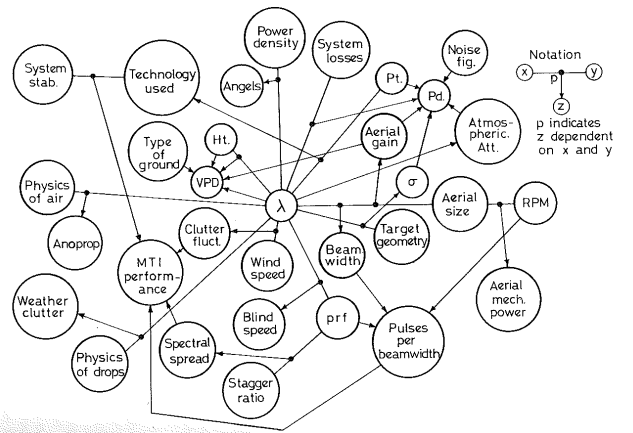

Fig. 7.6. Map of dependencies in radar. Legends: P_t = transmitted power, P_d = probability of detection, H_t = height of antenna phase centre above ground, VPD = vertical polar diagram shape, σ (sigma) = target echoing area, RPM = antenna rotation speed, p.r.f. = pulse repetition frequency, λ (lambda) = wavelength.

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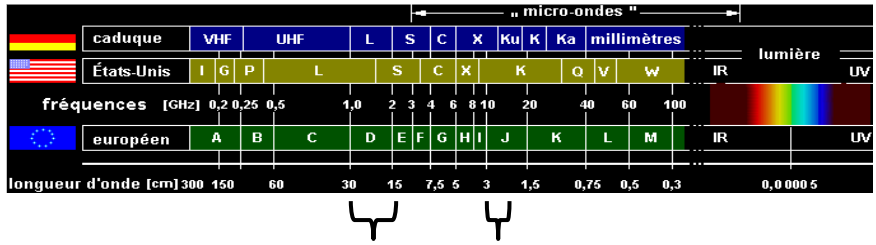
What type of sensor



Radio Detection And Ranging

RADAR

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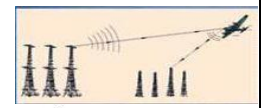
Brief History

1906 Huelsmeyer and the telemobiloskop

1936 Normandie

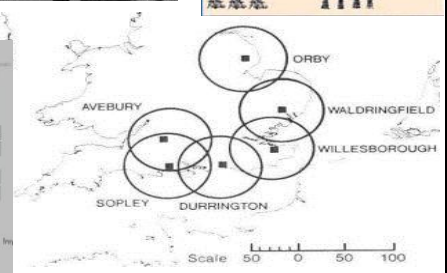


1940 Freya and chain Home

IFF

1943 Magnetron

1960 SSR



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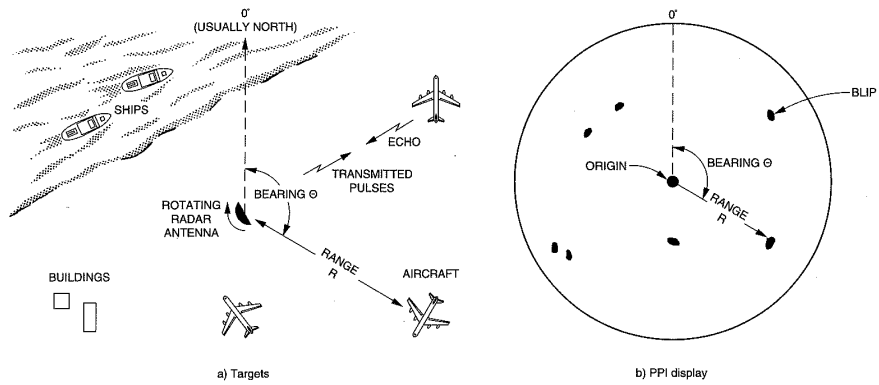
Plan Position Indicator



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PPI : Plan Position Indicator

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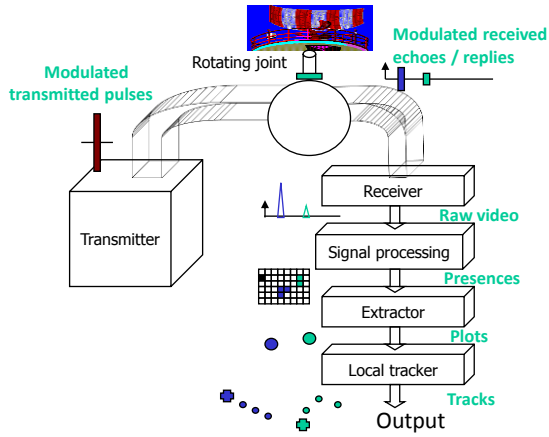
Radar architecture



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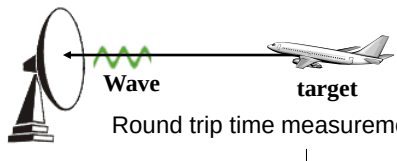
What do we measure with a RADAR

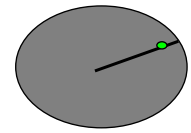
Scattering of an electromagnetic wave by a target



Round trip time measurement (s)

Transmitter directionality (antenna boresight / true North)

Wave Celerity (m/s) → $\frac{c\,\Delta t}{2} = D$ → D = 65 NM Az = 054°



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Maximum unambiguous Range

The range which can be covered by the wave between 2 pulses

Pulse Repetition Time

T_R

$$R_{\max}^{théo} = \frac{c.T_R}{2}$$

The pulse transmission rate can be expressed in terms of

- time between 2 consecutive pulses (Tr)
- Pulse Repetition Frequency (PRF = 1/Tr)

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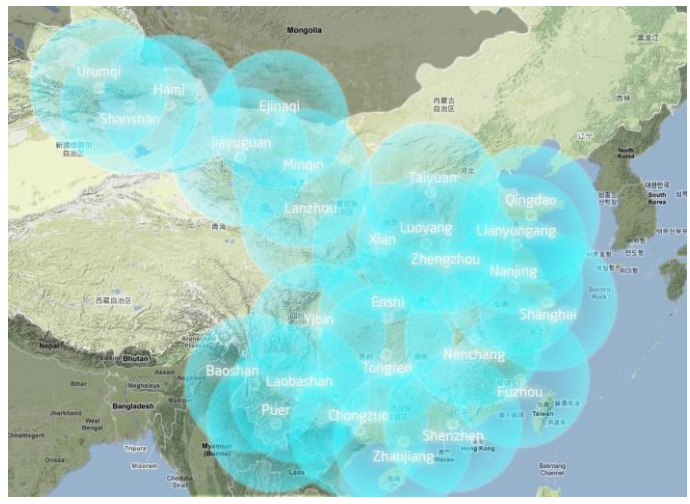

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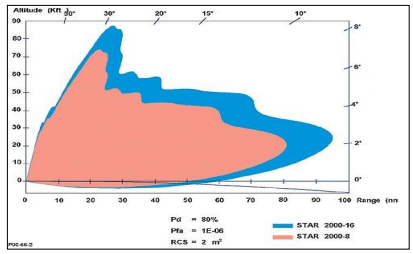
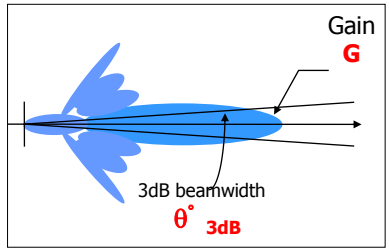
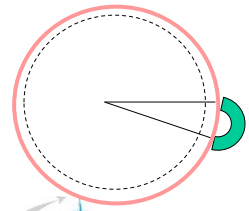
Antenna



Elevation radiation pattern



Azimuth radiation pattern



$$G_{ant} = \frac{P_{main\_lobe}}{P_{isotropic}}$$

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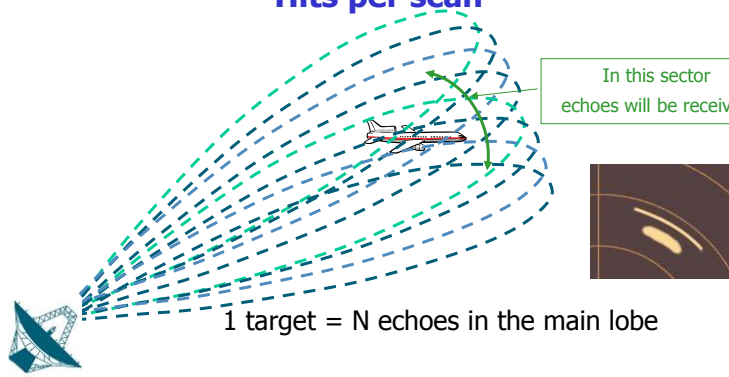
Hits per scan



$$N = \frac{\theta^{\circ}_{3db}}{6.V_{rotation}.T_R}$$

Units

- θ_{3dB} in degrees
- $V_{rotation}$ in rotations per minute (rpm)
- T_R in seconds

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Primary Radar

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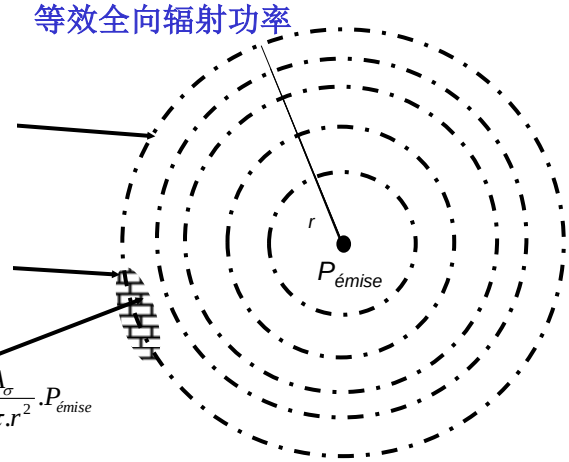
Isotropic propagation
等效全向辐射功率

The transmitted power is spread on the surface of a sphere

Effective area of the target A_σ

How much power does the target intercept ?

$$P_{reçue\_cible} = \frac{A_\sigma}{4.\pi.r^2}.P_{émise}$$



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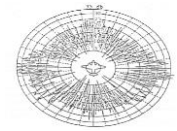
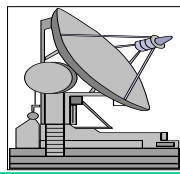
Link budget for a PSR

$$Step\ 1: P_{received\_target} = \frac{P_{transmitted\_radar}.G.\sigma}{4.\pi.R^2}$$

- gain G $G_{ant} = \frac{P_{main\_lobe}}{P_{isotropic}}$
- Effective area $\sigma_{antenna} = \frac{G.\lambda^2}{4\pi}$

target : Radar Cross Section σ





R

R

$$P_{received} = \frac{P_{transmitted}.G^2.\lambda^2.\sigma.L_s}{(4.\pi)^3.R^4}$$

$$Step\ 2: P_{received\_radar} = \frac{P_{transmitted\_target}.\sigma_{antenna}}{4.\pi.R^2}$$

L_s : atmospheric loss, internal system loss….

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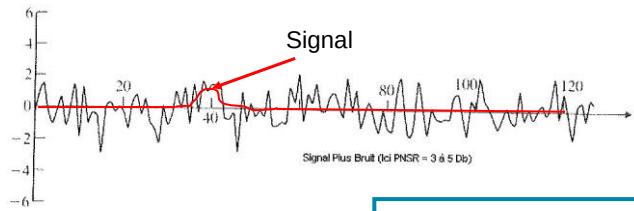
Signal to noise ratio

- We need to extract the useful signal (echo) from the received signal (echo + noise)



$$SNR = \frac{P_{received}}{P_{Noise}}$$

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Probability of detection

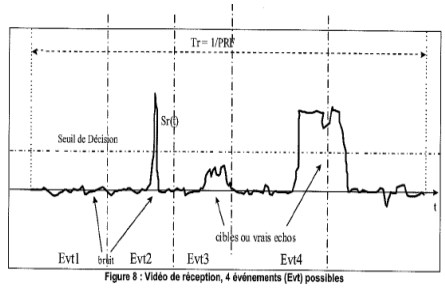
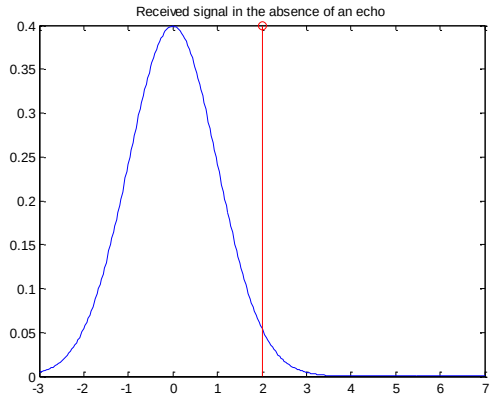


Figure 8 : Vidéo de réception, 4 événements (Evt) possibles

Target	Exists	Doesn't exist
detected	EVT 4	EVT 2
not detected	EVT 3	EVT 1

False alarm probability Pfa → EVT2
Detection probability Pd → EVT4

False alarm probability



- Here, there is no echo (i.e., received signal = noise)
- Assuming the noise is white and gaussian, can you spot Pfa in this figure ?

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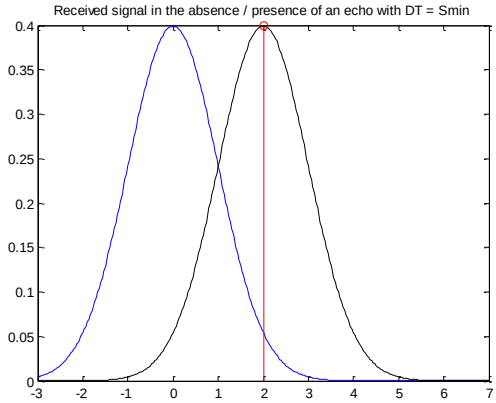
False alarm and detection probability (1)



- Assuming the noise is white and gaussian, can you spot Pfa in this figure ?
- Can you spot Pd in this figure ?
- In this example, how much is Pd ?

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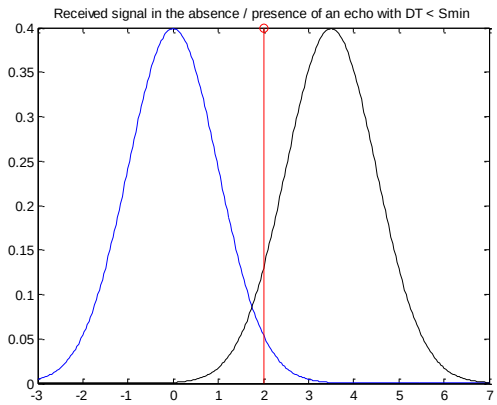
False alarm and detection probability (2)



- Assuming the noise is white and gaussian, can you spot Pfa in this figure ?
- Can you spot Pd in this figure ?
- Conclusion ?

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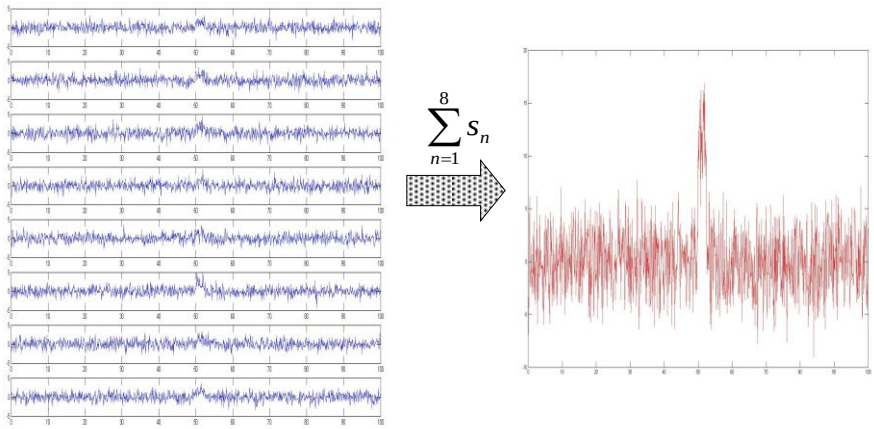
Interest of having several hits per scan



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PSR : characteristics

	APP	Ground
Transmitted power (peak power)	1 MW	10 kW
Antenna Gain	36 dB	25 dB
3dB beamwidth	3°	1.5°
Antenna rotation speed	15 rpm	60 rpm
Carrier Frequency f0	1 GHz	10 GHz
Pulse repetition time PRT	3 ms	100 µs
Pulse width	1 µs	40 ns

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Advantages / Drawbacks

- Advantages
  - No need for any on board equipment
  - Good accuracy
  - The only sensor for non cooperative detection
- Drawbacks
  - Detection depends on the RCS and location of the target
  - Huge transmitted power
  - Measurement of range and azimuth only
  - Complex signal processing
  - Costly installation and maintenance

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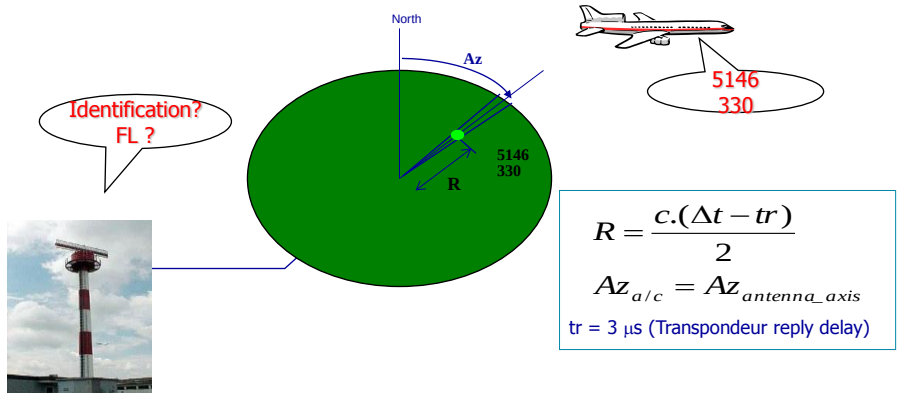
Secondary Radar

Measurement



$$R = \frac{c.(\Delta t - tr)}{2}$$

$$Az_{a/c} = Az_{antenna\_axis}$$

tr = 3 µs (Transpondeur reply delay)

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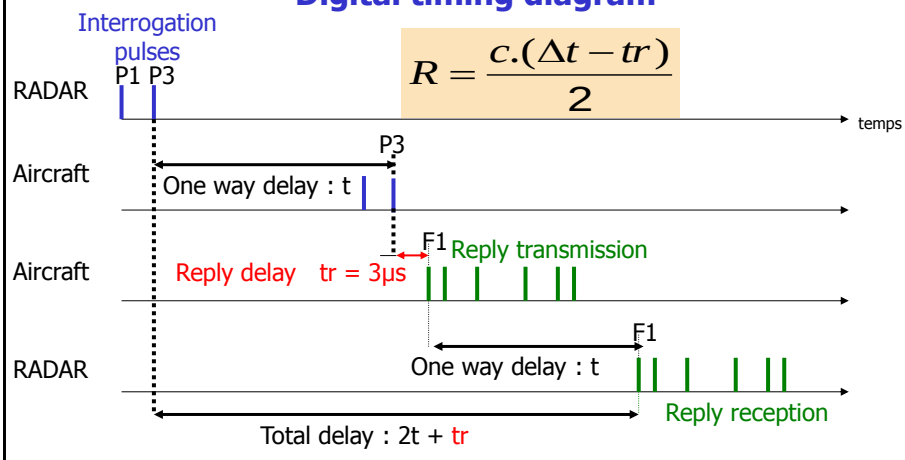
Digital timing diagram



$$R = \frac{c.(\Delta t - tr)}{2}$$

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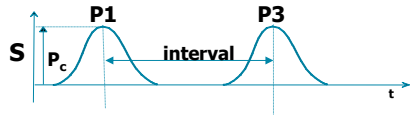
Interrogation

- Carrier Frequency of interrogation: f_i=1030 Mhz



Pulse duration (P1 ou P3) : 0.8µs

Military	Civilian
1 : 3 µs military ident	A : 8 µs Identification
2 : 5 µs military ident	B : 17 µs Not used
3 : 8 µs Same as mode A	C : 21 µs Flight level
	D : 25 µs Not used

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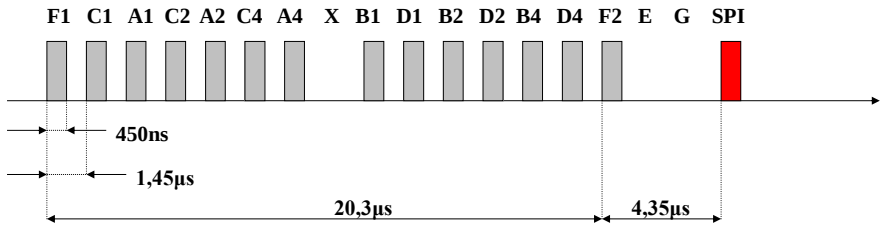
Reply

- Carrier Frequency of the reply: f_r=1090Mhz



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Mode A / Mode C coding

Mode A = 12 bits

C1	A1	C2	A2	C4	A4	X	B1	D1	B2	D2	B4	D4
0	1	1	0	0	1		1	1	0	0	1	0

$$A = 2^0.A_1 + 2^1.A_2 + 2^2.A_4 = 1.A_1 + 2.A_2 + 4.A_4$$

A4	A2	A1	B4	B2	B1		C4	C2	C1	D4	D2	D1
1	0	1	1	0	1		0	1	0	0	0	1
5			5				2			1		

The FL is coded from FL–10 to FL 1267 in 100ft increments

FL	D2	D4	A1	A2	A4	B1	B2	B4	C1	C2	C4
8750 ⇨ 8850	0	0	0	1	1	1	1	0	0	0	1
8850 ⇨ 8950	0	0	0	1	1	1	1	0	0	1	1
8950 ⇨ 9050	0	0	0	1	1	1	1	0	0	1	0
115150 ⇨ 115250	1	0	0	1	1	1	0	0	1	0	0
115250 ⇨ 115350	1	0	0	1	1	1	0	1	1	0	0
115350 ⇨ 115450	1	0	0	1	1	1	0	1	1	1	0

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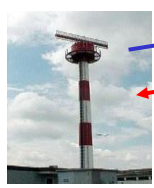
Link budget for a SSR

- **Interrogation**

pulses P1-P3

$$P_{r\_plane} = \frac{P_{t\_radar}.G_{radar}.G_{plane}.\lambda_i^2.Ls}{(4.\pi)^2.R^2}$$



On board transponder

Reply

Set of pulses

$$P_{r\_radar} = \frac{P_{t\_plane}.G_{radar}.G_{plane}.\lambda_r^2.Ls}{(4.\pi)^2.R^2}$$

- gain G $\quad G_{ant} = \frac{P_{main\_lobe}}{P_{isotropic}}$
- effective area $\quad \sigma_{antenne} = \frac{G.\lambda^2}{4\pi}$

SSR : Characteristics

	Radar	Transponder
Transmitted power (peak power)	1600 W	150 – 500W
Antenna Gain	24 dB	3 dB
3dB beamwidth	2.4°	
Antenna rotation speed	15 rpm	
Carrier Frequency f0	1030 MHz	1090 MHz
Receiver sensitivity	-80 dBm	-71 dBm

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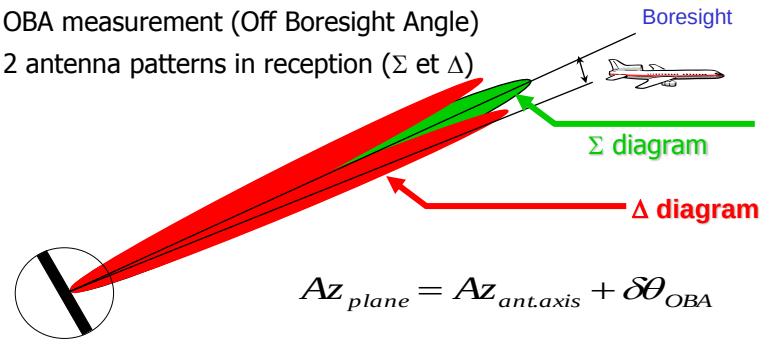
Monopulse

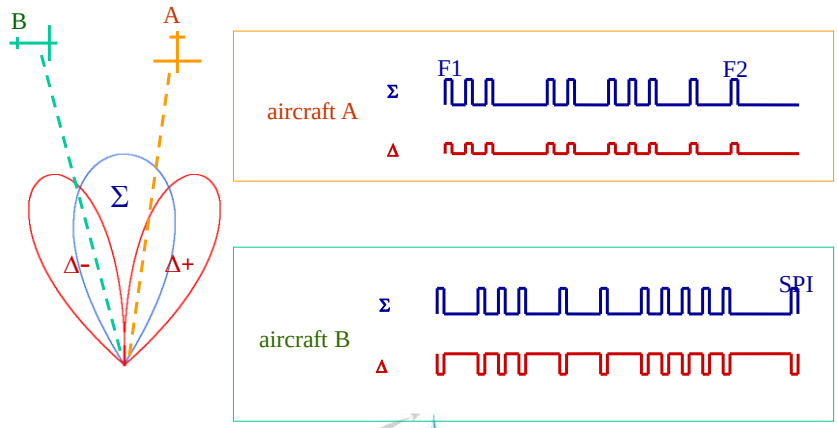
Better accuracy in azimuth measurement

- OBA measurement (Off Boresight Angle)
- 2 antenna patterns in reception (Σ et Δ)



$$Az_{plane} = Az_{ant.axis} + \delta\Theta_{OBA}$$

Example



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Advantages / Drawbacks

- Advantages
- More information given to ATC (identification and FL)
- Noticable improvement in azimuth measurement accuracy thanks to the monopulse technique
- The favorable link budget allows for Pfa=0 et Pd=1 (at the pulse level, that is)
- No clutter at all

- Drawbacks
- Cooperative detection (on board equipement needed)
- Risk of capacity overload in dense traffic areas (lots of replies, lots of interrogations)

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Mode S Secondary Radar

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Mode S communication

Founding principles

Each Mode S station is identified by an interrogator code (II or SI)

Each Mode S aircraft is identified by a unique 24 bit address (@mode S)

Working principles

A Mode S station takes into account only the replies that contain its own interrogator code

A Mode S aircraft replies only to interrogations that contain its own address

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Table 9-1. Allocation of aircraft addresses to States

Note.— The left-hand column of the 24-bit address patterns represents the most significant bit (MSB) of the address.

State	Number of addresses in block: 1 024	4 096	32 768	262 144	1 048 576	Allocation of blocks of addresses (a dash represents a bit value equal to 0 or 1)
Afghanistan		*				0111 00 000 000 -- ----------
Albania	*					0101 00 000 001 00 ----------
Algeria			*			0000 10 100 --- -- ----------
Angola		*				0000 10 010 000 -- ----------
Antigua and Barbuda	*					0000 11 001 010 00 ----------
Argentina				*		1110 00 --- --- -- ----------
Armenia	*					0110 00 000 000 00 ----------
Australia				*		0111 11 --- --- -- ----------
Austria			*			0100 01 000 --- -- ----------
Azerbaijan	*					0110 00 000 000 10 ----------
Bahamas		*				0000 10 101 000 -- ----------
Bahrain		*				1000 10 010 100 -- ----------
Bangladesh		*				0111 00 000 010 -- ----------
Barbados	*					0000 10 101 010 00 ----------
Belarus	*					0101 00 010 000 00 ----------
Belgium			*			0100 01 001 --- -- ----------
Belize	*					0000 10 101 011 00 ----------
Benin	*					0000 10 010 100 00 ----------
Bhutan	*					0110 10 000 000 00 ----------
Bolivia		*				1110 10 010 100 -- ----------
Bosnia and Herzegovina	*					0101 00 010 011 00 ----------
Botswana	*					0000 00 110 000 00 ----------
Brazil				*		1110 01 --- --- -- ----------
Brunei Darussalam	*					1000 10 010 101 00 ----------
Bulgaria			*			0100 01 010 --- -- ----------
Burkina Faso		*				0000 10 011 100 -- ----------
Burundi		*				0000 00 110 010 -- ----------
Cambodia		*				0111 00 001 110 -- ----------
Cameroon		*				0000 00 110 100 -- ----------
Canada				*		1100 00 --- --- -- ----------
Cape Verde	*					0000 10 010 110 00 ----------
Central African Republic		*				0000 01 101 100 -- ----------
Chad		*				0000 10 000 100 -- ----------
Chile		*				1110 10 000 000 -- ----------
China				*		0111 10 --- --- -- ----------

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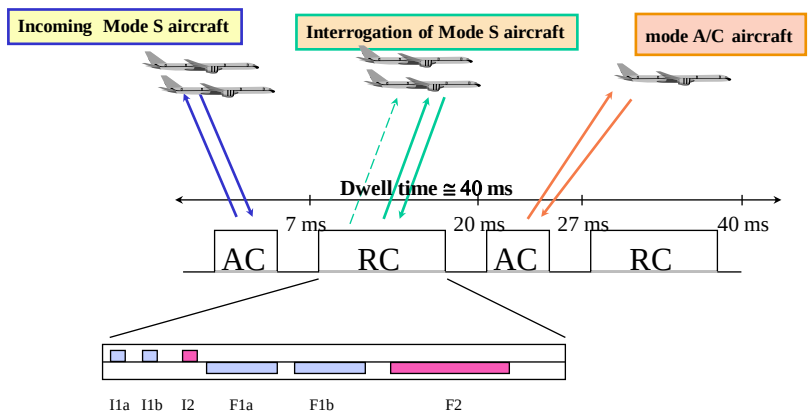
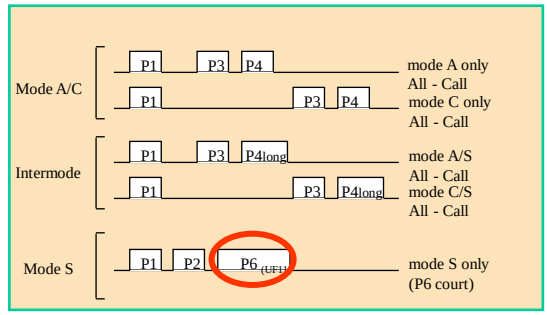
All Call / Roll Call



All Call Interrogation



Mode A/C Transponder	Mode S Transponder
mode A	No reply
mode C	No reply
mode A	mode A
mode C	mode C (25fts)
No reply	mode S address

Pulse width

P1, P2, P3 et shortP4 = 0.8 µs

Long P4 = 1.6 µs

Short P6 = 16.25 µs

Long P6 = 30.25 µs

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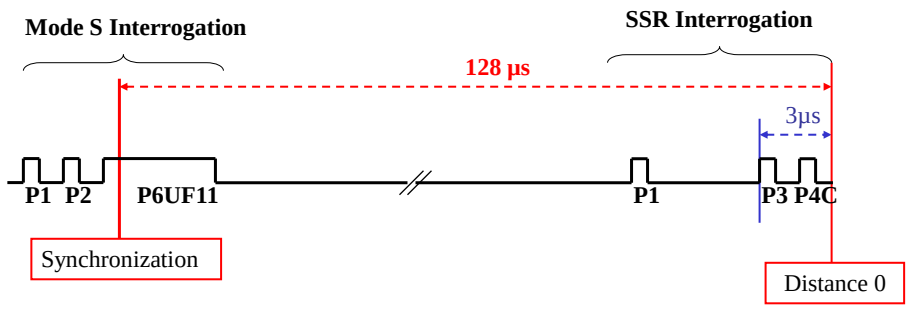
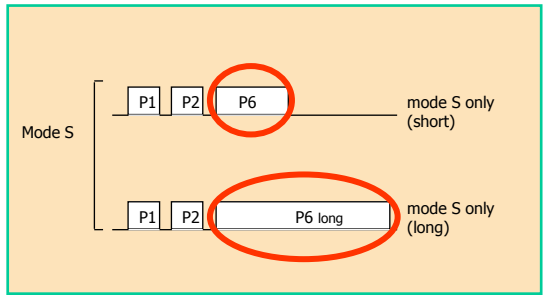
All-Call structure



Roll Call Interrogations



Mode A/C transponder	Mode S Transponder
No reply	Surveillance (only for the called aircraft)
No reply	Surveillance + Data link (only for the called aircraft)

Pulse width

P1, P2, P3 et short P4 = 0.8 µs

Long P4 = 1.6 µs

Short P6 = 16.25 µs

Long P6 = 30.25 µs

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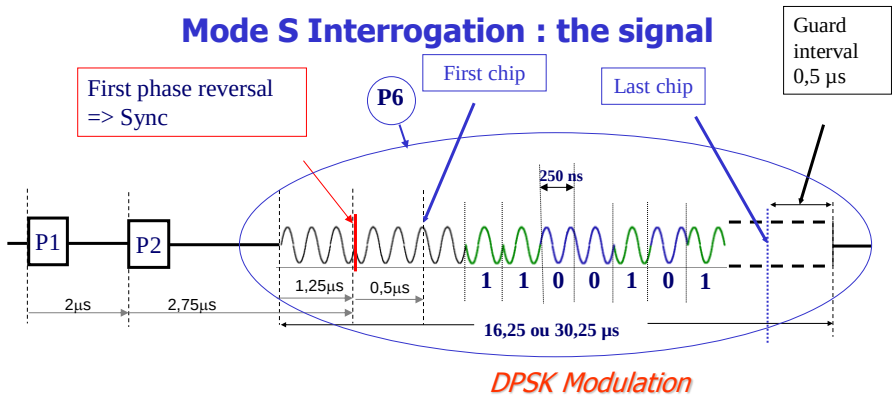
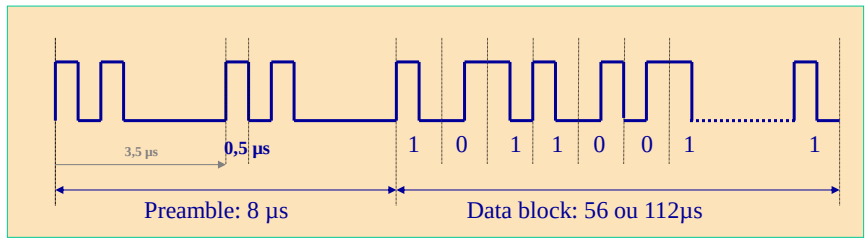
Mode S Interrogation : the signal



DPSK Modulation

DPSK: Differential Shift Keying

Mode S Reply : the signal



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UF and DF

UF

UF0	**56bits**	**Short air-air Surveillance ACAS**
UF4	56bits	Surveillance; Mode C request
UF5	56bits	Surveillance; Mode A request
UF11	56bits	All Call
UF16	**112bits**	**Long air-air Surveillance ACAS**
UF20	112bits	Comm-A ; Mode C request
UF21	112bits	Comm-A ; Mode A request
UF24	112bits	Comm-C ; ELM

Other transponder communication (T-CAS , ADS-B…)

DF

DF0	**00000**	**Short air-air Surveillance ACAS**
DF4	00100	Surveillance; Mode C reply
DF5	00101	Surveillance; Mode A reply
DF11	01011	All call reply
DF16	**10000**	**Long air-air Surveillance ACAS**
DF17	**10001**	**Extended Squitter**
DF18	**10010**	**Extended Squitter / non-transponder**
DF19	**10011**	**Military extended Squitter**
DF20	10100	Comm-B ; Mode C reply
DF21	10101	Comm-B ; Mode A reply
DF24	11- - -	Comm-D ; ELM

Mode S transponder Reply

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Interrogation and reply formats (1/2)

ALL-CALL

Interrogation

UF 11	II ou SI	AP
Uplink Format (5bits)	Radar code	Parity (24 bits)

Reply

DF 11	AA	PI
Downlink Format (5bits)	@Mode S (24 bits)	Radar code + Parity (24 bits)

ROLL-CALL

Interrogation

UF 4 - 5	PC	II ou SI	AP
UF 4 : Mode C ? UF 5 : Mode A ?		Radar code + more Info	@Mode S + Parity (24 bits)

Reply

DF 4 - 5	FS	AC ou ID	AP
DF 4 :Mode C DF 5 :Mode A		ID or Flight level	@Mode S + Parity (24 bits)

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Interrogation and reply formats (2/2)

Interrogation

UF 20-21	PC	II ou SI	MA	AP
UF 20 =>Mode C ? UF 21 =>Mode A ?		Radar code + more info	data (56 bits)	Mode S Address + Parity (24 bits)

Reply

DF 20-21	FS	AC ou ID	MB	AP
DF 20 :Mode C DF 21 :Mode A	Flight Status	ID or Flight level	Data (56 bits)	Mode S address + Parity (24 bits)

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BDS

Table 5-24. Register number assignments

Transponder register No.	Assignment
00_{16}	Not valid
01_{16}	Unassigned
02_{16}	Linked Comm-B, segment 2
03_{16}	Linked Comm-B, segment 3
04_{16}	Linked Comm-B, segment 4
05_{16}	Extended squitter airborne position
06_{16}	Extended squitter surface position
07_{16}	Extended squitter status
08_{16}	Extended squitter identification and type
09_{16}	Extended squitter airborne velocity
$0A_{16}$	Extended squitter event-driven information
$0B_{16}$	Air/air information 1 (aircraft state)
$0C_{16}$	Air/air information 2 (aircraft intent)
$0D_{16}$-$0E_{16}$	Reserved for air/air state information
$0F_{16}$	Reserved for ACAS
10_{16}	Data link capability report
11_{16}-16_{16}	Reserved for extension to data link capability reports
17_{16}	Common usage GICB capability report
18_{16}-$1F_{16}$	Mode S specific services capability reports
20_{16}	Aircraft identification
21_{16}	Aircraft and airline registration markings
22_{16}	Antenna positions
23_{16}	Reserved for antenna position
24_{16}	Reserved for aircraft parameters
25_{16}	Aircraft type
26_{16}-$2F_{16}$	Unassigned
30_{16}	ACAS active resolution advisory
31_{16}-$3F_{16}$	Unassigned
40_{16}	Selected vertical intention
41_{16}	Next waypoint identifier
42_{16}	Next waypoint position
43_{16}	Next waypoint information
44_{16}	Meteorological routine air report

Transponder register No.	Assignment
45_{16}	Meteorological hazard report
46_{16}	Reserved for flight management system Mode 1
47_{16}	Reserved for flight management system Mode 2
48_{16}	VHF channel report
49_{16}-$4F_{16}$	Unassigned
50_{16}	Track and turn report
51_{16}	Position report coarse
52_{16}	Position report fine
53_{16}	Air-referenced state vector
54_{16}	Waypoint 1
55_{16}	Waypoint 2
56_{16}	Waypoint 3
57_{16}-$5E_{16}$	Unassigned
$5F_{16}$	Quasi-static parameter monitoring
60_{16}	Heading and speed report
61_{16}	Extended squitter emergency/priority status
62_{16}	Reserved for target state and status information
63_{16}	Reserved for extended squitter
64_{16}	Reserved for extended squitter
65_{16}	Aircraft operational status
66_{16}-$6F_{16}$	Reserved for extended squitter
70_{16}-75_{16}	Reserved for future aircraft downlink parameters
76_{16}-$E0_{16}$	Unassigned
$E1_{16}$-$E2_{16}$	Reserved for Mode S BITE
$E3_{16}$	Transponder type/part number
$E4_{16}$	Transponder software revision number
$E5_{16}$	ACAS unit part number
$E6_{16}$	ACAS unit software revision number
$E7_{16}$-$F0_{16}$	Unassigned
$F1_{16}$	Military applications
$F2_{16}$	Military applications
$F3_{16}$-FF_{16}	Unassigned

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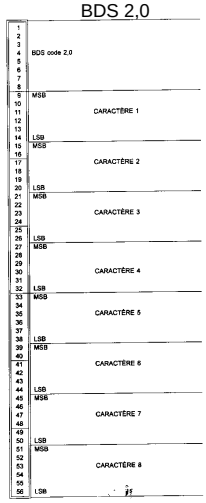
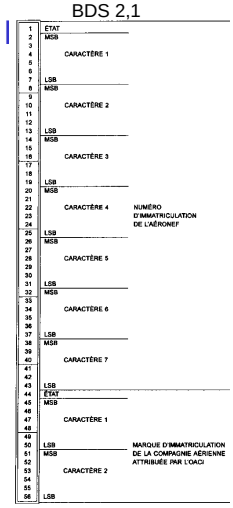
Identification d'aéronef

BDS 2,0



BDS 2,1



			b6	0	0	1	1
			b5	0	1	0	1
b4	b3	b2	b1				
0	0	0	0		P	Sp	0
0	0	0	1	A	Q		1
0	0	1	0	B	R		2
0	0	1	1	C	S		3
0	1	0	0	D	T		4
0	1	0	1	E	U		5
0	1	1	0	F	V		6
0	1	1	1	G	W		7
1	0	0	0	H	X		8
1	0	0	1	I	Y		9
1	0	1	0	J	Z		
1	0	1	1	K			
1	1	0	0	L			
1	1	0	1	M			
1	1	1	0	N			
1	1	1	1	O			

Deficiencies

	PSR	SSR	Mode S
2nd sweep			
Blind zone			
Cone of silence			
Paper hat			
garbling			
Phantom			
Sidelobe			
FRUIT			

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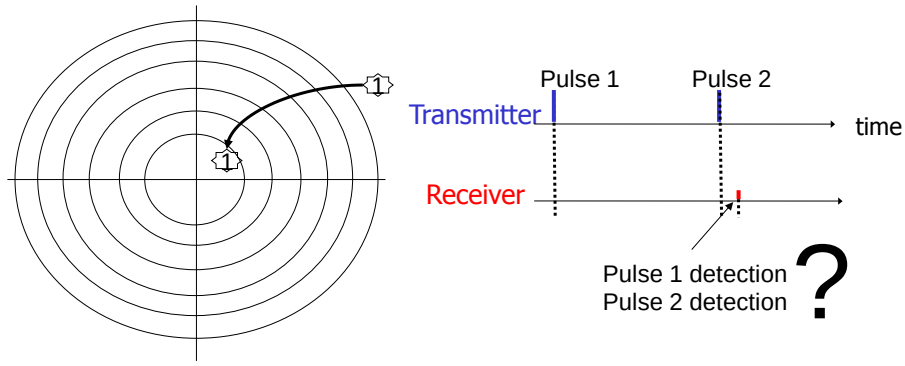
Deficiencies : 2nd sweep echoes/replies



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Deficiencies

	PSR	SSR	Mode S
2nd sweep	Yes	Yes	No
Blind zone			
Cone of silence			
Paper hat			
garbling			
Phantom			
Sidelobe			
FRUIT			

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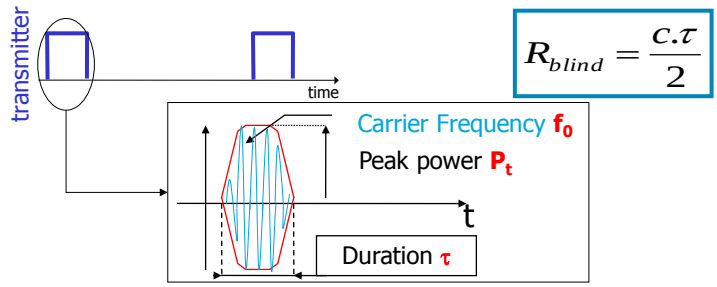
Deficiencies : Blind Zone



$$R_{blind} = \frac{c.\tau}{2}$$

Radars are like students… they can not listen and speak at the same time

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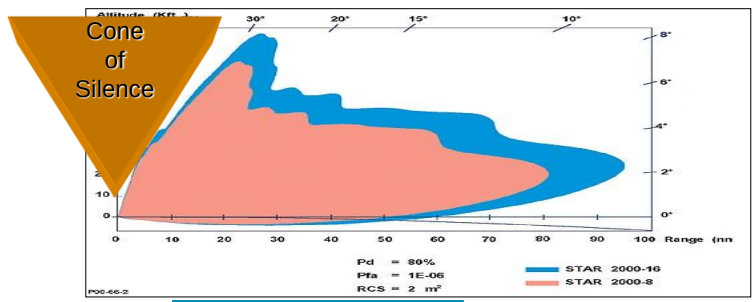
Deficiencies

	PSR	SSR	Mode S
2nd sweep	Yes	Yes	No
Blind zone	Yes	No	No
Cone of silence			
Paper hat			
garbling			
Phantom			
Sidelobe			
FRUIT			

Deficiencies : cone of silence



$$\varphi^{\circ}_{silence} \cong 2 \times 45^{\circ}$$

Deficiencies

	PSR	SSR	Mode S
2nd sweep	Yes	Yes	No
Blind zone	Yes	No	No
Cone of silence	Yes	Yes	Yes
Paper hat			
garbling			
Phantom			
Sidelobe			
FRUIT			

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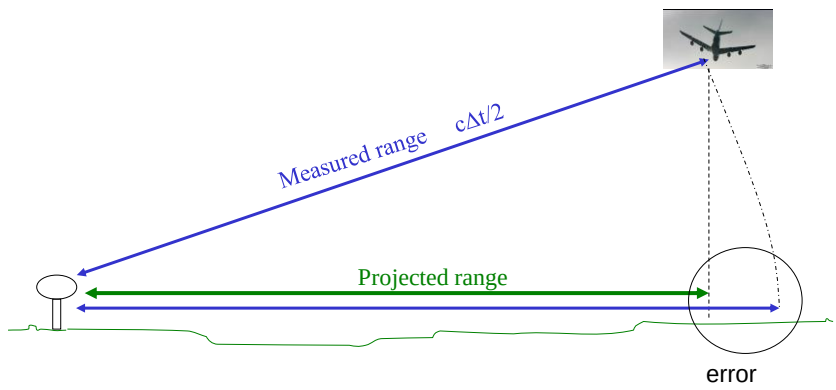
Deficiencies : Paper hat



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Deficiencies

	PSR	SSR	Mode S
2nd sweep	Yes	Yes	No
Blind zone	Yes	No	No
Cone of silence	Yes	Yes	Yes
Paper hat	Yes	No	No
garbling			
Phantom			
Sidelobe			
FRUIT			

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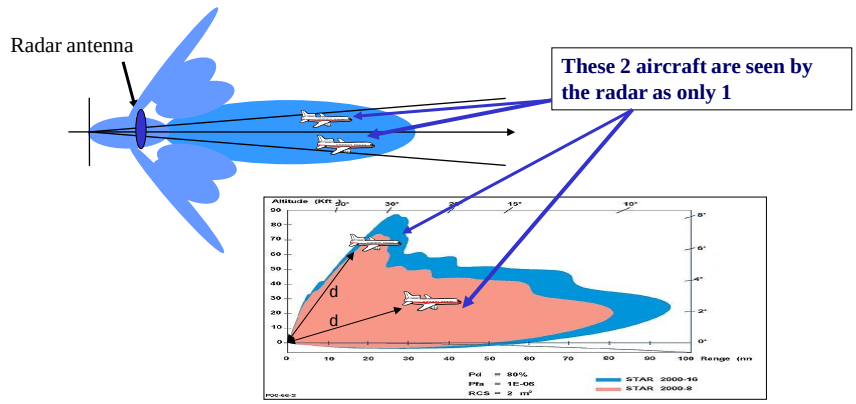
Deficiencies : garbling



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Deficiencies

	PSR	SSR	Mode S
2nd sweep	Yes	Yes	No
Blind zone	Yes	No	No
Cone of silence	Yes	Yes	Yes
Paper hat	Yes	No	No
garbling	Yes	Yes	No
Phantom			
Sidelobe			
FRUIT			

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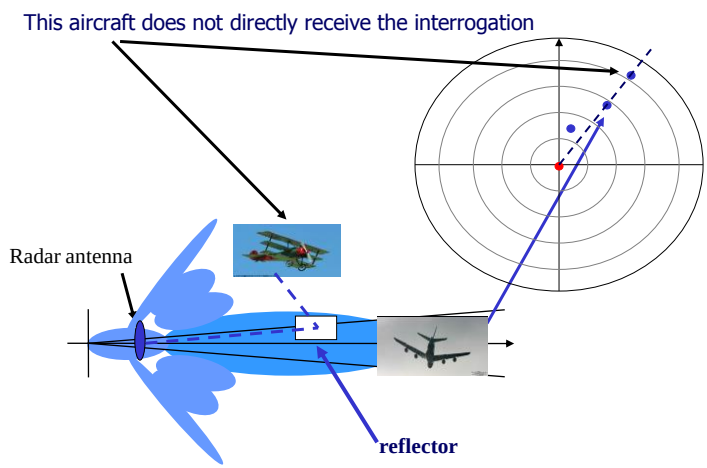
Deficiencies : phantom



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Deficiencies

	PSR	SSR	Mode S
2nd sweep	Yes	Yes	No
Blind zone	Yes	No	No
Cone of silence	Yes	Yes	Yes
Paper hat	Yes	No	No
garbling	Yes	Yes	No
Phantom	Yes	Yes	Yes
Sidelobe			
FRUIT			

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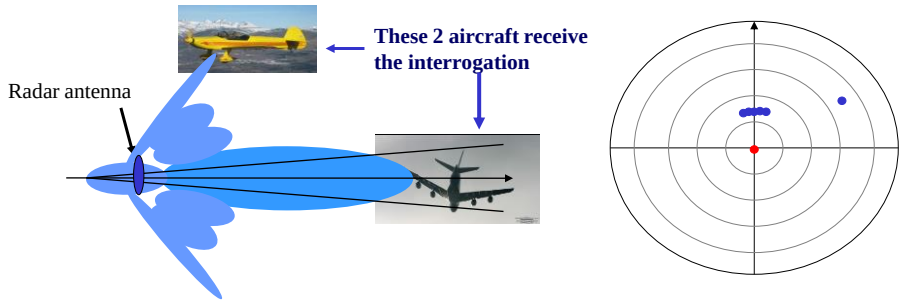
Deficiencies : sidelobes



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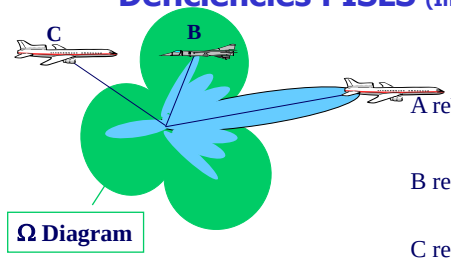
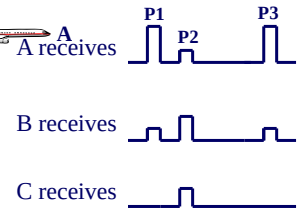
Deficiencies : ISLS (Interrogation path Side Lobe Suppression)



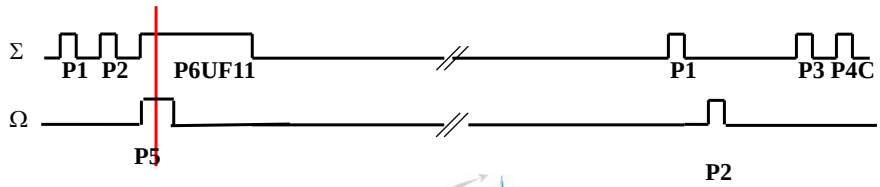
Ω Diagram



A receives — if P1 & P3 > P2+ 9db, A shall reply

B receives — if P1 & P3 < P2+9db, B does not reply

C receives — Only P2, Nothing happens



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Deficiencies

	PSR	SSR	Mode S
2nd sweep	Yes	Yes	No
Blind zone	Yes	No	No
Cone of silence	Yes	Yes	Yes
Paper hat	Yes	No	No
garbling	Yes	Yes	No
Phantom	Yes	Yes	Yes
Sidelobe	Yes	ISLS => No	ISLS => No
FRUIT			

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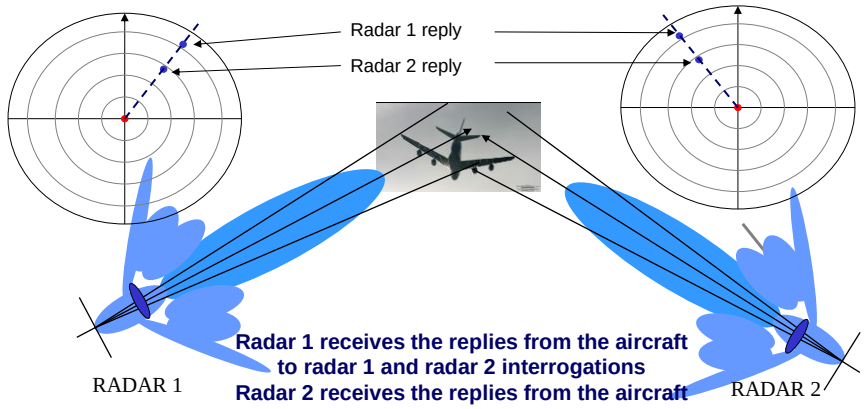
Deficiencies : FRUIT (False Replies Unsynchronized with Interrogator Transmissions)



Radar 1 receives the replies from the aircraft to radar 1 and radar 2 interrogations
Radar 2 receives the replies from the aircraft to radar 1 and radar 2 interrogations

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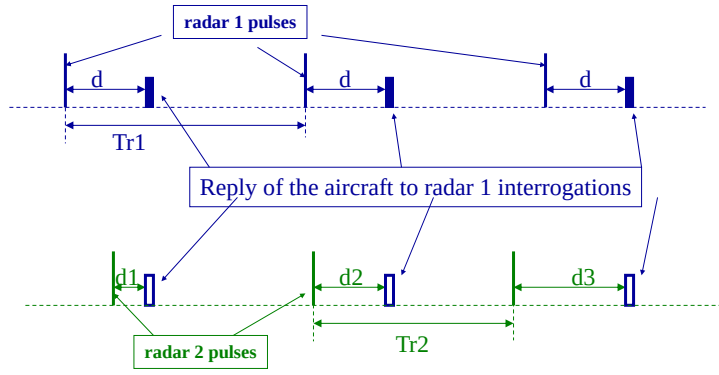
Deficiencies : PRF Staggering



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Deficiencies

	PSR	SSR	Mode S
2nd sweep	Yes	Yes	No
Blind zone	Yes	No	No
Cone of silence	Yes	Yes	Yes
Paper hat	Yes	No	No
garbling	Yes	Yes	No
Phantom	Yes	Yes	Yes
Sidelobe	Yes	ISLS => No	ISLS => No
FRUIT	PRFS => No	PRFS => No	PRFS => No

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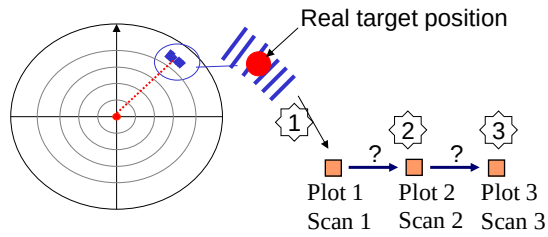
Track initiation in PSR



1 **Plot Creation** — Hit processing : comparison of measured ranges and azimuths and Doppler frequency estimation

2 **Tentative track** — Coherent position of plots
Comparison of Doppler speeds
There are not many criteria in PSR except for cinematics

3 **Confirmed track** — Speed vector calculation inculding modulus and track angle

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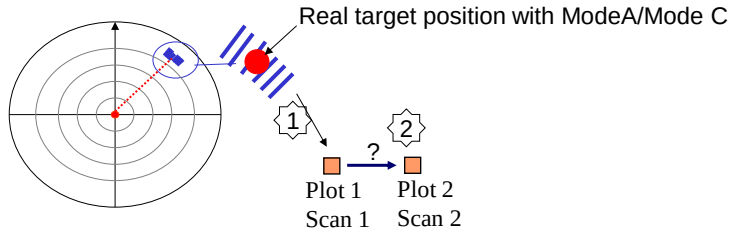
Track initiation in SSR



1 **Plot Creation** Hit processing : comparison of measured ranges, azimuths, mode A and mode C

2 **Confirmed track** Speed vector calculation inculding modulus and track angle

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ADS

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Types of ADS

- ADS Contract and ADS Broadcast
  - ADS-C is air-to-ground surveillance only
  - ADS-B is air-to-ground, air-to-air and ground-to-ground surveillance
- Fundamental concept is the same …
  - … but they are very different !
- Developed with different applications in mind
  - Different communities work on each
  - Different standards developed

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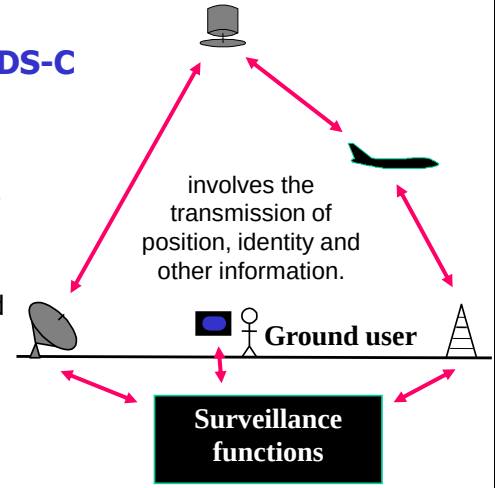
ADS-C

- Each ADS report goes to one recipient on the ground
- Ground establishes 'Contract' for data
  delivery (hence ADS-C)
- Two-way end-to-end guaranteed communications



ADS-C Contracts

- 3 types of contracts:
  - **Periodic:** position reporting at regular intervals
  - **Event:** position reporting following certain events
  - **On-demand:** position reporting as requested by the ground function
- Emergency mode
  - The aircraft transmits its position at a high rate
  - Only contract initiated by the aircraft

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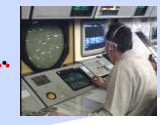
2

Here is:
- Basic Report
- Non compliance notification
- Optional Data

Period per item (multiple of basic rate)

1

Please:
Basic Data Every …
Optional Data Every … (Per Item!)

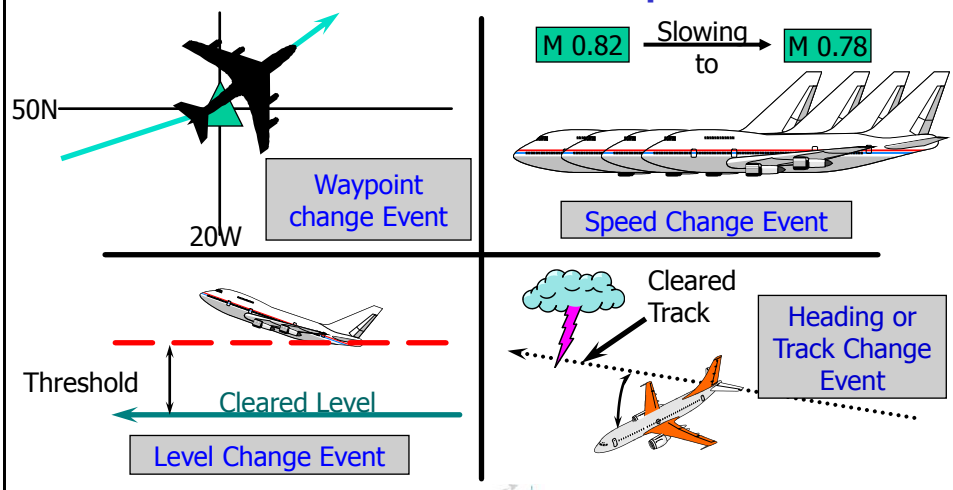


ADS Event Contract

- Vertical rate change,
- Way-point change,
- Lateral deviation change,
- Level change,
- Level range deviation,
- Airspeed change,
- Ground speed change,
- Heading change,
- Extended projected profile change,
- FOM (Figure of Merit) field change,
- Track angle change.

Event contract operation is extremely beneficial as an ATC monitoring tool.

ADS Event Contract Examples



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2

Here is:
- Basic Report
- Non compliance notification
- Information Requested

1

Please:
- Basic ADS Report
- Optional ADS Data

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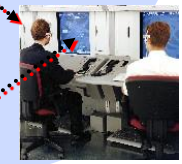
ADS Emergency Contract

MAYDAY!!



Both air and ground systems must support an emergency mode capability

Emergency Identification

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ADS-C Possible Implementations

- CNS/ATM-1 (ICAO standard)
- FANS-1/A (industry standard)
  - FANS-1 ⟹ Boeing
  - FANS-A ⟹ Airbus

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ADS-B

Automatic dependent surveillance - Broadcast

- Automatic: No interrogation from the ground
- dependent: Position estimated on board
- surveillance: Surveillance data
- Broadcast: Sent without reception check

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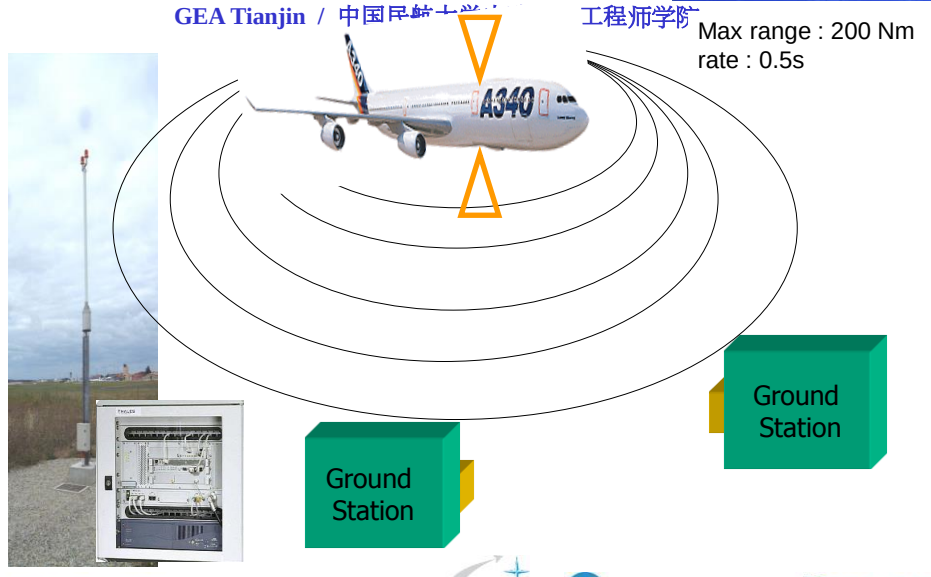

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Data Links

Extended Squitter (1090ES) used as ADS-B data-link by

- Europe
- USA (commercial aviation)
- Australia
- China (commercial aviation)

UAT used as ADS-B data-link by

- USA (general aviation)
- China (general aviation)

VDL mode 4 used as ADS-B data-link by

- Russia
- Northern Europe countries (Sweden, Finland, Norway …)

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Surveillance

Position
- Longitude
- Latitude
- Barometric Altitude

} WGS 84

24 bit Address, Flight ID, ground speed or air speed, vertical speed, heading, emergency or priority messages (medical, short on petrol, radio failure, hijacking, …), status messages ….

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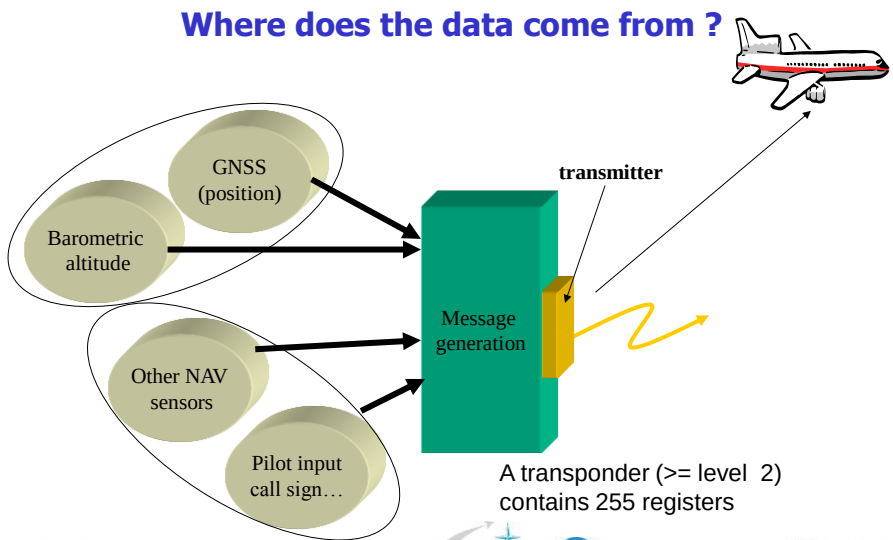
Where does the data come from ?



A transponder (>= level 2) contains 255 registers

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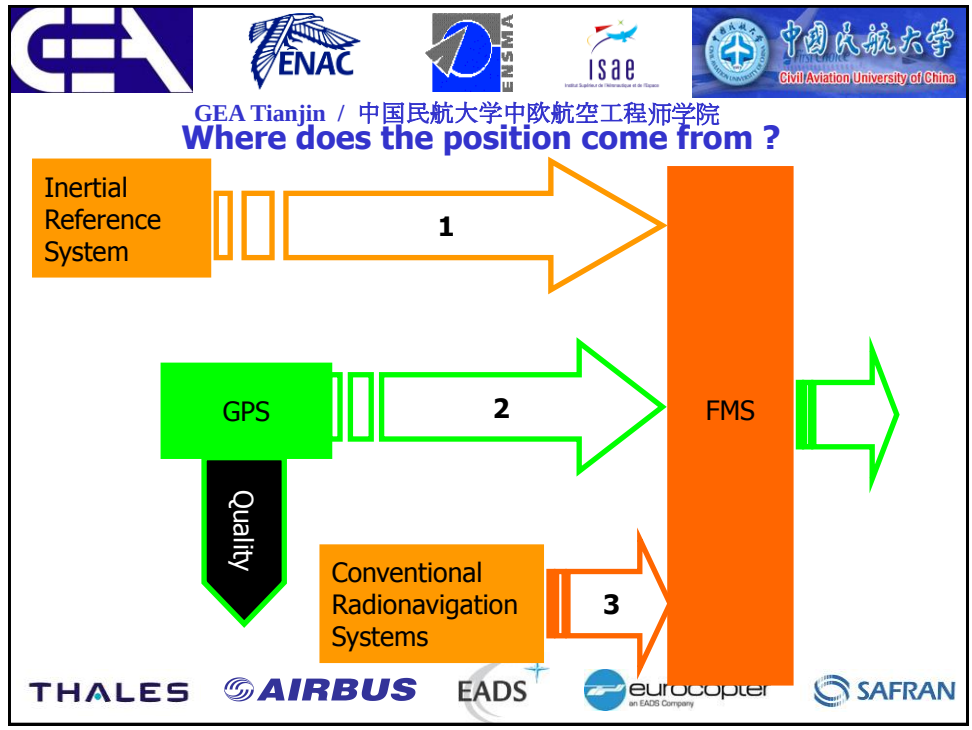
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Where does the position come from ?
Inertial Reference System
1
GPS
2
FMS
Quality
Conventional Radionavigation Systems
3
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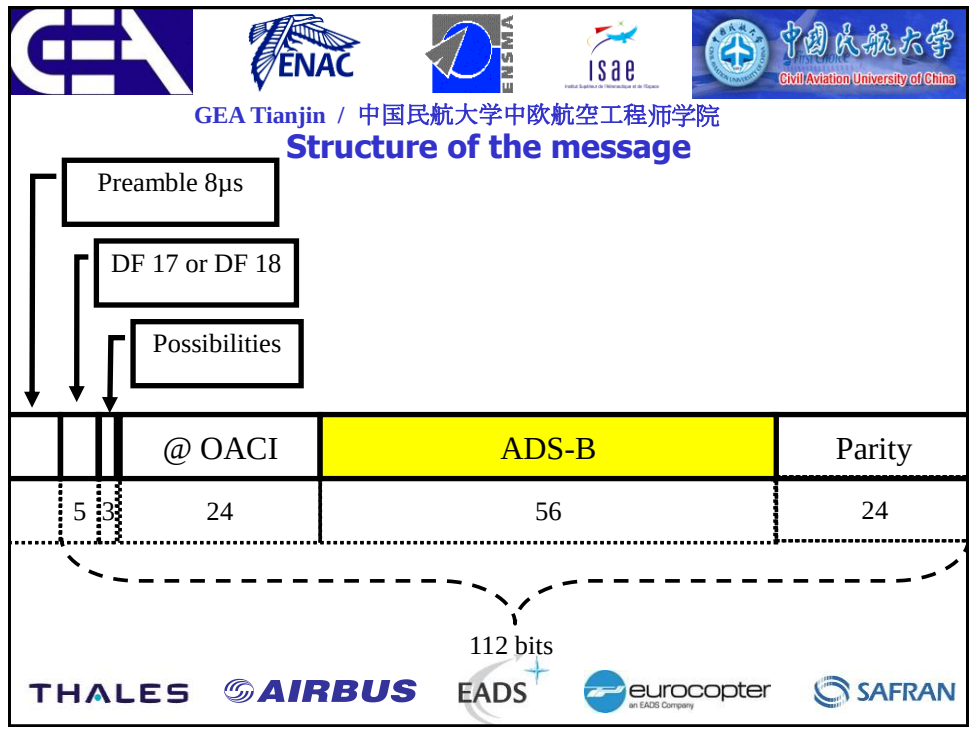
AIRBUS
EADS
eurocopter
SAFRAN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Structure of the message
Preamble 8µs
DF 17 or DF 18
Possibilities
@ OACI
ADS-B
Parity
5
3
24
56
24
112 bits
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AIRBUS
EADS
eurocopter
SAFRAN

Table 5-24. Register number assignments

Transponder register No.	Assignment
00_{16}	Not valid
01_{16}	Unassigned
02_{16}	Linked Comm-B, segment 2
03_{16}	Linked Comm-B, segment 3
04_{16}	Linked Comm-B, segment 4
05_{16}	Extended squitter airborne position
06_{16}	Extended squitter surface position
07_{16}	Extended squitter status
08_{16}	Extended squitter identification and type
09_{16}	Extended squitter airborne velocity
$0A_{16}$	Extended squitter event-driven information
$0B_{16}$	Aircraft information 1 (aircraft state)
$0C_{16}$	Air/air information 2 (aircraft intent)
$0D_{16}$-$0E_{16}$	Reserved for air/air state information
$0F_{16}$	Reserved for ACAS
10_{16}	Data link capability report
11_{16}-16_{16}	Reserved for extension to data link capability reports
17_{16}	Common usage GICB capability report
18_{16}-$1F_{16}$	Mode S specific services capability reports
20_{16}	Aircraft identification
21_{16}	Aircraft and airline registration markings
22_{16}	Antenna positions
23_{16}	Reserved for antenna position
24_{16}	Reserved for aircraft parameters
25_{16}	Aircraft type
26_{16}-$2F_{16}$	Unassigned
30_{16}	ACAS active resolution advisory
31_{16}-$3F_{16}$	Unassigned
40_{16}	Selected vertical intention
41_{16}	Next waypoint identifier
42_{16}	Next waypoint position
43_{16}	Next waypoint information
44_{16}	Meteorological routine air report

Transponder register No.	Assignment
45_{16}	Meteorological hazard report
46_{16}	Reserved for flight management system Mode 1
47_{16}	Reserved for flight management system Mode 2
48_{16}	VHF channel report
49_{16}-$4F_{16}$	Unassigned
50_{16}	Track and turn report
51_{16}	Position report coarse
52_{16}	Position report fine
53_{16}	Air-referenced state vector
54_{16}	Waypoint 1
55_{16}	Waypoint 2
56_{16}	Waypoint 3
57_{16}-$5E_{16}$	Unassigned
$5F_{16}$	Quasi-static parameter monitoring
60_{16}	Heading and speed report
61_{16}	Extended squitter emergency/priority status
62_{16}	Reserved for target state and status information
63_{16}	Reserved for extended squitter
64_{16}	Reserved for extended squitter
65_{16}	Aircraft operational status
66_{16}-$6F_{16}$	Reserved for extended squitter
70_{16}-75_{16}	Reserved for future aircraft downlink parameters
76_{16}-$E0_{16}$	Unassigned
$E1_{16}$-$E2_{16}$	Reserved for Mode S BITE
$E3_{16}$	Transponder type/part number
$E4_{16}$	Transponder software revision number
$E5_{16}$	ACAS unit part number
$E6_{16}$	ACAS unit software revision number
$E7_{16}$-$F0_{16}$	Unassigned
$F1_{16}$	Military applications
$F2_{16}$	Military applications
$F3_{16}$-FF_{16}	Unassigned

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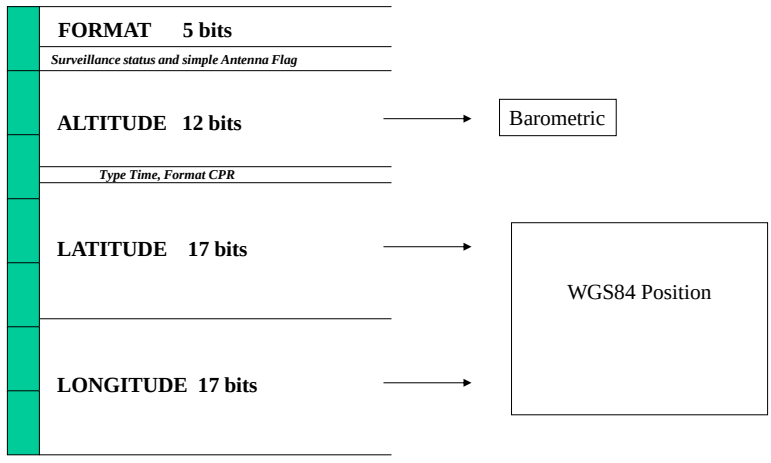
BDS 0,5 : Extended Squitter airborne position



Transmission intervals

The core of the message (register) is only 56 bits long.

-> we need to collect several messages to get the complete information on a given aircraft

-> all messages are not sent at the same rate

Position	0.5s
Flight ID	5s

To avoid overlapping of messages coming from different aircraft

Fixed interval +/- random delay
0,5s +/- 0,1s
5s +/- 0,2s

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Quality of the positioning

- ADS-B = **dependent**

Advantage
The accuracy of positioning does not depend on the distance between the aircraft and the ground station

Drawback
Poor quality positioning data may imply dangerous situations

Indicators such as NIC/NAC/SIL give an estimate of the positioning and speed data quality

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ADS-B Full

ADS-B Out

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ADS-B Full

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Multilateration

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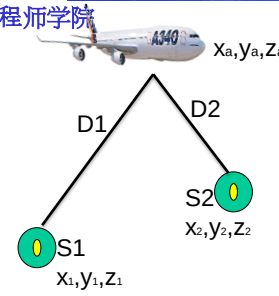
Multilateration

We know the position of 2 receiving stations in a 3D orthonormal basis (x,y,z)

The following equation has to be solved



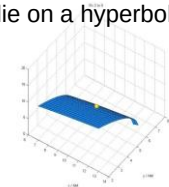
$$D = D1 - D2$$

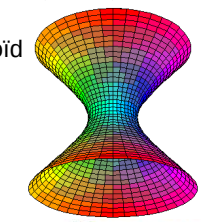
$$D = \sqrt{(x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2} - \sqrt{(x-x_2)^2 + (y-y_2)^2 + (z-z_2)^2}$$

With two stations, the solutions of this equation lie on a hyperboloïd

We need 4 stations, to get the 3D position

(3 will be enough for a 2 D position)





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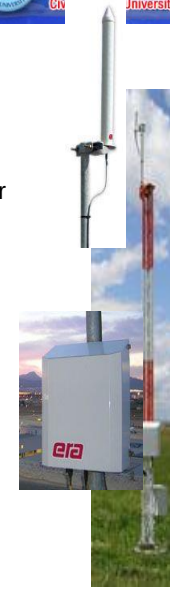
MLat Sensors

Sensor
SENSIS

Sensor
ERA



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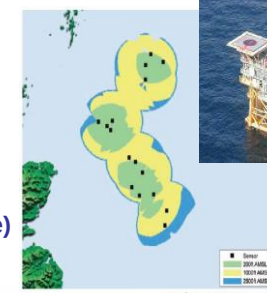
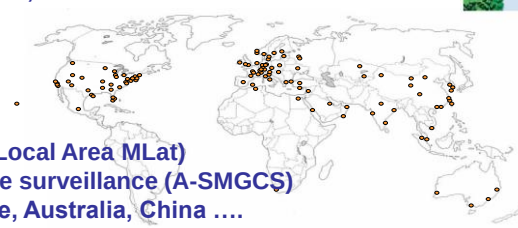
Multilateration



Type WAM (Wide Area MLat)

- **long range surveillance (Approach and En Route)**
- **Eg : Canada, Slovenia**



Type LAM (Local Area MLat)

- **short range surveillance (A-SMGCS)**
- **Eg : France, Australia, China ….**

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Advantages / Drawbacks

- Advantages
- Small size
- Low energy consumption
- Non dependent

- Drawbacks
- Need for a very accurate synchronization system
- Network of « n » stations (depending on the a rea to be covered)
- Garbling and reflections may appear

Cooperative system
Based on Mode S squitters or ADS-B squitters

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Future Sensors : combination of MLat and ADS-B