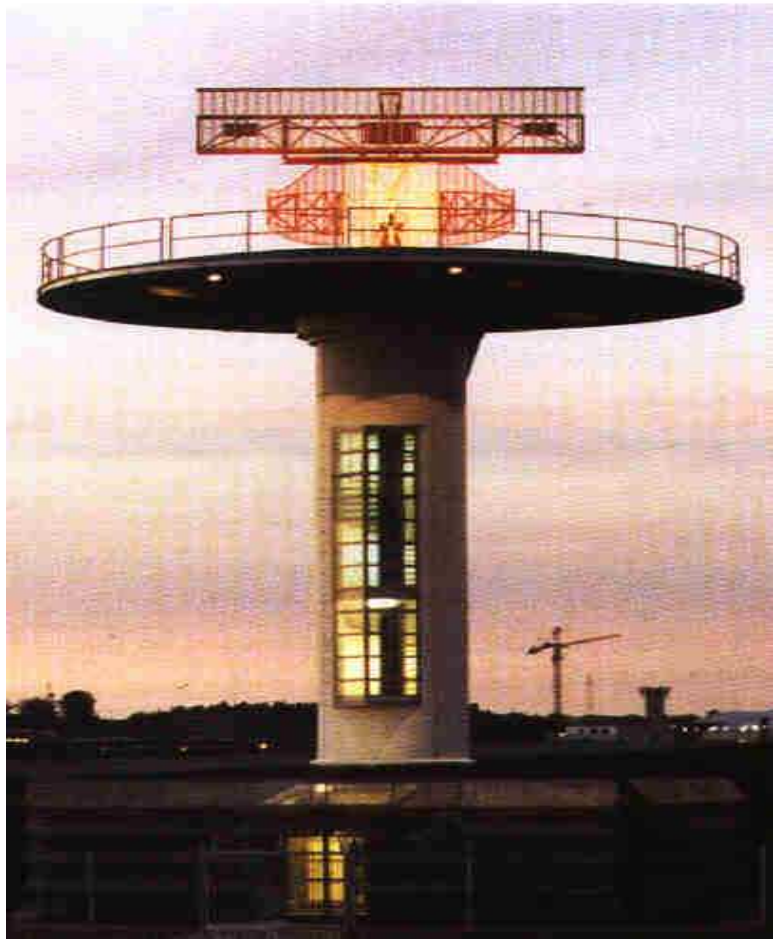
Secondary Surveillance Radar - SSR



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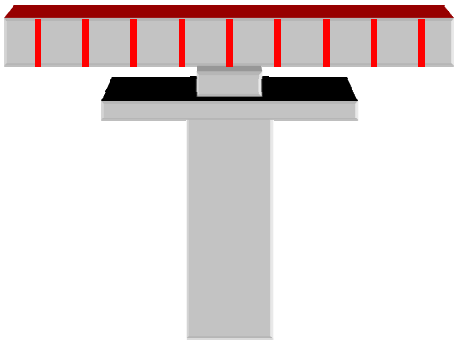
Introduction (1/2)

- Radar Primary (Primary Surveillance Radar - PSR) radiates an EM wave and receives the echo reflected from any objects detecting the presence, distance and azimuth, but not the identity.

- *Identification Friend or Foe* (IFF) - first identification system used by the Air Britain during World War II: airplanes equipped with IFF were able to respond with a precise signal (radio) the question (radio) received from a transmitter to the ground;

- Il Radar Secondario (*Secondary Surveillance Radar* - SSR) IFF represents an evolution that meets the needs of the Air Traffic Control(*Air Traffic Control* - ATC)

Introduction (2/2)



◊ The secondary radar (SSR) is co-operative because it requires the transponder on board the aircraft.

The secondary radar gives 3 coordinates of the plane:

- distance from the sensor
- azimuth with respect to a reference direction
- quote obtained from a dedicated altimeter

◊ The secondary radar (SSR), with the exception of barometric altitude, is independent because is the ground unit that calculates the distance and azimuth of the plane.

generality

primary radar (PSR) ➡ plane is a **passiv element**

Reflects part of the electromagnetic energy that invests itself

Secondary radar (SSR) ➡ plane is as **active element**

answers to the solicitation raised by the radar

Principle (1/3)

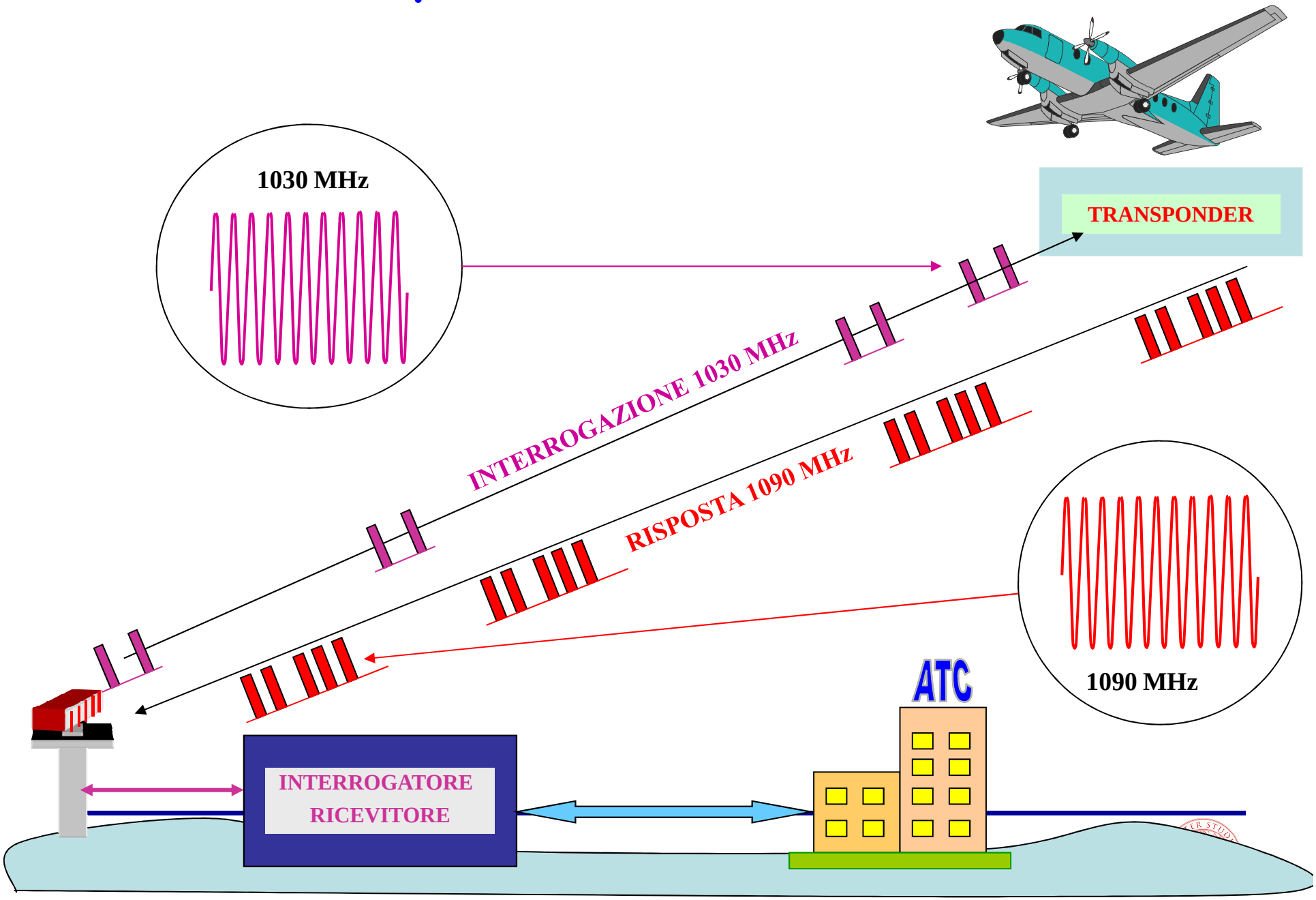
- The secondary radar system is capable of detecting the presence of aircraft that are equipped with a special unit (Transponder) to respond to the solicitation that come from the ground.

- The unit of land (Query-RECEIVER) SSR periodically broadcasts (with time interval = PRT - Pulse Repetition Time), the "coded questions" by means of a rotating directional antenna;

- TRANSPONDER :The board receives the individual questions, after decoding them, it will transmit single "responses coded" (sequences of pulses of appropriate features).

- RESPONDER: The response obtained from the satellite allow to calculate ground station azimuth and distance, using the same technique of a primary radar, and decoding the pulses of the response can give also additional information additional information.

Principle(2/3)



Principle (3/3)

Receiver

⇨ Directional Antenna especially in the horizontal plane to obtaine ottenere:

- precisione
- azimut resolution

⇨ interrogation frequency Fi = 1030 MHz (Up-Link)

TRANSPONDER

⇨ quasi Omnidirectional antenna

⇨ answer frequency Fr = 1090 MHz (Down-Link)

SSR frequencies

- standardized by the ICAO
- allow you to use the same antenna to transmit and receive
- not interfere with the PSR

ICAO regulation

DISTANCE and azimuth calculated as the primary radar
IDENTIFICATION initial and continuing
AUTOMATIC TRANSMISSION of barometric altitude
PULSE SPECIAL IDENTIFICATION

Indication of: ⇨ EMERGENCY

⇨ RADIO FAILURE

⇨ ILLEGAL INTERFERENCE

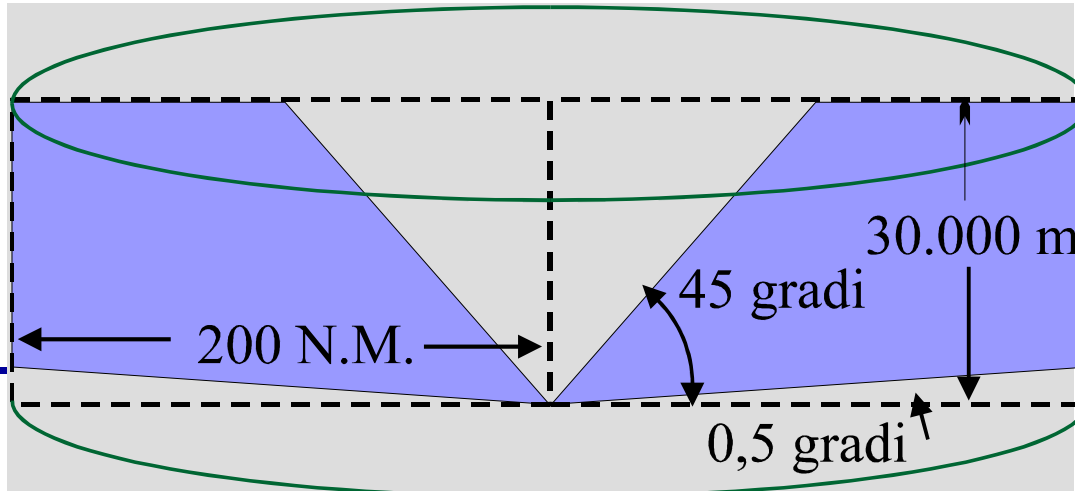
con:

flow = 200 nm (nautical mile) ~ 370 km

quote = 30 km for elevation between 0,5° e 45°

AZIMUT = 360°

PRF = max 450 interr./sec



EUROCONTROL – Coverage requirement

EN-ROUTE AIRSPACE (min separation radar 5 nm)

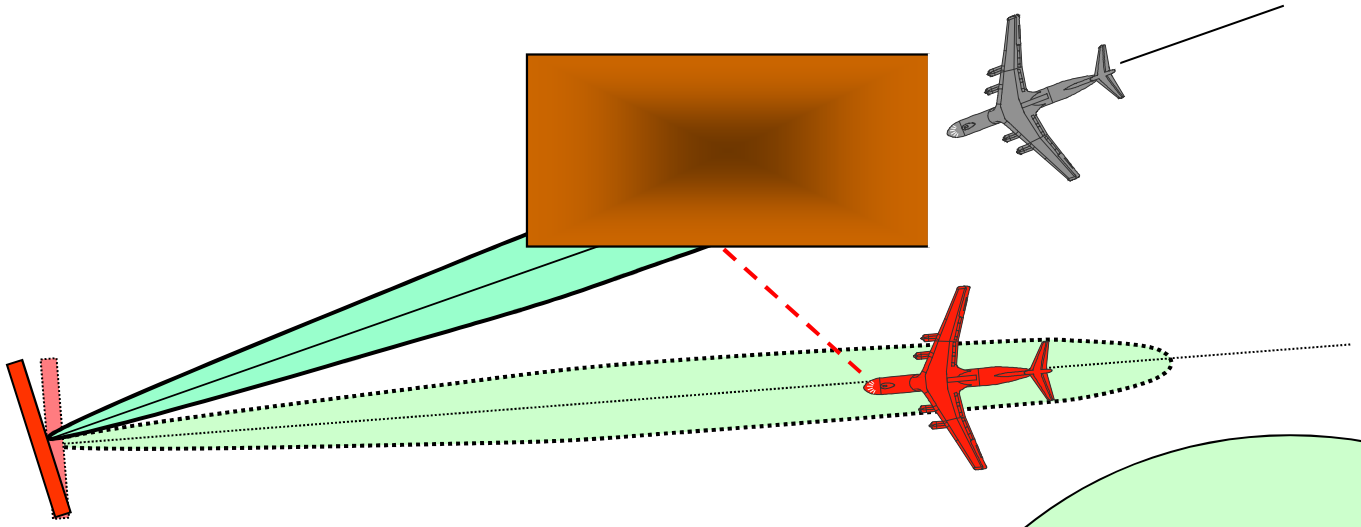
SSR DUPLICATE COVERAGE:
The horizontal scope of coverage must be at least 30 nm over the relevant area of responsibility of the ACC except when this is not possible because of geographical limitations.

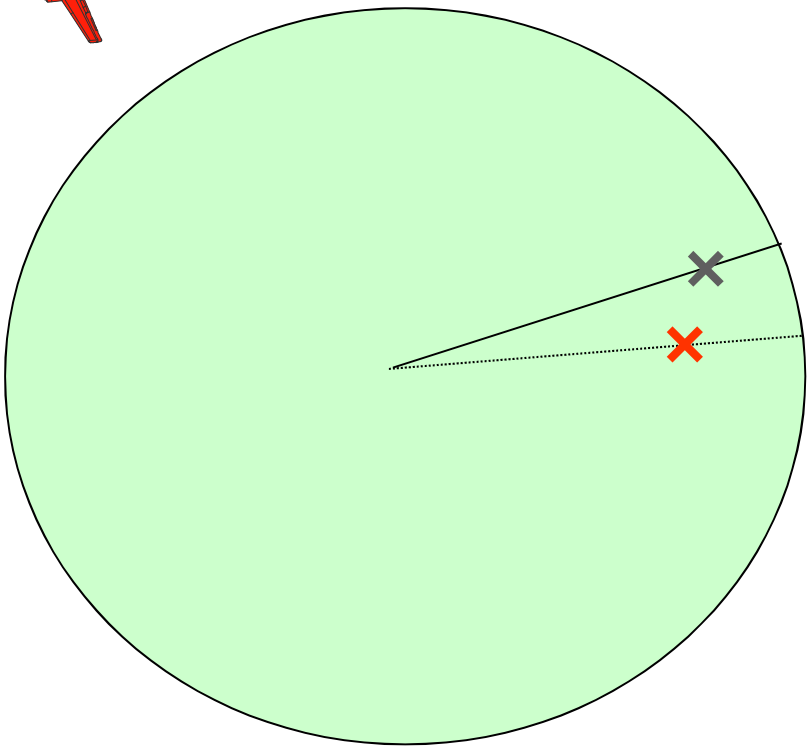
HIGH COMPLEXITY TMA (minima separazione radar 3nm)

INSURANCE COVERAGE primary radar and SSR DUPLICATA SINGLE:
This combination ensures the continuous availability of radar information and allows the position of the aircraft to provide ATC services to aircraft unable to respond to questions SSR.

Note: duplicated SSR coverage means that for a given point in space radar data center used by ATC for the monitoring function are derived from at least two independent units SSR and working separately.

LIMITATION - MULTIPATH



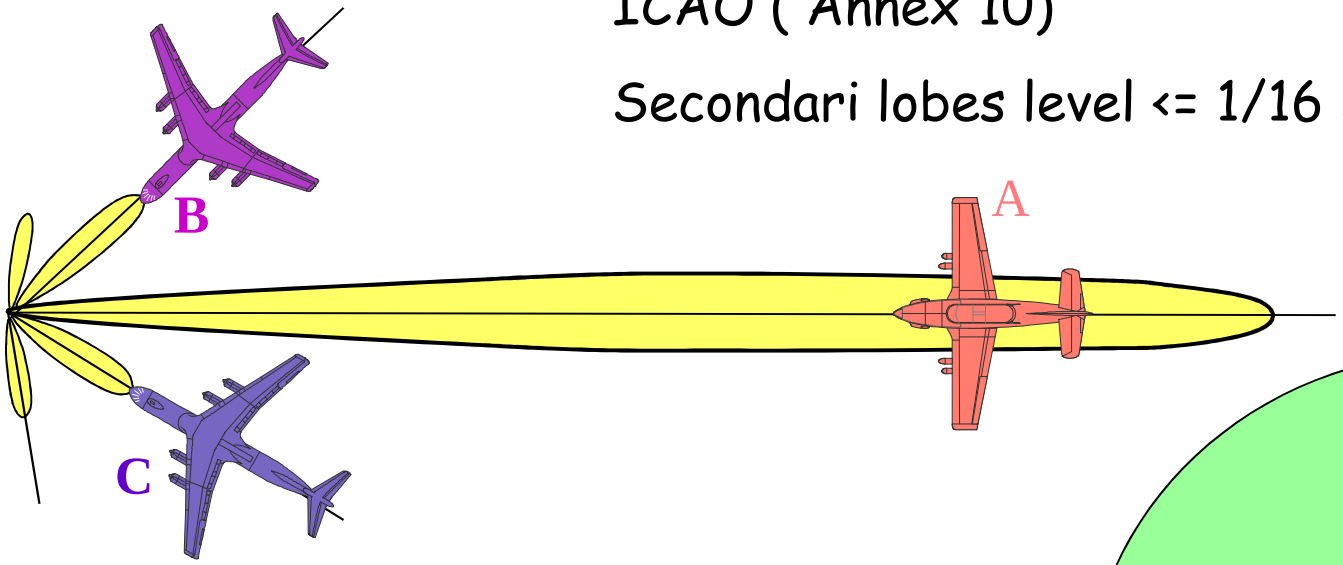


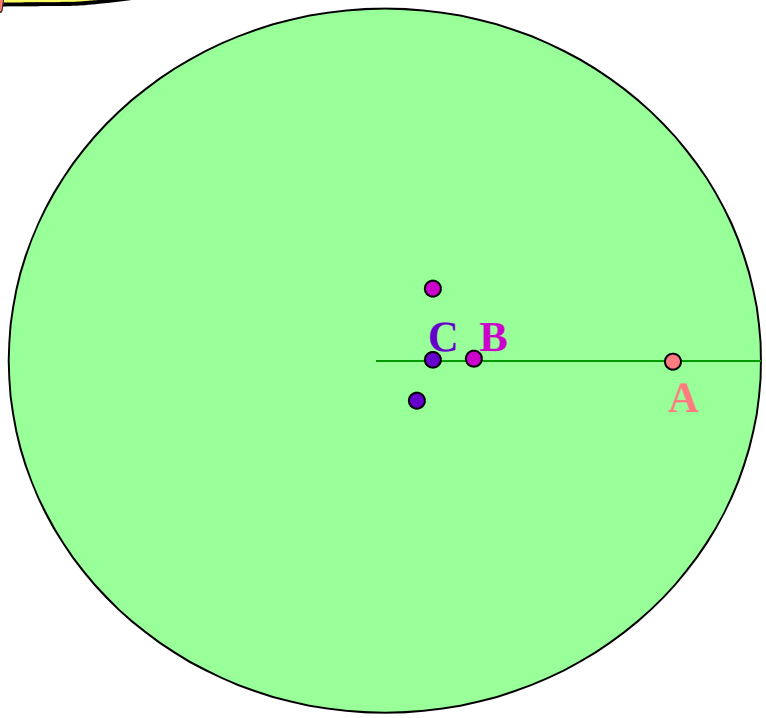
Multipaths can produce " non-existent tracks " (Trace Ghost) that do not correspond to the presence of a plane

LIMITTION – Queries of the secondary lobes

ICAO (Annex 10)

Secondari lobes level <= 1/16 main lobe





Queries

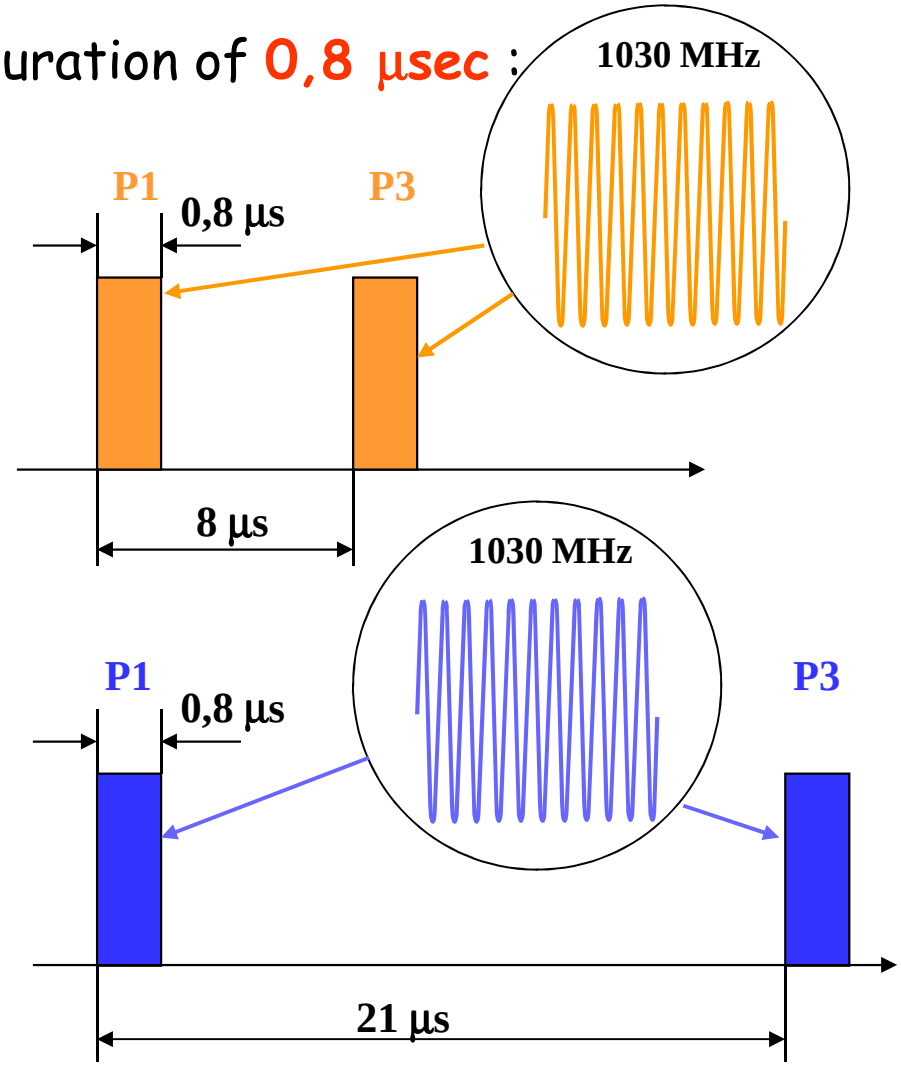
consist of 2 RF pulses (1030 MHz) of duration of 0,8 µsec :

Mode 3/A

Identification and monitoring

Mode C

height of the aircraft



SLS -Side Lobe Suppression

In the secondary radar transponder can be triggered by questions from the detection of secondary lobes producing aircraft in the wrong locations.

The SLS technique allows the transponder to "recognize" if the query comes from the main lobe (in this case the transponder responds) or lobes (in this case the query is ignored).

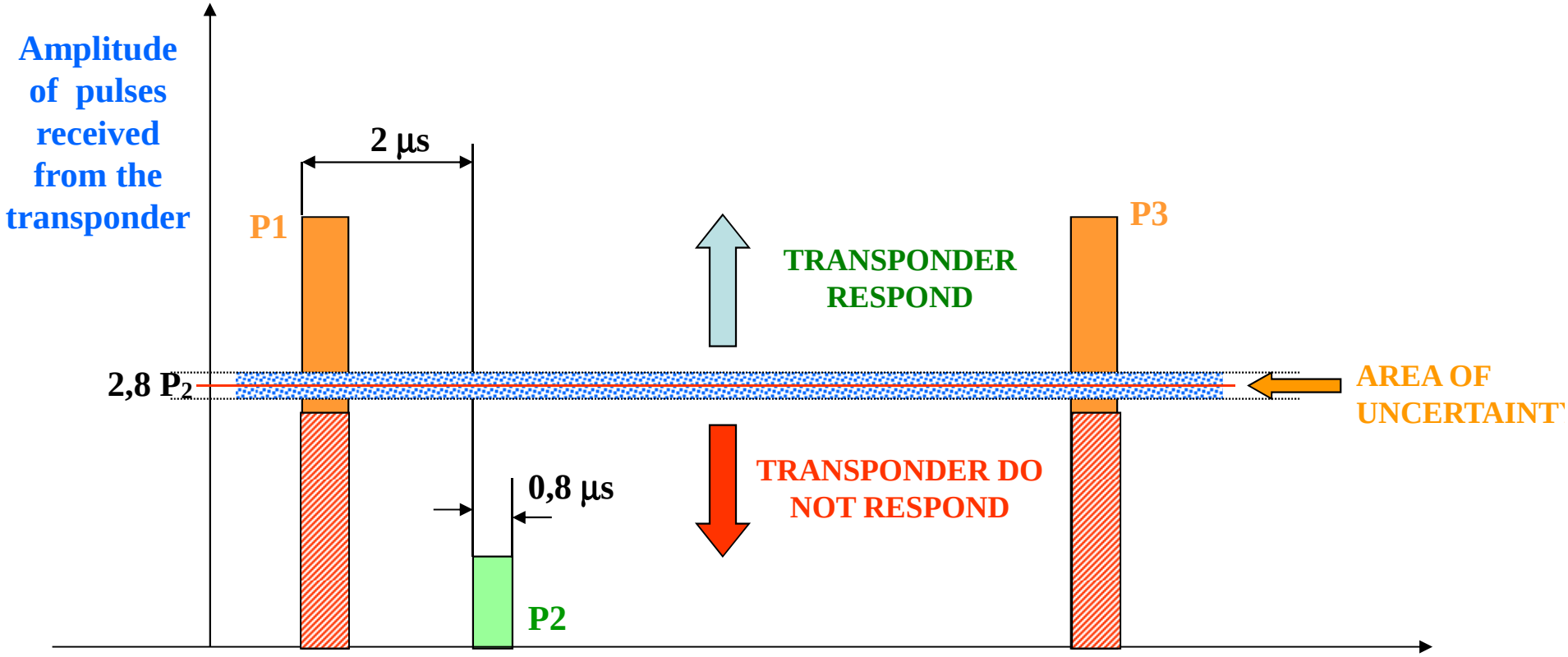
The SLS technique is performed with the transmission of a control pulse P2 (same duration and frequency of P1 and P3) sent 2 usec. after the pulse P1.

The transponder performs the "recognition" of the origin of the question (from the main lobe or side lobes) by comparing the amplitudes of the pulses received (P_1, P_2, P_3).

- Amplitude P_1 of $P_3 \geq 2,8$ time that of P_2 → transponder respond

- Amplitude di P_1 e $P_3 < 2,8$ time that of P_2 → il transponder do not respond

SLS -Side Lobe Suppression



The amplitude of P1 must be > 2.8 times that of P2

The pulse P2 is not participating in the determination of the mode

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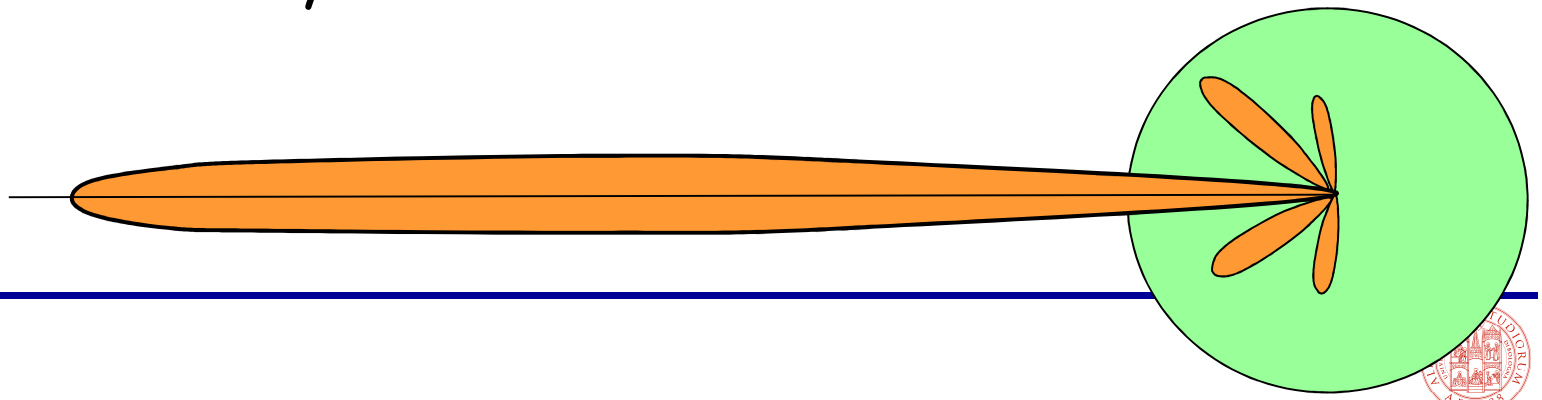
SLS -Side Lobe Suppression

The SLS technique can be performed with two different solutions:

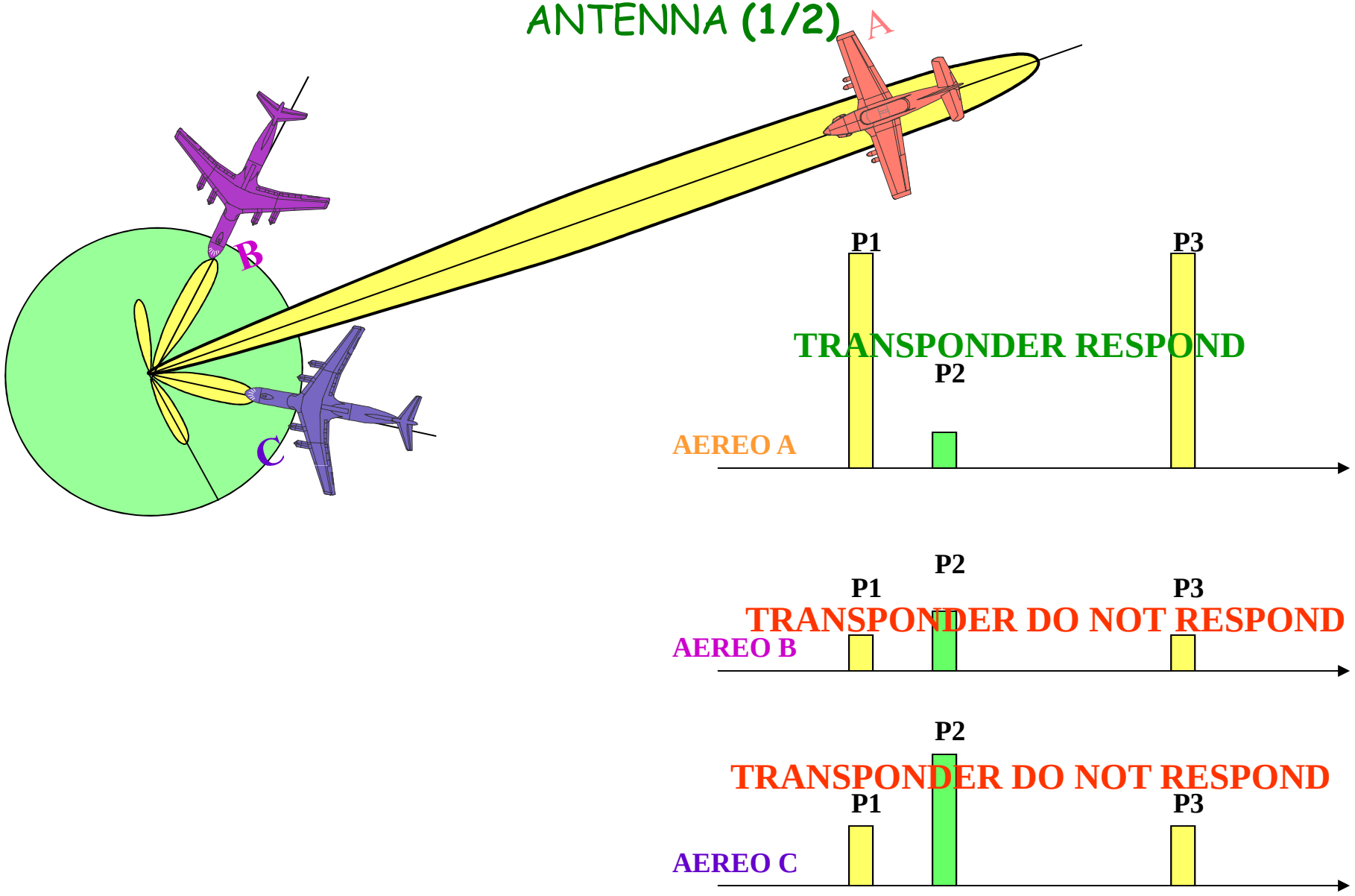
- SLS auxiliary omnidirectional antenna
- SLS antenna "monopulse"

SLS WITH AUXILIARY OMNIDIRECTIONAL ANTENNA

In this realization P1 and P3 pulses are transmitted through the directive antenna while the pulse P2 is transmitted through the auxiliary omnidirectional antenna.
The omnidirectional antenna characteristics must be such that the signal in all directions, P2 must be larger than (P1 and P3) transmitted from the largest lobe and considerably less than that transmitted by the main lobe of the antenna directive.

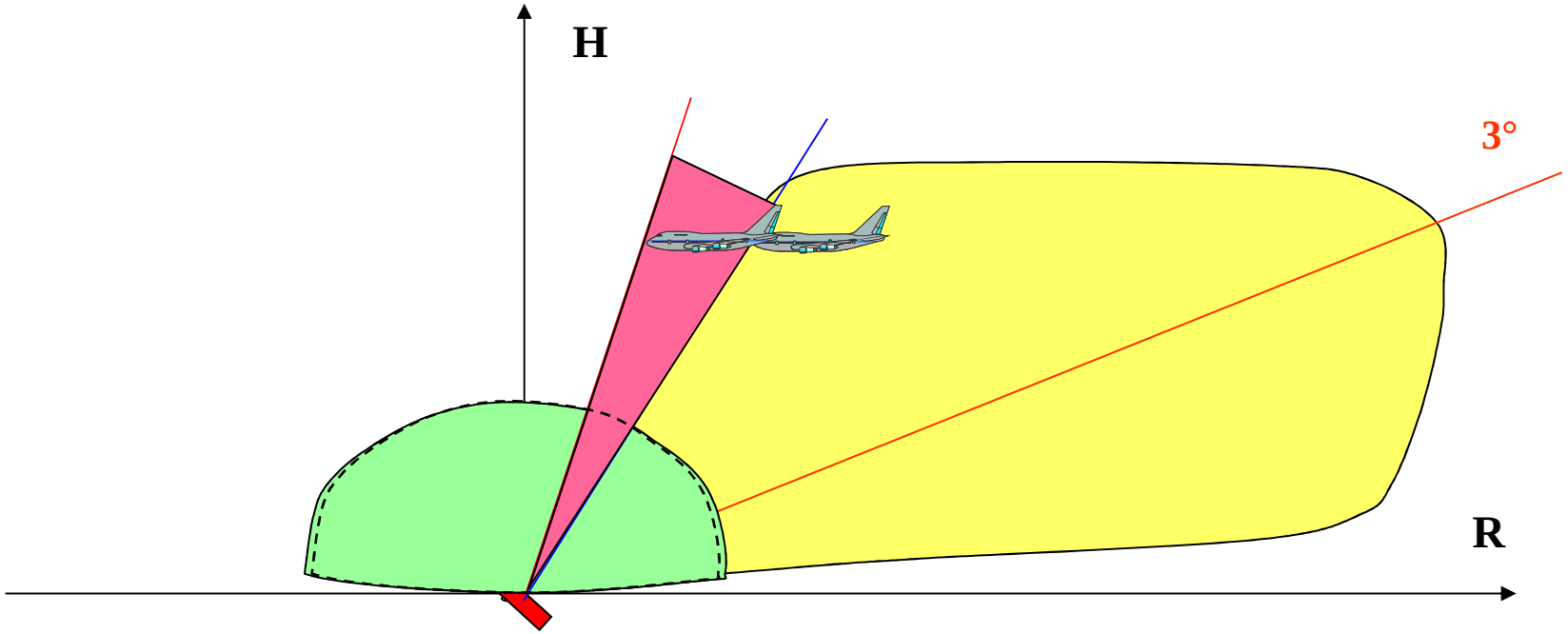


SLS WITH AUXILIARY OMNIDIRECTIONAL ANTENNA (1/2)



SLS WITH AUXILIARY OMNIDIRECTIONAL ANTENNA (2/2)

The SLS carried out with the Auxiliary omnidirectional antenna does not give a good response to high angles where it is difficult to keep under control the radiation pattern of the two antennas (main and auxiliary) to ensure the correct amplitude ratios between P1 and P2-P3 .

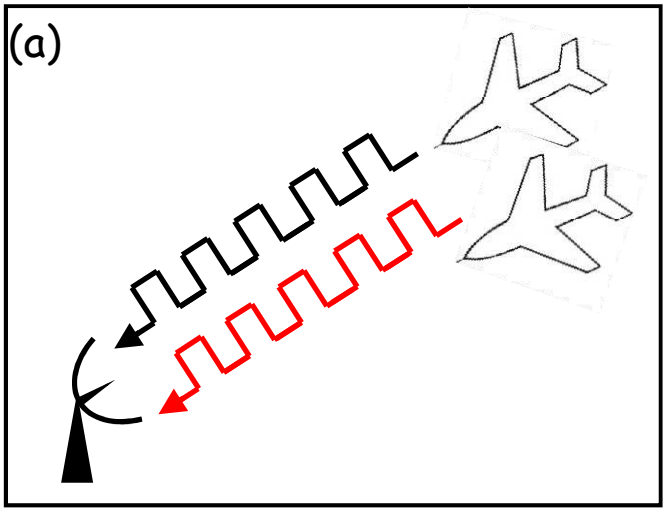


The sum and difference antenna SLS offers better performance.

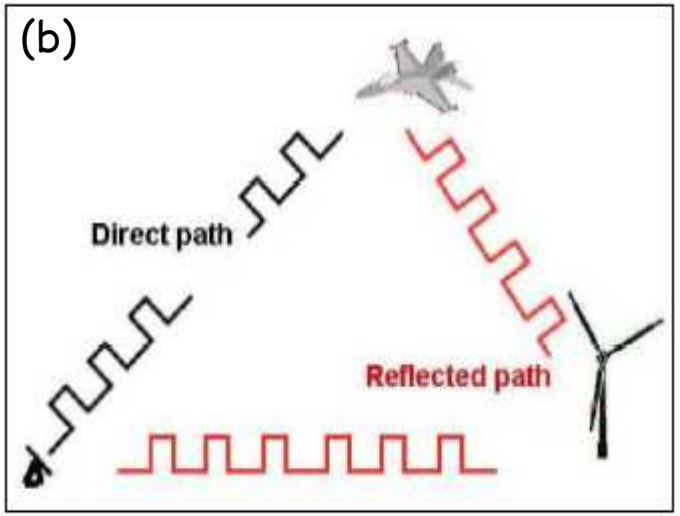
LIMITATION – *Garbling* (1/5)

◊ Garbling = simultaneous overlapping (even partially) to the land receiver at the multiple signals generated in response to the SSR

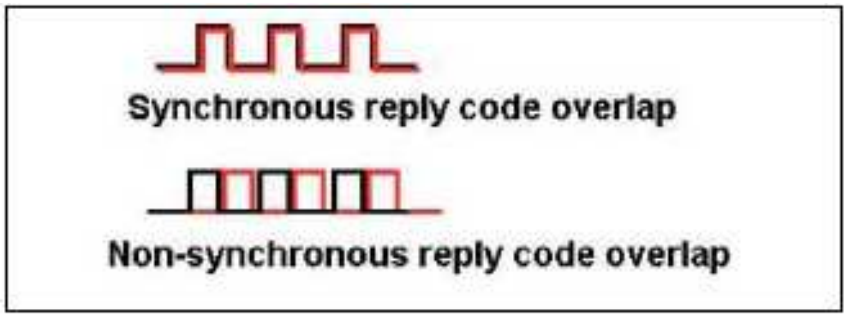
a. Overlapping transponder replies of aircraft relatively close.



b. Superposition of replicas of the response of a single transponder due to multipath



LIMITATION – *Garbling* (2/5)

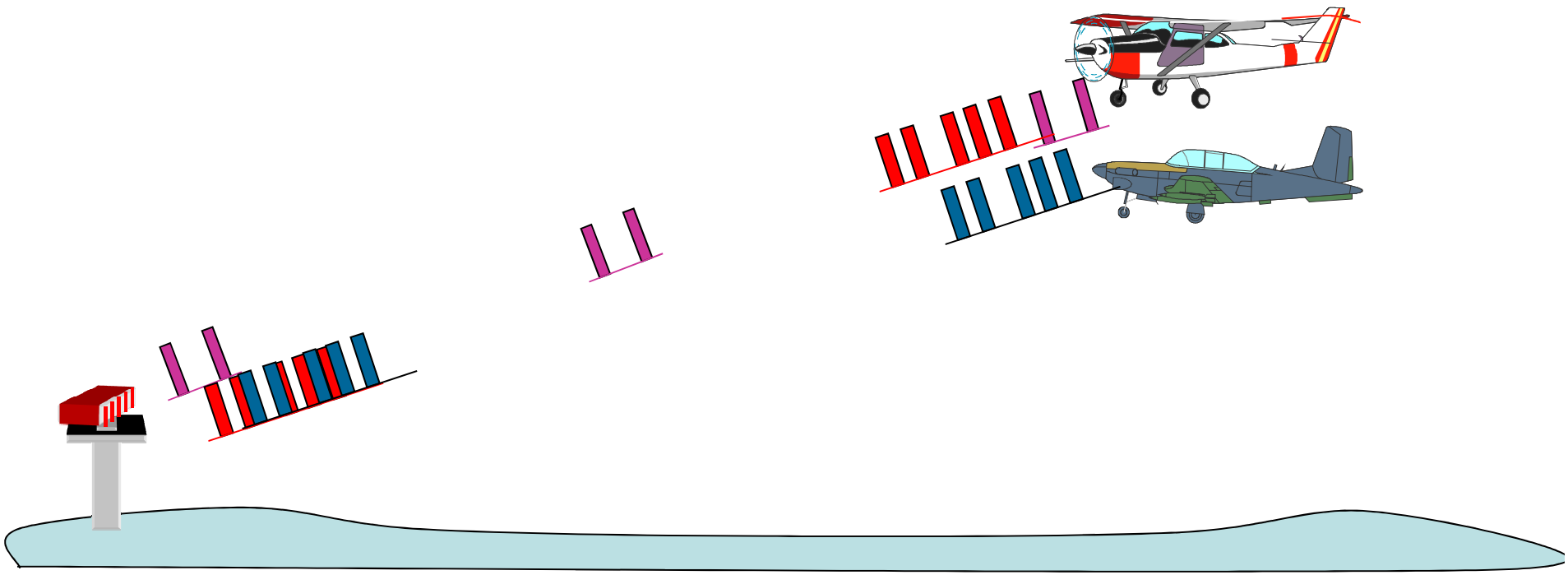


- Synchronous Overlap: the resulting signal meets all specifications in time and amplitude (*) and can appear as a new code word (which no one really sent -> ghost code)
- the two signals are indistinguishable and can not be recovered;
- Potentially damaging situation -> the system must be able to discard the code ghost
- Overlapping asynchronous: the resulting signal does not meet the necessary timescales and so may not appear as ghost queues
- the two signals are potentially distinguishable and can be retrieved;

(*) Each answer consists of a sequence of pulse amplitude and equi-distant 1,45 usec. (or multiples of this value)

LIMITATION – Garbling (3/5)

Overlapping transponder replies of aircraft relatively close.



EffeCT

Inability to distinguish both aircraft

Normally, information and code share will be lost

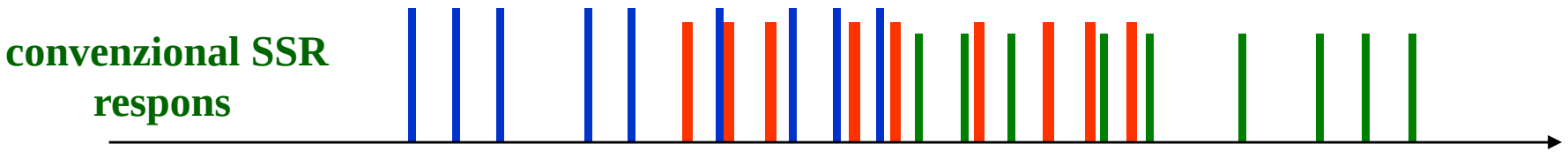
Possibility of "receive" ghost codes (phantom or ghost code)

In high-density airspace traffic aircraft in flight along the same airway can produce "garbling" for long periods

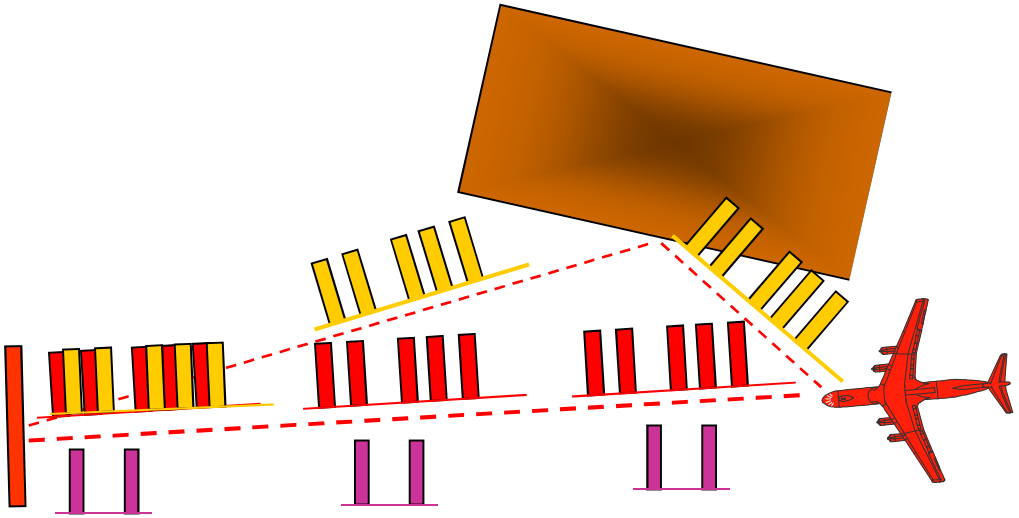
LIMITATION – Garbling (4/5)

PROTECTION

- Ignore the impulse responses with the presence of unexpected
- Store the received codes, when the planes were not so close as to produce garble, and extract the correct codes from correlation algorithms using garble;
- Separate the pulses from a transponder from the other through an accurate measure of the duration and amplitude of individual pulses and the time interval between one pulse and the other (The transponders are not all "equal" and the pulses belonging to a same answer - the same transponder - they normally have similar amplitude and duration)



LIMITATION – Garbling (5/5)



Overlap of replicas of the response of a single transponder due to multipath

- Very often the echo amplitude has a different (lower) than the direct signal -> garbling can be detected and the code recovered by means of algorithms of correlation;

- If the transponder is activated by a lobe, the echo can be detected by the main lobe and then the amplitudes of the two signals can be comparable -> potential "ghost code"

FF30

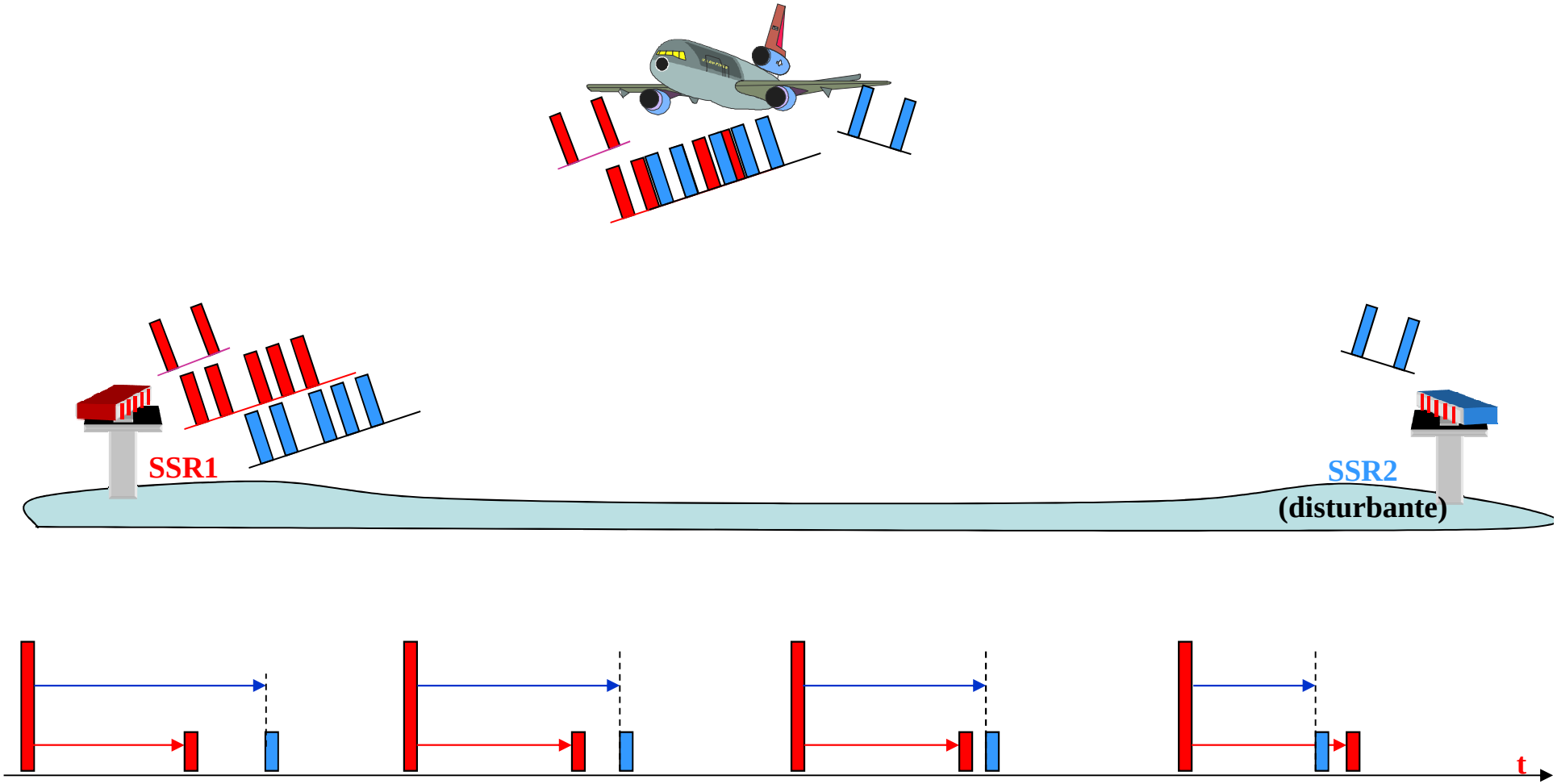
Diapositiva 22

FF30 Si noti che in questo caso, ANCHE qualora il garbling venisse risolto, la stima di posizione sarebbe comunque errata perche' se il Transponder e' attivato da un lobo secondario comunque la posizione verrebbe stimata lungo la direzione del lobo principale

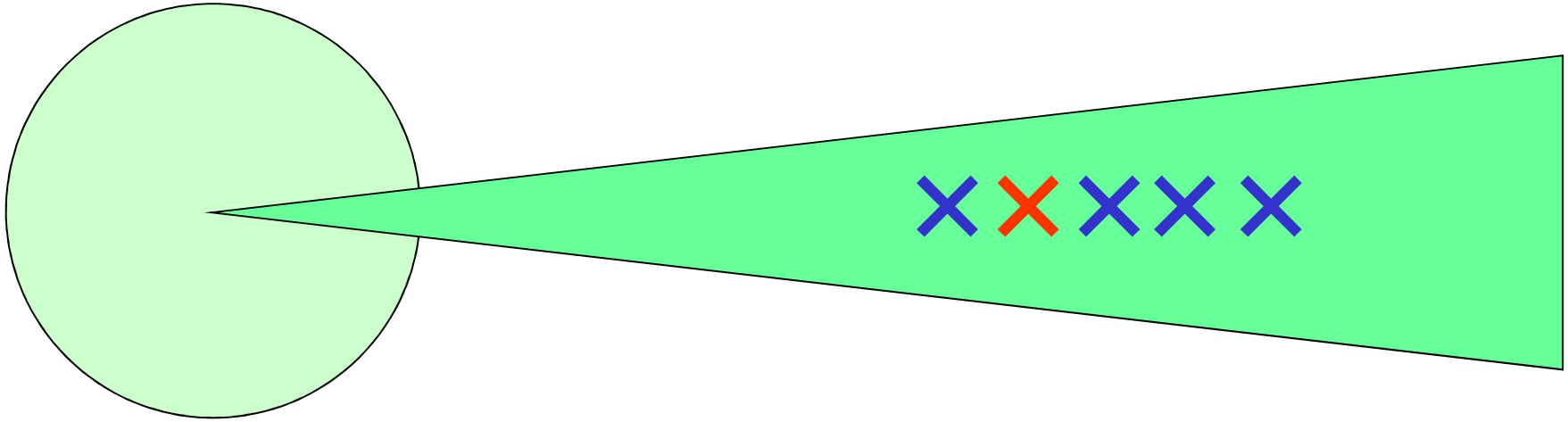
Franco Fuschini; 26/05/2008

False Replies Unsynchronised In Time (FRUIT)

Fruiting = an SSR receives responses to queries made by different SSR (in air spaces at multiple coverage)



FRUITING - Effect



- Receiving answers to questions other SSR (the phenomenon is enhanced by the presence of secondary lobes)
- formally correct answers
- Asynchronous replies
- Introducing non existing traces

FRUITING – Protection (1/2)

- The probability of FRUIT increases with the number of aircraft, the number of interrogations-receivers and the number of questions -> can be limited by minimizing the number of queries (without degrading the performance of the radar);
- Very often the "false replicas" are received by an SSR "through" the lobes of the radiation pattern -> Side Lobe Suppression of reduces the number of FRUIT;

FRUITING – Protection (2/2)

- The asynchronous replication can be "filtered" by controlling the PRT receive:
- - Depending on the PRT of SSR, the rotation speed and scale of the antenna radiation lobe, each aircraft is subject to a number nI of queries each time it is "pointing" the antenna of the SSR (typically nI ~ 16);
- - The transponder responds to all queries and therefore the "repetition period of the answers" is the same period of the interrogation signal (and therefore equal to PRT)
- - SSR have different different PRTs -> "false replicas" can be recognized because they are repeated with a period different from that SSR receives the PRT
- - Circuits Defruiting: store all the responses received, grouped according to the period of repetition and eliminate all the answers with a period of PRT ≠ by SSR

SSR + PSR

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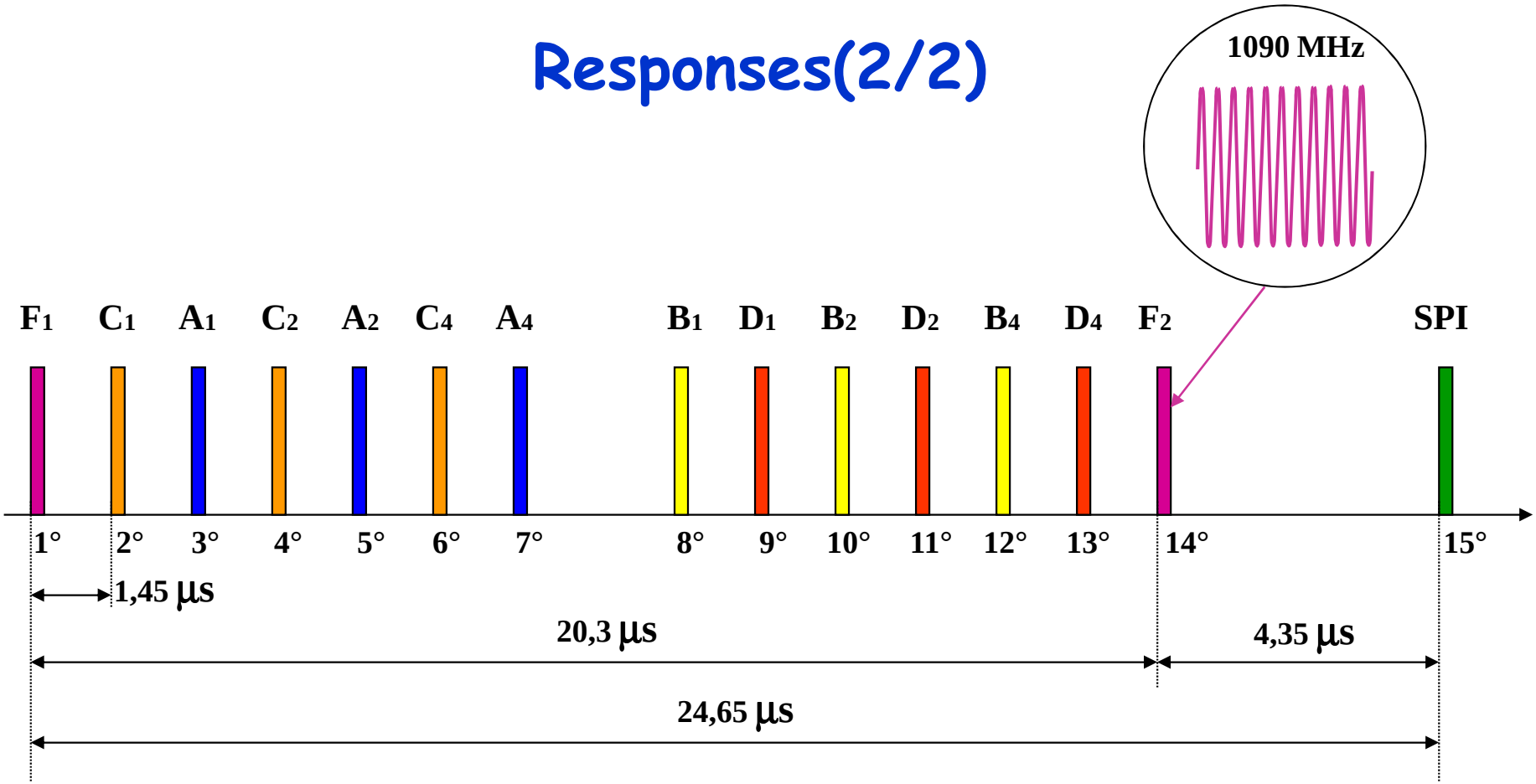
Responses(1/2)

- Series of pulses each lasting 0.45 usec
- Duration of response = 20.3 usec (the length is constant)
- Maximum number of pulses in response = 14
- 1 ° and 14 ° pulse (pulse-frame brackets pulses) are always present
- Interval between one pulse and the other = 1.45 □ sec or multiples
- The answer to Question A is the mode ID CODE
- The answer to questions is the Mode C FEE
- The response code is selected manually
- The answers to questions are Mode C automatic
- Number and location of the pulses in the answer varies depending on:

- query mode (A or C)
- response code or selected value of the share

- Ability to pass a special impulse SPI (Special Position Identification)
- SPI transmitted 4.35 usec after the second frame pulse
- The transmission of the SPI is activated manually and is repeated for a time between 15 and 30 seconds.

Responses(2/2)



CODE

SSR CODE ⇨ 4-digit number expressed in octal number system

(can not use the digits 8 and 9)

Code (1/2)

Rules for the calculation of the code

Pulse A1, B1, C1, D1 associated value 1 if present in the response, 0 if absent

Pulse A2, B2, C2, D2 associated value 2 if present in the response, 0 if absent

Pulse A4, B4, C4, D4 4 if present value associated with the response, 0 if absent

1th digit identification code associated with the sum of the pulses A

2th digit identifier sum of the values associated with the pulses B

3th digit identification code associated with the sum of the pulse C

4th digit of the sum of the identification code associated with the pulses D

ORDERING INFORMATION AVAILABLE = 4096 (from 0000 to 7777)

RESERVED CODES

7500 Hijack

7600 Radioavaria

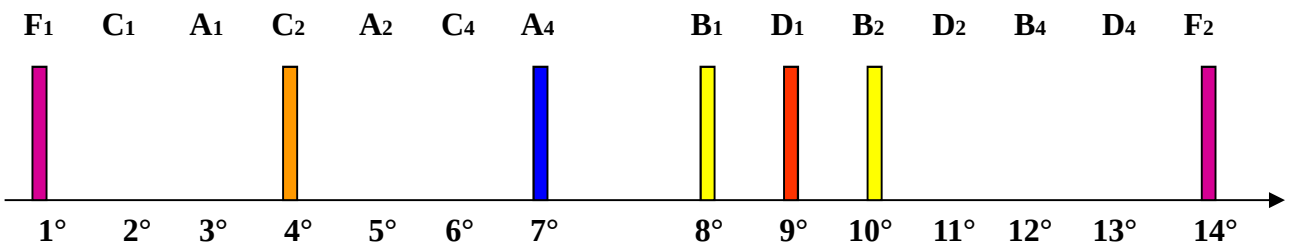
7700 Emergency

0000 General Purpose (regional agreements)

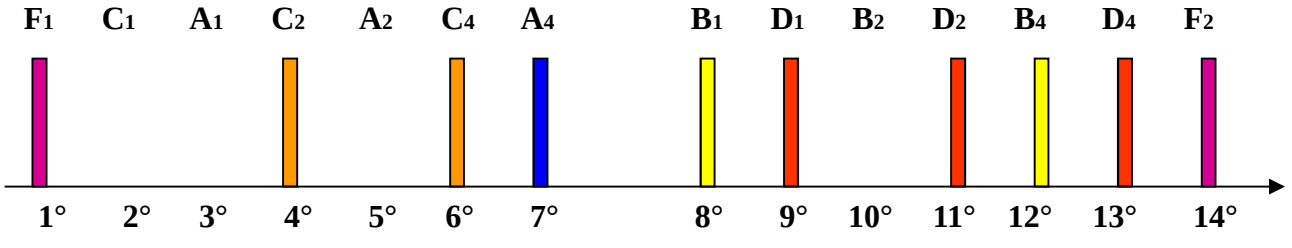
2000 ATC received no instruction to operate the transponder

I Codici (2/2)

EXAMPLE:



4321



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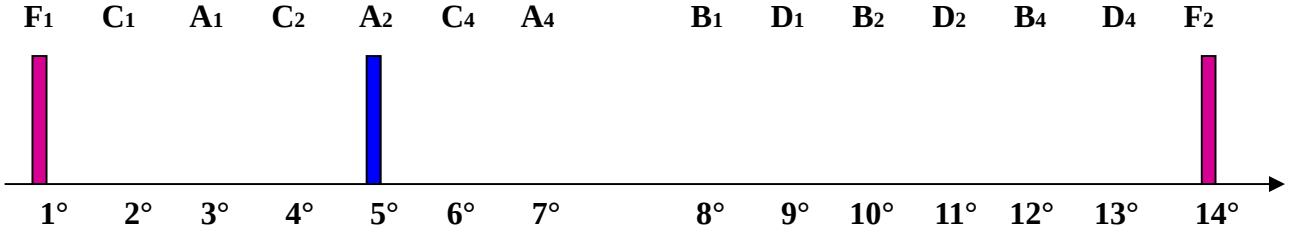
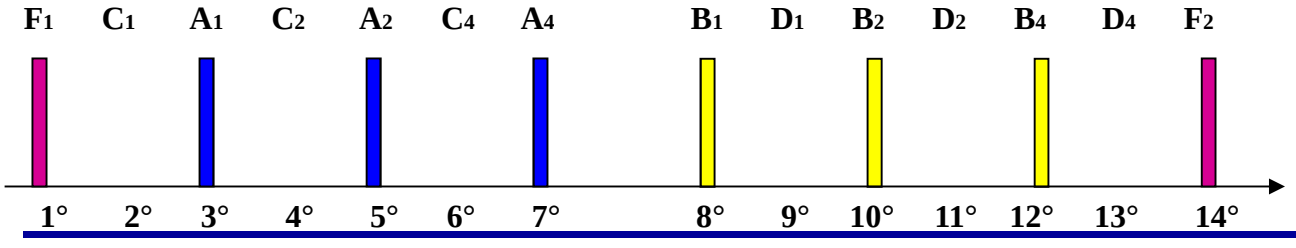


2000



7700

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SSR – height(1/2)

The information obtained from an altimeter altitude are "dedicated" and sent to an analog-digital converter (encoder) that automatically selects the answer to the altitude in increments / decrements of 100 feet in +126,750 -1,000 feet.

You need only 1278 different combinations (available 4096) of the pulse response.

- Enabling the automatic transmission of information is carried by the pilot.
- The information transmitted is always referred to the share standard pressure (1013.25 hPa).
- Share the information submitted have an uncertainty of ± 50 ft (eg in the range +9,950 +10,050 ft and the unit value is always sent in response to +10,000 ft.)

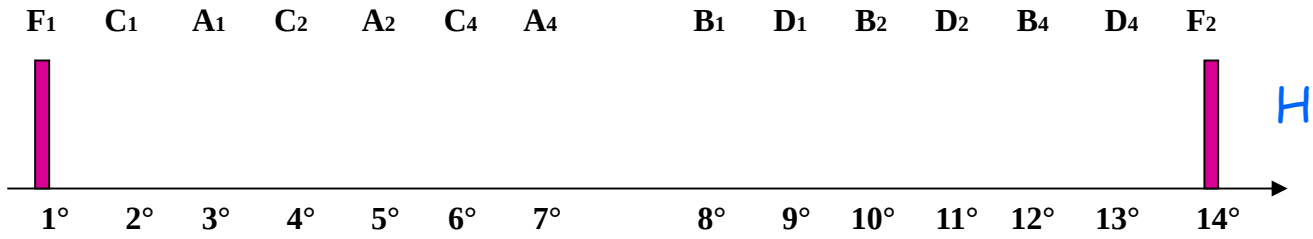
Share information to the controller are presented (as shown in the label):

immediately after decoding the transition level (TL) up

relate them to the correct pressure at sea level (QNH) in that area below the TL.

SSR – height(2/2)

The method of encoding, specified in Annex 10 of ICAO, are such as to avoid ambiguities and errors.
If the transponder does not have the information available pressure-part answer to a question Mode C transmitting only the pulses parentheses.



Height data not availble

The information of altitude are always referred to the standard pressure (the pilot can not change the altimeter setting encoder that sends data to the transponder).
If the pilot manually adjusts the altimeter on board the local QNH, share information verbally transmitted to ATC and the data transmitted from the transponder altitude are different.
Only if the user (ATC) "corrects" the information received, relating them to the local QNH, the two data (verbal transmission of the pilot and altitude on the label) coincide.

SSR –height encoding

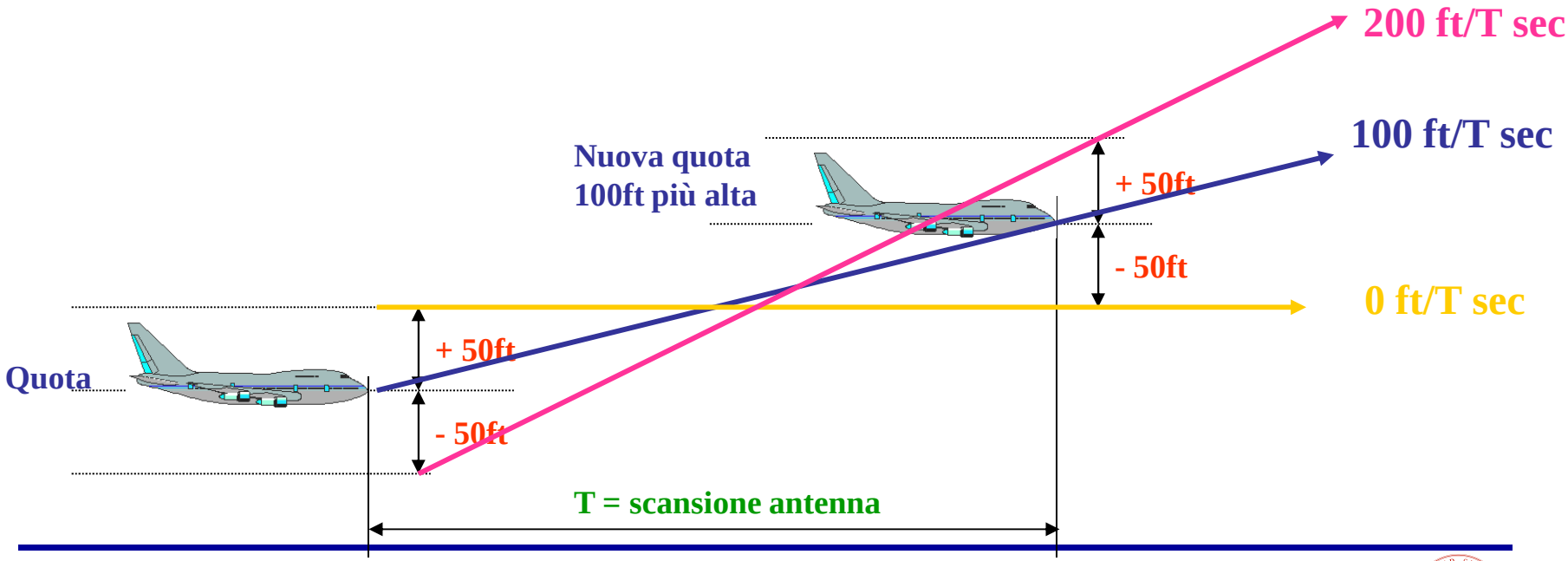
For the transmission of data pulses shall be used A and B, C pulse. C is always present but at least one C1 and C4 never appear together in the same response, the pulse D1 is never used.

RANGE	PULSE POSITIONS (0 or 1 in a pulse positions denotes absence or presence of a pulse, respectively)										
INCREMENTS (Feets)	D_2	D_4	A_1	A_2	A_4	B_1	B_2	B_4	C_1	C_2	C_4
9750 to 9850	0	0	0	1	1	1	0	1	0	0	1
9850 to 9950	0	0	0	1	1	1	0	1	0	1	1
9950 to 10050	0	0	0	1	1	1	0	1	0	1	0
10050 to 10150	0	0	0	1	1	1	0	1	1	1	0
10150 to 10250	0	0	0	1	1	1	0	1	1	0	0
10250 to 10350	0	0	0	1	1	1	0	0	1	0	0
10350 to 10450	0	0	0	1	1	1	0	0	1	1	0
10450 to 10550	0	0	0	1	1	1	0	0	0	1	0
10550 to 10650	0	0	0	1	1	1	0	0	0	1	1
10650 to 10750	0	0	0	1	1	1	0	0	0	0	1

Uncertainty in the height encoding

The height information provided from SSR is encoded in increments of 100ft and have an uncertainty of ± 50 ft, while the modern aircraft altimeters generally have greater accuracy and resolution.

The encoding in increments of 100 ft is sufficiently accurate to be displayed in the label associated to the plane and presented to the controller but it's pretty gross if you want to accurately determine the vertical rate.



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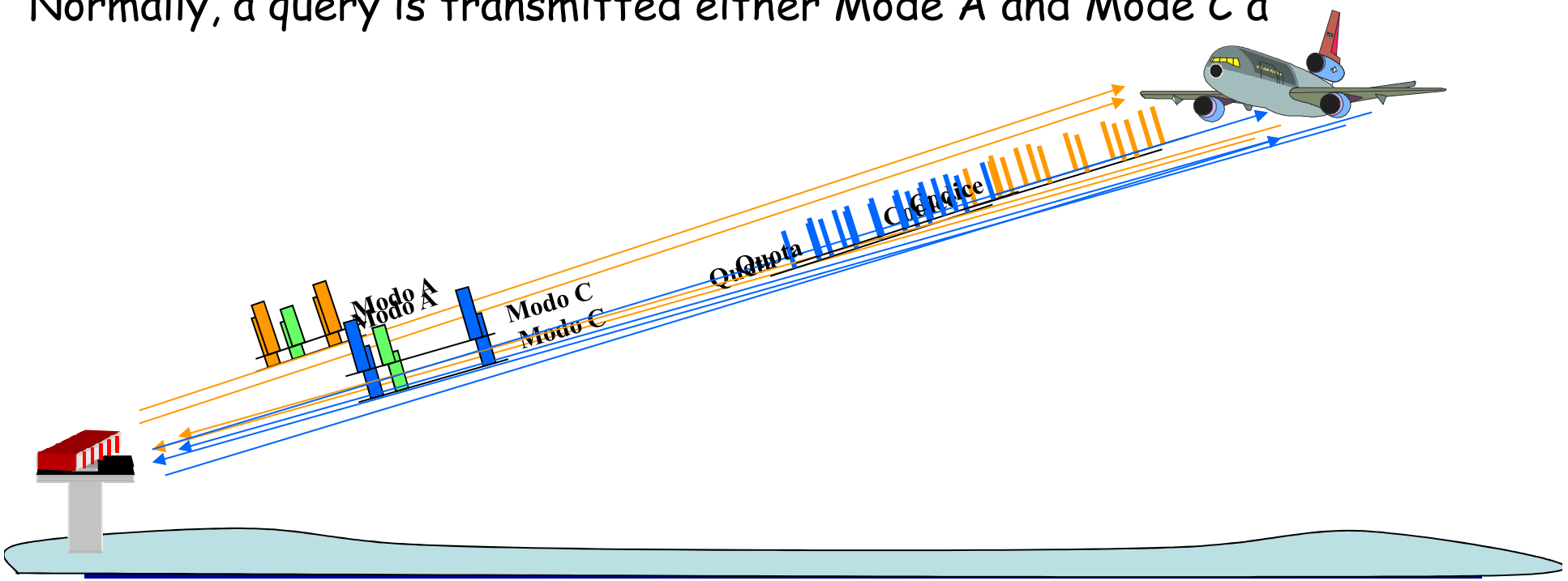
Interleaved queries

The SSR is able to perform a query at a time.
The query mode allows to obtain in response to the ID code, the Mode C's share of the aircraft.

ATC NEEDS => to know the code and the height of the aircraft at each antenna revolution

THE SOLUTION => questions interlaced

The 'query interlaced alternates cyclically queries Mode A and Mode C
Normally, a query is transmitted either Mode A and Mode C a



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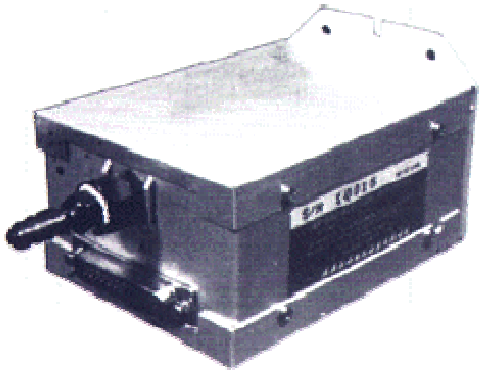
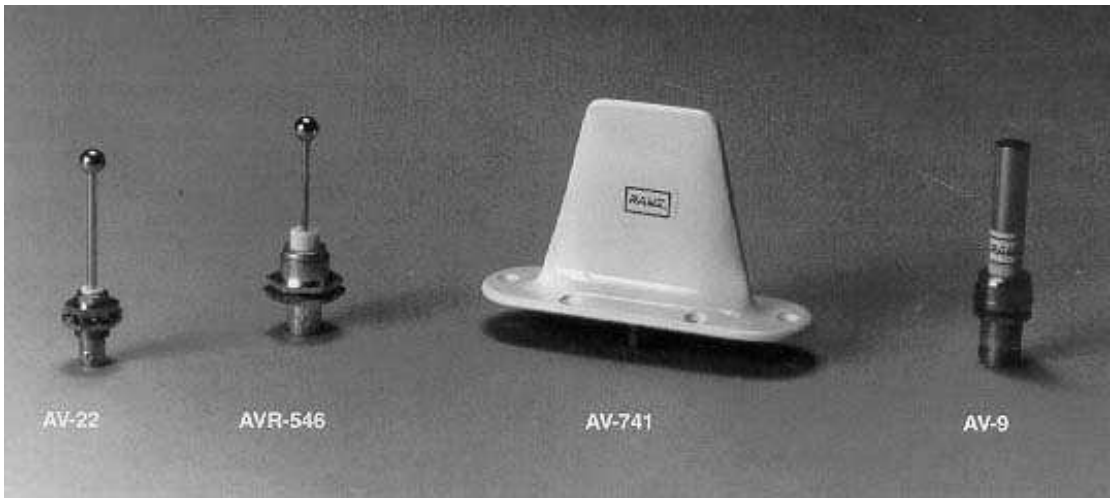
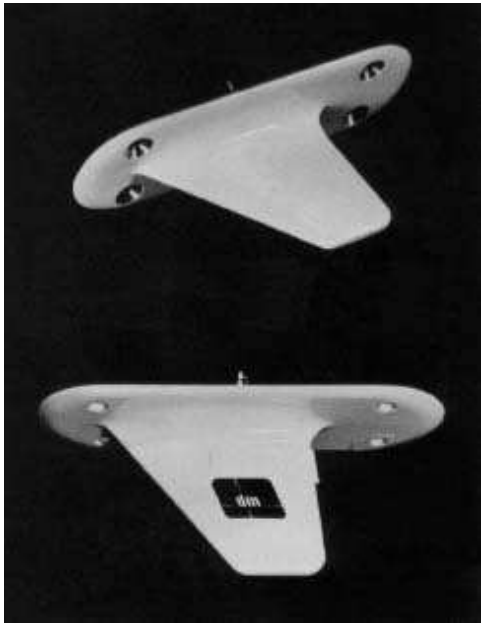
on-board equipment (1/2)







Marconi Wireless

on-board equipment (2/2)

Versione compatta

BLIND ENCODER

Marconi Wireless

on-board equipment - Control Panel

On board equipement– the receiver

The receiver board explores the extent and duration of the pulses received and enable replication after making the following checks:

- amplitudes of P1 and P3 should not differ by more than 12%

- duration of the pulses P1, P2, P3 = 0.8 ± 0.1 usec

- received no pulses in the range 1.3 to 2.7 usec after the P1 or P1 amplitude of at least 2.8 (9dB) times greater than P2

amplitude of P1, P2, P3, at least 3.2 times (10 dB) greater than that of any spurious pulses received during the interrogation

Recognized as valid an interrogation, the transponder does not respond to any other questions for an interval of time between the duration of the response itself and not more than 45 usec last impulse response (dead time).

NOTE: Transponder older generation had a "dead time" of 125 usec

The receiver, if it finds that a query comes from the side lobes, is disabled for a period of 35 ± 10 usec.

On-board equipment– the Transmitter

Transmission frequency 1090 MHz ± 3 MHz

vertical polarization

Transmitting power from 120 to 500 W

Pulse duration 0.1 ± 0.45 usec

Tolerance of separation between pulses ± 0.1 usec

Capacity of 1200 replies per second

On-board equipmenet – Antenna

The antenna or antenna system board must have omnidirectional coverage in horizontal plane and at least ± 40 ° in the vertical plane.

We use two or more antennas with automatic selection of the one with the best reception to avoid blind spots in coverage (analysis of the quality of the received pulses).

Land equipment – the Transmitter

Transmission frequency 1030 MHz ± 0.2 MHz

vertical polarization

Power transmission P1/P3: 0.5 - 1.5 kW

Transmission power P2: 0.5 to 9 kW

Relative amplitude of P2> P1 by the maximum radiated lobe

<9dB radiated from the main lobe of P1

Pulse duration: 0.8 ± 0.1 usec

Tolerance of separation between P1 and P3: ± 0.2 usec

Separation between P1 and P2: 2 ± 0.15 usec

Capacity of 450 queries per second (Max PRF = 450)

Land equipment - Receiver

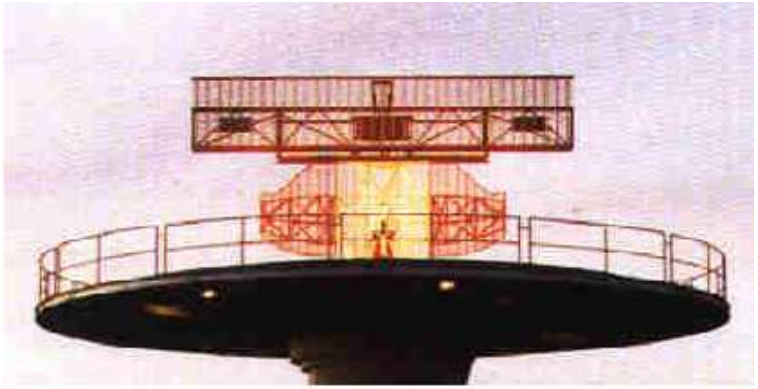
Reception frequency 1090 MHz ± 3 MHz
STC to reduce unwanted signals a short distance
Pulse duration: 0.45 ± 0.1 usec
Filtering of the pulses of primary radar
Circuits defruiting
Circuits degarbling

- The RECEIVER of SSR radar must:
  - Detect the pulse of the response (single impulses in Freq. 1090MHz)
  - Demodulate pulses SSR (control the duration and intervals between pulses)
  - Recognizing pulses brackets
  - Extract information (code or height)

Land equipemt- Antenna (1/3)

Land equipment – L'Antenna (2/3)

- ◊ Coubicata e corotante con quella del radar primarioCo-location and co-rotating with the primary radar
- ◊ vertical polarization
- ◊ Beam width in the vertical plane: 45 ° - 55 °
- ◊ Beam width in the horizontal plane: 2 ° - 4 °
- ◊ Polarizzazione verticale
- ◊ Larghezza del fascio nel piano verticale : 45° - 55°
- ◊ Larghezza del fascio nel piano orizzontale : 2°- 4°

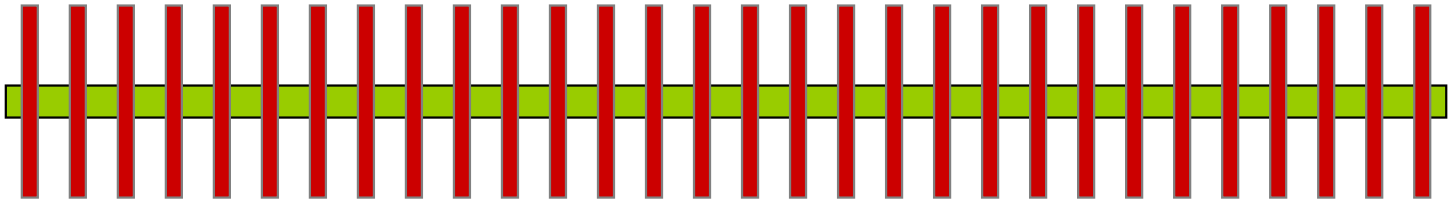


The SSR antenna is generally composed of a series of individual elements arranged in row ("linear array") and fed by a network of signal distribution placed posteriorly.

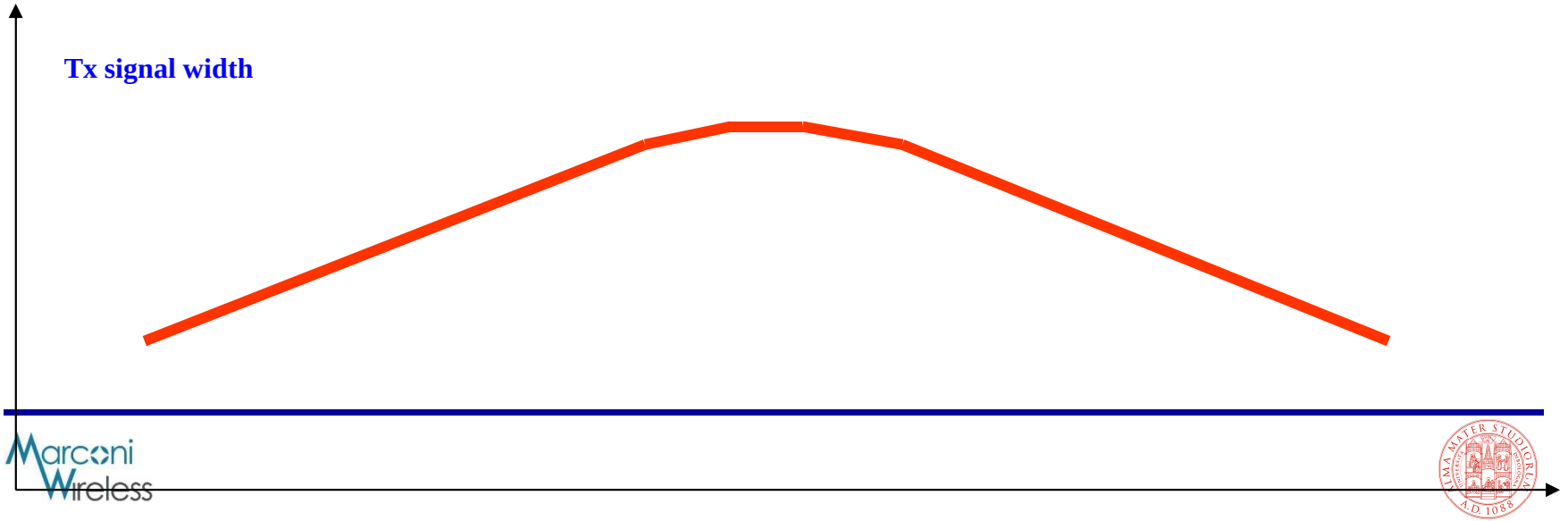
The power sent to each element is not constant along the length of the antenna, and usually has the maximum values for the elements decreases toward the central and terminal elements in order to obtain the expected directivity and reduce levels of secondary lobes.

The typical length of an antenna used in ATC SSR is about 8 meters.

Land equipment- Antenna (3/3)



Signal distribution to the individual elements



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PRIMARY radar + SECONDARY radar

The two radar sensors to obtain the distance data using the same technique..

PRIMARY RADAR	SECONDARY RADAR
Distance from plane ⇨ $D = c \cdot T_{PSR}/2$	Distance from plane ⇨ $D = c \cdot T_{SSR}/2$

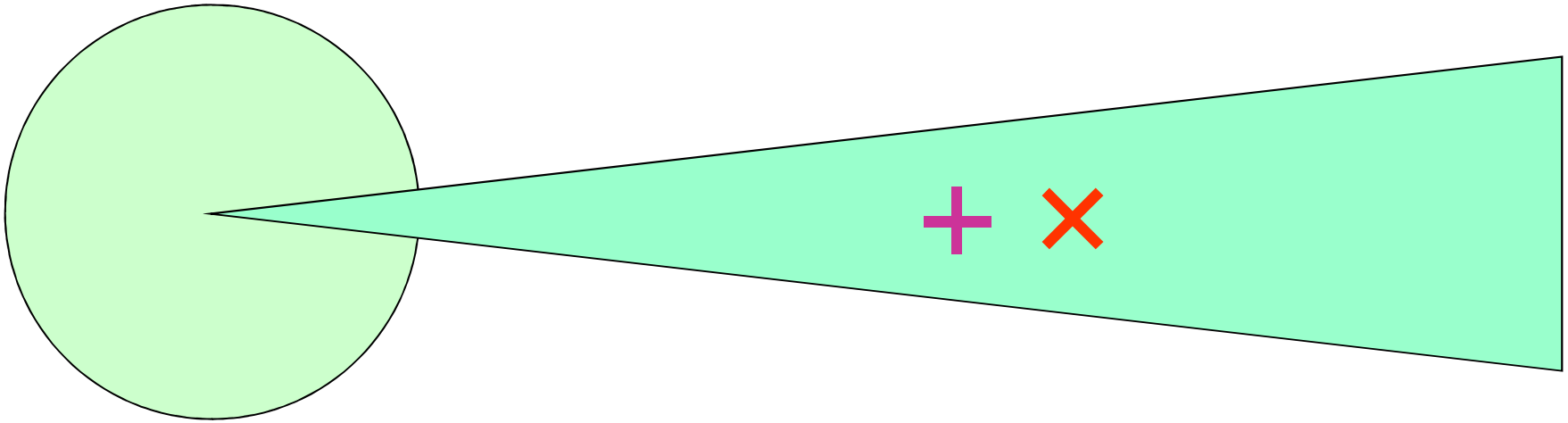
where:

TPSR = time from transmission of the reception of the echo signal.

TSSR = time from transmission to receipt of the answer of the question.

PRIMARY radar + SECONDARY radar

RESULT



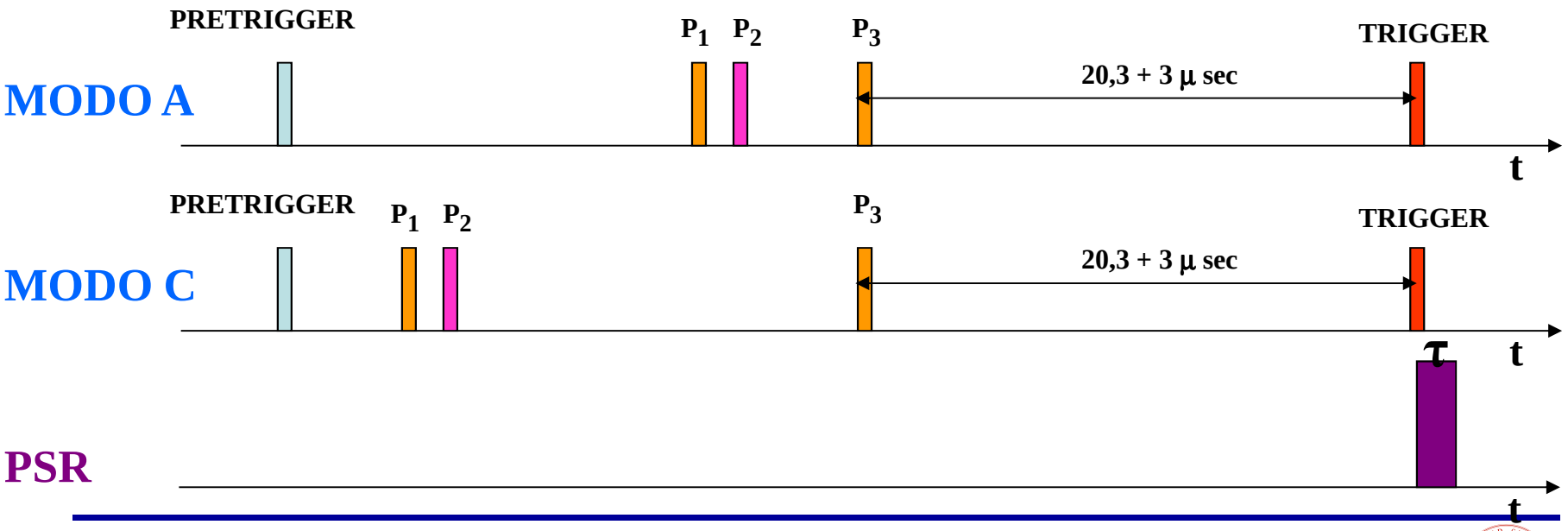
SOLUTION

Anticipating the transmission ofsecondary radar interrogation to the transmission of the primary radar.

PRIMARY radar + SECONDARY radar

To present the indicator tracks the primary radar and secondary coinciding the SSR is synchronized by a pulse of "pretrigger" which triggers the advance of the primary radar must be calculated considering:

- the duration of the question
- the delay in developing the interrogation of the transponder and provide the answer
- duration of response
- the delay in the development of the radar response.

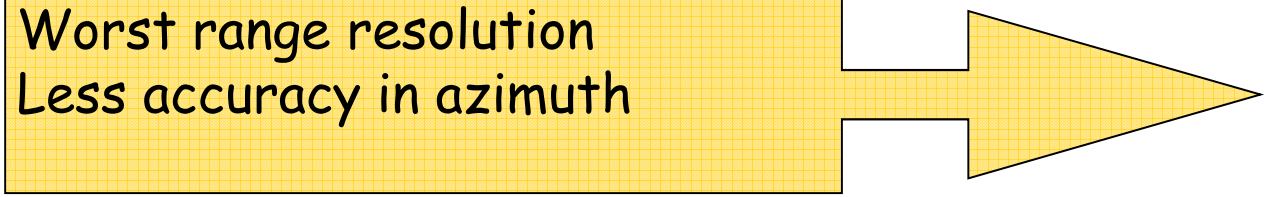


SSR vs PSR

Lower transmit power (kW vs. MW)
PSR: Received power proportional to 1/r4
SSR received power proportional to 1/r2
Additional information (ID)
No problem of clutter
Up-Down-link link using different frequencies (1030 / 1090 MHz) -> receive any response to the interrogation signal (1030) do not degrade the response is received (1090)
3D (distance, azimuth, altitude)

Garbling and fruiting
Must be present on board the transponder
Necessary efficiency of the transponder

Worst range resolution
Less accuracy in azimuth



SSR Monopulse