Rungis
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Automatic real-time collection of RCS of airplanes in a real bistatic configuration using a passive SDR based on illuminators of opportunity

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OUTLINE

- Motivation for collecting RCS
- Computation of RCS
- System requirements
- System architecture
- Signal processing
- Classification of air targets based on collected data
- Conclusions

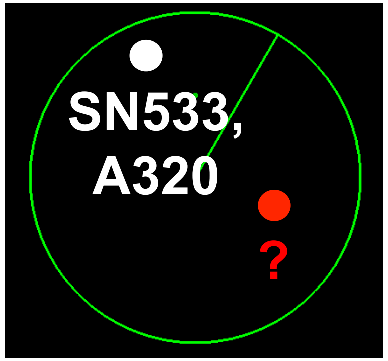
MOTIVATION : CLASSIFICATION OF AIR TARGETS

SN533, A320
transponder ON

?

Unknown airplane
transponder OFF

Radar

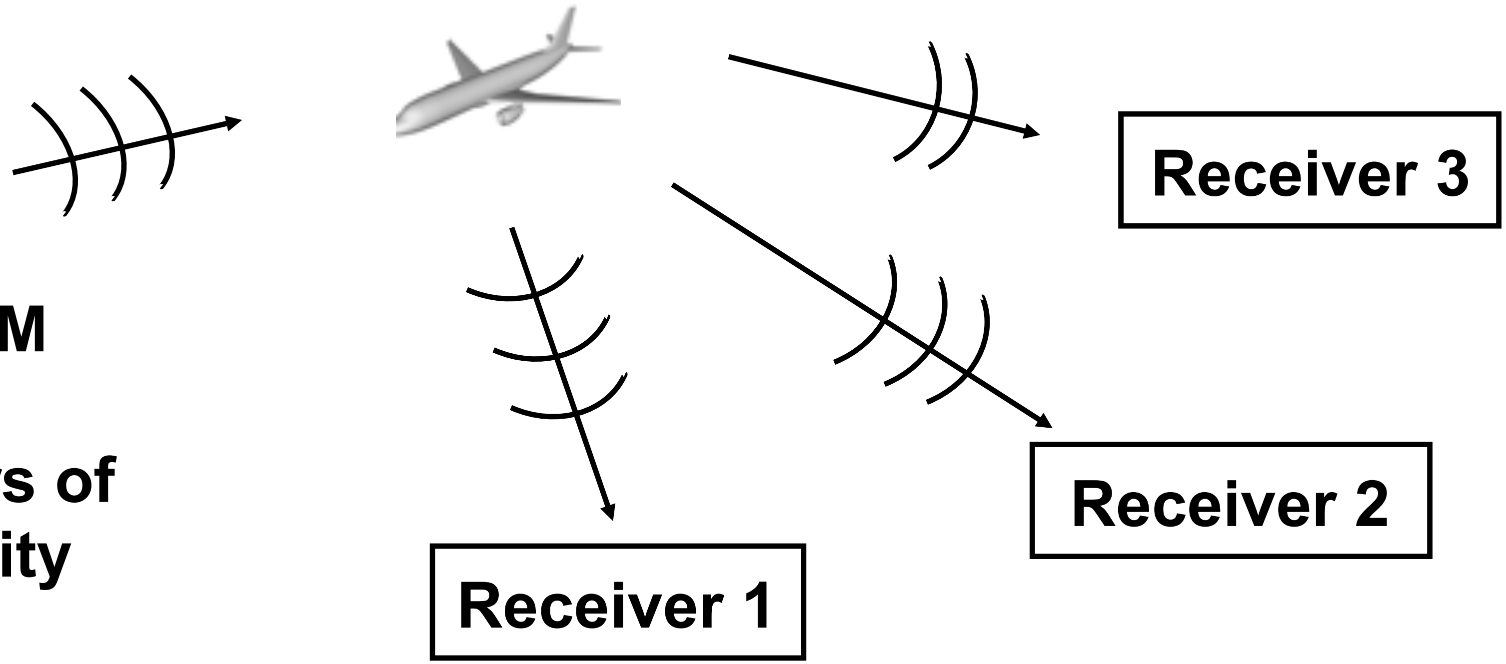


PPI

Goal: Identify ?'s (+ check response from ADS-B)

MOTIVATION: ENVISIONED SYSTEM

GSM



Illuminators of opportunity

DVB-T

- Bistatic configuration
- Operate at low frequency (<1GHz)
- Data = RCS of airplanes
- No image reconstruction

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COMPUTATION OF RCS

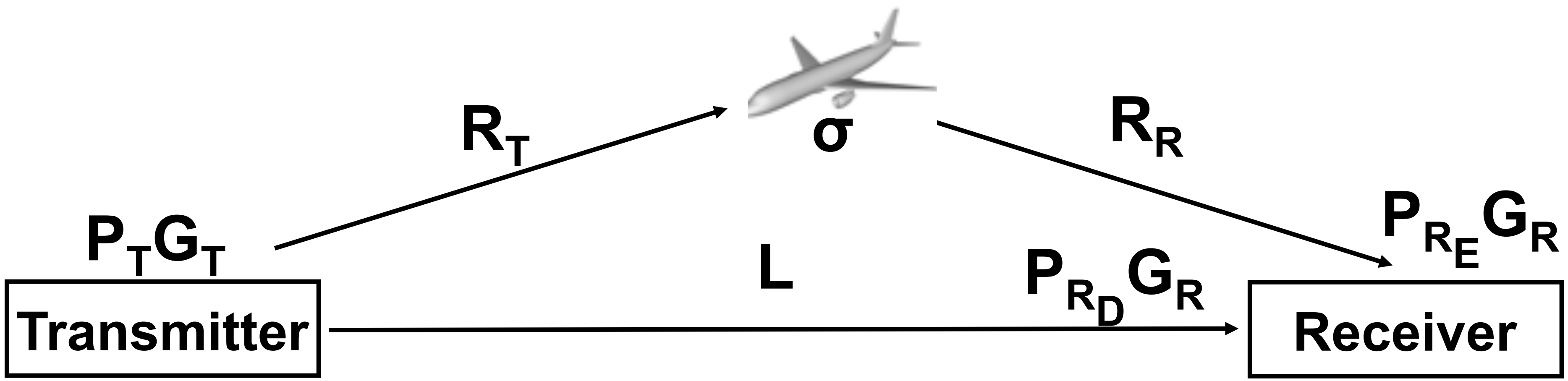
Direct-path signal:

$$P_{R_D} = \frac{P_T G_T G_R}{L}$$

Echo signal:

$$P_{R_E} = \frac{P_T G_T G_R \lambda^2 \sigma}{(4\pi)^3 R_T^2 R_R^2}$$

$$\Rightarrow \quad \sigma = \frac{P_{R_E}}{P_{R_D}} \frac{(4\pi)^3 R_R^2 R_T^2}{\lambda^2 L}$$



SYSTEM REQUIREMENTS

- Detection of airplane
- Geometry of configuration to be known:

  => Distances R_R and R_T

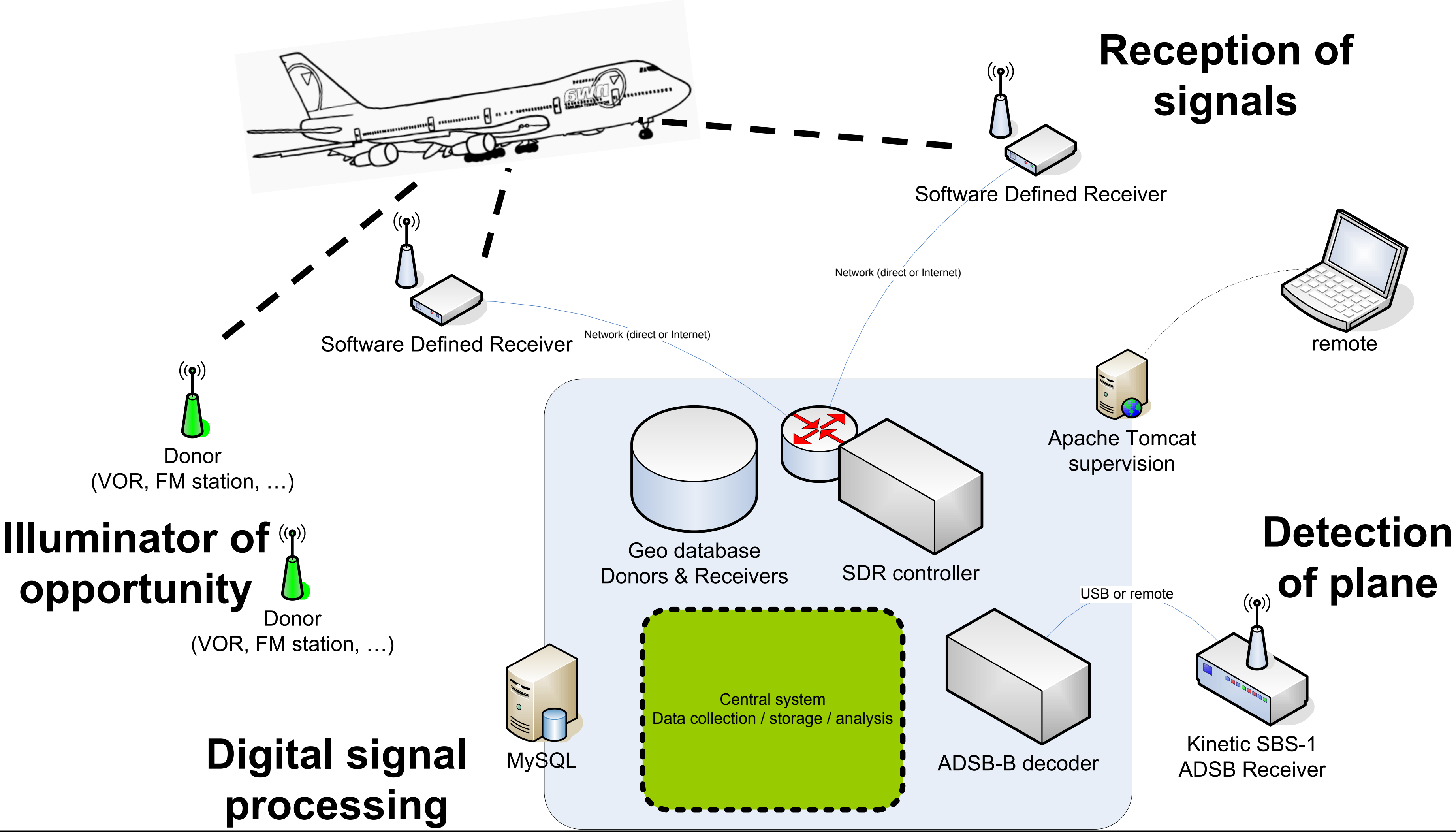
- Selection of transmitter
- Acquisition of received signals
  => Powers P_{R_E} and P_{R_D}

  => Quasi constant loss L

- Signal processing to compute « true » RCS σ

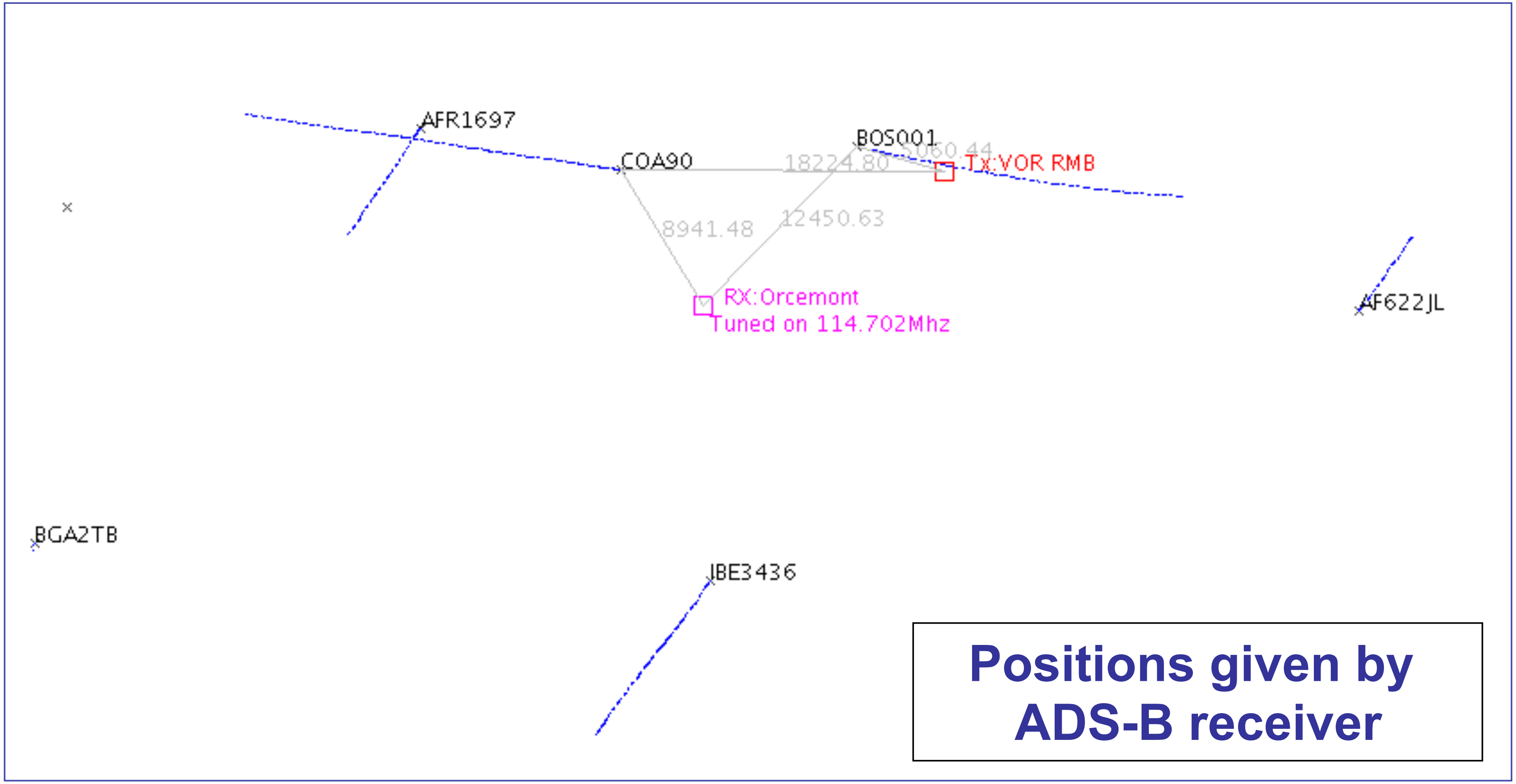
$$\sigma = \frac{P_{R_E}}{P_{R_D}} \frac{(4\pi)^3 R_R^2 R_T^2}{\lambda^2 L}$$

SYSTEM ARCHITECTURE



PRACTICAL IMPLEMENTED SYSTEM

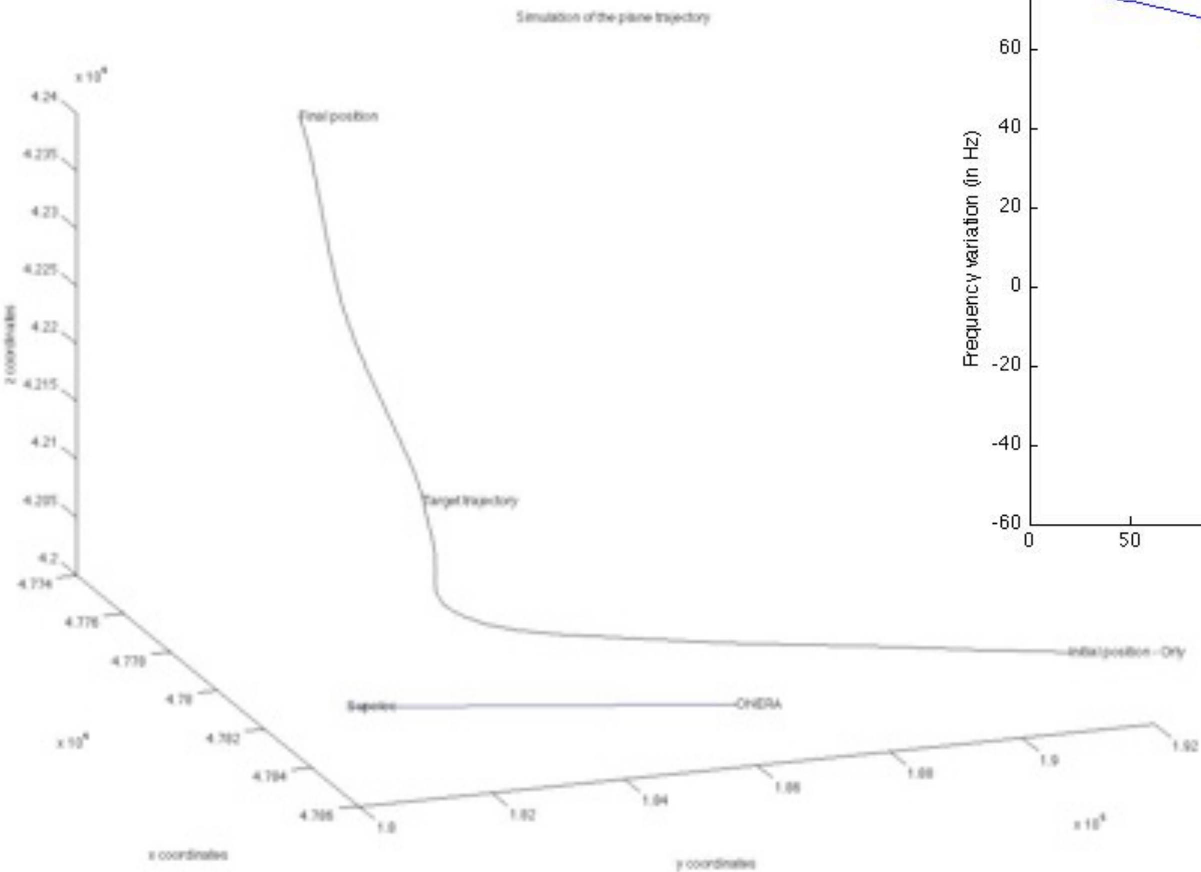
RECEIVED POSITIONS OF AIRPLANES

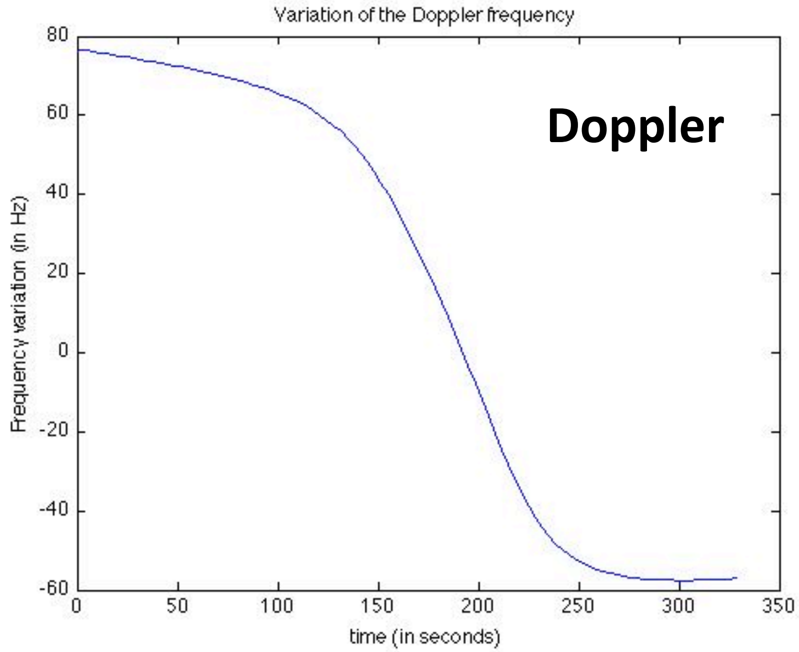


Positions given by ADS-B receiver

AIRPLANE DATA RECONSTRUTED FROM DECODED ADS-B FRAMES

Airplane trajectory

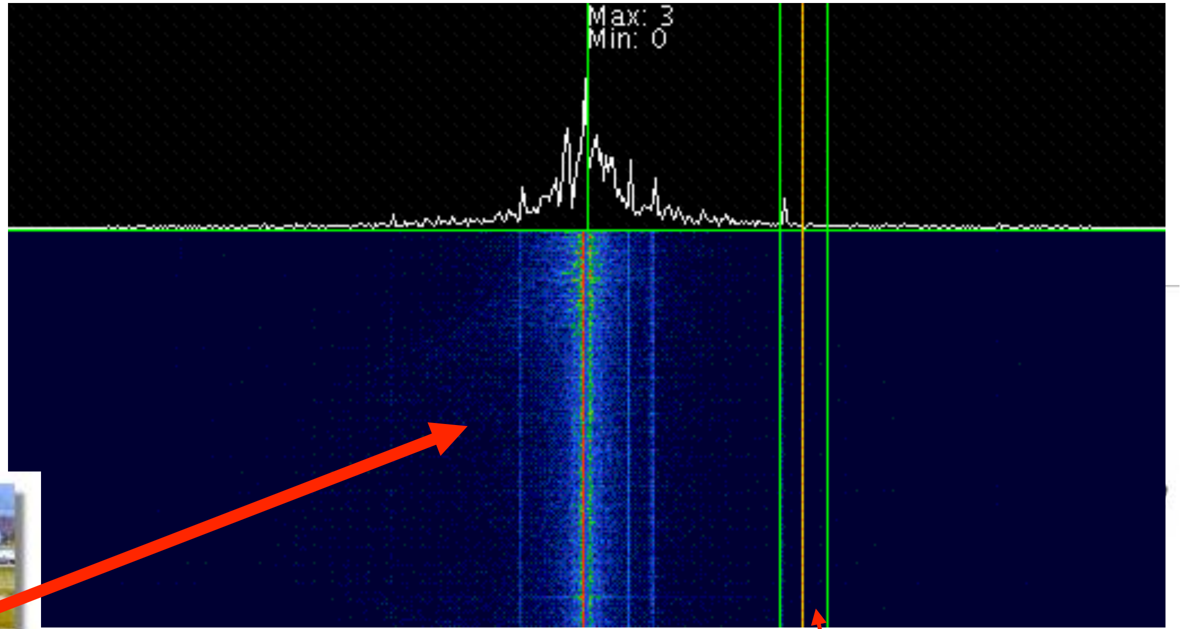


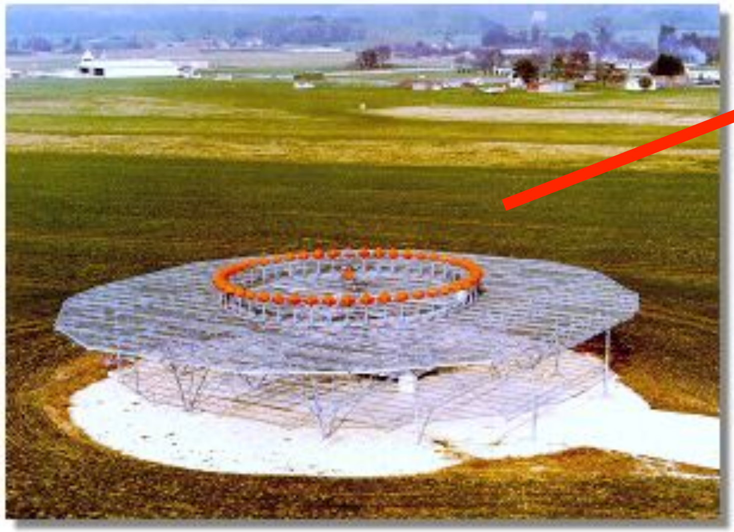


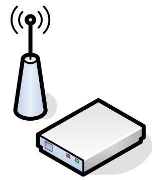
SELECTED VOR TRANSMITTER

Needs:
- **Constant frequency**
- **Constant power**
- **Few modulation**

$$s(t) = Ae^{j\phi(t)}e^{2\pi ft}$$



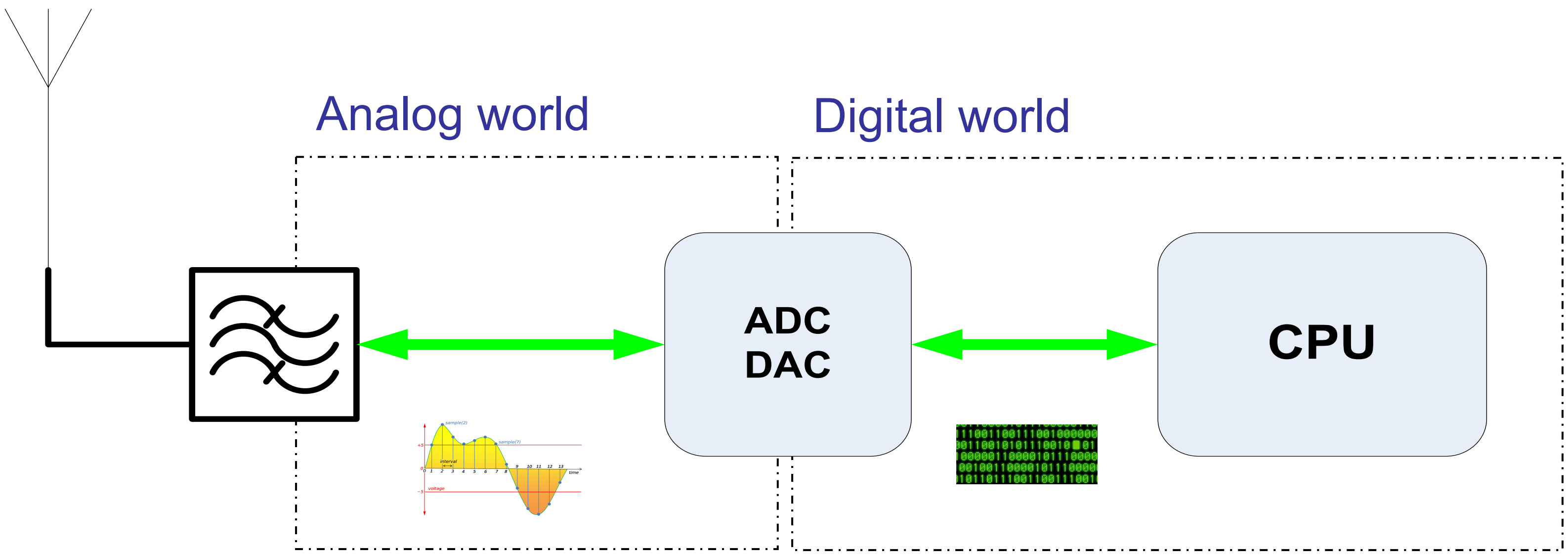




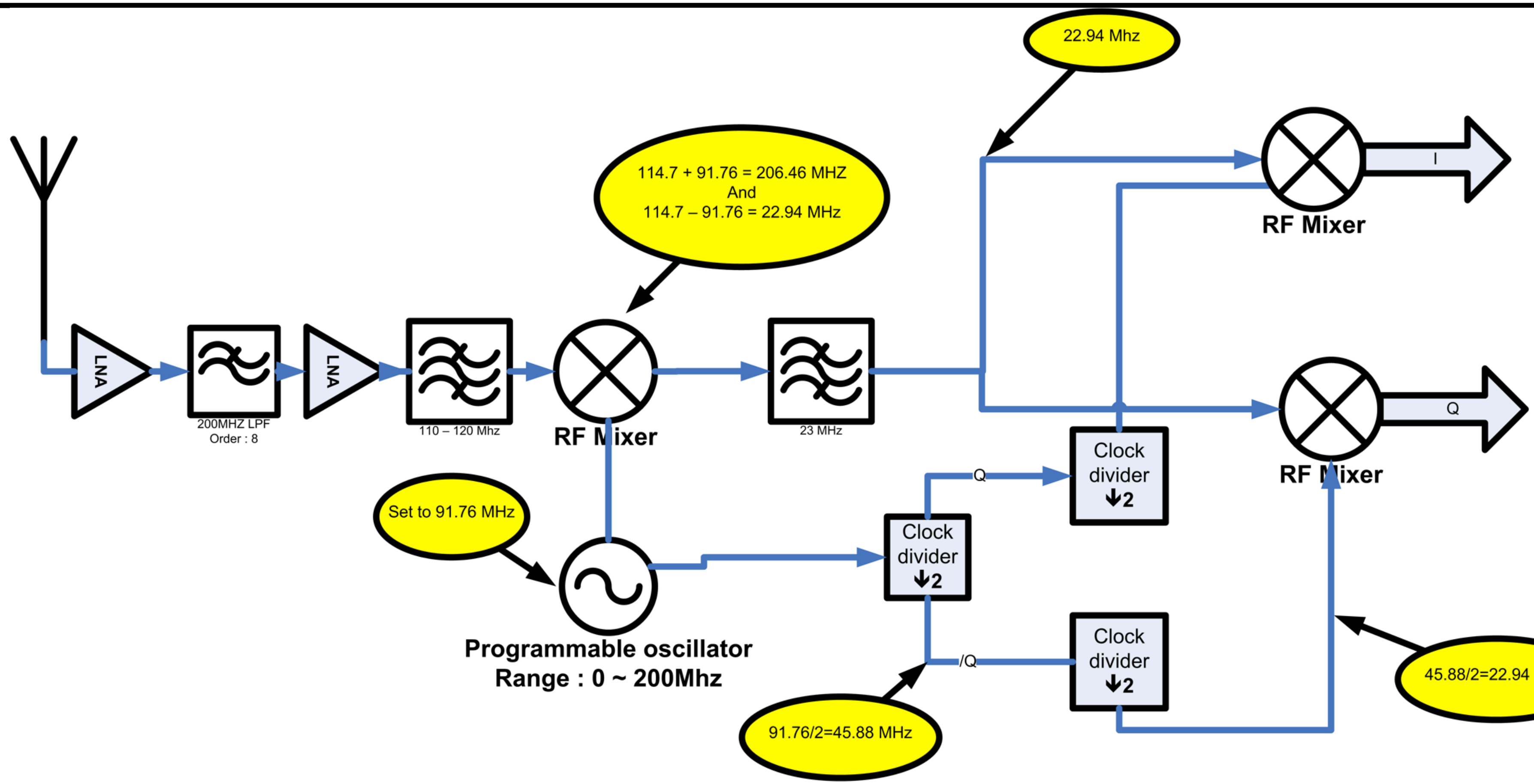
Software Defined Receiver

Receiver tuned on a "quiet" area of the spectrum to have good SNR

SDR RECEIVER: PRINCIPLE



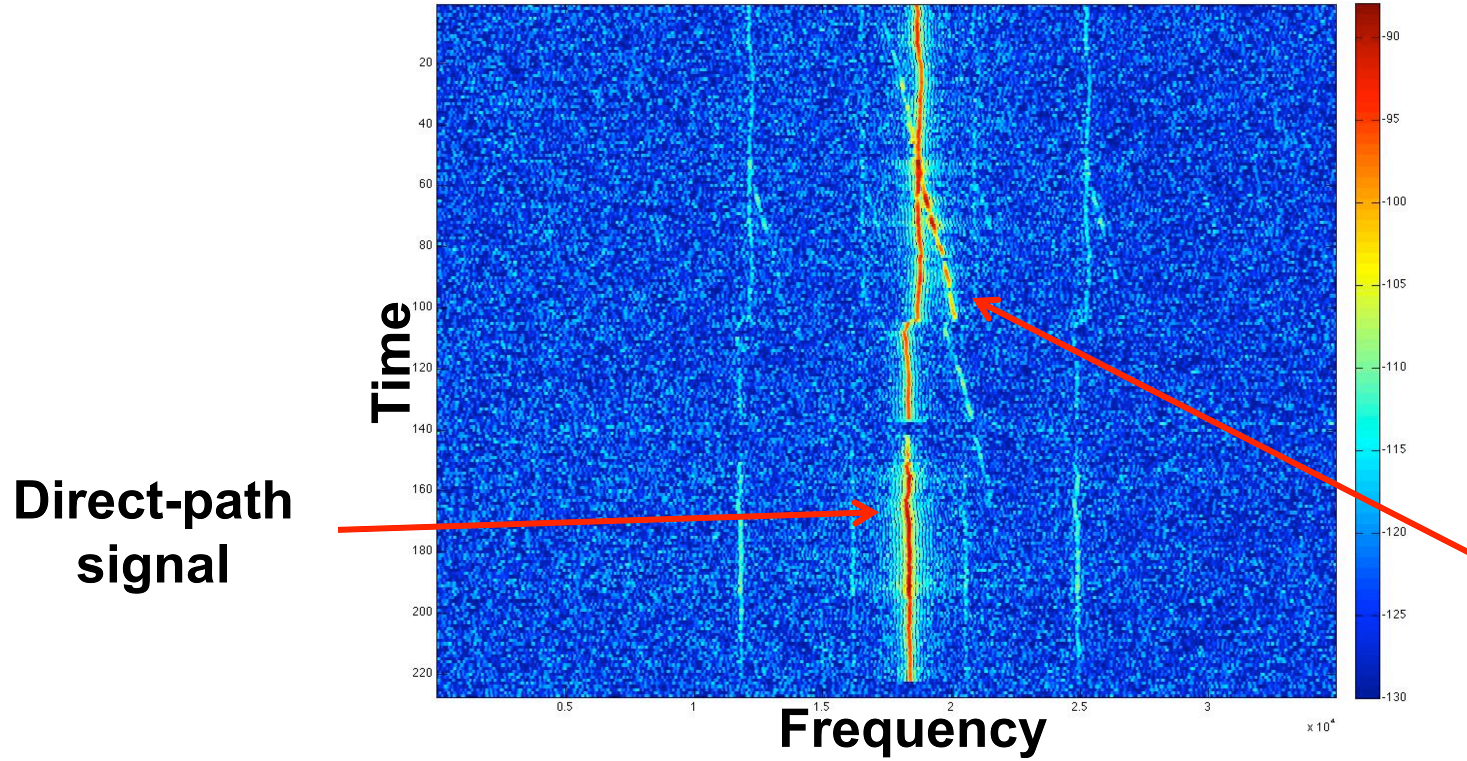
SDR FRONT-END ARCHITECTURE



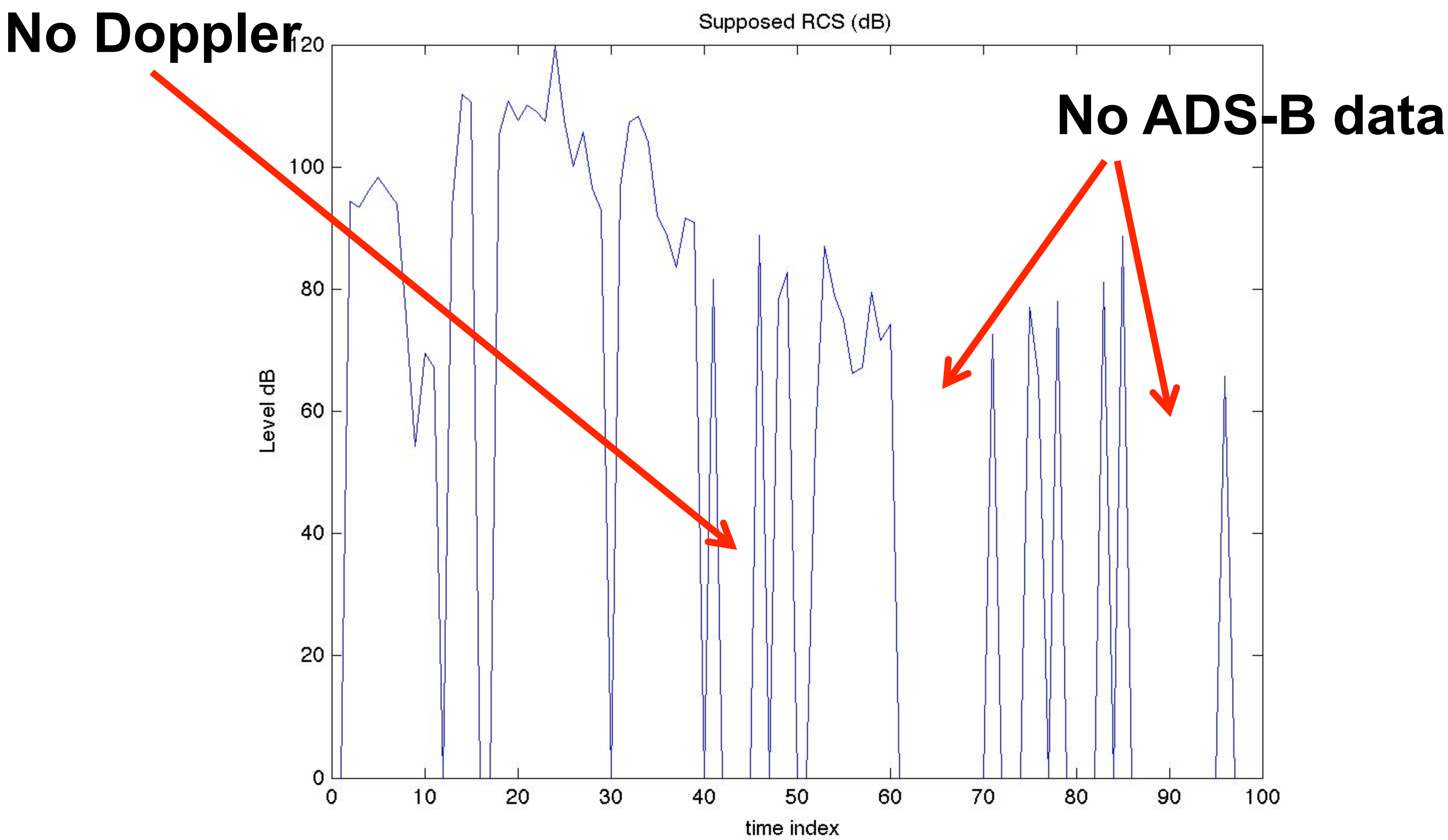
Freq example : F_{rx}=114.7 MHz
Set LO = F_{rx} x 0.8 = 91.76 MHz

DIGITAL SIGNAL PROCESSING

- I(t), Q(t) => I[n], Q[n]: digitizing by computer sound card
- Doppler processing + $P_R = \left| I[n] + jQ[n] \right|^2$ → Estimated from ADS-B data



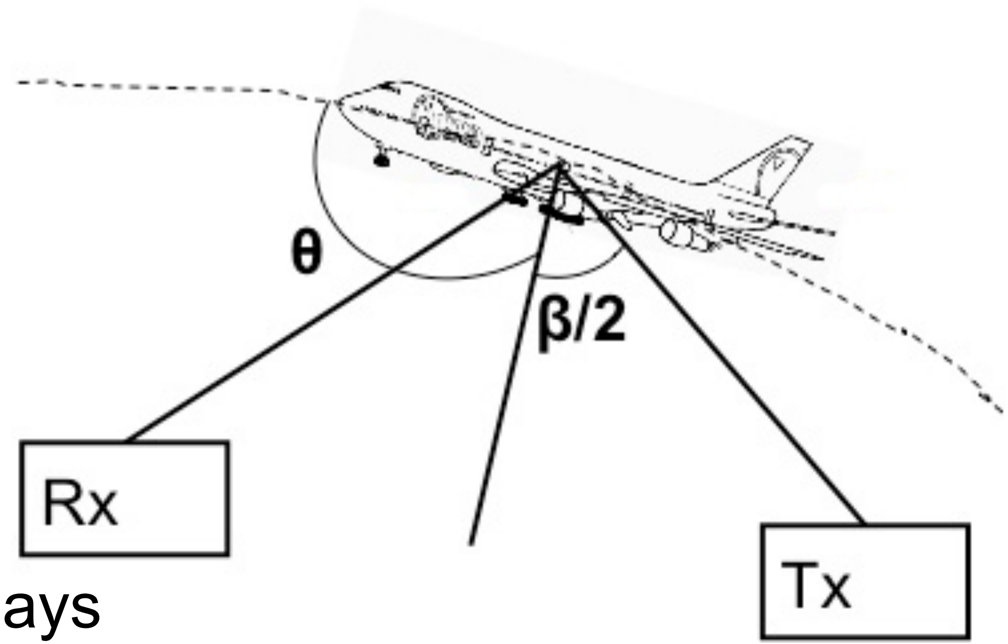
COMPUTED RCS



CLASSIFICATION: DATA & CLASSES

- Objects to be classified:

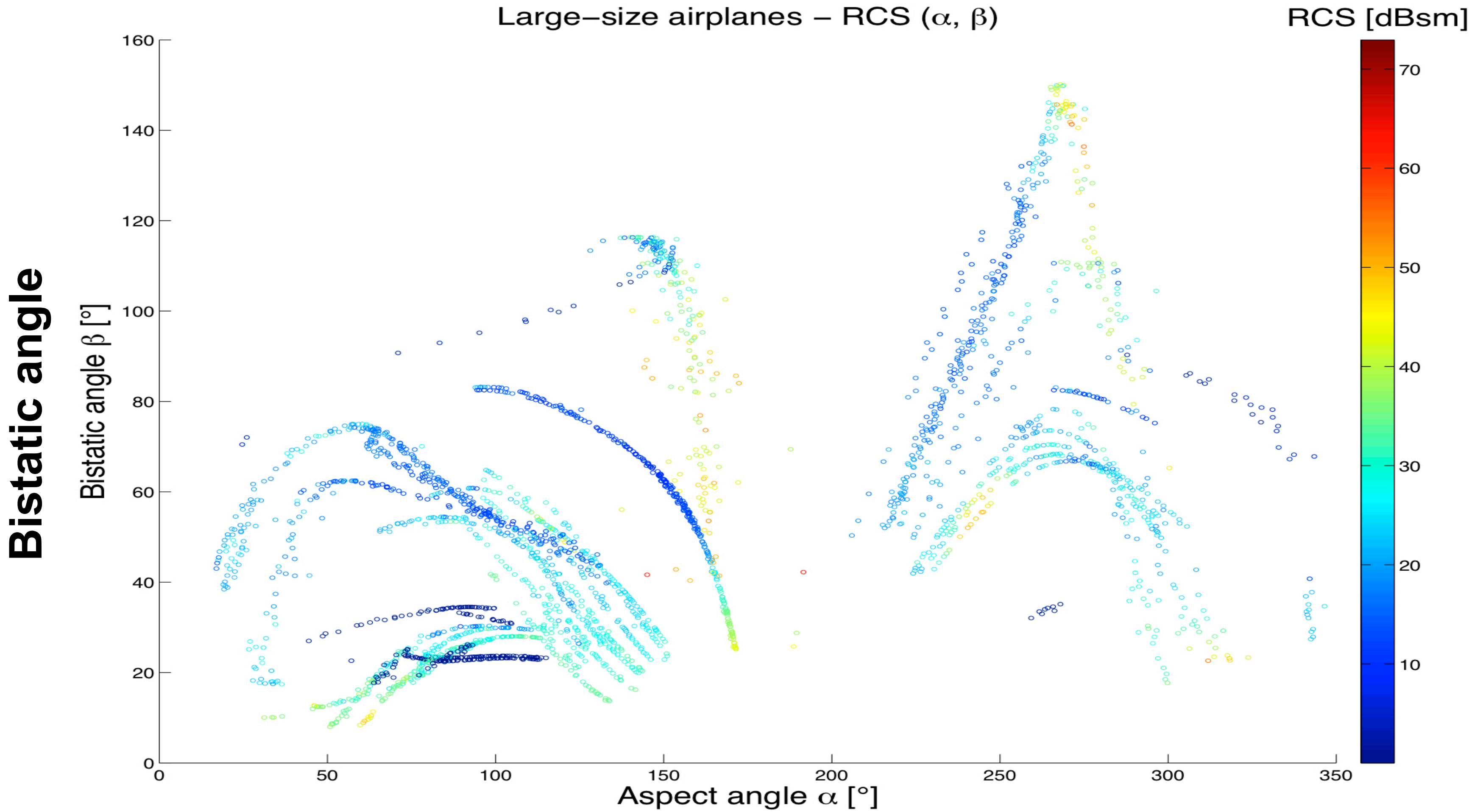
$$z^{(i)} = \sigma(\beta, \theta),$$
$$\beta \in [\beta_{\min}, \beta_{\max}]$$
$$\theta \in [\theta_{\min}, \theta_{\max}]$$



- Experiments run for 10 days
  => 1329 airplanes of 41 different types detected
  => 54154 sample RCS's computed

- Large-size: 47 airplanes, 2672 sample RCS's
- Mid-size: 549 airplanes, 25741 sample RCS's (+small-size)

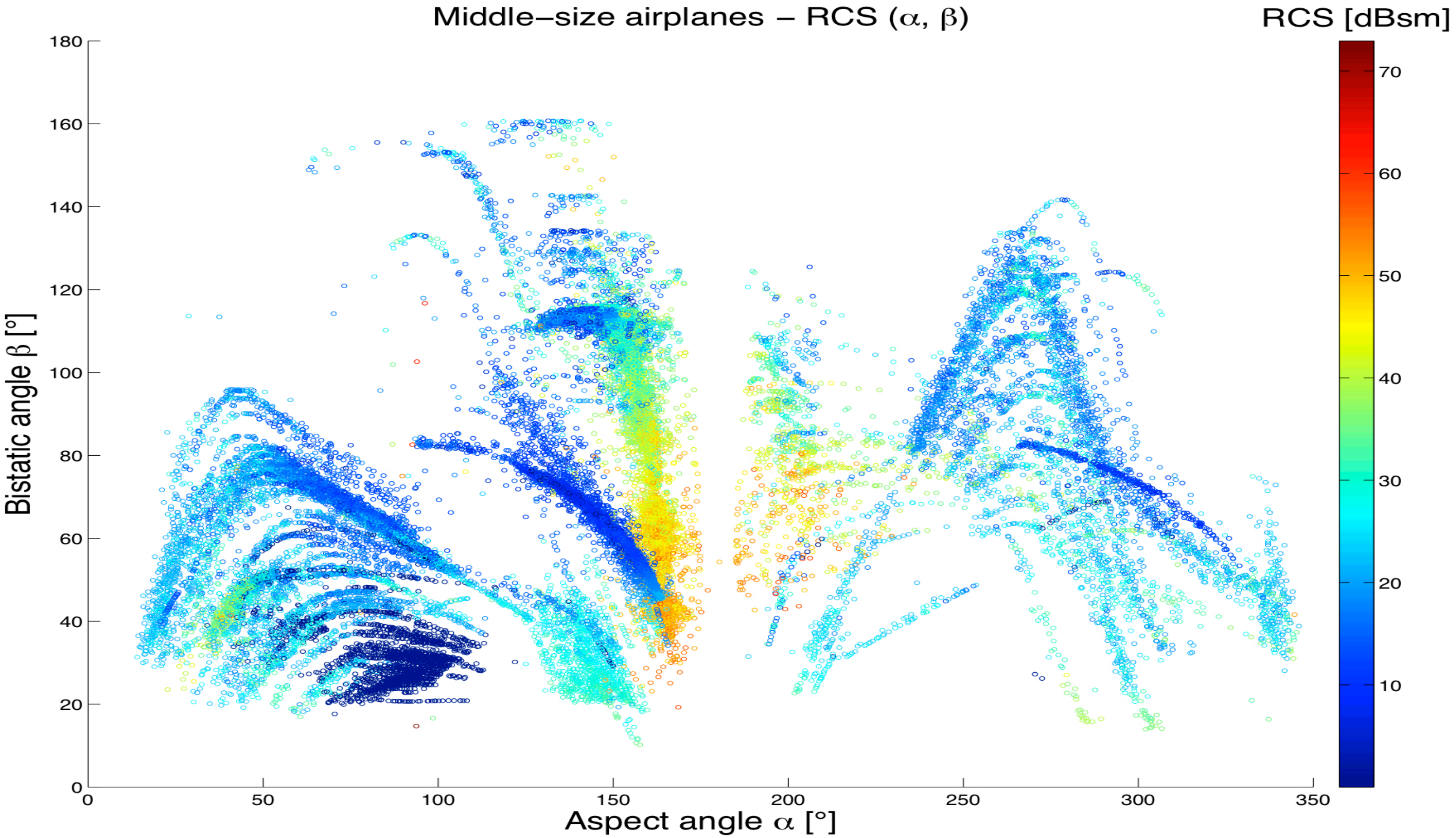
RCS(β,θ)
FOR LARGE-SIZE AIRPLANES



Orientation angle

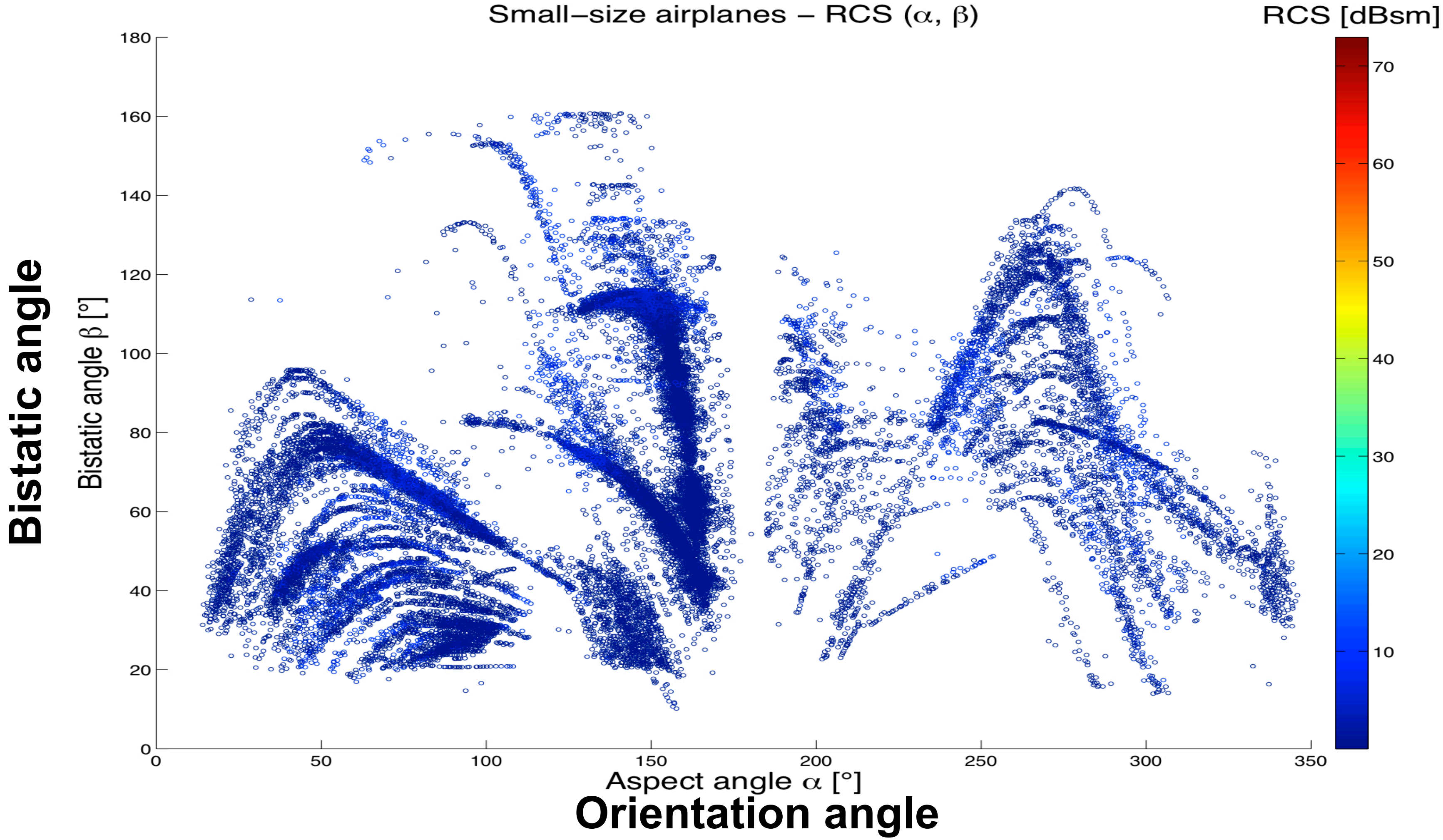
RCS(β,θ)
FOR MID-SIZE AIRPLANES

Bistatic angle

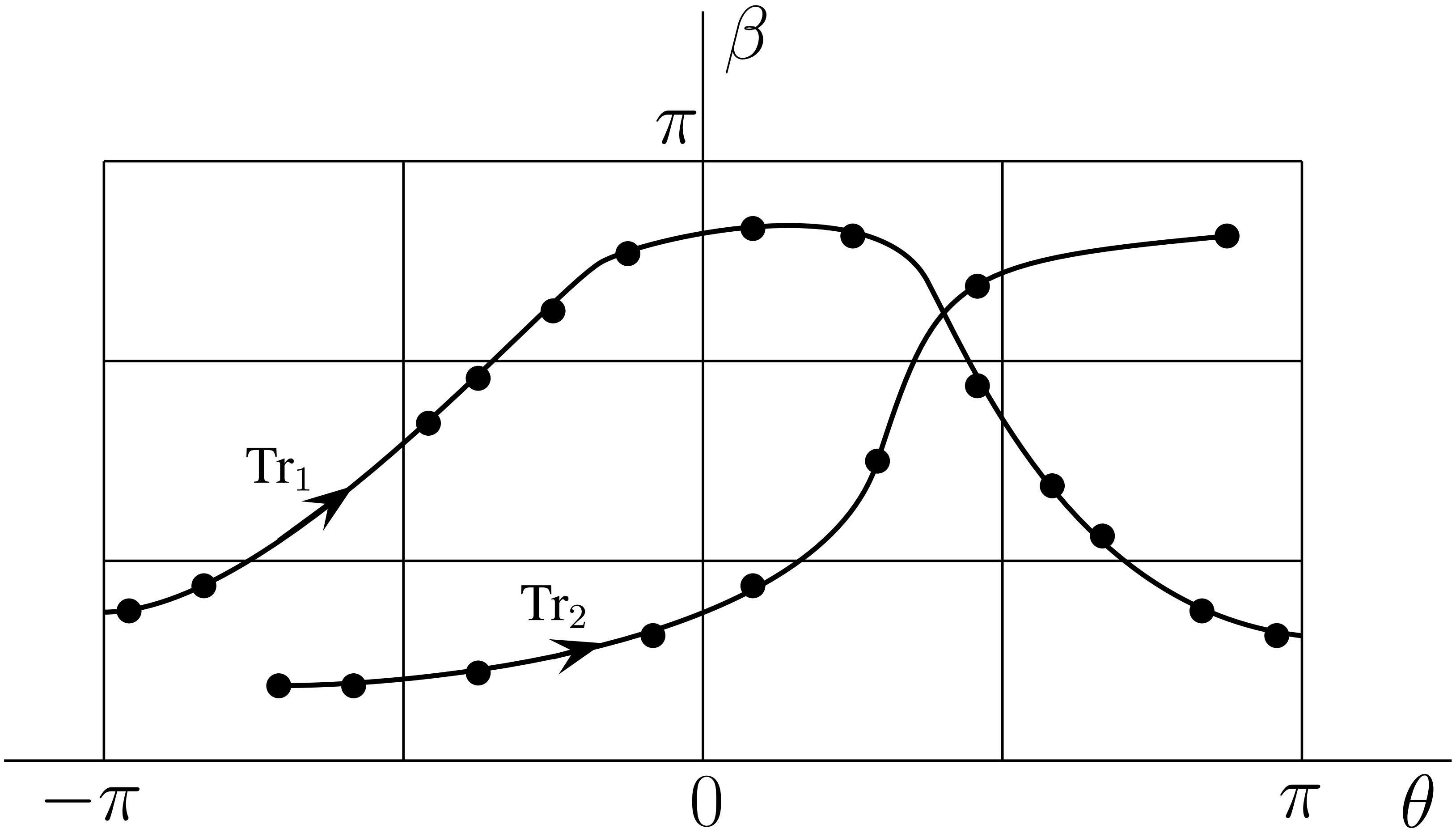


Orientation angle

RCS(β,θ)
FOR SMALL-SIZE AIRPLANES



CLASSIFICATION: PARAMETER SPACE



CLASSIFICATION

- Each target class j characterized by a vector space $U^{(j)}$ of K singular vectors

- Classification criteria (Projection):
  ρ = weight of sing. vectors

$$E_\rho^{(j)} = \sum_{i=1}^{K} \left(\frac{\lambda_i}{\lambda_1} \right)^{\rho} \frac{z^H u_i^{(j)} u_i^{(j)^H} z}{z^H z}, \rho = \{0, 0.05, 1\}$$

- Class(z) attributed corresponds to higher $E^{(j)}$

- Aggregation according to majority vote

CLASSIFICATION OF AIR TARGETS BASED ON THEIR RCS : RESULTS

Université de Liège

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- 3 classes: large-size (A343), mid-size (A319), small (simulated) airplanes

	θ = [0°; 360°]											
β = [0°; 180°]	-0.25	0.70	0.76	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	0.99	-0.25	-0.25
	0.88	0.78	0.91	0.85	0.93	0.79	0.98	0.91	0.96	0.88	0.99	0.96
	-0.25	0.81	0.74	-0.25	0.80	0.50	0.93	0.87	0.79	0.74	-0.25	-0.25
	-0.25	0.93	-0.25	-0.25	0.73	0.49	0.91	-0.25	0.88	0.72	-0.25	-0.25
	-0.25	-0.25	-0.25	-0.25	0.77	0.99	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25
	-0.25	-0.25	-0.25	-0.25	0.83	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25

Angular step = 30°

Overall classif: 83%

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CONCLUSIONS

- Motivation: classify air targets according to their RCS, acquired in bistatic mode, at low-frequency
- RCS computed based on received direct-path and echo signals
- Needed components:
  - Existing transmitter of opportunity
  - ADS-B receiver & decoder
  - SDR receiver + digital signal processor
- Real RCS computed at low cost
- Entirely automated system
- Classification based on vector spaces
- Achieved classification rate = 83%
- Interesting and non-interesting configurations

Thank you for listening

Any question?

This work has been funded by Belgian FRIA scholarship