www.thalesgroup.com

Extract Before Detect

N-signal Complex Approximate Message Passing applied to radar signals

Guy DESODT, Thales Air Systems, France
Linda AOUCHICHE, Thales Air Systems, France
Olivier Rabaste, ONERA, France

THALES

Extract Before Detect

Summary

- Compressive Sensing radar processing
- CAMP (Complex Approximate Message Passing) applied to multiple burst signal
- Simulation results
- Conclusion

THALES

Extract Before Detect

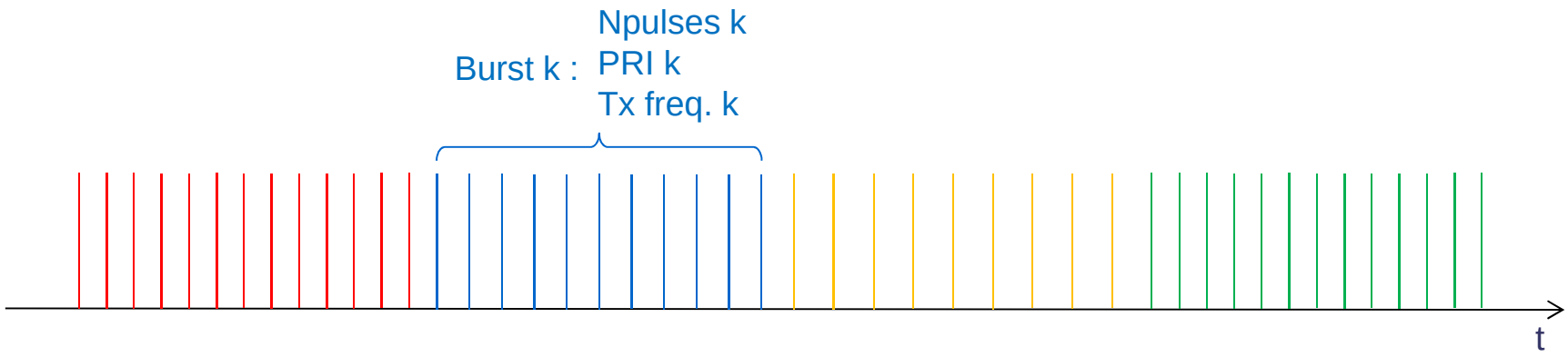
Summary

- **Compressive Sensing radar processing**
  - Radar signals
  - Compressed Sensing
  - Radar processing objective in terms of Compressive Sensing
  - Extract Before Detect
- **CAMP (Complex Approximate Message Passing) applied to multiple burst signal**
- **Simulation results**
- **Conclusion**

THALES

Compressive Sensing radar processing

Radar signals



Radar signal received during 1 burst

$$y^k = n^k + \sum_i A_i^k \cdot x_i^k$$

Burst index, k=1…K

Echo index, i=1…I

Echo complex amplitude

noise

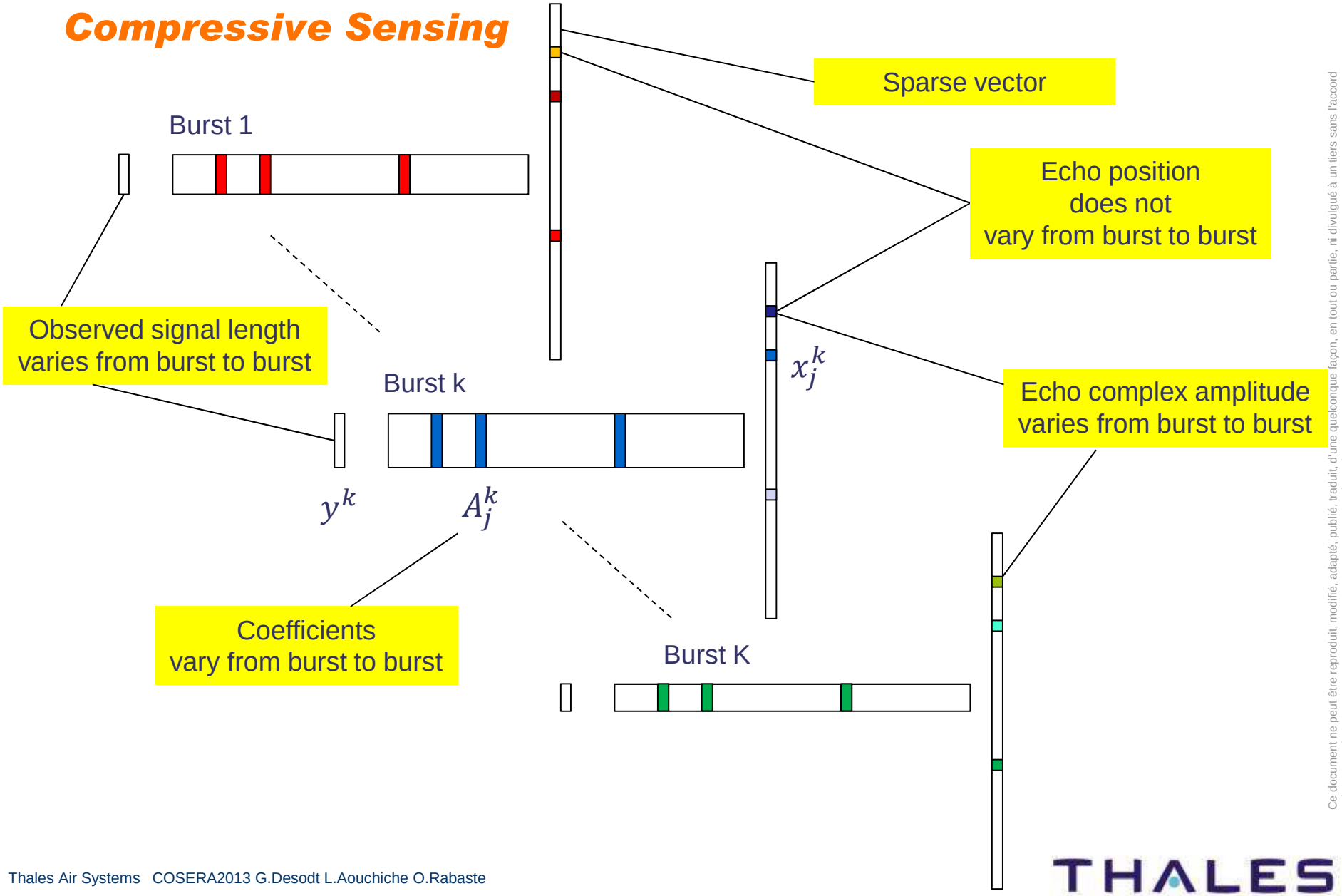
Echo "signature"
Steering vector

- Receivers (function of echo direction)
- Coherent pulses (function of echo radial speed)
- Range bins (function of the range radar-echo)

THALES

Compressive Sensing radar processing

Compressive Sensing



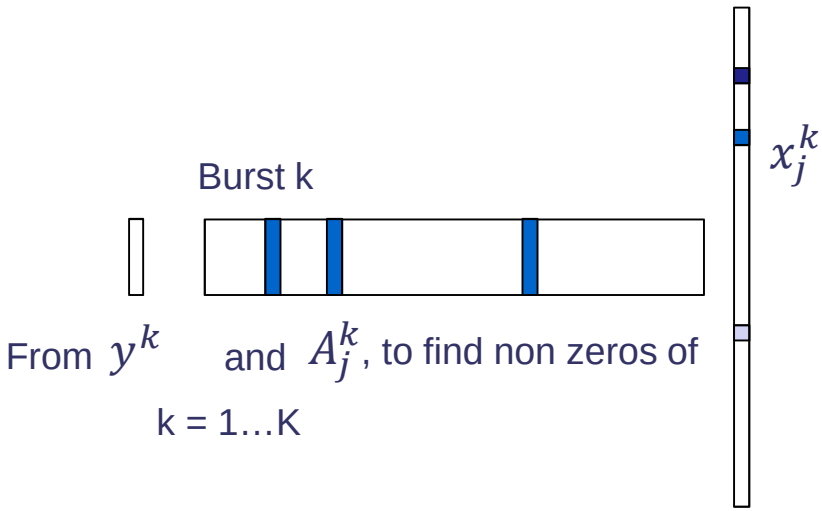
THALES

Compressive Sensing radar processing

Radar processing objective …

- **To detect ⇔ To find echo complex amplitudes**
- **To locate ⇔ To find echo positions**

… in terms of Compressive Sensing



"Block sparse recovery"

THALES

Compressive Sensing radar processing

- **Compressive Sensing processing produces at once**

  echo positions

  and their amplitudes

Extract Before Detect

Related COSERA 2013 presentation :
R. Pribic, I Kyriakydes, "Bayesian Compressive sensing in radar systems", session A3
J. Ender, De-ghosting before detect, "A CS approach to the fusion of PCL sensors", session A8

THALES

Extract Before Detect

Summary

- Compressive Sensing radar processing
- CAMP (Complex Approximate Message Passing) applied to multiple burst signal
  - N-burst criterion
  - CAMP (Complex Approximate Message Passing)
  - N-signal complex soft threshold variation
  - N-signal CAMP (N-CAMP)
- Simulation results
- Conclusion

THALES

CAMP applied to multiple burst signal

Single burst criterion (LASSO)

- $$\min_{x} \frac{1}{2}\underbrace{(y - A \cdot x)^H \cdot (y - A \cdot x)}_{\text{Quadratic terms}} + \lambda \cdot \sum_j \sqrt{\underbrace{|x_j|^2}_{\text{Quadratic terms}}}$$

N-burst criterion

- $$\min_{\ldots x^k \ldots} \frac{1}{2}\sum_k \left(y^k - A^k \cdot x^k\right)^H \cdot \left(y^k - A^k \cdot x^k\right) + \lambda \cdot \sum_j \sqrt{\sum_k |x_j^k|^2}$$

Quadratic terms are summed over the bursts

L1-2 norm

Related COSERA 2013 presentations :
S. Wenger, M. Magnor, L1-∞ norm, "Group sparsity imaging algorithm for transient radio sources", session A2
Z. Bingchen et al, Lq norm, "Azimuth ambiguity suppression for SAR imaging based on group sparse reconstruction", session A4

THALES

CAMP applied to multiple burst signal

CAMP : Complex Approximate Message Passing

- D. Donoho, A. Maleki, A. Montanari, Message Passing algorithms for Compressed Sensing, Proceedings of the National Academy of Sciences 106, 2009
- A. Maleki, L. Anitori, Z. Yang, R. Baraniuk, Asymptotic analysis of complex LASSO via Complex Approximate Message Passing Algorithm (CAMP), IEEE Trans. Information Theory, 2012

- CAMP is based on complex soft threshold variation

THALES

CAMP applied to multiple burst signal

N-signal complex soft threshold variation

- **N-signal complex soft threshold**

Quadratic term is summed over the bursts

  - $\eta^k(v;\lambda) = max\left(0; 1 - \lambda \cdot \left(\sum_m v^{m*} \cdot v^m\right)^{-\frac{1}{2}}\right) \cdot v^k$

Scaling factor common to all bursts
If it is 0
then all burst amplitudes are 0

- **N-signal complex soft threshold derivatives**
  - $\frac{\partial \eta^k(v;\lambda)}{\partial v^n} = \left(1 - \lambda \cdot \left(\sum_m v^{m*} \cdot v^m\right)^{-\frac{1}{2}}\right) \cdot \delta(k-n) + \frac{\lambda}{2} \cdot \left(\sum_m v^{m*} \cdot v^m\right)^{-\frac{3}{2}} \cdot v^{n*} \cdot v^k$
  - $\frac{\partial \eta^k(v;\lambda)}{\partial v^{n*}} = \frac{\lambda}{2} \cdot \left(\sum_m v^{m*} \cdot v^m\right)^{-\frac{3}{2}} \cdot v^n \cdot v^k$
- **N-signal complex soft threshold differential**
  - $\eta^k(v+dv;\lambda) - \eta^k(v;\lambda) =$

$$\left(1 - \frac{\lambda}{\left(\sum_m v^{m*} \cdot v^m\right)^{\frac{1}{2}}}\right) \cdot dv^k + \frac{\lambda}{2} \cdot \frac{v^k}{\left(\sum_m v^{m*} \cdot v^m\right)^{\frac{1}{2}}} \cdot \sum_n \frac{v^{n*}}{\left(\sum_m v^{m*} \cdot v^m\right)^{\frac{1}{2}}} \cdot \frac{dv^n}{\left(\sum_m v^{m*} \cdot v^m\right)^{\frac{1}{2}}} + \frac{\lambda}{2} \cdot \frac{v^k}{\left(\sum_m v^{m*} \cdot v^m\right)^{\frac{1}{2}}} \cdot \sum_n \frac{dv^{n*}}{\left(\sum_m v^{m*} \cdot v^m\right)^{\frac{1}{2}}} \cdot \frac{v^n}{\left(\sum_m v^{m*} \cdot v^m\right)^{\frac{1}{2}}}$$

THALES

CAMP applied to multiple burst signal

N-signal CAMP (N-CAMP)

- **CAMP expressions applied to K vectors of observed signals**
  - $v_j^{k,t} = \sum_b A_{b,j}^{k\,*} \cdot z_b^{k,t-1} + x_j^{k,t-1}$
  - $x_j^k = \eta^k\left(v_j^k; \tau_t\right)$
  - $z_a^{k,t} = y_a^k - \sum_j A_{a,j}^k \cdot x_j^{k,t} - \sum_j A_{a,j}^k \cdot \left(\eta^k\left(v_j^t + dv_{a,j}^t; \tau_t\right) - \eta^k\left(v_j^t; \tau_t\right)\right)$

- **where the kth term of $dv_{a,j}^t$ in η^k variation is the only non zero term**
  - $dv_{a,j}^t = \left(0, \cdots, 0, -A_{a,j}^{k\,*} \cdot z_a^{k,t-1}, 0, \cdots, 0\right)$

THALES

Extract Before Detect

Summary

- Compressive Sensing radar processing
- CAMP (Complex Approximate Message Passing) applied to multiple burst signal
- Simulation results
  - Domain of application : Doppler axis
  - Scenario 1, targets separated by about 1 ambiguous speed
  - Scenario 2, targets close each other
  - Scenario 3, target separated by exactly 1 ambiguous speed
  - Overall results analysis
- Conclusion

THALES

Simulation results

Domain of application : Doppler axis

- 5 bursts
- Same Doppler resolution : 10 m/s
- Ambiguous speeds : 170, 190, 210, 230, 250 m/s
- Radial speed range : [-1000 ; 1000] m/s
- Grid step : 5 m/s
  - Oversampling: factor 2
  - Targets are on the grid

Objective

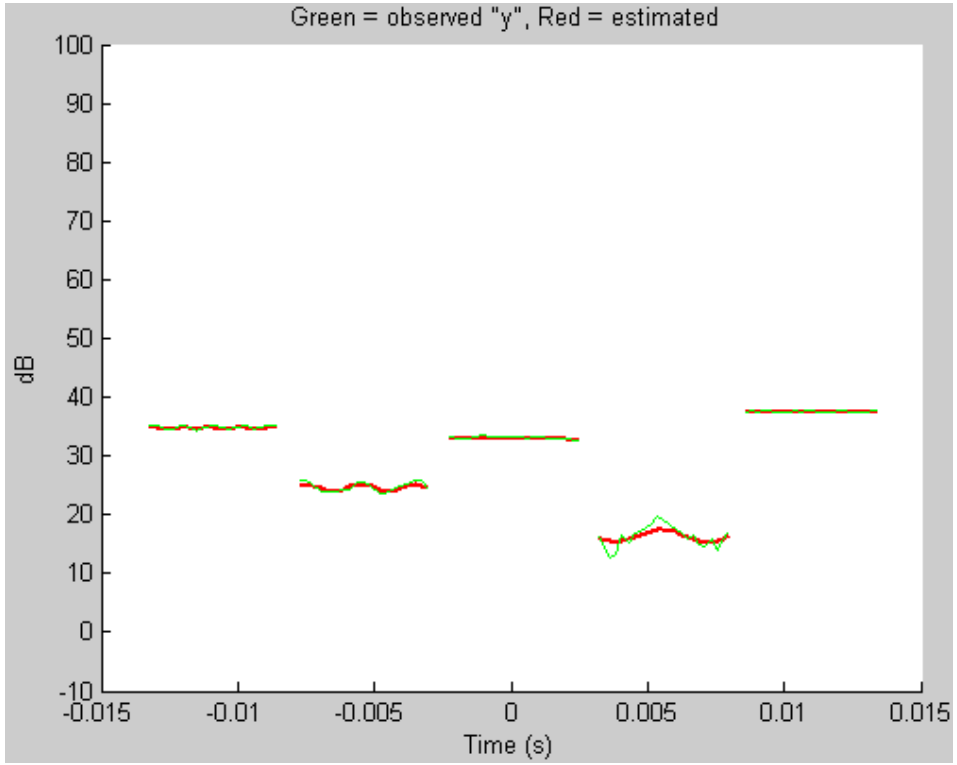
- To detect and to locate on the Doppler axis
  - Including Doppler ambiguity solving
  - At least 2 targets simultaneously

THALES

Simulation results

Scenario 1: targets separated by 1 ambiguous speed + $\frac{1}{2}\delta v$

- **Target 1: 60 m/s, 50 dB per burst, Swerling 2 fluctuation**
- **Target 2: 275 m/s, 20 dB per burst, Swerling 2 fluctuation**
  - $v_{target\_2} = v_{target_1} + V_{ambiguous\_3} + \frac{1}{2}\delta v$



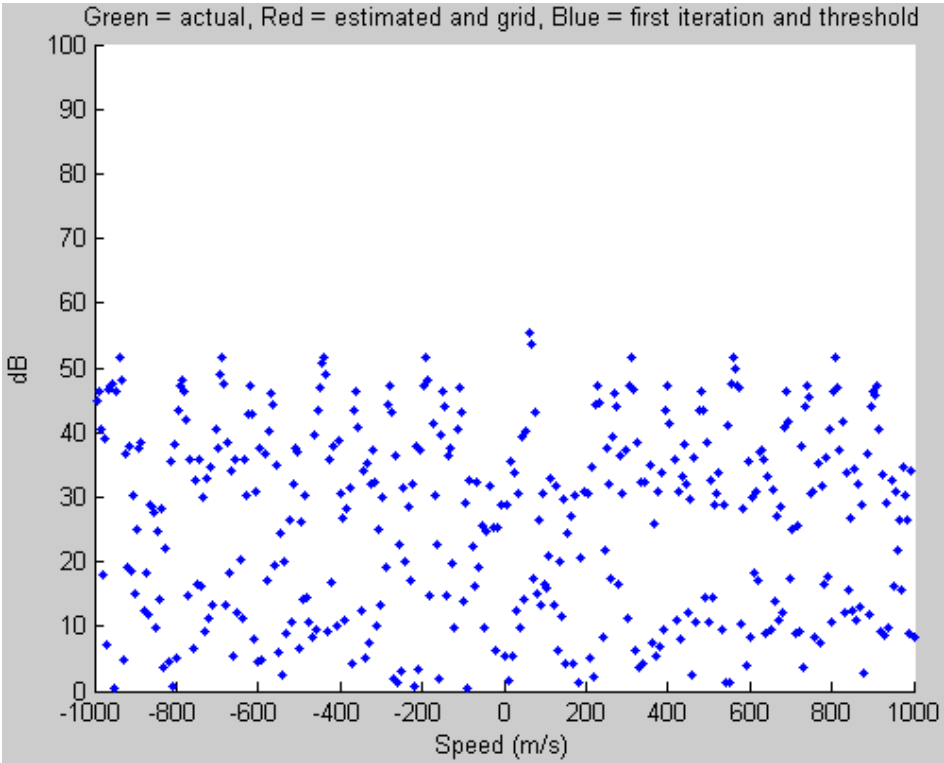
THALES

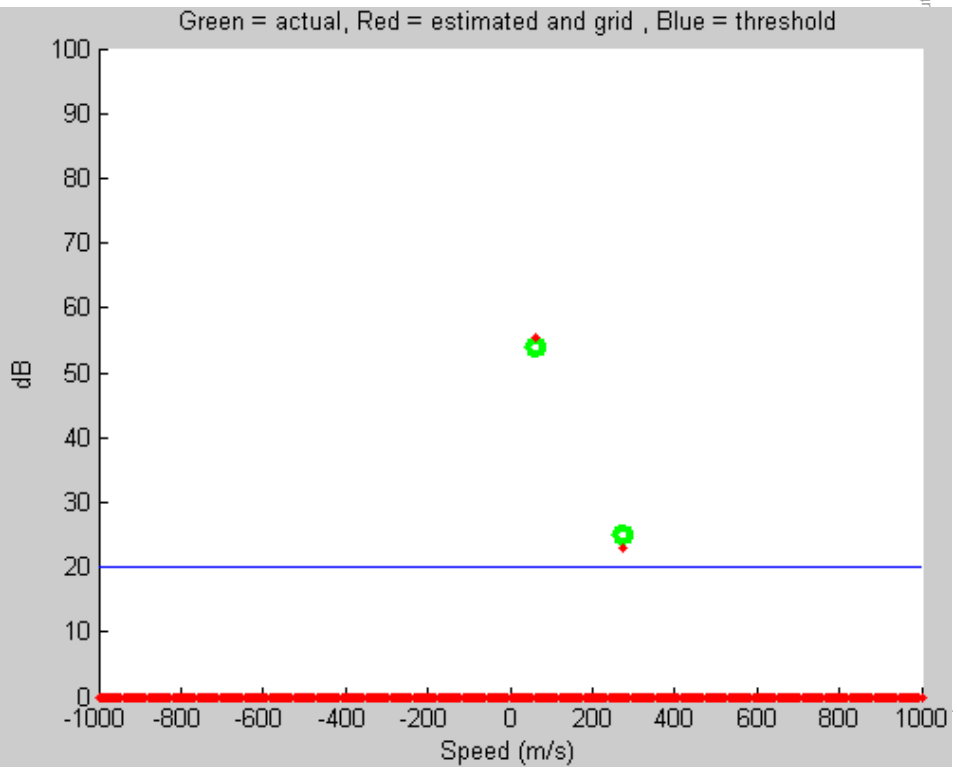
Simulation results

Scenario 1: targets separated by 1 ambiguous speed + $\frac{1}{2}\delta v$

- **Target 1: 60 m/s, 50 dB per burst, Swerling 2 fluctuation**
- **Target 2: 275 m/s, 20 dB per burst, Swerling 2 fluctuation**

  - $v_{target\_2} = v_{target_1} + V_{ambiguous\_3} + \frac{1}{2}\delta v$



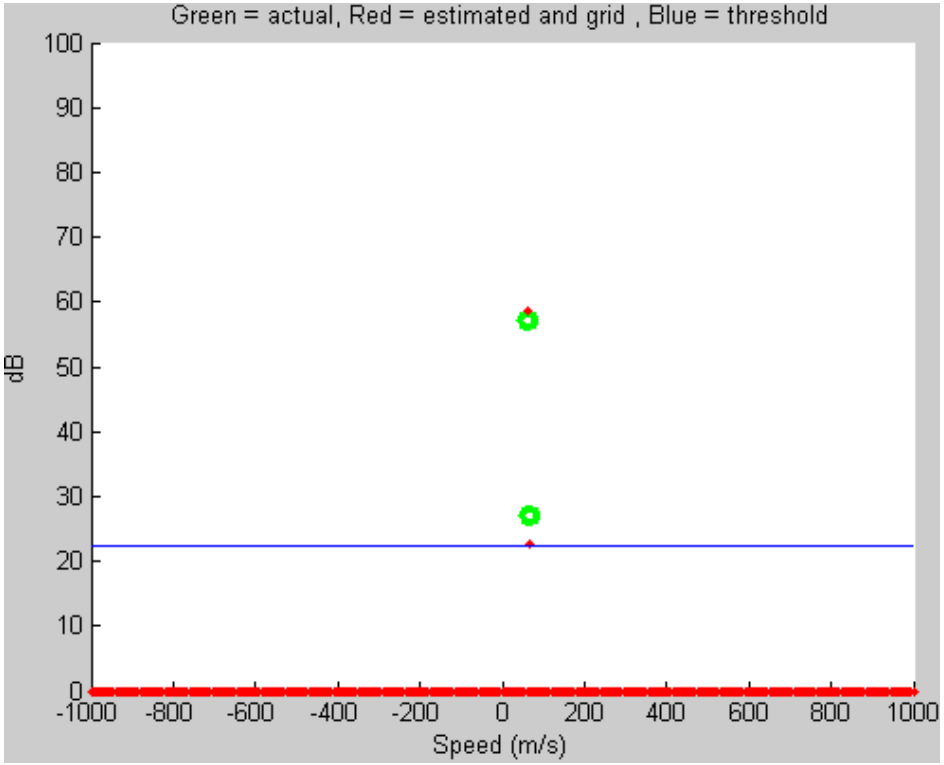


THALES

Simulation results

Scenario 2 : targets separated by $\frac{1}{2}\delta v$

- Target 1: 60 m/s, 50 dB per burst, Swerling 2 fluctuation
- Target 2: 65 m/s, 20 dB per burst, Swerling 2 fluctuation
  - $v_{target\_2} = v_{target_1} + \frac{1}{2} \cdot \delta v$

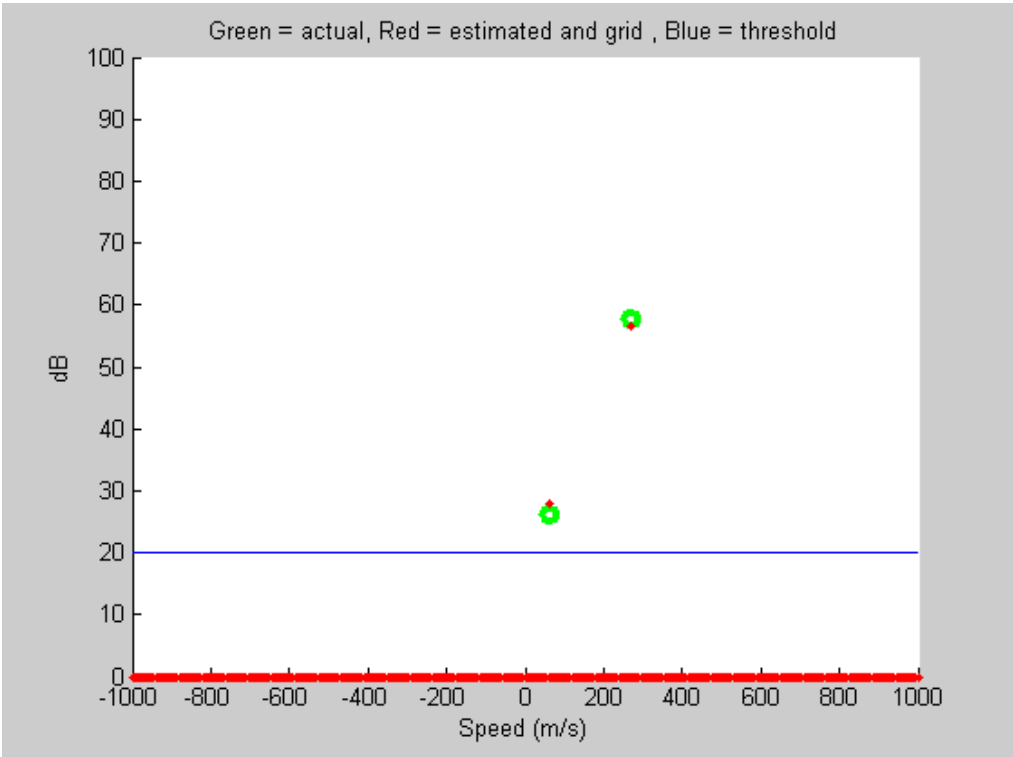


THALES

Simulation results

Scenario 3 : 2 targets separated by 1 ambiguous speed

- Target 1: 60 m/s, 50 dB per burst, Swerling 2 fluctuation
- Target 2: 270 m/s, 20 dB per burst, Swerling 2 fluctuation
  - $v_{target\_2} = v_{target_1} + V_{ambiguous\_3}$



THALES

Simulation results

Overall results analysis

- **In all cases, Compressive Sensing**
- **Detects both targets**
- **Estimates perfectly target positions**
  - While solving Doppler ambiguity
- **Estimates correctly energy levels**
  - Even in the case where both targets have a common ambiguous speed
  - Slight difference with input energies

THALES

Extract Before Detect

Summary

- Compressive Sensing radar processing
- CAMP (Complex Approximate Message Passing) applied to multiple burst signal
- Simulation results
- Conclusion
  - Compressive Sensing reduces complexity
  - Compressive Sensing reduces losses
  - Further works

THALES

Conclusion (1/3)

CAMP has been extrapolated to N-burst signals

- **N-CAMP**
  - N-signal complex soft threshold
  - Complex derivatives
  - 1 single non-zero term in $dv_{a,j}^{t}$
  - A few lines of code

Compressive Sensing reduces complexity

- **Compressive Sensing achieves at once detection, measurement, ambiguity solving and multiple targets discrimination**
  - Extract Before Detect
  - Easier to settle than a series of tests to solve ambiguities from hits

THALES

Conclusion (2/3)

Compressive Sensing reduces losses

- **Detection is based on the sum of the energies over all the bursts**
  - Standard process "K over N" is based on K times a 1-burst detection
  - Reduced detection loss
- **Weighting functions are not necessary**
  - Compressive Sensing extracts weak signals below strong signal sidelobes
  - Reduced weighting loss
- **Folded echoes hardly affect target detection**
  - Even in the case where 2 targets have a common ambiguous speed
  - Reduced interfering targets loss

THALES

Conclusion (3/3)

Further works

- **Grid adaptation to target positions**
- **Merging Compressive Sensing and coherent functions**
  - Digital Beam Forming
  - Doppler Filtering
  - Pulse Compression
- **Merging Compressive Sensing and noise measurement**
  - CFAR (Constant False Alarm Rate)
  - Clutter maps

Compressive sensing is a very promising approach to improve radar processing efficiency

THALES

Thank you for your attention

Any question ?

THALES