Vehicle Identification and Classification System Using Electromagnetic Waves

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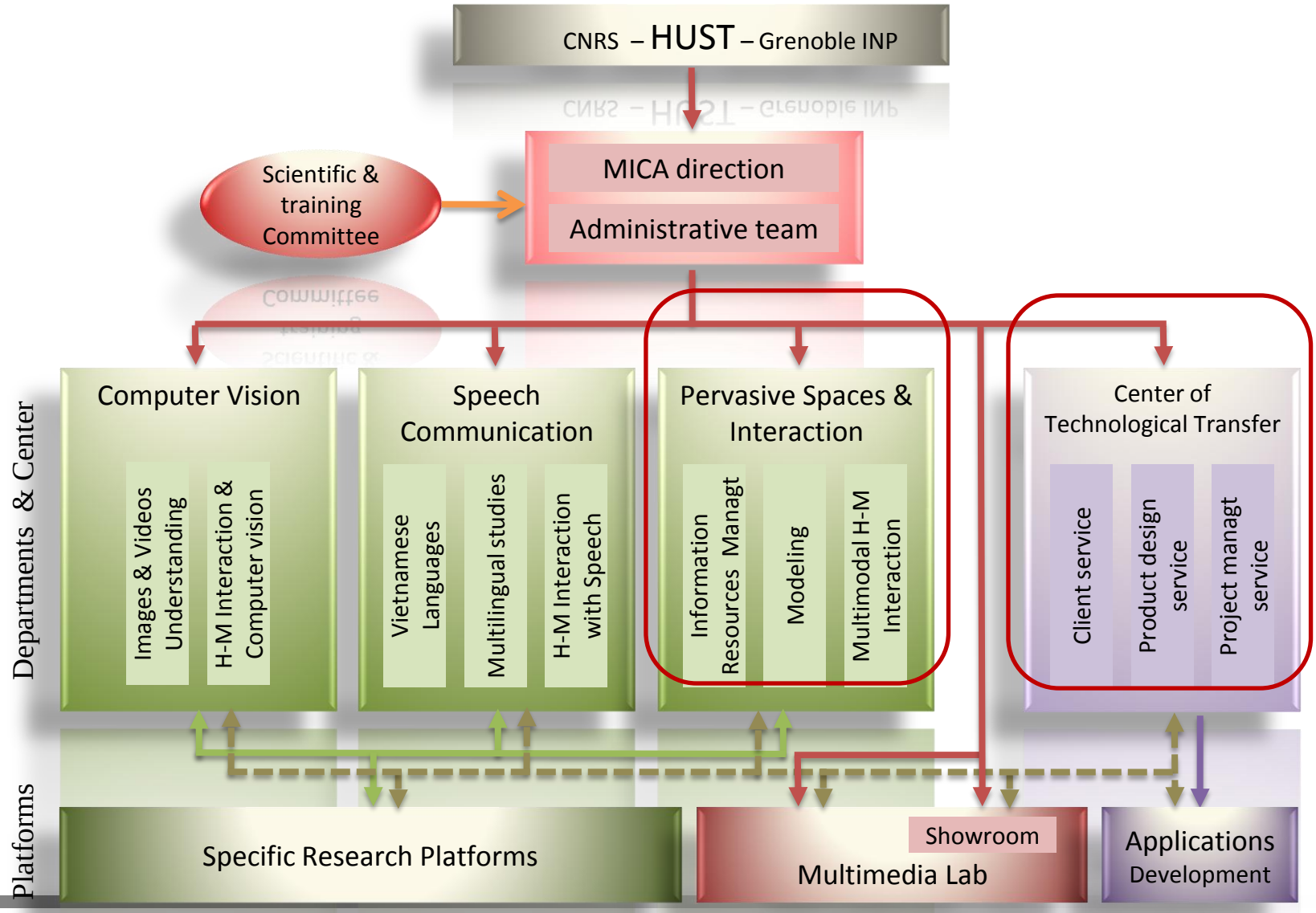
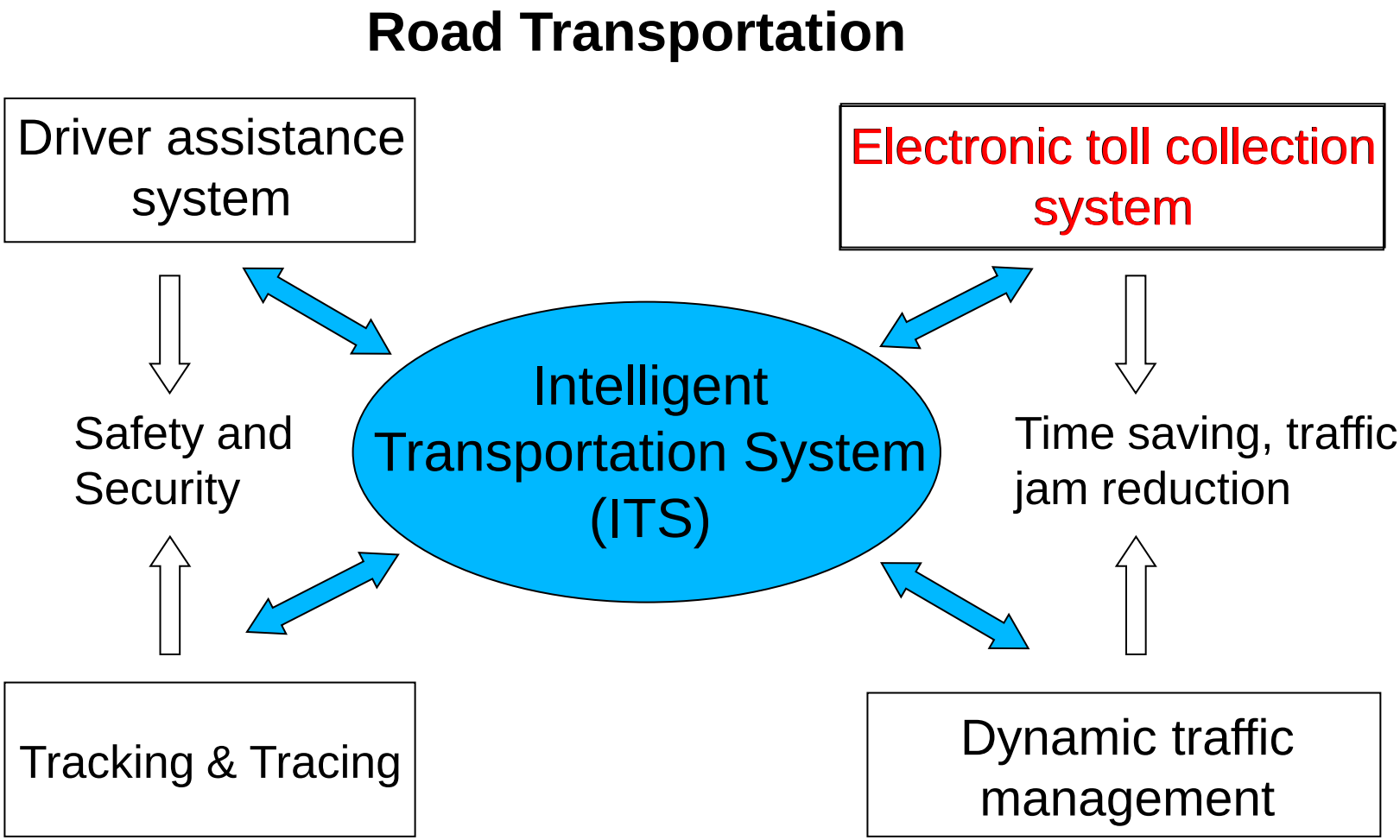
MICA Institute



Context



- In co-operation with IMEP-LAHC laboratory

Context

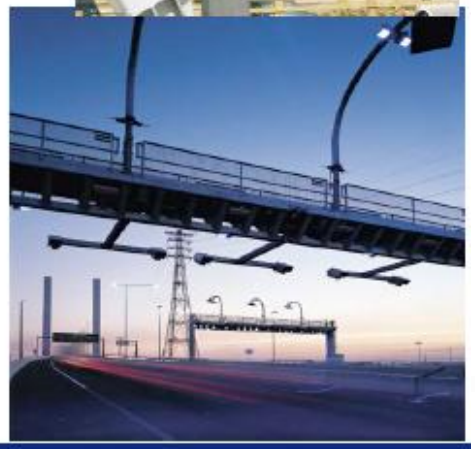
Automatic toll payment system without stopping vehicles, or Free-Flow toll system

Free-Flow Toll Collection Components




System Components:

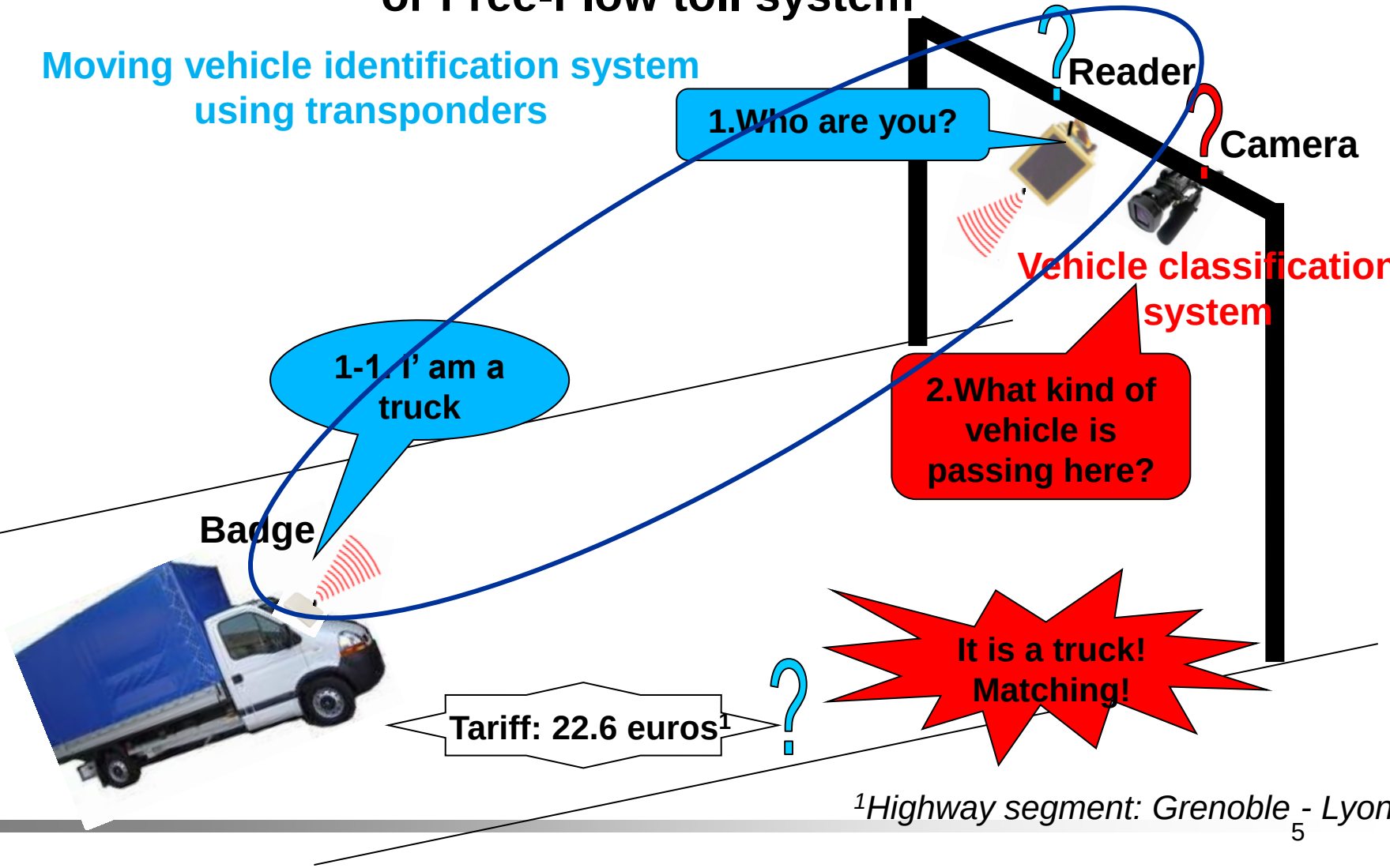
- In-Vehicle Unit or Transponder
- Roadside Equipment
- Call Centre
- Back Office System



Operating principle

Automatic toll payment system without stopping vehicles or Free-Flow toll system

Moving vehicle identification system using transponders

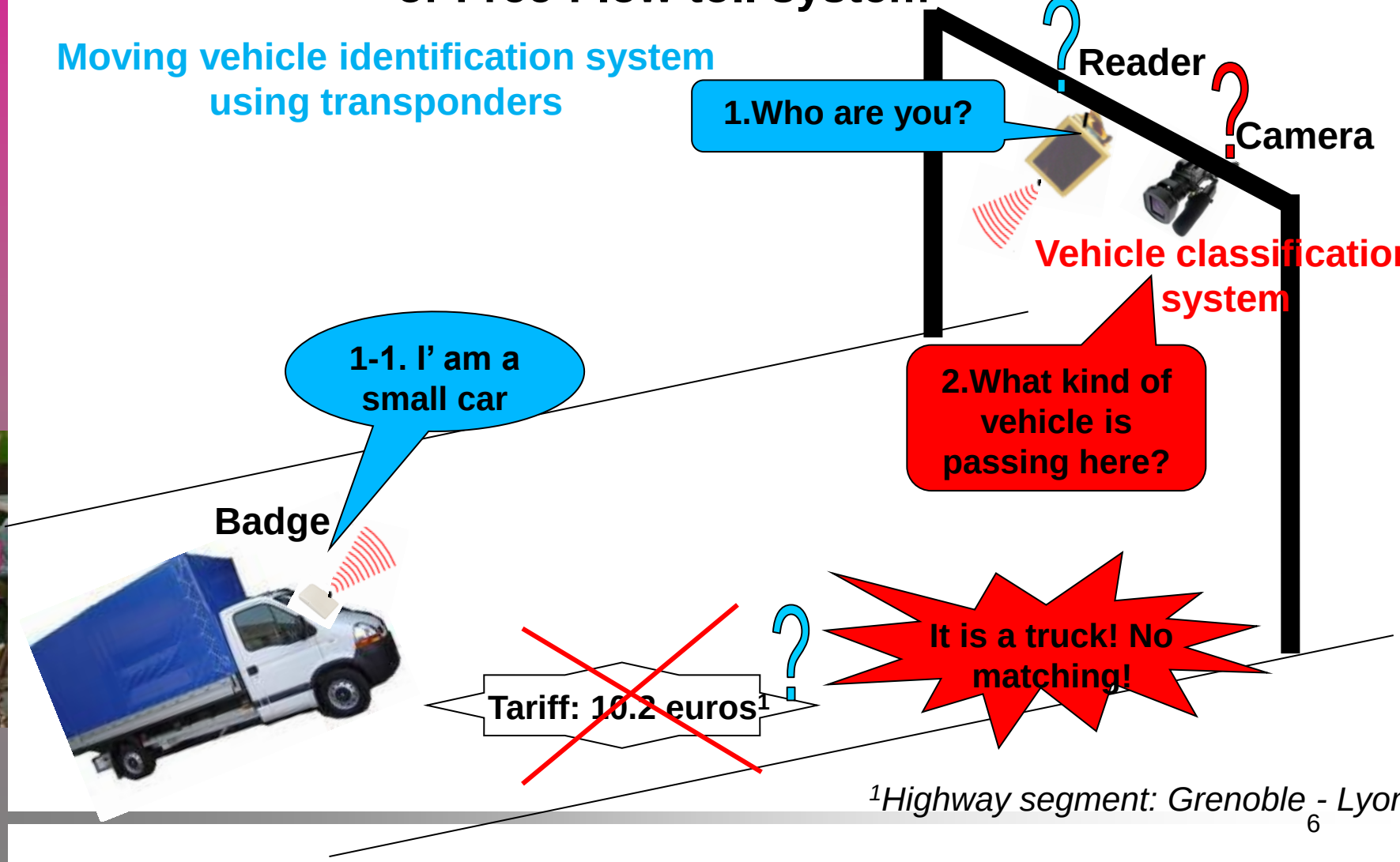


[1]Highway segment: Grenoble - Lyon

Operating principle

Automatic toll payment system without stopping vehicles or Free-Flow toll system

Moving vehicle identification system using transponders



[1]Highway segment: Grenoble - Lyon

Outline

- **Moving Vehicle Identification System using Transponders (VST system)**
  - Objectives
  - VST system: State of the art
  - Our high-gain antenna: low profile, low cost
- **Vehicle Type Classification System using Electromagnetic Waves (VTC system)**
  - Objectives
  - VTC system: State of the art
  - Our VTC system
- **Conclusions and Perspectives**

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VST system: State of the art

Comparison of RF technologies using in transponders of VST system

	DSRC (5.795-5.815 GHz)	RFID UHF (865-868 MHz)	FM radio	Cellular	GNSS
Max range	< 1 km	Max.300m (at required - 30dBm sensitivity)	Hundreds km	< 10km	Thousands km
Data rate	6-27 Mbps	0.5 Mbps	>10 kbps	Actually : >10 kbps 3G : 2-3 Mbps	100-200 Mbps
Coverage	Line of Sight	Line of Sight	Area	Area	Area
Price (per bit)	$	$	$	$$	$$$

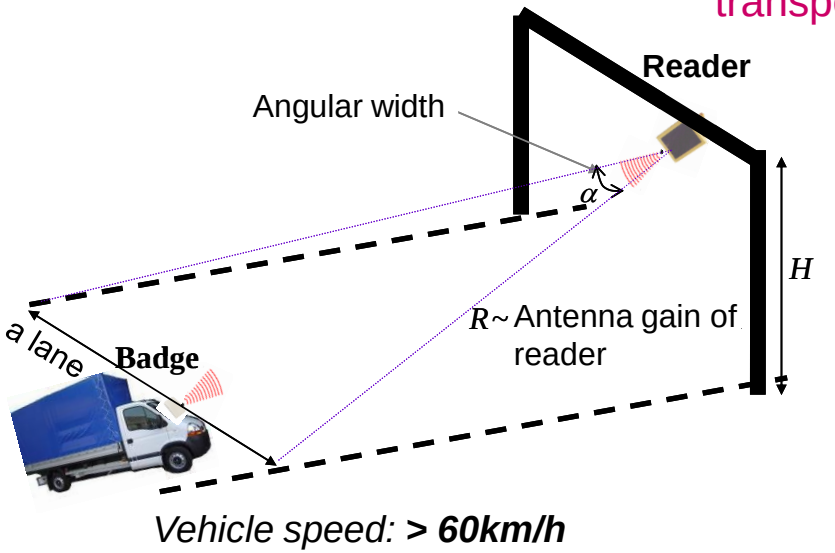
DSRC: **D**edicated **S**hort **R**ange **C**ommunication
RFID UHF: **R**adio **F**requency **Id**entification at **U**ltra **H**igh **F**requency
GNSS: **G**lobal **N**avigation **S**atellite **S**ystem

Y.L. Morgan, *IEEE of Communications Surveys & Tutorials*, 2010

Objectives of VST system

A - Moving Vehicle Identification System using Transponders (VST system)

Automatic toll payment using transponders



Challenge	Improving antenna performance
➢ Extending of operation range	➢ High gain antenna, covering a lane
➢ System size	➢ Low profile
➢ Price	➢ Low cost

Performance antenna design for VST system

➢Center frequency: 868 MHz (RFID UHF)

➢Gain : from 10dBi

➢Angular width (-3dB): 30°

➢Center frequency: 5.8 GHz (DSRC)

➢Gain : from 12dBi

➢Angular width (-3dB): 30°

Objectives of VST system

A - Moving Vehicle Identification System using Transponders (VST system)

Existing antennas	Name	Horizontal (degrees)	Vertical (degrees)	Gain (dBi)	Dimension (mm)	Wavelength (λ)
TagProduct Inc.	RFID 7dBi	68	68	7	240x240x30	0.7x0.7x0.09
TagProduct Inc.	ANTE0090	68	70	8.9	243x290x85	0.7x0.84x0.25
SkyRFID Inc.	SkyRFID	70	70	10	405x405x35	1.17x1.17x0.1
DGGate Inc.	RFID 12dBi UHF	65	**34**	12	440x440x50	1.27x1.27x0.15
DGGate Inc.	RFID 16dBi UHF	60	14	16	1200x280x130	3.48x0.81x0.38

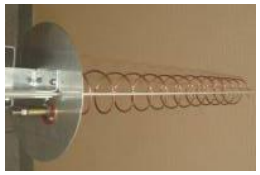
Performance antenna design for VST system

- Center frequency: 868 MHz (RFID UHF)
- Gain : from 10dBi
- Angular with (-3 dB): 30°

- Center frequency: 5.8 GHz (DSRC)
- Gain : from 12dBi
- Angular with (-3 dB): 30°

Different types of high-gain antenna

- **Helical antenna**



- **Horn antenna**

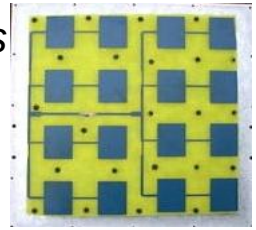
- **Yagi-Uda antenna**

- **Reflector antenna**

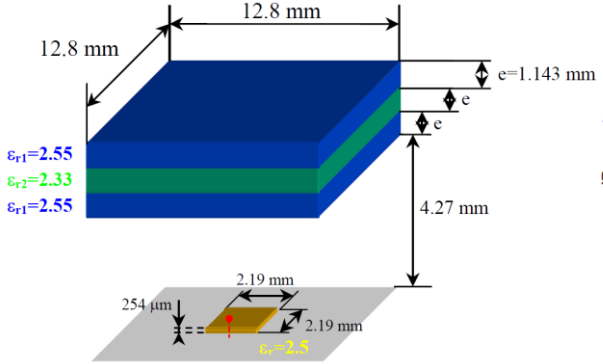
- **Len antenna**

- **Antenna arrays**

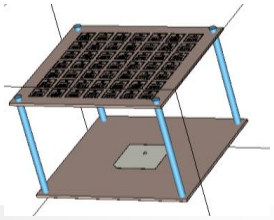
Patch antenna arrays



- **EBG[1] antenna**



- **Meta-material antenna**



Part A: VST system

MICA 2013

[1] Electromagnetic Bandgap Material

Our high-gain antennas

Reducing price of system

Extending of operating zone

Design and fabrication of high-gain, low cost antenna

- Gain : from 10dBi for UHF and 12 dBi for DSRC frequency
- Angular width (-3dB): 30°

Frequency: UHF (868 MHz)

- Metallic antenna (11 dBi)
- Cylinder-Yagi antenna (9.9 dBi)

Frequency: DSRC (5.8 GHz)

- Cylinder-Yagi antenna (12 dBi)
- Meta-materials antenna (15 dBi)

Our UHF high-gain antennas (868 MHz)

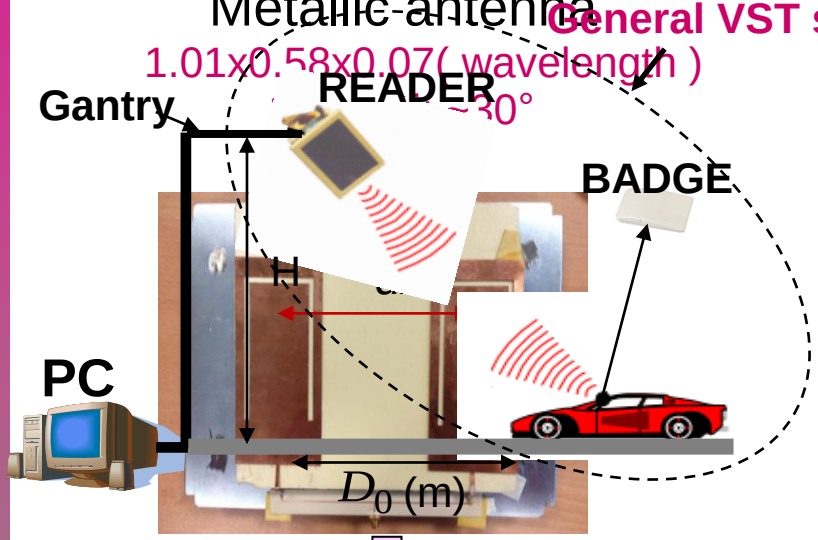
Low cost, easy to industrialize

Metallic-antenna

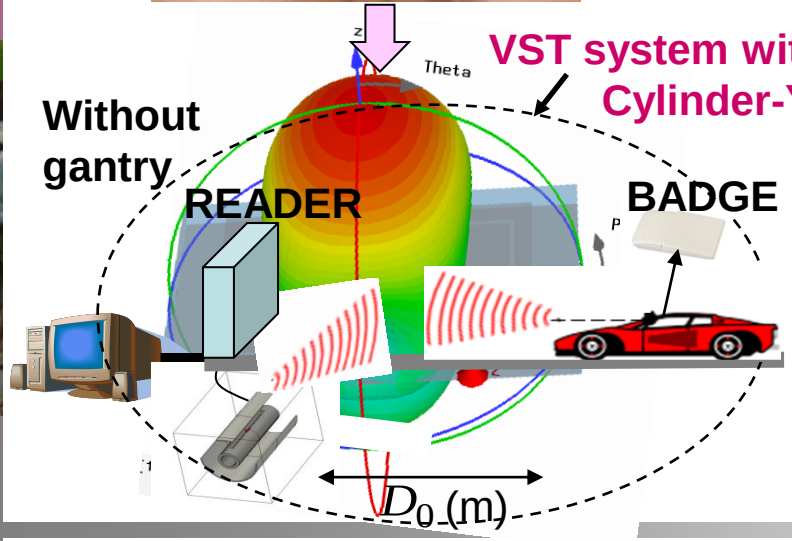
1.01x0.58x0.07(wavelength)

~30°

General VST system



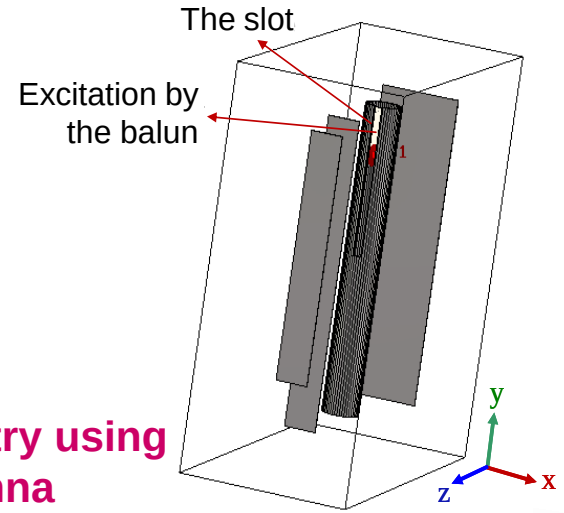
VST system without gantry using Cylinder-Yagi antenna

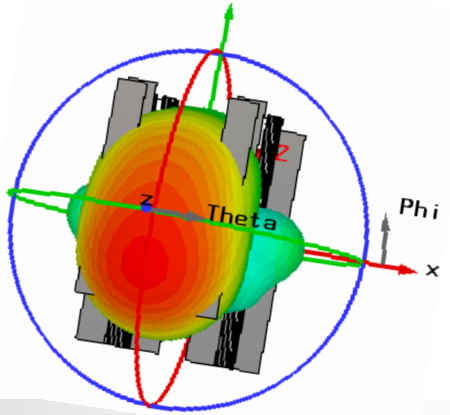


Cylinder-Yagi antenna

0.77x1.37x1.15 (wavelength)

9.9 dBi, ~30°



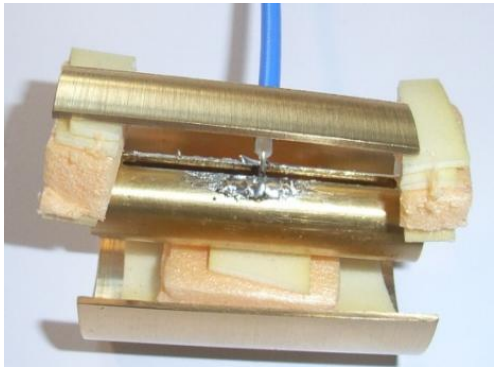


Ground antenna

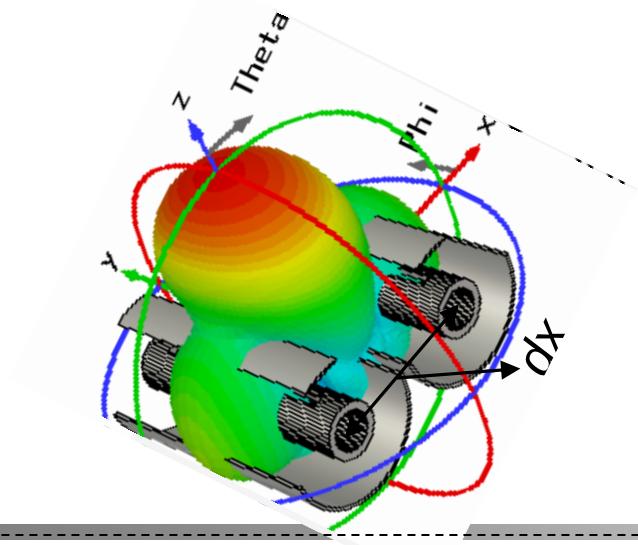
Our DSRC high-gain antennas (5.8 GHz)

Cylinder-Yagi antenna

1.46x1.23x0.69 (wavelength)
12 dBi, ~30°



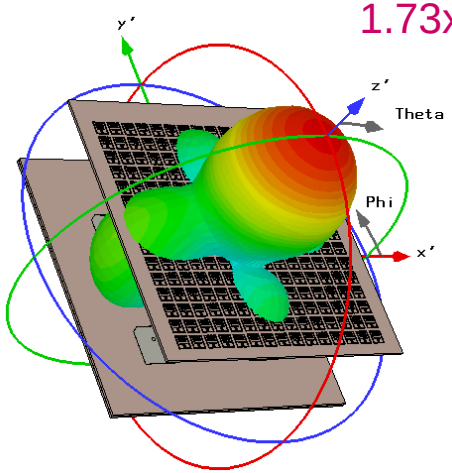
M .T. Le et al . , *Proc. of SEATUC*, 2011

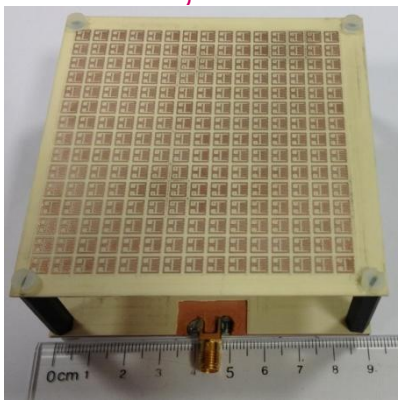


VST system without gantry

Meta-material antenna

1.73x1.73x0.61 (wavelength)
15 dBi; ~30°



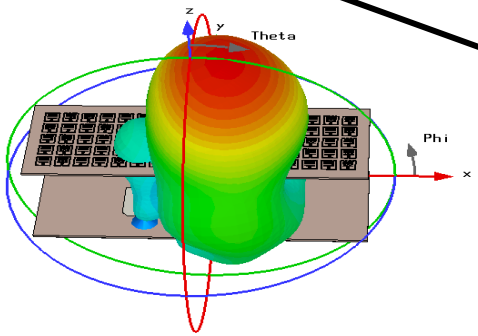


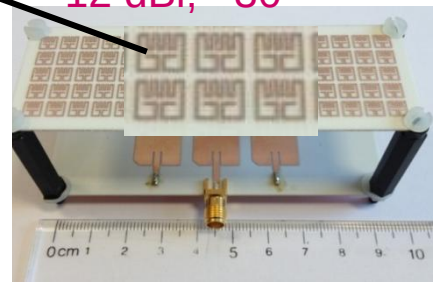
M .T. Le et al . , *Proc. of IEEE ICWITS*, 2012

New LHM unit-cell structure

Beam steering LHM antenna

1.73x0.57x0.61 (wavelength)
12 dBi; ~30°





Low profile
VST multi-lane system

Comparison with existing antennas

UHF: 868 MHz

Existing antennas	Name	Horizontal (degrees)	Vertical (degrees)	Gain (dBi)	Dimension (mm)	Wavelength (λ)
TagProduct Inc.	RFID 7dBi	68	68	7	240x240x30	0.7x0.7x0.09
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DGGate Inc.	RFID 16dBi UHF	60	14	16	1200x280x130	3.48x0.81x0.38
Our antenna	**Metallic antenna**	**39**	**55**	**11.6**	**350x200x23**	**1.01x0.58x0.07**

DSRC: 5.8 GHz

Existing antennas	Name	Horizontal (degrees)	Vertical (degrees)	Gain (dBi)	Dimension (mm)	Wavelength (λ)
Mobimark Inc.	DSRC 12dBi	**30**	55	12	161x70x14	3.09x1.35x0.27
Q-free Inc.	DSRC 14dBi	45	45	14	320x76x1	6.15x1.46x0.02
Norbit Inc.	DSRC 19dBi	19	9.5	19	580x110x10	11.2x2.11x0.19
Laird Inc.	Plat Antenna 58	16	8	19	190x190x20	3.66x3.66x0.38
Our antenna	**LHM DSRC 58**	**30**	**36**	**15**	**90x90x32**	**1.73x1.73x0.61**

➡ Small dimension; Low cost

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  - Our VTC system
- **Conclusions and Perspectives**

VTC system: State of the art

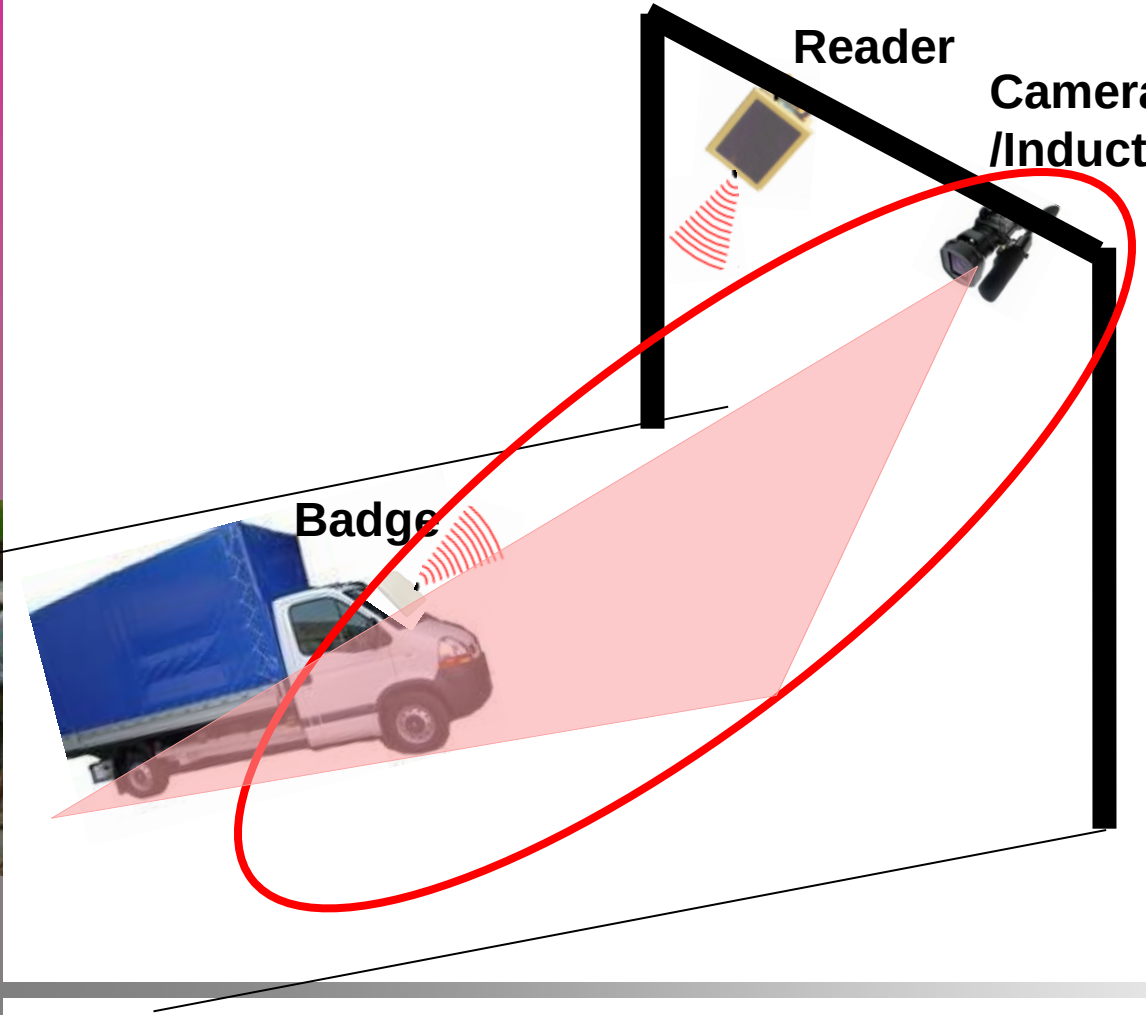
➢ Actual vehicle classification systems

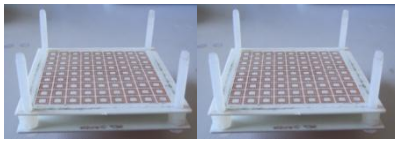
TECHNOLOGY	PRECISION	COMMUNICATION BANDWIDTH	PRICE	CONDITION OF ENVIRONMENT
Inductive loop	++	Low to moderate	+	
Infrarred	+	Low to moderate	++	
Lidar	+++	Moderate	+++	
Camera	+++	Low to high	++++	

Infrared, Lidar, Camera are sensitive to inclement weather, day and night lighting as well as day-to-night transition

Objectives of VTC system

B - Vehicle **T**ype **C**lassification system using electromagnetic waves (VTC system)





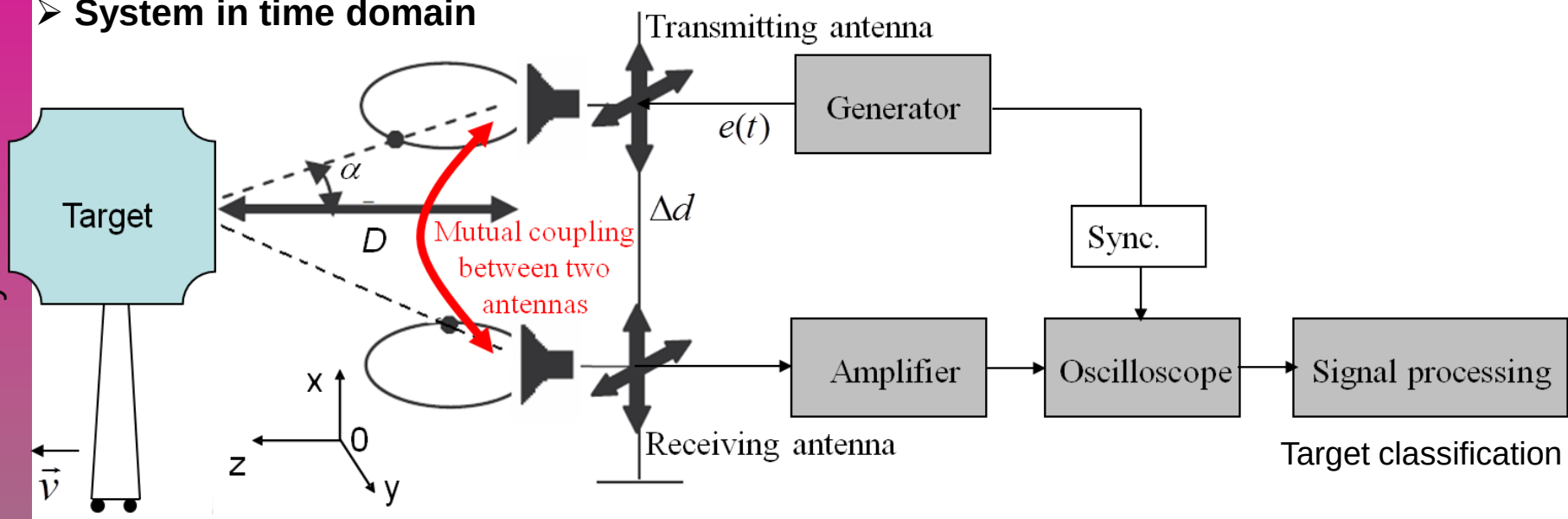
Problematic

- System price
- Precision
- Sensibility of climate, day and night light

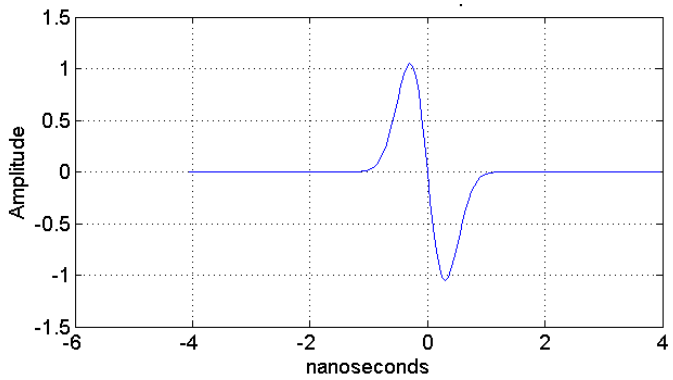
VTC system using electromagnetic waves

CTV system implementation

➢ **System in time domain**



➢ **Transmitting signal: monocycle pulse**



Total energy:

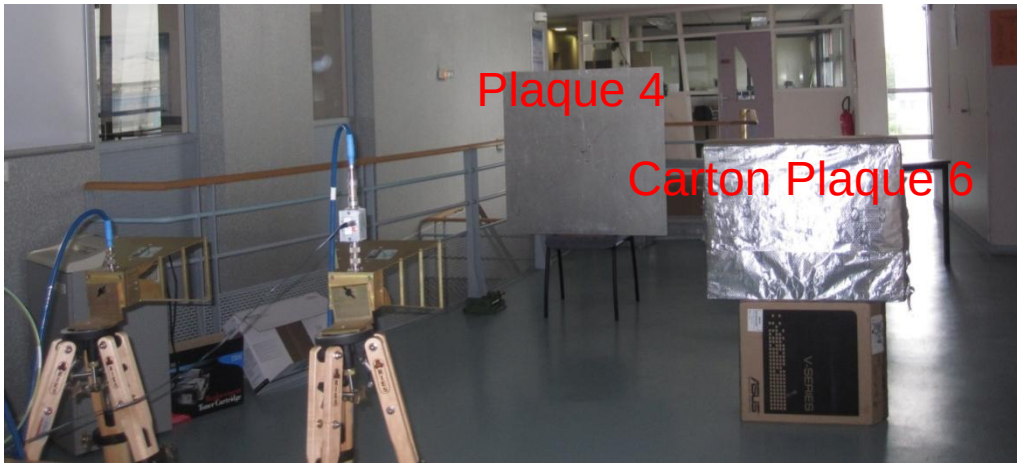
$$E \approx \lim_{T\to\infty} \int_{-\infty}^{\infty} x^2(t)dt$$

Advantages :

- ✓ Mobile target measurement (Doppler)
- ✓ High accuracy distance measurement
- ✓ Target response separation

Target classification based on backscattered waves captured by receiver

Backscattered wave measurement



Experiment 1: Different plaques

Experiment 2: Head and back of vehicles

Methodology of target classification

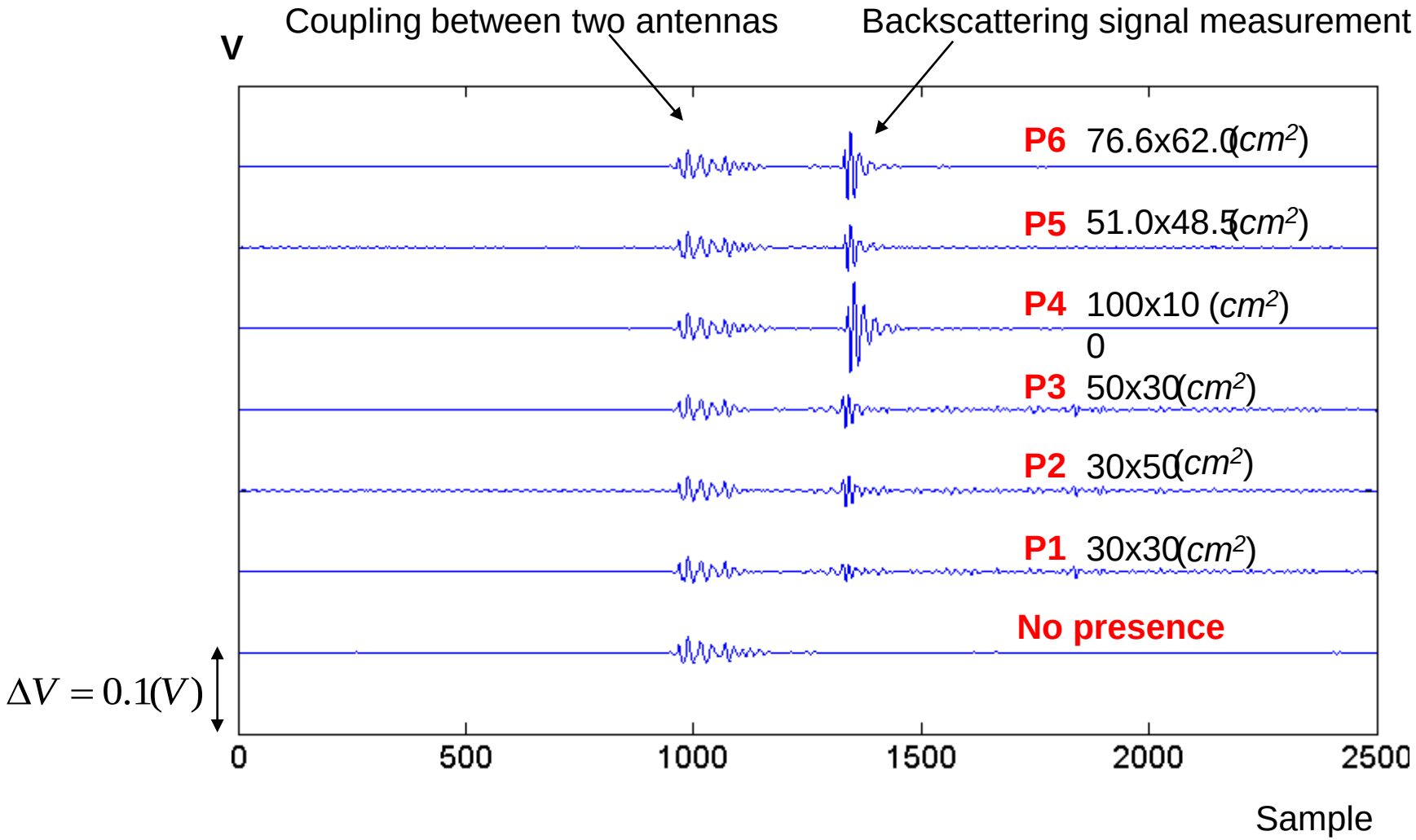
(A) **Target presence detection** — Based on Signal to Noise Ratio

(B) **Distance calculation** — Time delay of backscattering signal

(C) **Target Type Classification** (Three proposed methods) — Three proposed methods

- **Method 1**: target classification based on **C**hanging waveform using a **W**ide **B**eamwidth **A**ntenna (**CWBA** method)
- **Method 2**: target classification based on backscattered **P**ower using a **W**ide **B**eamwidth **A**ntenna (**PWBA** method)
- **Method 3**: target classification based on backscattered **P**ower using a **B**eam-**S**teering **A**ntenna (**PBSA** method)

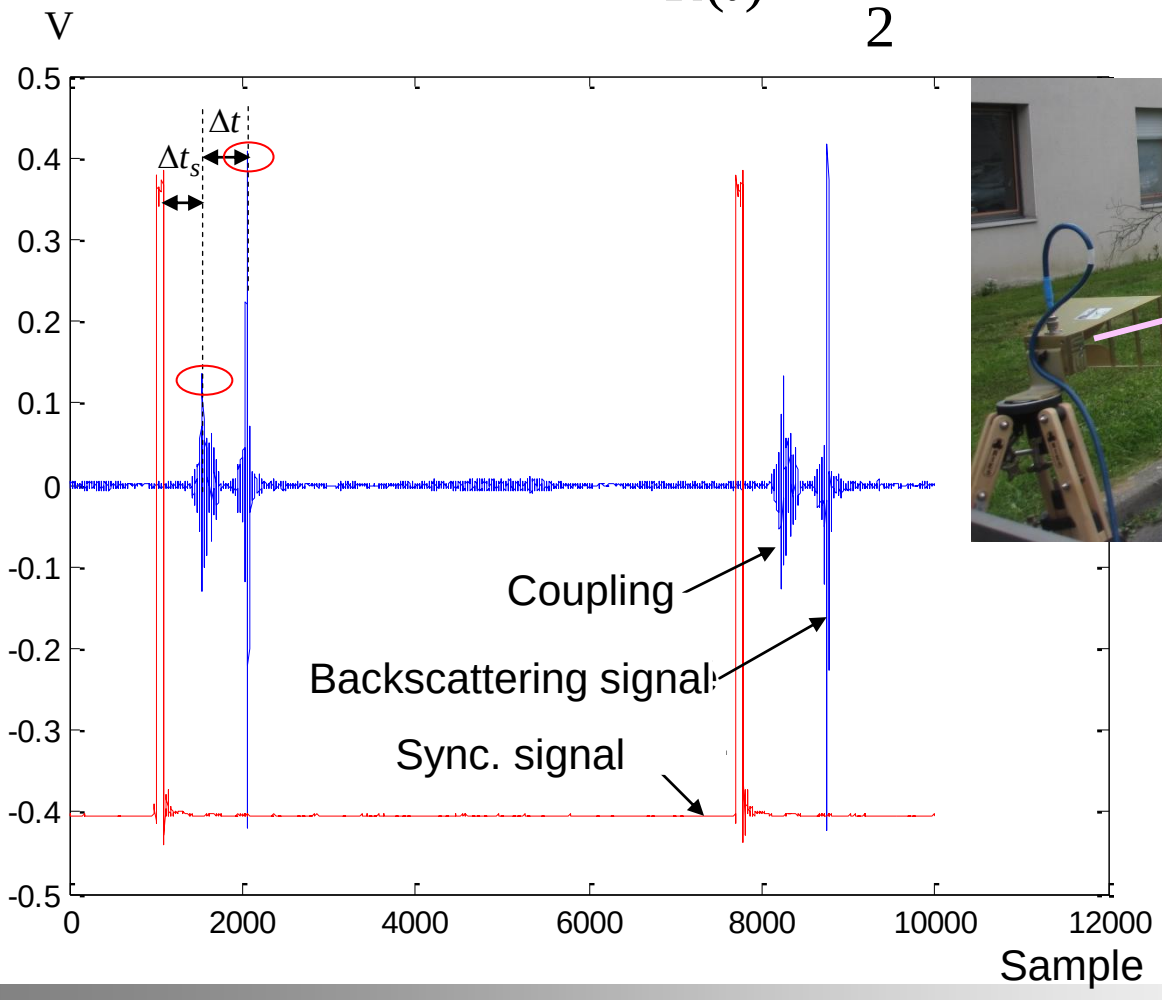
Target presence detection

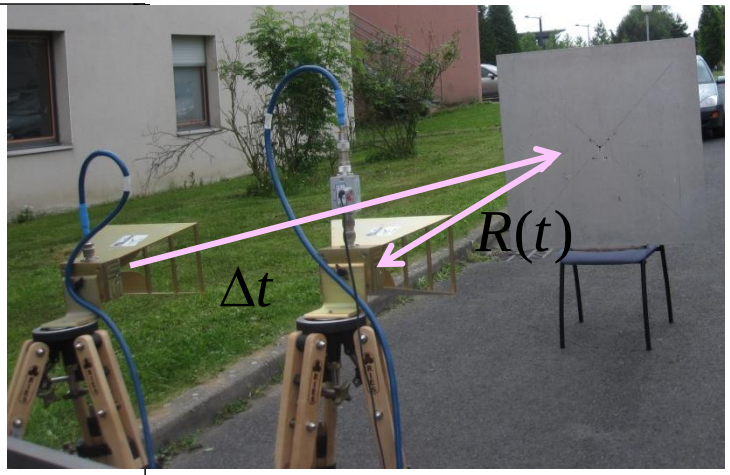


Distance measurement

- Based on delay time of backscattered wave captured by receiver:

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



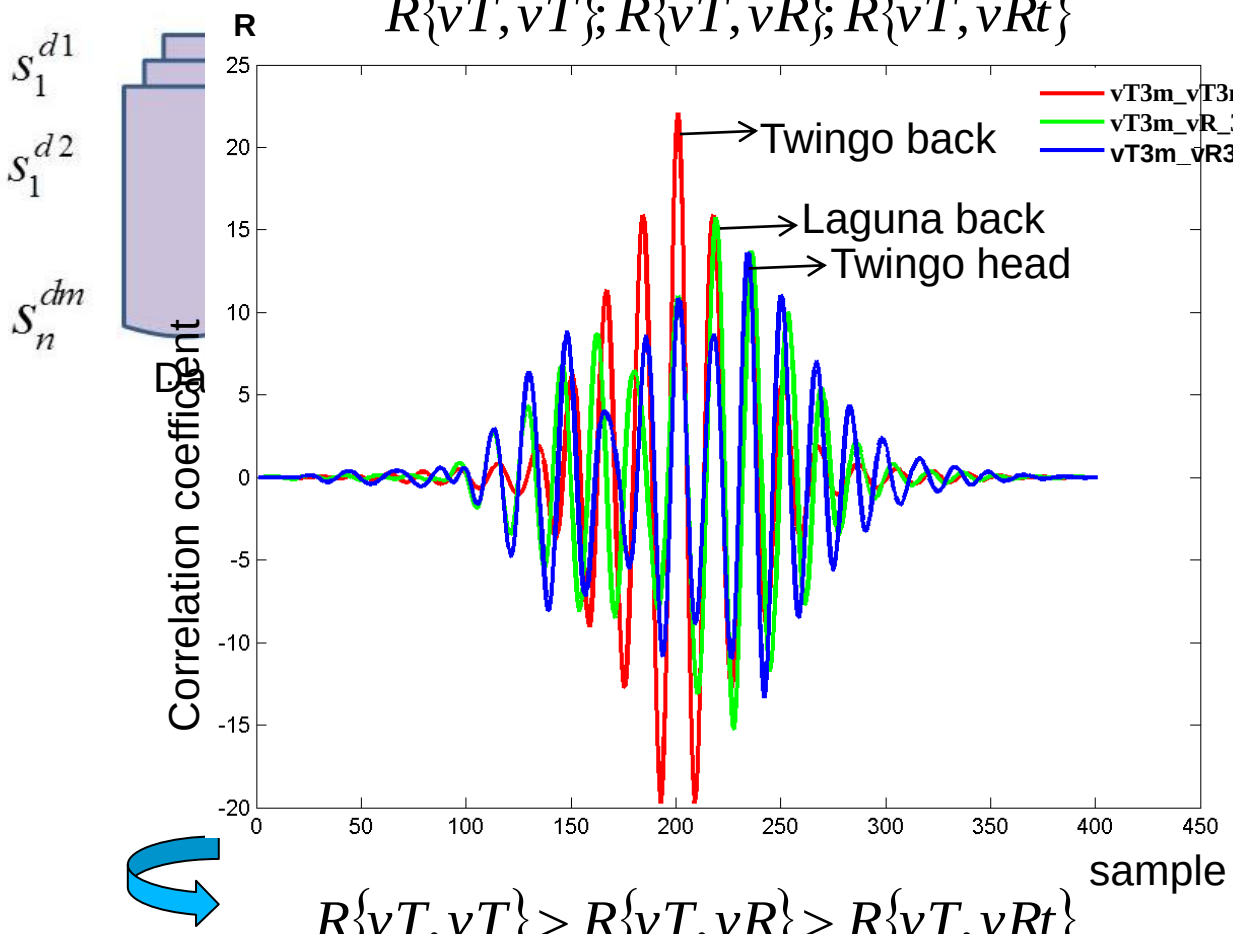


Target classification (1/3): CWBA method

- Method 1: based on correlation coefficient $R_{12}(\tau) = \int_{-\infty}^{+\infty} s_1(t).s_2(t+\tau)dt$

  Back of Twingo observation: $S_{target}^{d_x}$

$$R\{vT, vT\}; R\{vT, vR\}; R\{vT, vRt\}$$



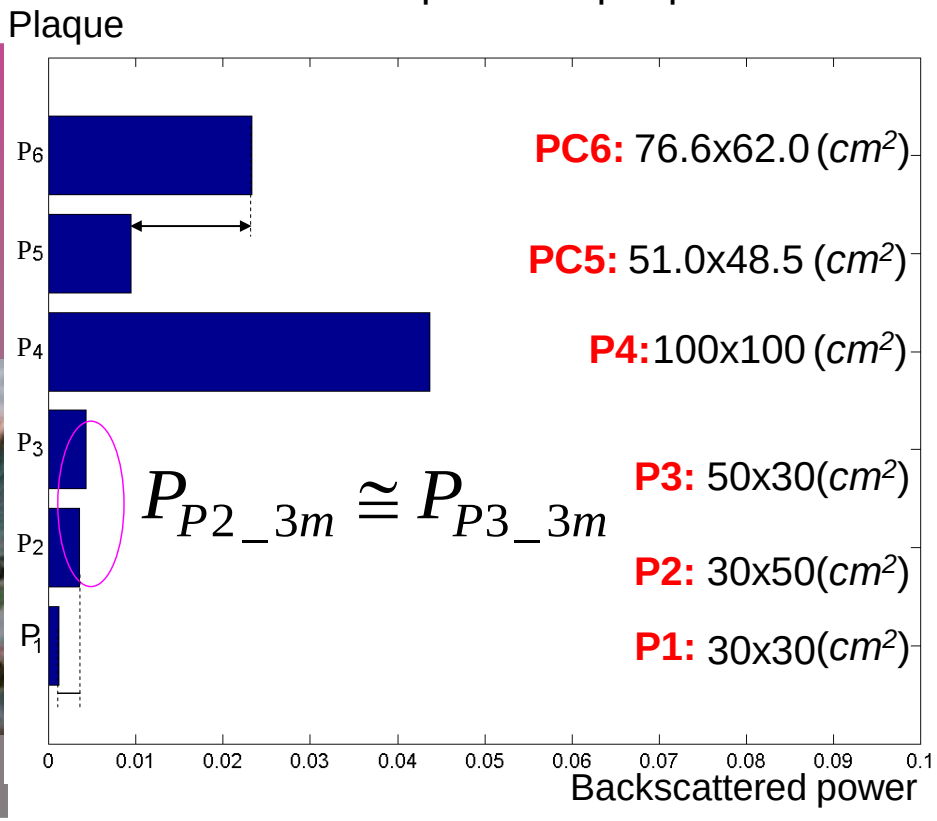
$$R\{vT, vT\} > R\{vT, vR\} > R\{vT, vRt\}$$

Target classification (2/3): PWBA method

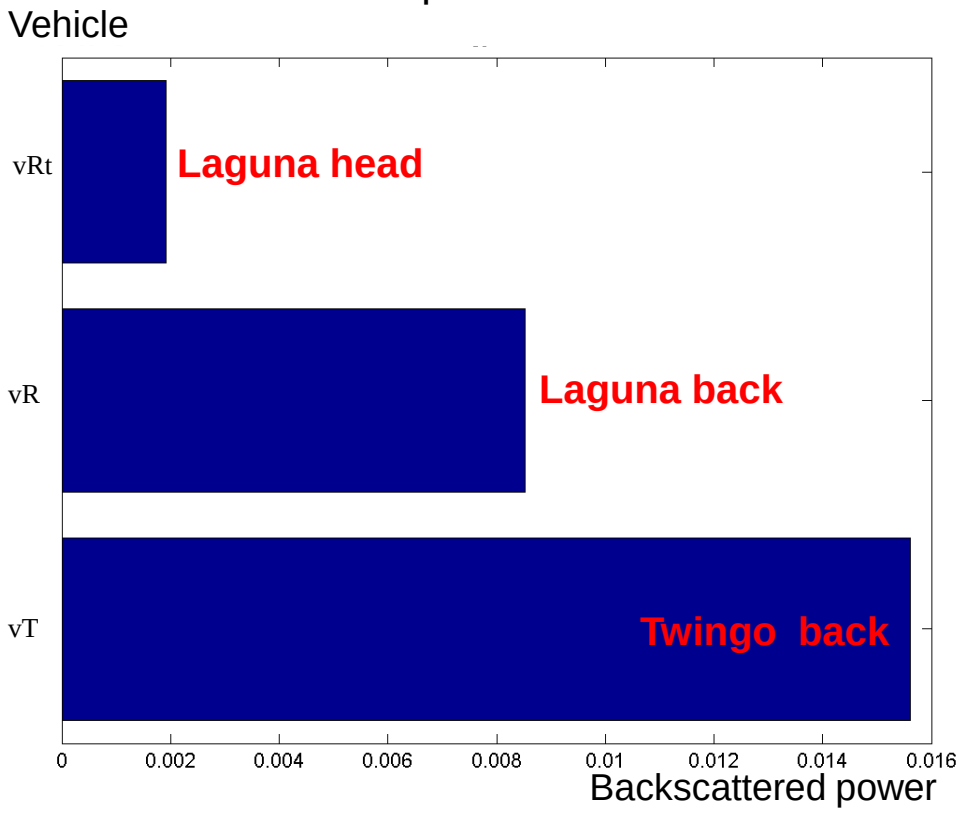
- Method 2: based on backscattered power at a certain distance $P_{target}^{d_x}$

$$\sigma_{target} = \chi.R_i^2.R_r^2.\frac{P_r}{P_e} = \chi.R^4.\frac{P_{target}^R}{P_e}$$

Backscattered power of plaques at 3m

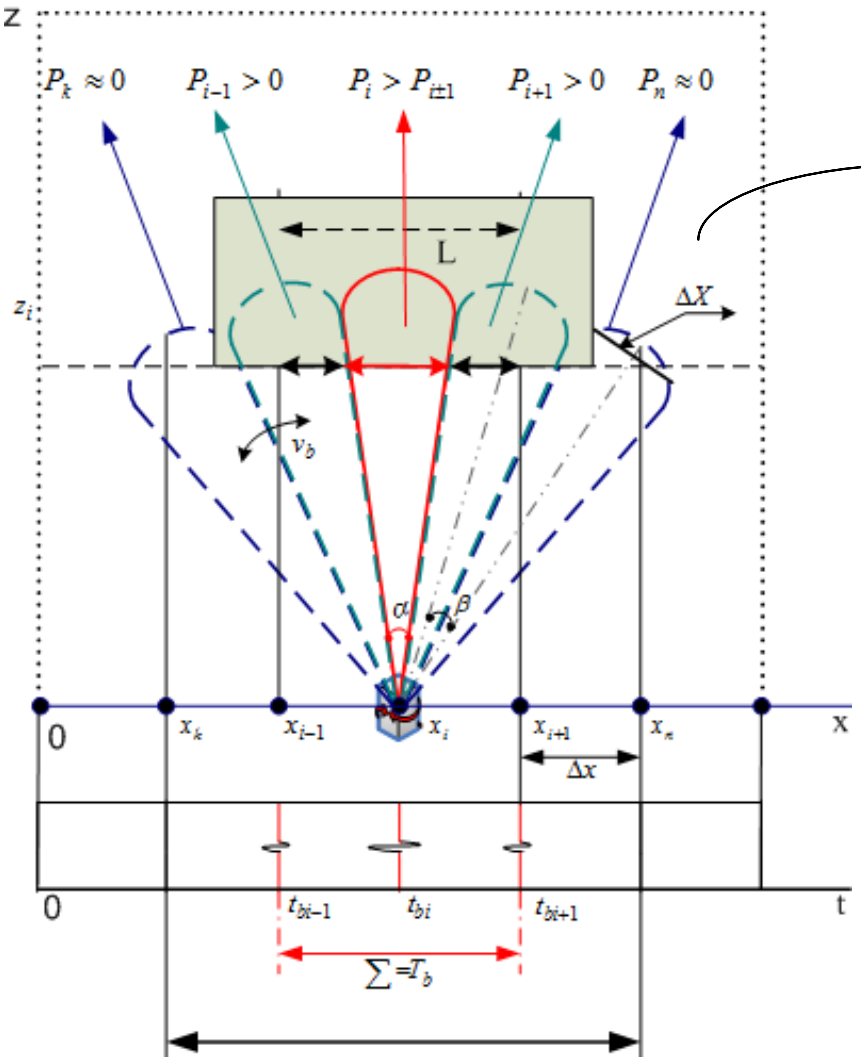


Backscattered power of vehicles at 3m



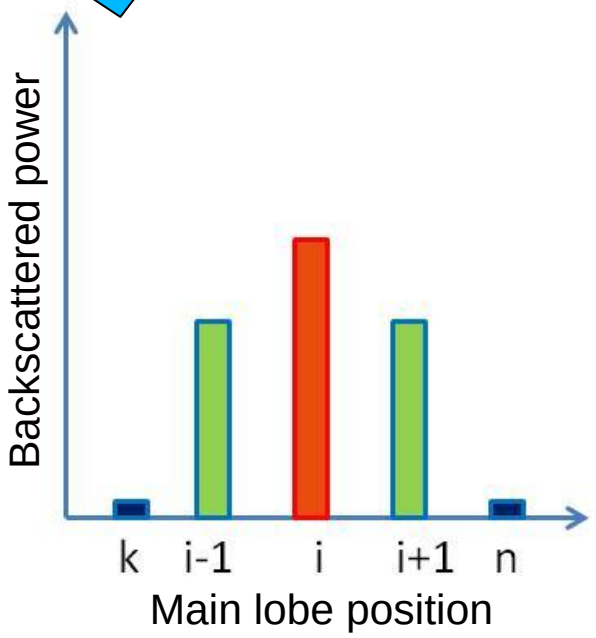
Target classification (3/3): PBSA method

- Method 3: based on target width calculation from backscattered power



Target width calculation :

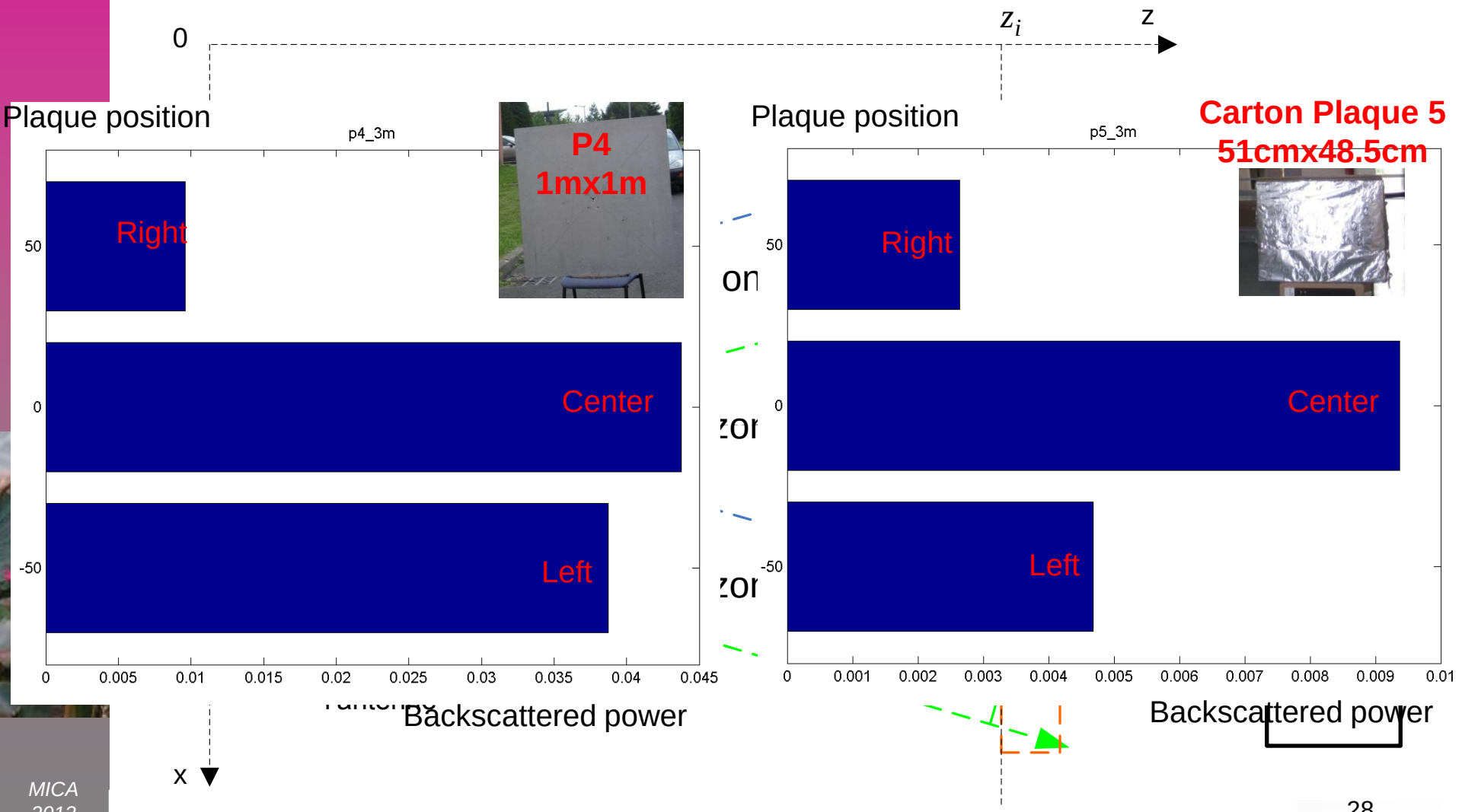
$$L = v_b.T_b$$



Principal method

Target classification (3/3): PBSA method

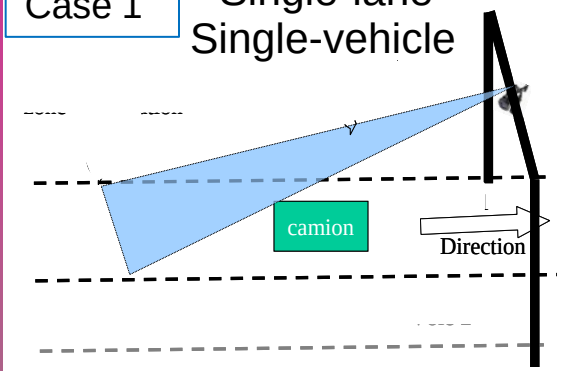
- Method 3: based on target width calculation from backscattered power



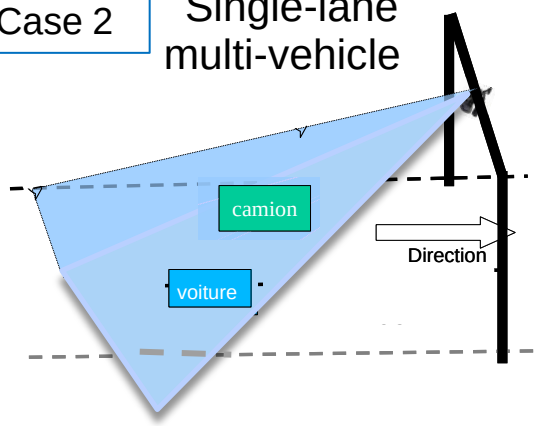
Summary of three methods

- Our first study shows the ability of three methods
- First results are encouraging for the next work

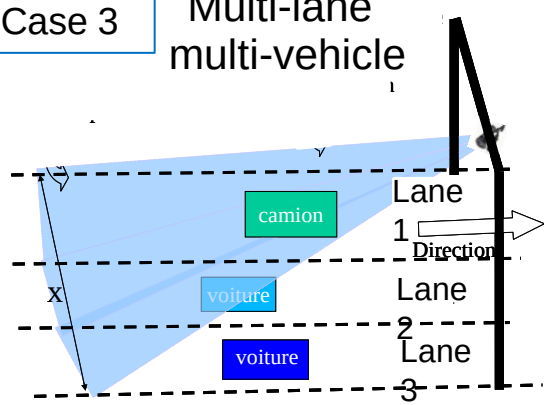
Case 1 Single-lane Single-vehicle



Case 2 Single-lane multi-vehicle



Case 3 Multi-lane multi-vehicle



Method 1: CWBA	Method 2: PWBA	Method 3: PBSA
▪ Based on correlation coefficient ▪ Depending on the backscattered waveform ▪ Less precision when targets are in the same family ▪ Not able to work in the case 2 & 3	▪ Based on backscattered power ▪ Stable with backscattered waveform ▪ Not able to work in the case 2 ▪ Able to work in the case 3 (with condition)	▪ Based on target width calculation from backscattered power (like method 2) combining with beam-steering time => more accuracy ▪ Stable with backscattered waveform ▪ Able to work in the case 2 ▪ Able to work in the case 3 (with condition)

Outline

- **Moving Vehicle Identification System using Transponders (VST system)**
  - Objectives
  - VST system: State of the art
  - Our high-gain antenna: low profile, low cost
- **Vehicle Type Classification System using Electromagnetic Waves (VTC system)**
  - Objectives
  - VTC system: State of the art
  - Our VTC system
- **Conclusions and Perspectives**

Conclusions

- Fabrication and measurement high-gain antenna for VST system for improving operation range
  - UHF RFID frequency (868 MHz):
    - Metallic antenna
    - Cylinder-yagi antenna => VST system without gantry
  - DSRC frequency (5.8 GHz):
    - Cylinder-yagi antenna
    - Meta-material antenna => New LHM structure for high-gain antenna
    - Meta-material beam-steering antenna=> Multi-lane system

Very low cost

- Design of VTC system using electromagnetic waves
  - Using antenna instead of camera/lidar sensor
  - Three proposed methods
  - Implementation in lab

Perspectives

- VST system
  - Taking into account the ground effect to our Cylinder-yagi antenna
  - DSRC beam-steering antenna => develop a controllable radiation diagram antenna

- VTC system
  - Increase the database for developing target classification algorithm
  - Improve the Ultra-Wide Band antenna gain used in the system
  - Develop a receiver for VTC system


Thank you!
for attending my presentation

No question off limits