Passive Radars on Mobile Platforms - New Changes and New Benefits

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WUT is the largest of 18 Polish technical universities

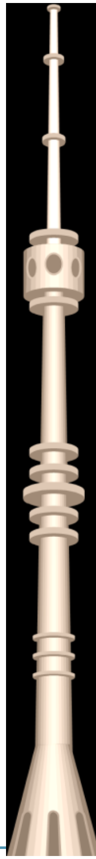
Public state school

Passive radars on mobile platforms

- Passive early warning
- Platform protection
- No own emission

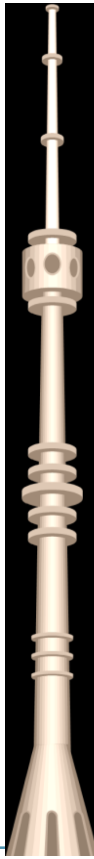
Passive radars on ground platforms

- Low platform speed
- Detection of aerial targets (airplanes, missiles)
- Detection of surface targets (vehicles, peoples)



Passive radars on sea platforms

- Low platform speed
- Detection of aerial targets (airplanes, missiles)
- Detection of surface targets (ships)



Passive radars on airborne platforms

- High platform speed
- Detection of aerial targets (airplanes, missiles)
- Detection of surface targets (vehicles, ships)
- Ground imaging

Why we need Airborne Radars?

We want to:

- know where we are

- search all arounded us air volume (are we alone here?)

- survailance

- ….

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- ….

Airborne Radars is:

An  for airborne operations

The all weather, day&night operation

Active Radars

Emitted pulses

Airborne **ACTIVE** radar
LPI required

LPI – Low Probability Interception

ESM SYSTEM

Active Radars

Long radar detection range => high power ~ R^4

ESM detection range => 1000 km ~ R^2

Emitted pulses

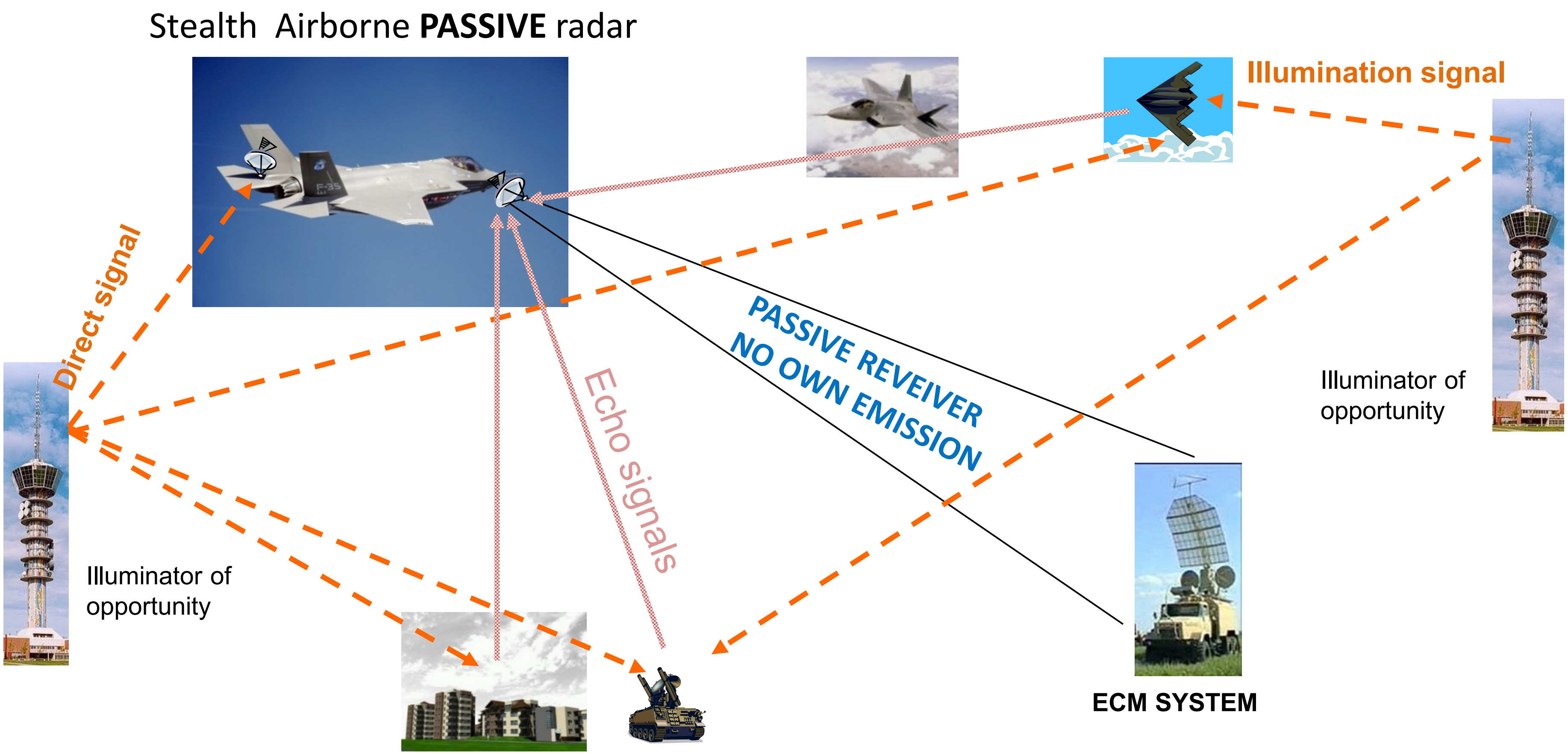
Airborne **ACTIVE** radar
LPI required

LPI – Low Probability Interception

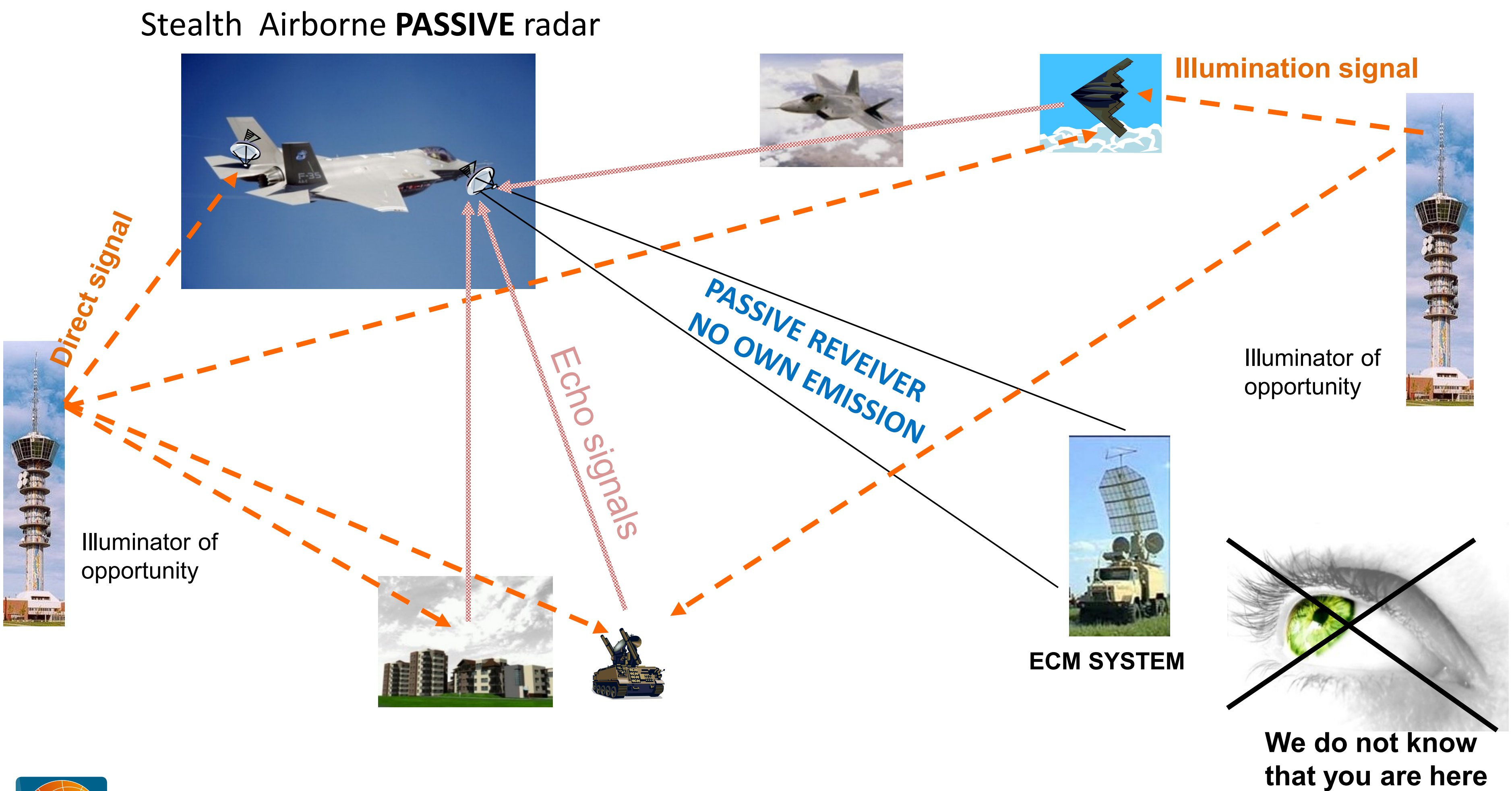
We know that you are here

ESM SYSTEM

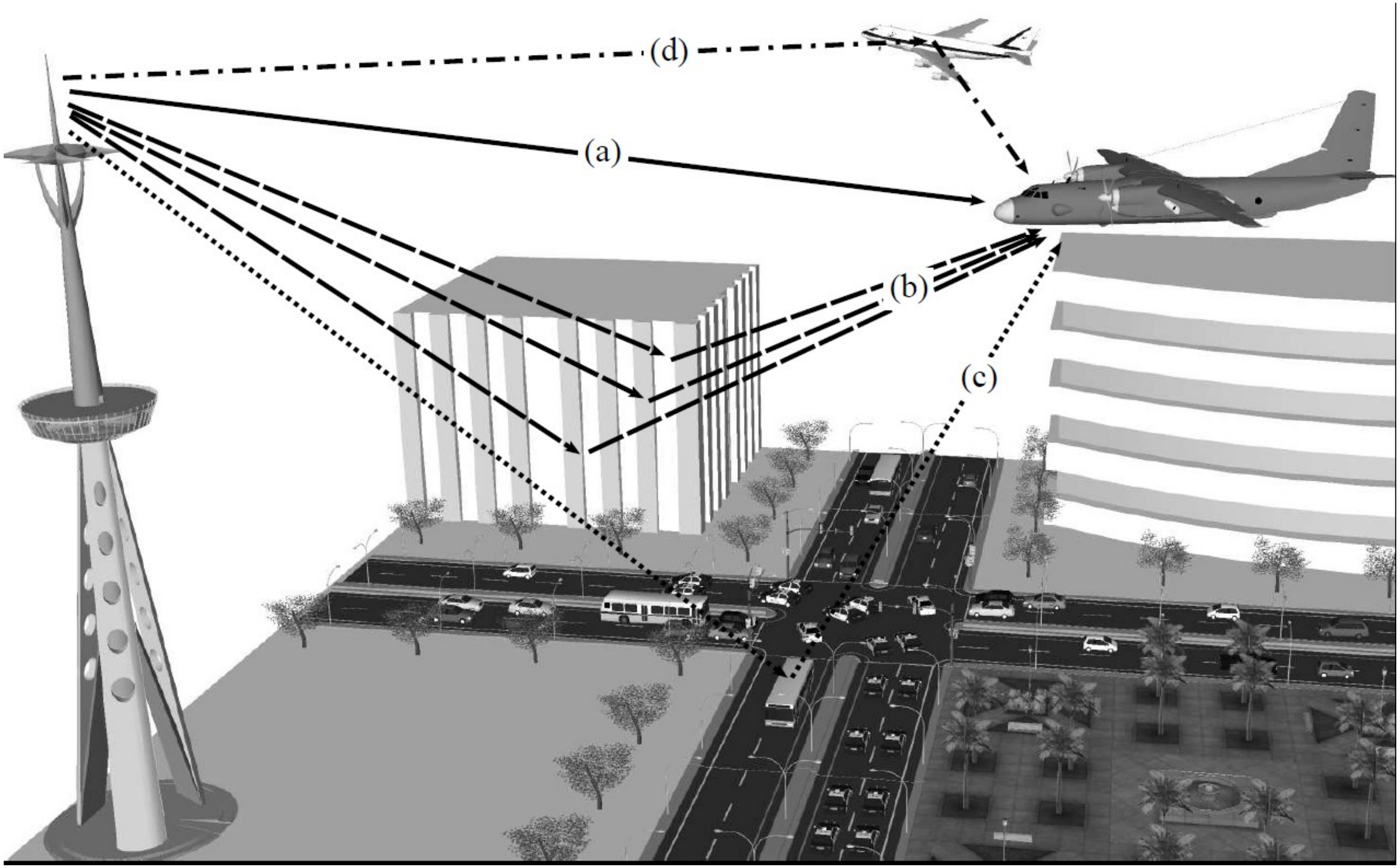
Silent Operation => APCL



Silent Operation => APCL

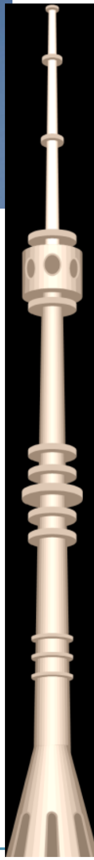


APCL Scenario

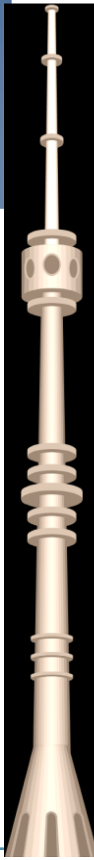


Why Airborne Passive Radar?

- No own emission
- Covert operation
- Detection of small targets
- Detection of stealth targets
- Long detection range (20-300 km)
- Low power consumption
- Multistatic operation
- Light weight
- High probability of detection (due to multistatic operation)
- Multiband capabilities
- Possibility of installation on UAV
- Large coverage using several airborne PCL & networking
- Long time-on target
- Fast update rate (0.1-3 s)
- ISAR capability
- …



APCL – main challenges



Problems:

- High direct signal power
- High ground clutter power
- Wide Doppler spread of ground clutter
- Visibility of multiple illuminators
- High dynamic range required (150 dB)
- Limited antenna size

Challenges:

- Doppler spread clutter cancelation
- Transmitter signal selection

APCL – main challenges

Problems:

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- High ground clutter power
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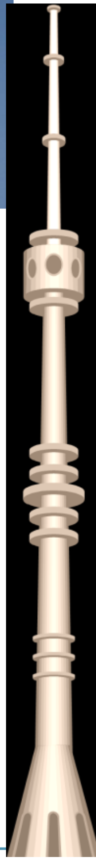


Solutions:

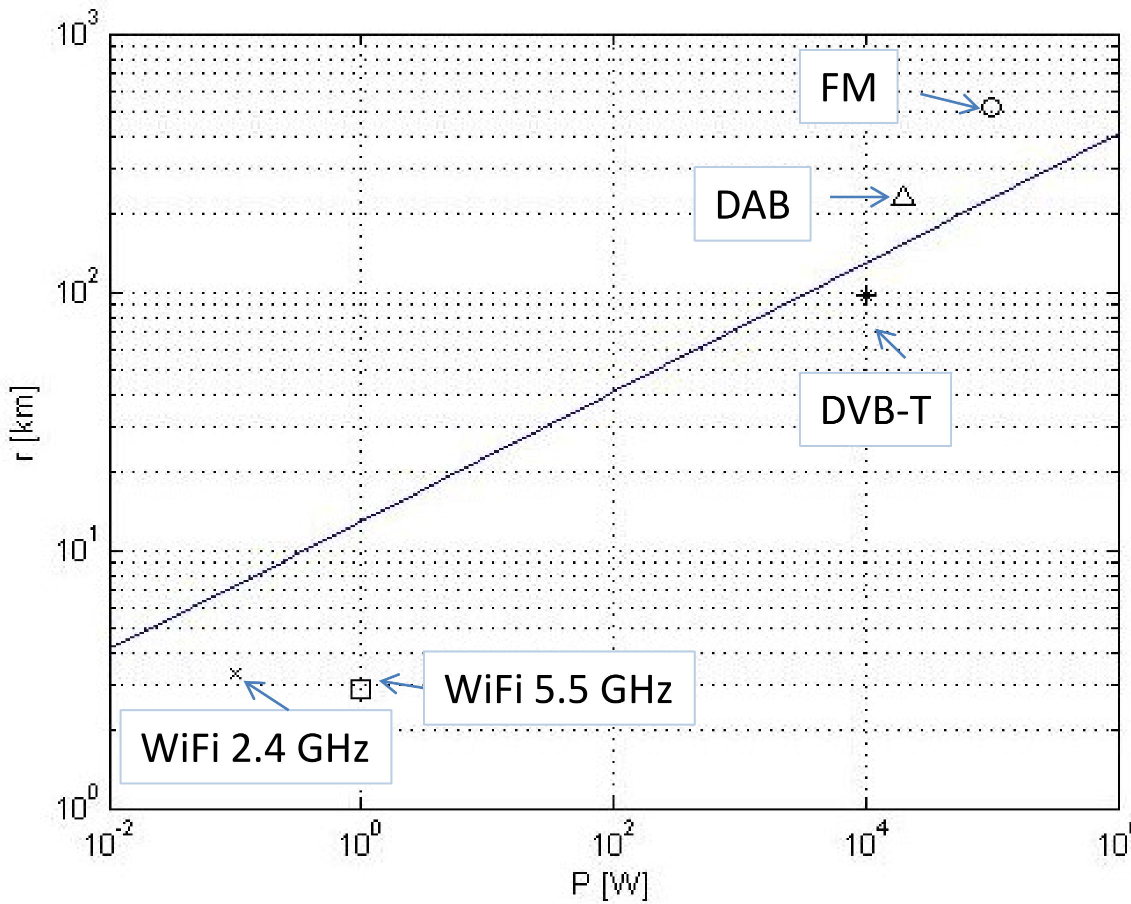
- Multi-element antenna system
- DPCA, STAP (space-time adaptive processing)
- CLEAN processing
- Multistatic operation
- Sensors networking, exchange on data and signal levels

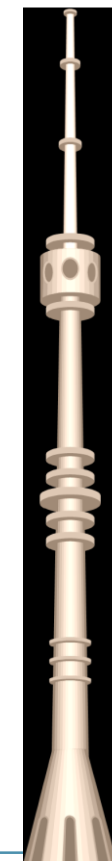
APCL – illuminators

$$r < \sqrt[4]{\frac{P_T G_T S_O S_A t_i}{(4\pi)^2 kTND_o}}$$

Other illuminators of opportunity:

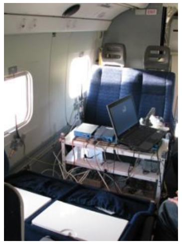
DVB-S
GPS
Radio data links
Active radars
Etc…

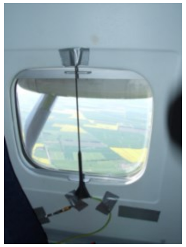




APCL – first steps

2008: WUT & PIT Airborne Passive Radar Trials, Baltic Coast, Poland [(1)]



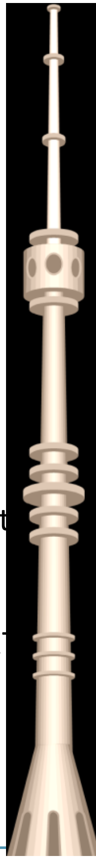


2010: UCL Airborne Passive Radar Trials, London, UK [(2)]

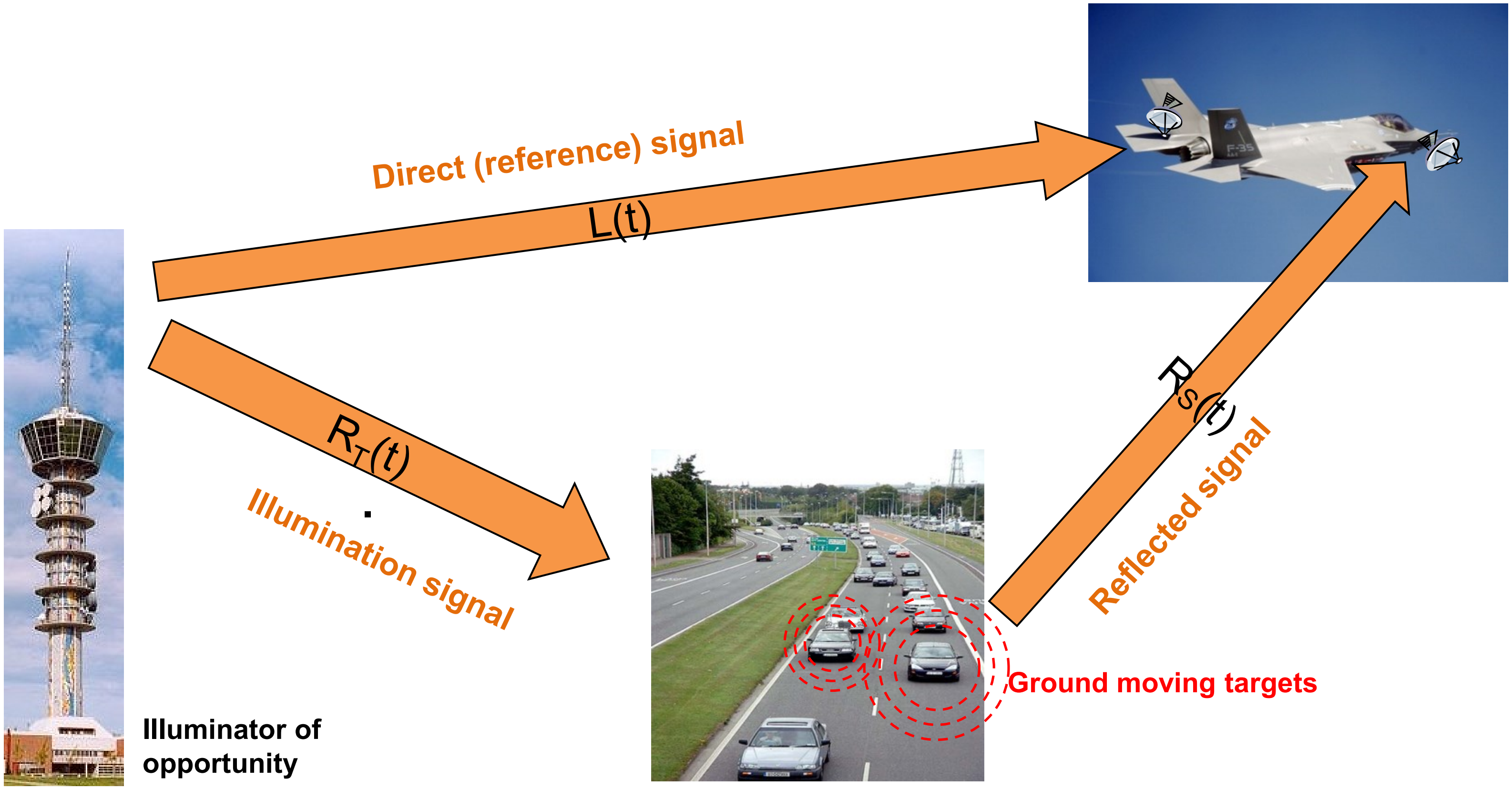
And many more nowadays, including Sweden, Russia ……

(1) K.Kulpa, M.Malanowski, J.Misiurewicz, M.Mordzonek, P.Samczyński, M.Smolarczyk, "Airborne PCL Radar: t Concept and Primary Results", Proceedings of Military Radar 2008 , 28-29 October 2008, Amsterdam, Netherlands,. CD

(2) J. Brown, K. Woodbridge, A. Stove, S. Watts, „Air target detection using airborne passive bistatic radar", IE Electronic Letters, 30th September 2010, Vol. 46, No. 20

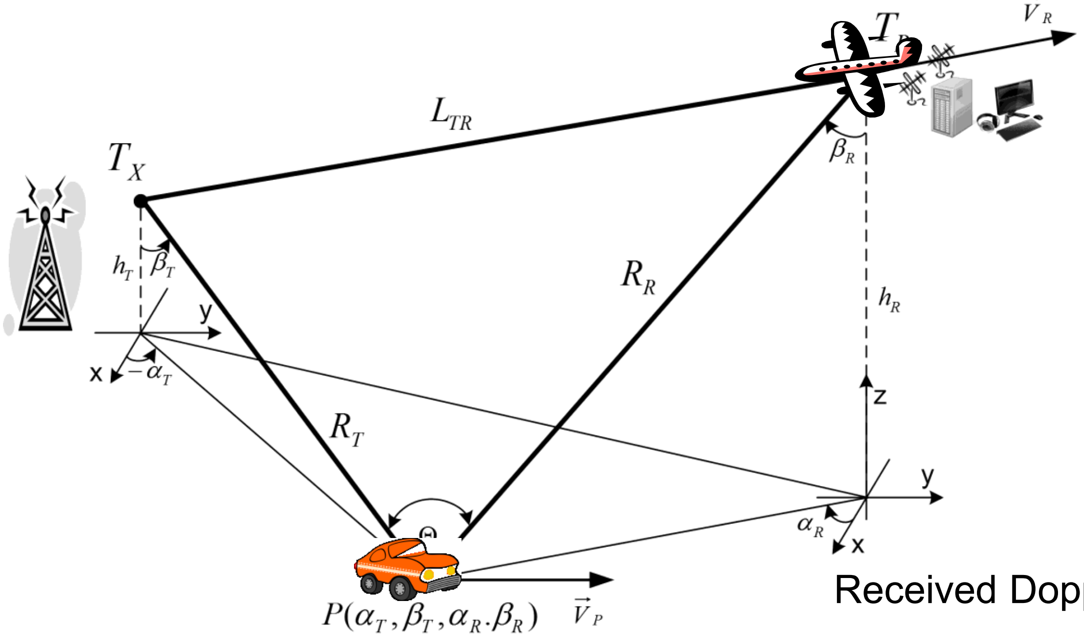


APCL – GMTI



Direct (reference) signal
L(t)
$R_T(t)$
Illumination signal
$R_S(t)$
Reflected signal
Ground moving targets
Illuminator of opportunity

GMT Airborne PCL geometry



$$\vec{k}_T(\alpha_T.\beta_T) = \sin(\beta_T)\cos(\alpha_T)\hat{x}_T + \\ -\sin(\beta_T)\sin(\alpha_T)\hat{y}_T + \\ -\cos(\beta_T)\hat{z}_T$$

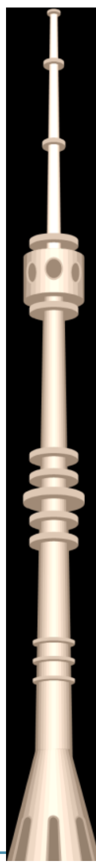
$$\vec{k}_R(\alpha_R.\beta_R) = \sin(\beta_R)\cos(\alpha_R)\hat{x}_R + \\ -\sin(\beta_R)\sin(\alpha_R)\hat{y}_R + \\ -\cos(\beta_R)\hat{z}_R$$

Received Doppler frequency in bistatic configuration

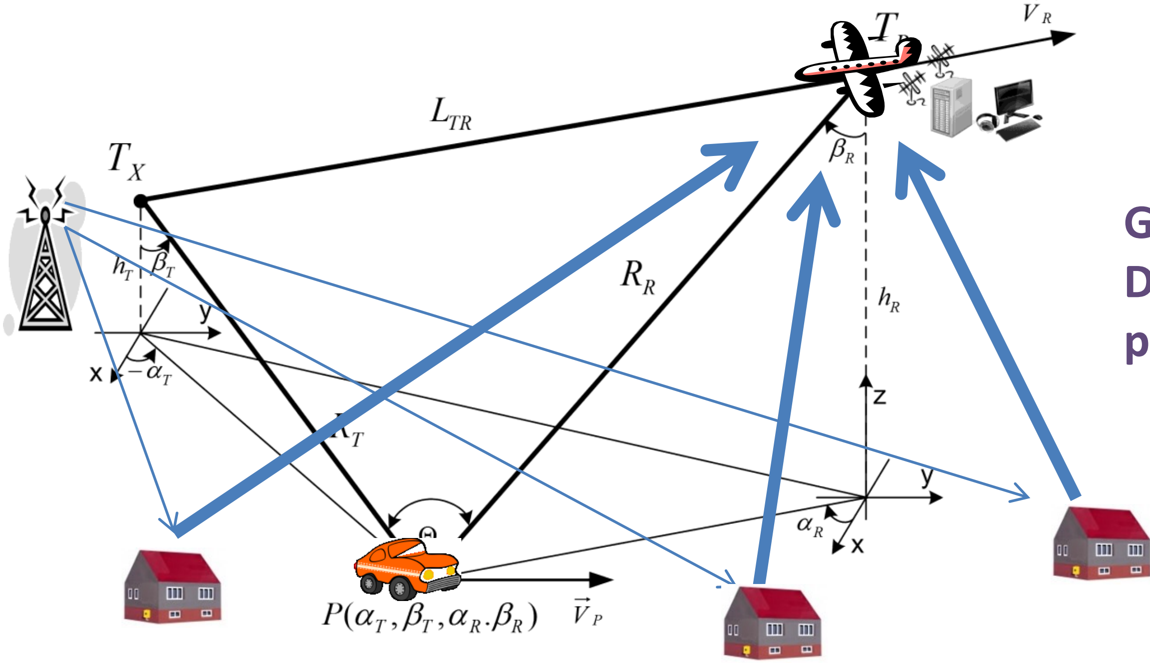
$$f_d = \frac{\vec{k}_T(\alpha_T.\beta_T)\cdot\vec{V}_P}{\lambda} + \frac{\vec{k}_R(\alpha_R.\beta_R)\cdot(\vec{V}_R - \vec{V}_P)}{\lambda}$$

Range-Doppler Correlation function for PCL processing

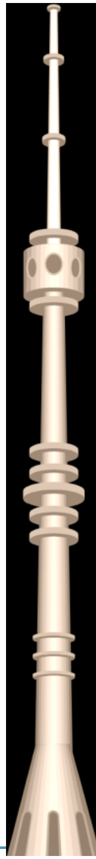
$$y_r(r,v,t_0) = \int_{t=t_0}^{t_i+t_0} x(t)x^*_{ref}\left(t - \frac{r(t)}{c}\right)e^{-j2\pi\left(-\frac{2vF}{c}\right)t}\,dt$$



GMT Airborne PCL geometry



Ground echoes has different Doppler shift due to platform movement !!!



$$f_d = \frac{\vec{k}_R(\alpha_R.\beta_R)\cdot(\vec{V}_R)}{\lambda}$$

Range-Doppler Correlation function for PCL processing

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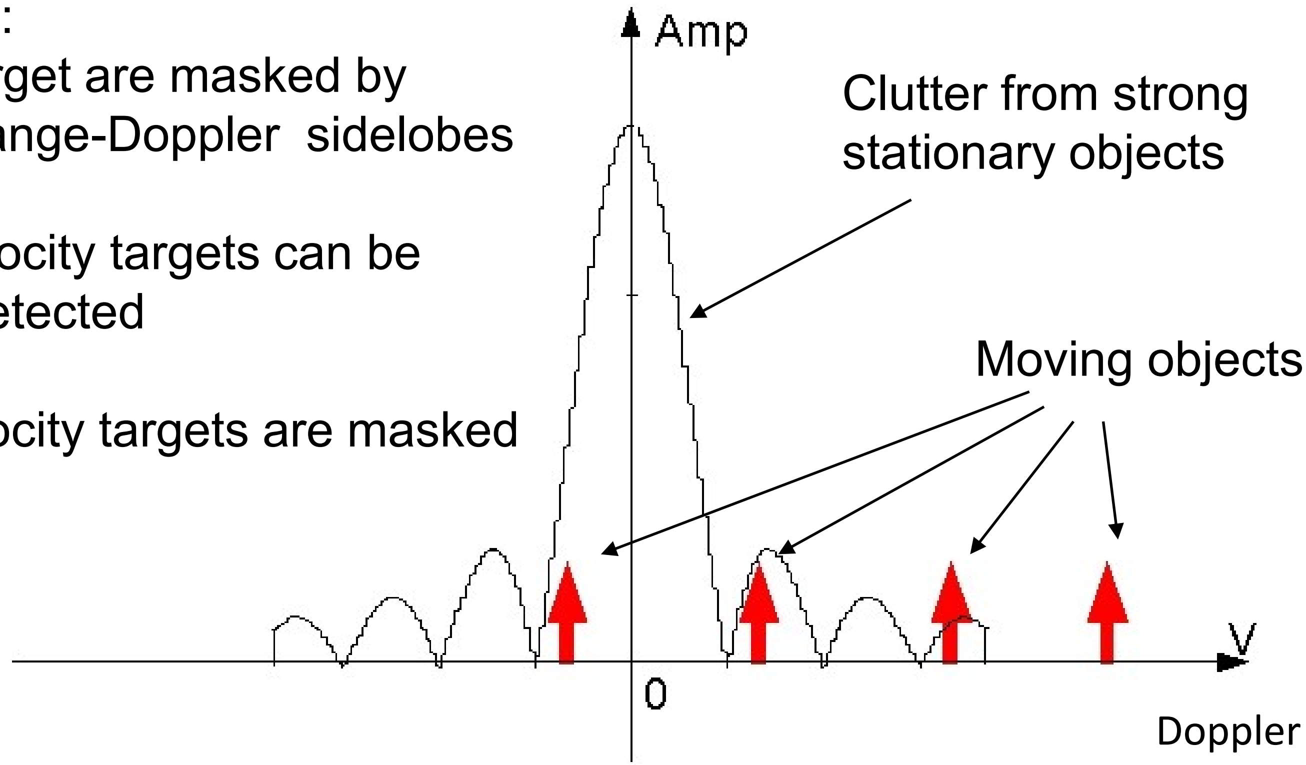
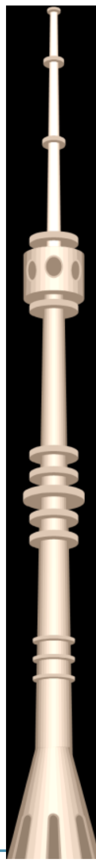
APCL – Clutter problem

Problem:
small target are masked by clutter range-Doppler sidelobes

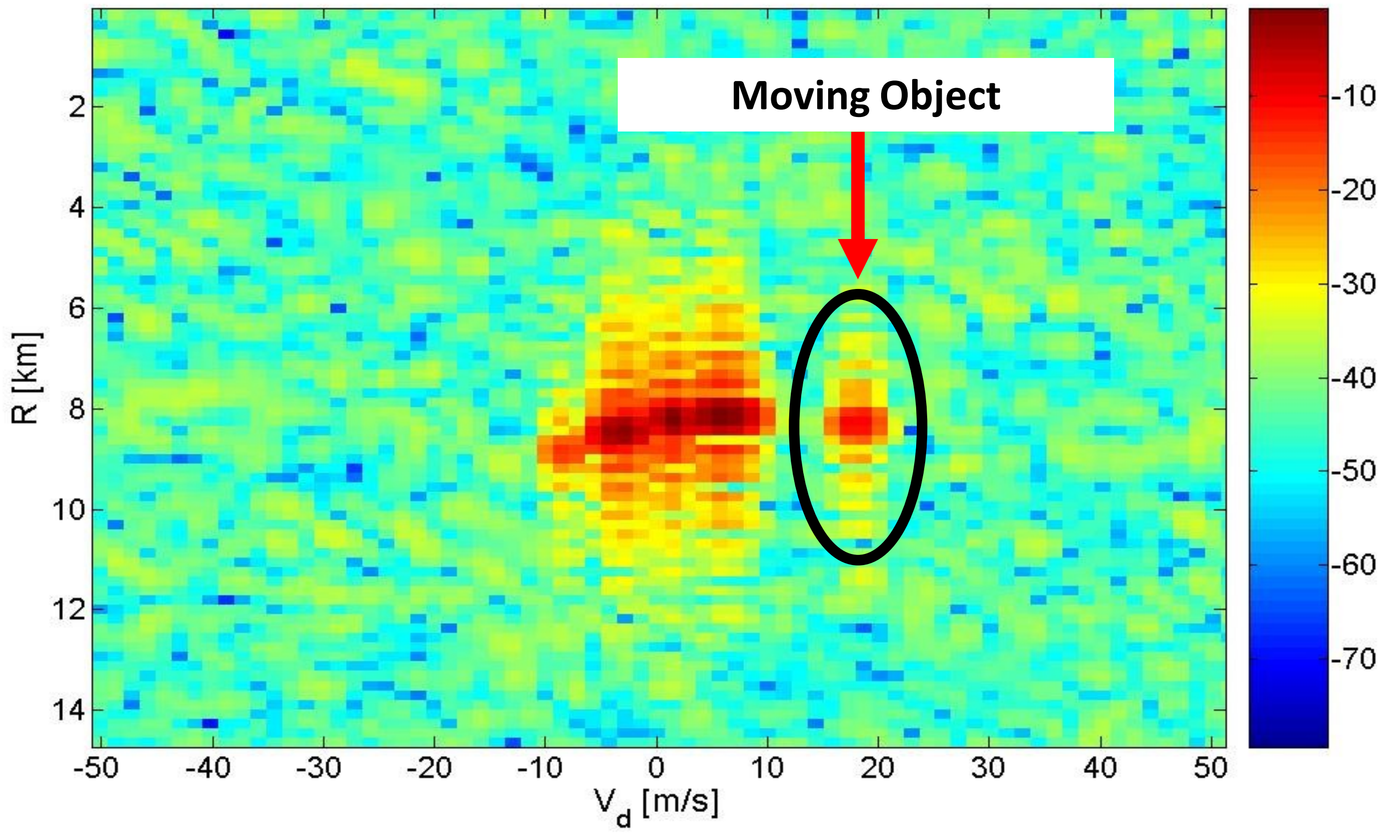
High velocity targets can be easily detected

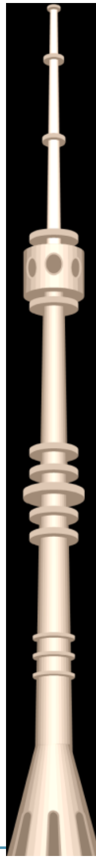
Low velocity targets are masked





APCL – masking problem

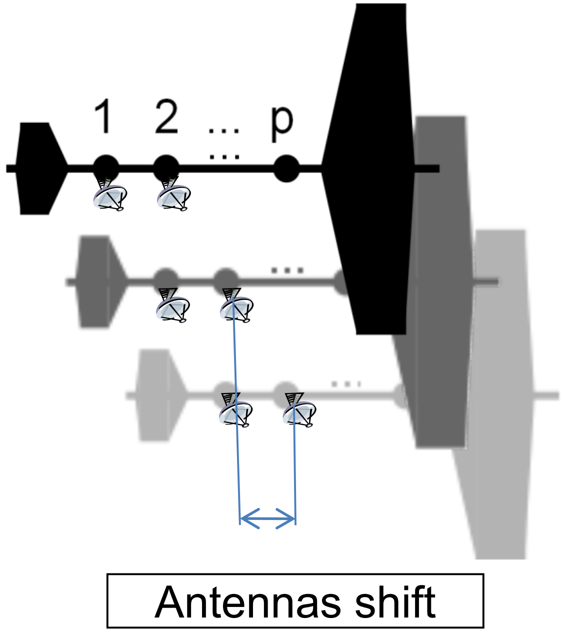


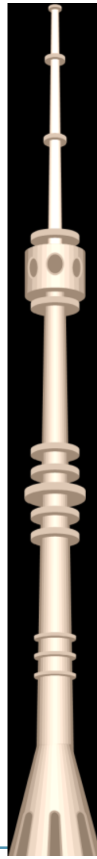


DPCA method

Displaced phase center antenna (*DPCA*) processing is a concept of *radar* space–time processing

After time T antenna 1 is in position of antenna 2





Advantages

-Simplicity

-Robust against non uniform receiver channel characteristics

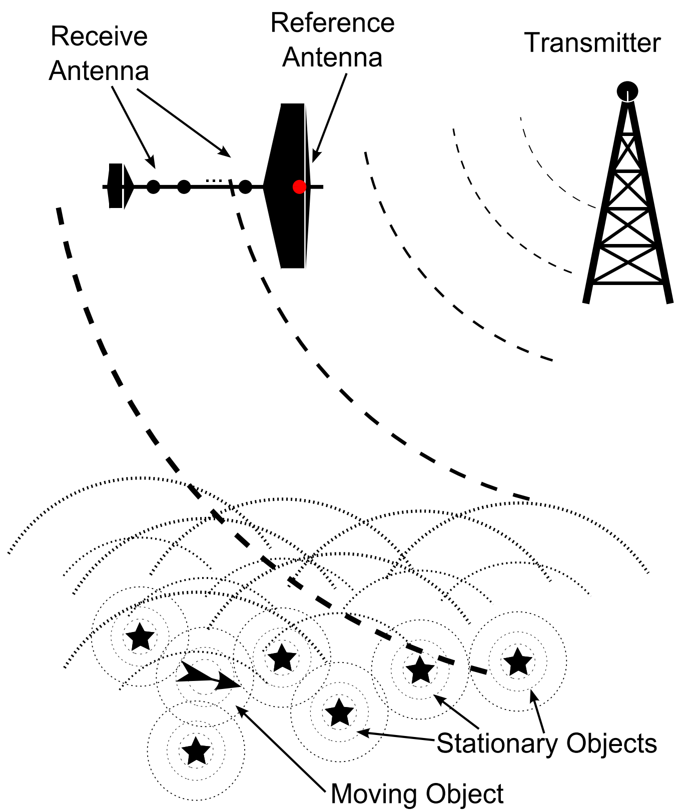
-Robuts against not linear flight path

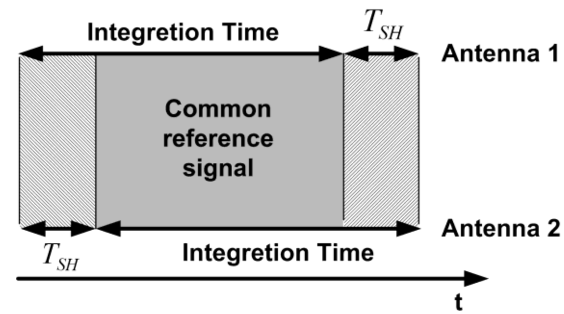
Drawbacks

-Good synchronization needed

-Constant space-time ground clutter suppression filter characteristics

DPCA method



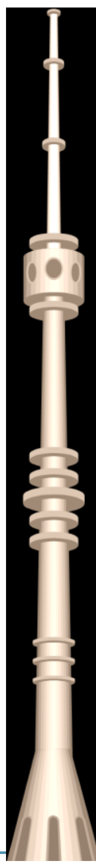


DPCA Processing Equation

$$y_{DPCA}(r,v) = y_2(r,v,t_0) - y_1(r,v,t_0+T)$$

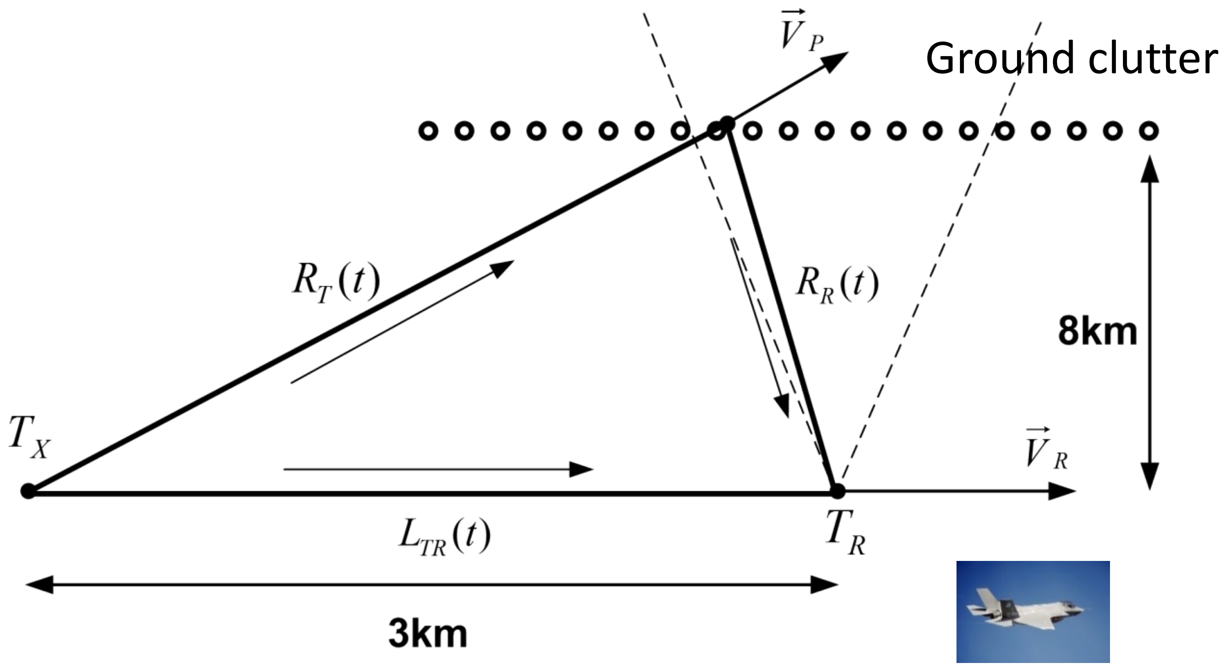
Parameter *T* depends on the velocity of the radar platform *V* and the baseline *d* between the antenna 1 and antenna 2

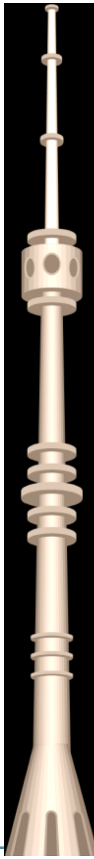
$$T = \frac{d}{V}$$



APCL – simulations

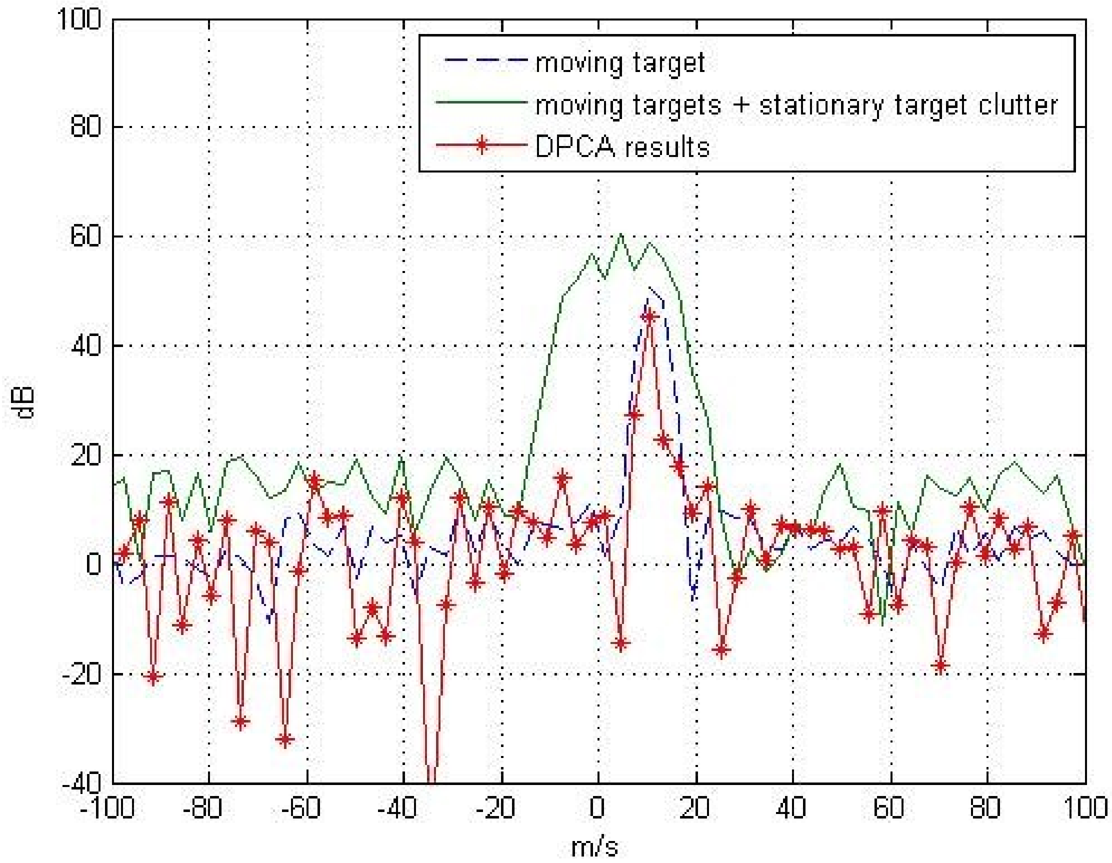
Airborne PCL - Geometry for simulation

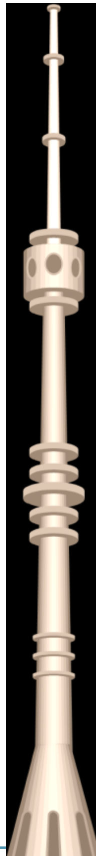




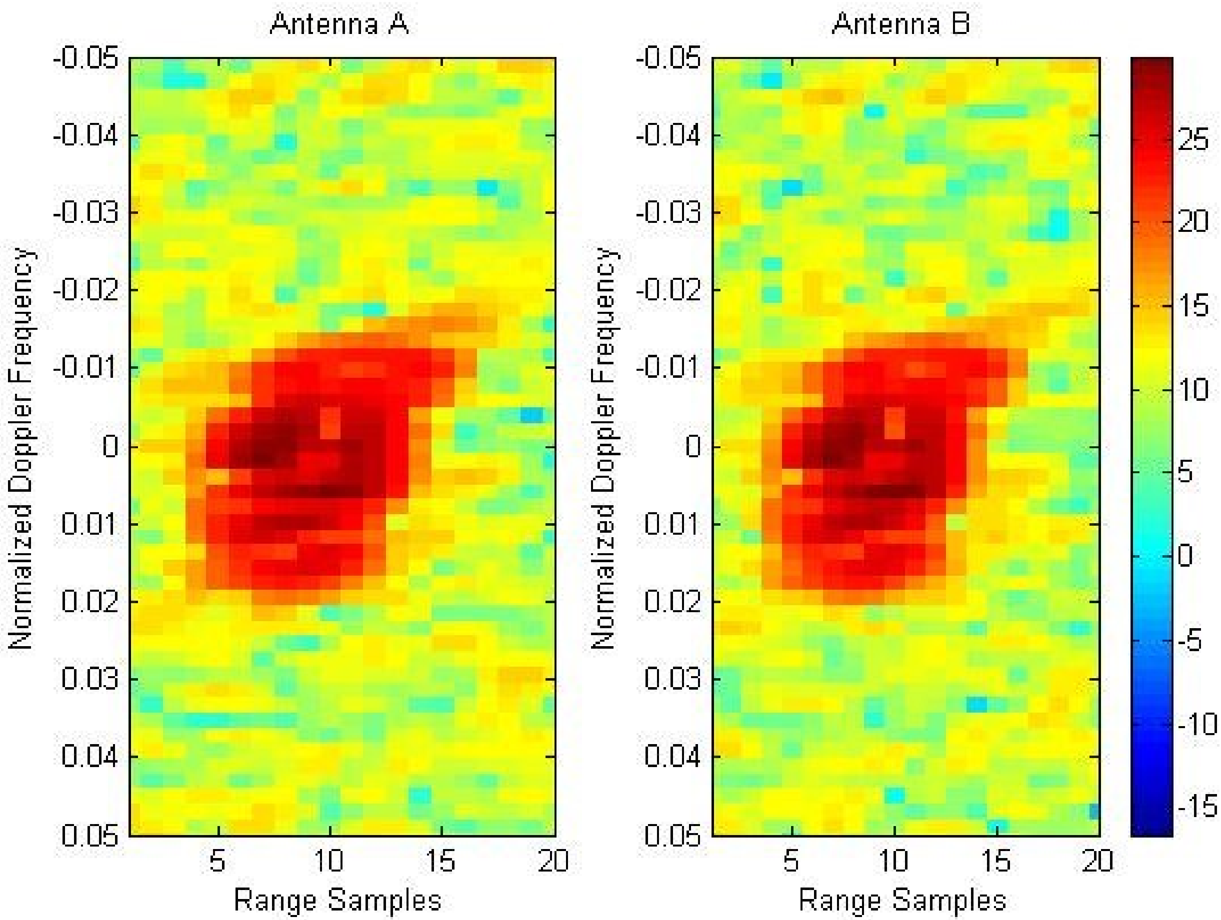
APCL – simulations

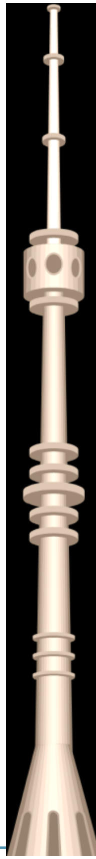
Simulation Results: Ideal antennas characteristics





APCL – simulations





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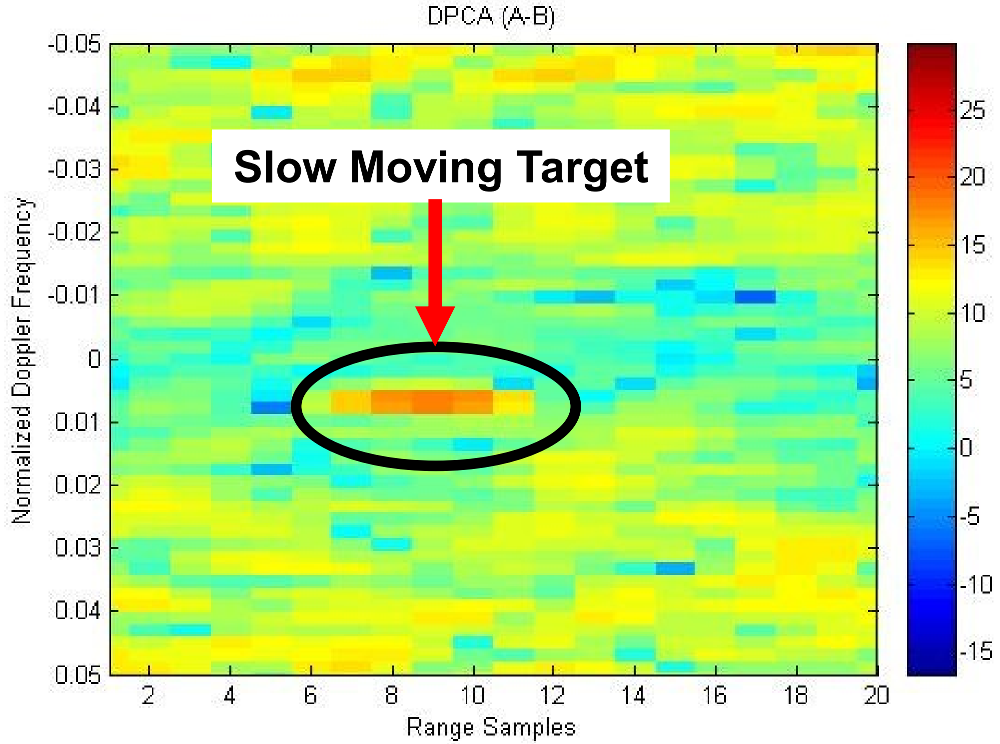
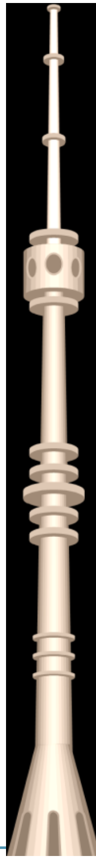
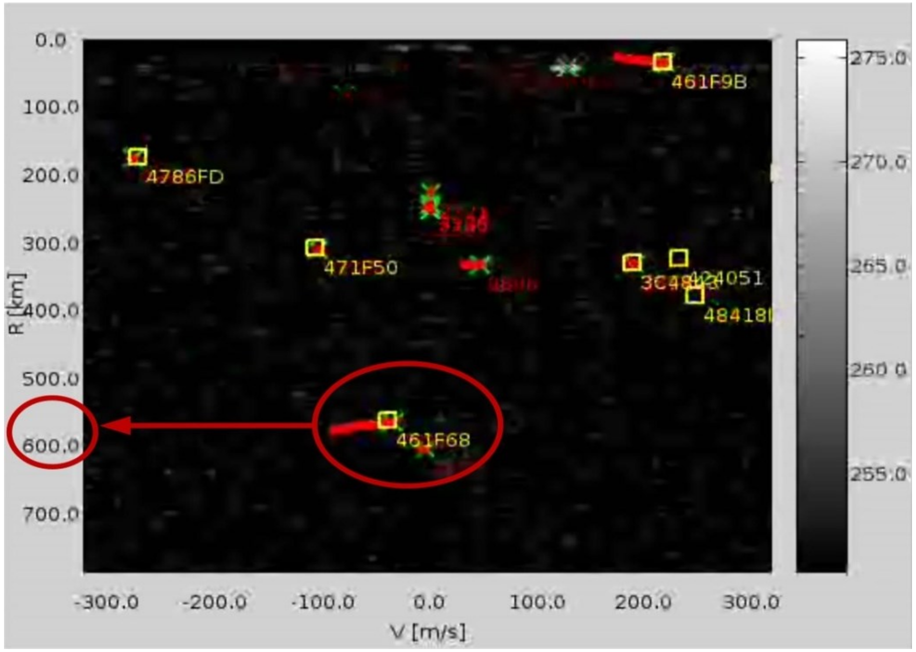
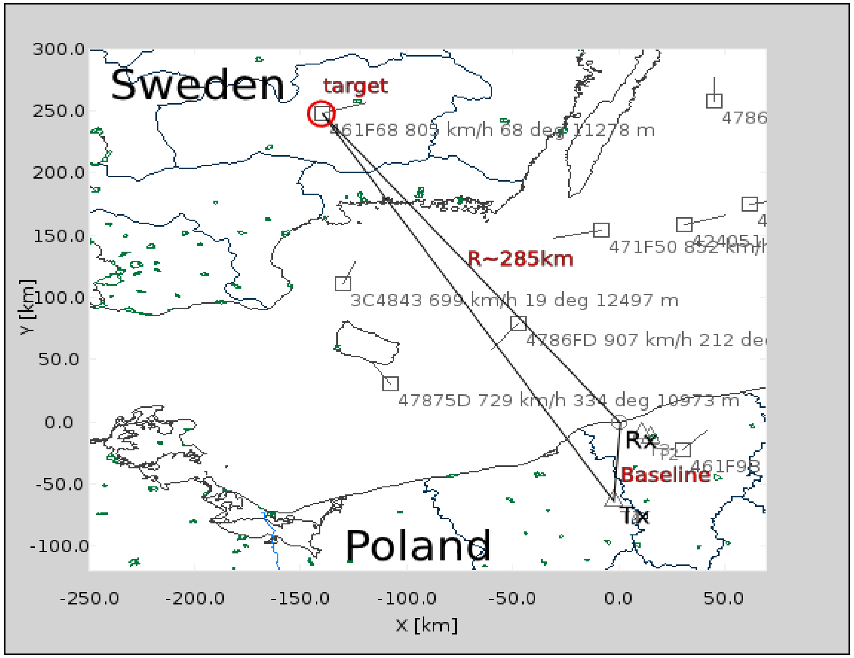




WUT PaRaDe PCL

PaRaDe
long range detection

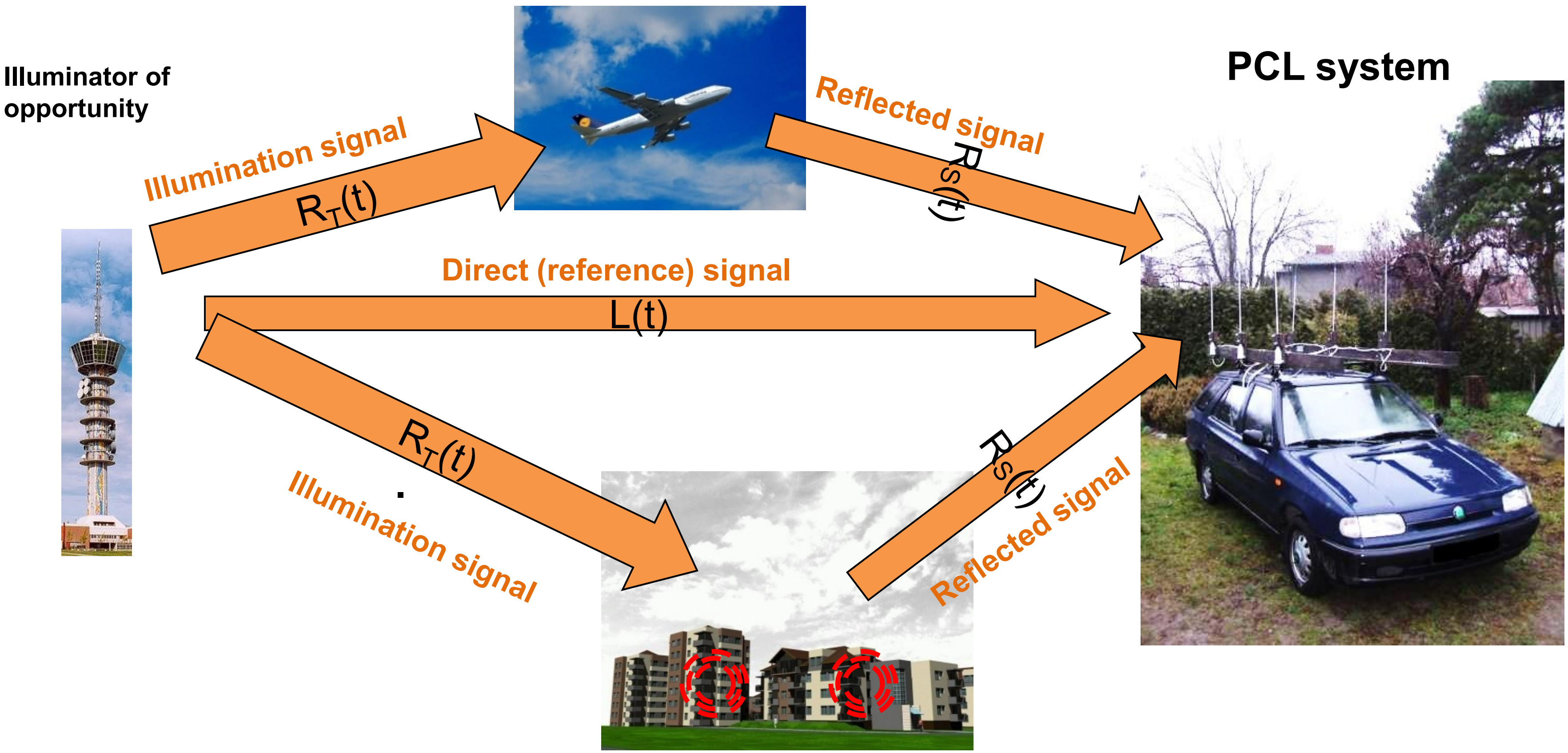




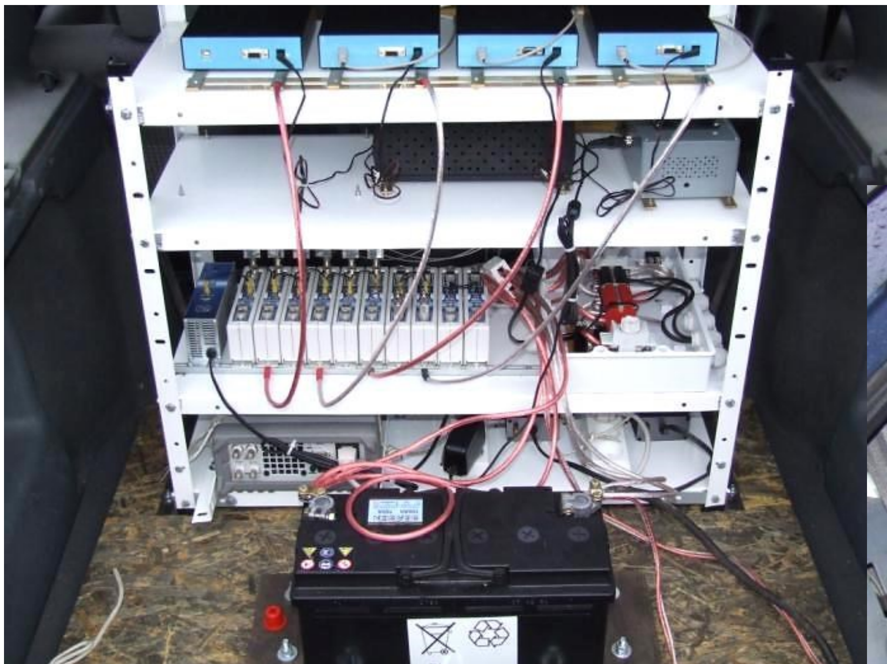
R>350 km

PCL on moving (car) platform

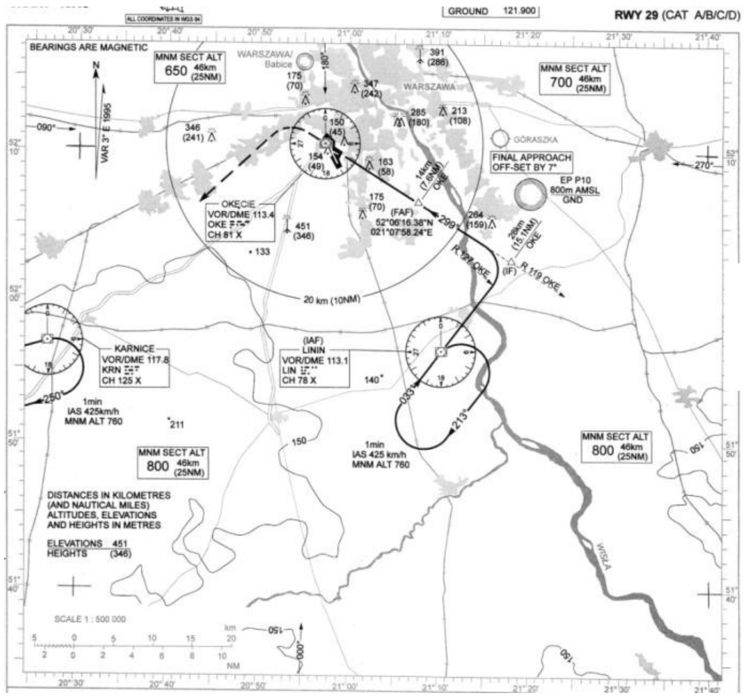
The preliminary experiment with CAR PCL system for data acquisition and processing (2007)



Car-PCL (PaRaDe) hardware



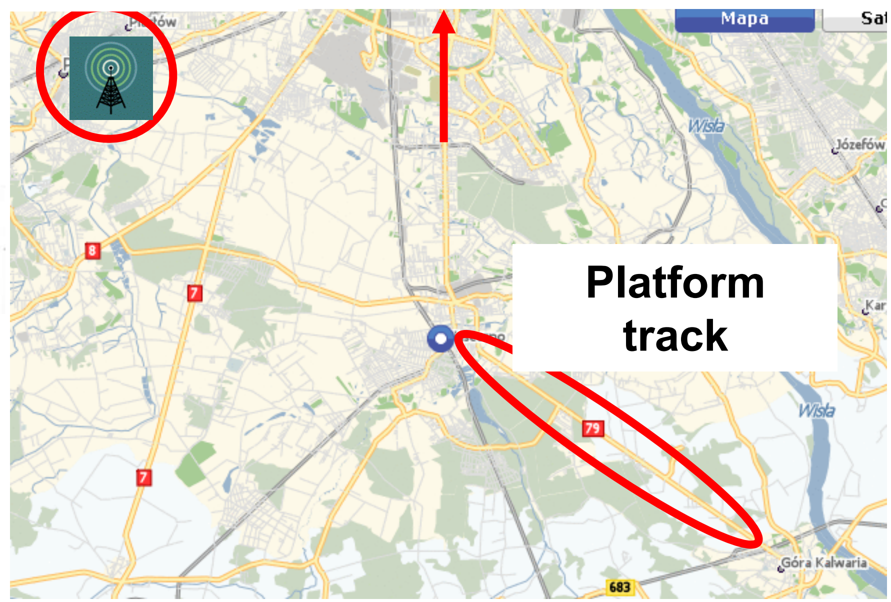
Car-PCL experiment scenario



The map of airplane roots

Proszkow transmitter

PKiN transmitter



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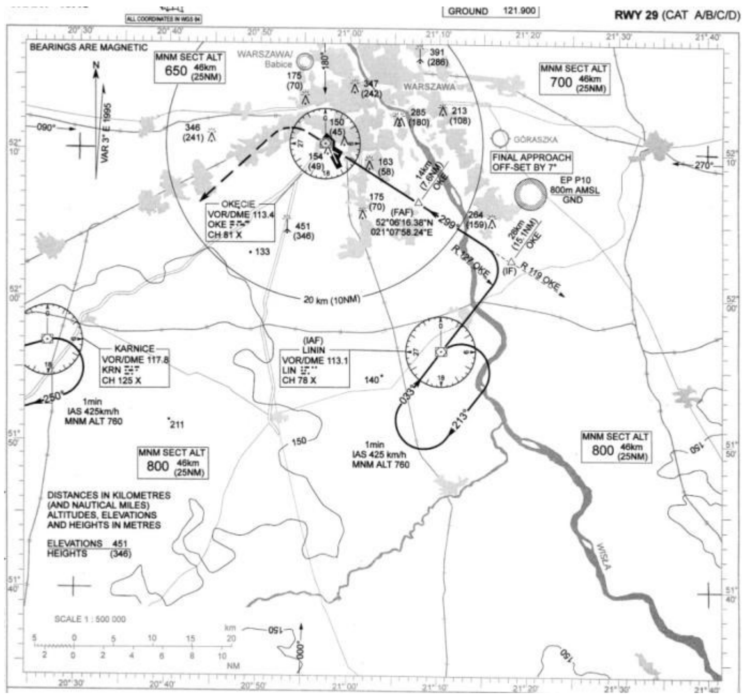

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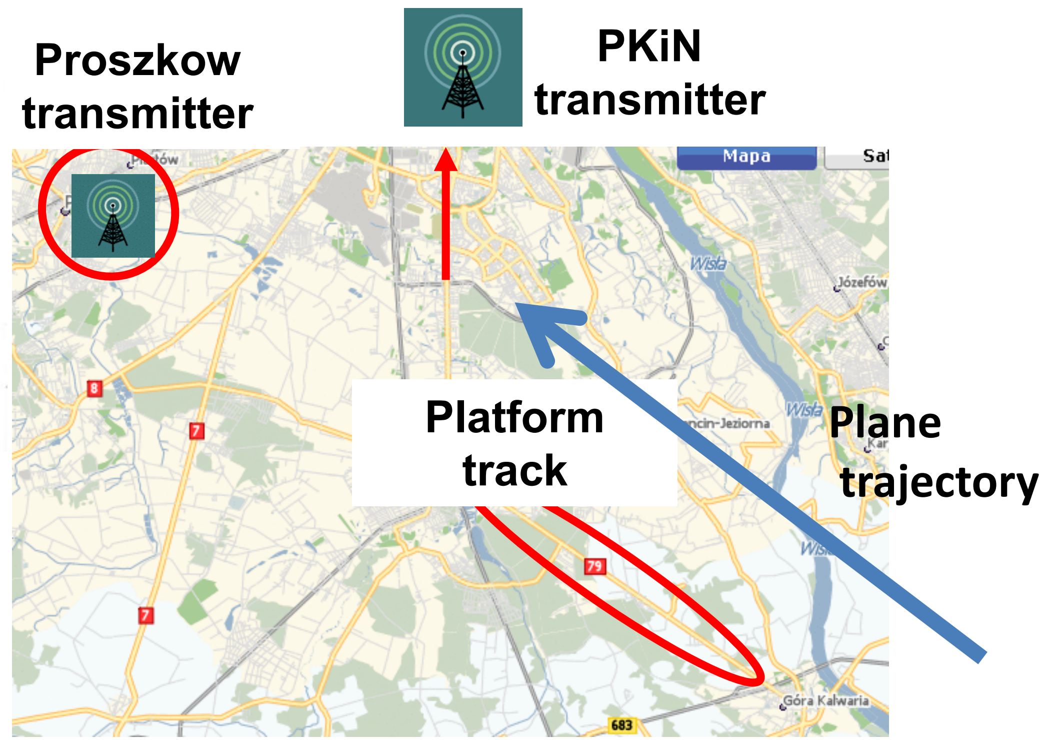
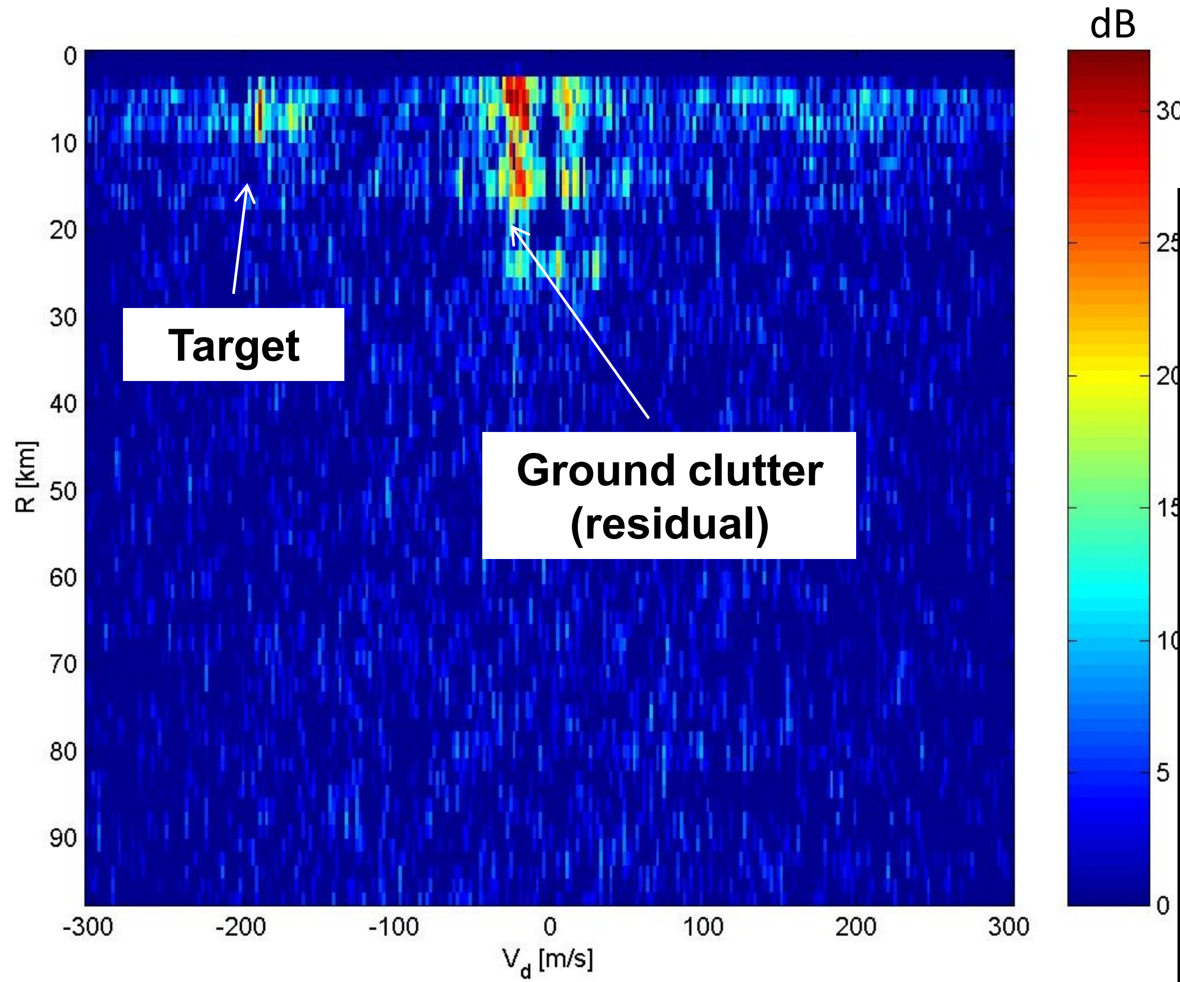


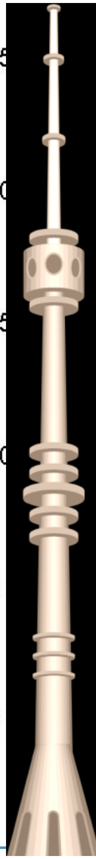
Car-PCL – results

STAP processing (Space-time adaptive processing) to remove ground clutter.

The multi-beam antenna is needed for STAP processing.

Multi-beam is formed by digital beam forming





First Polish APCL trials

Gdynia - 2008

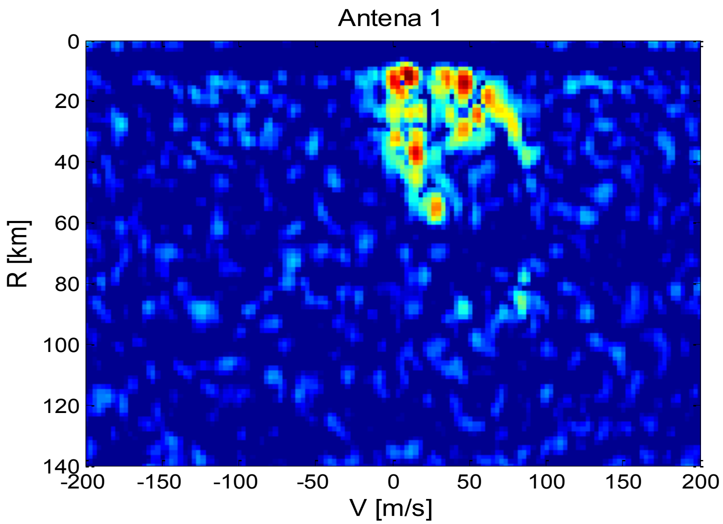
PCL airborne platform

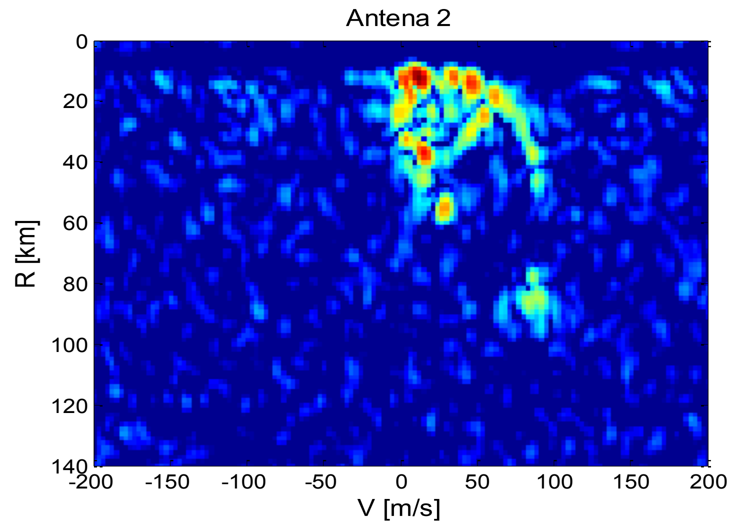
First Polish APCL trials

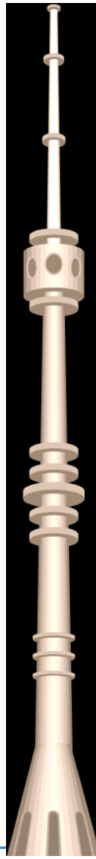
Inside airplane

First Polish APCL trials

Real data processing – Results







First Polish APCL trials

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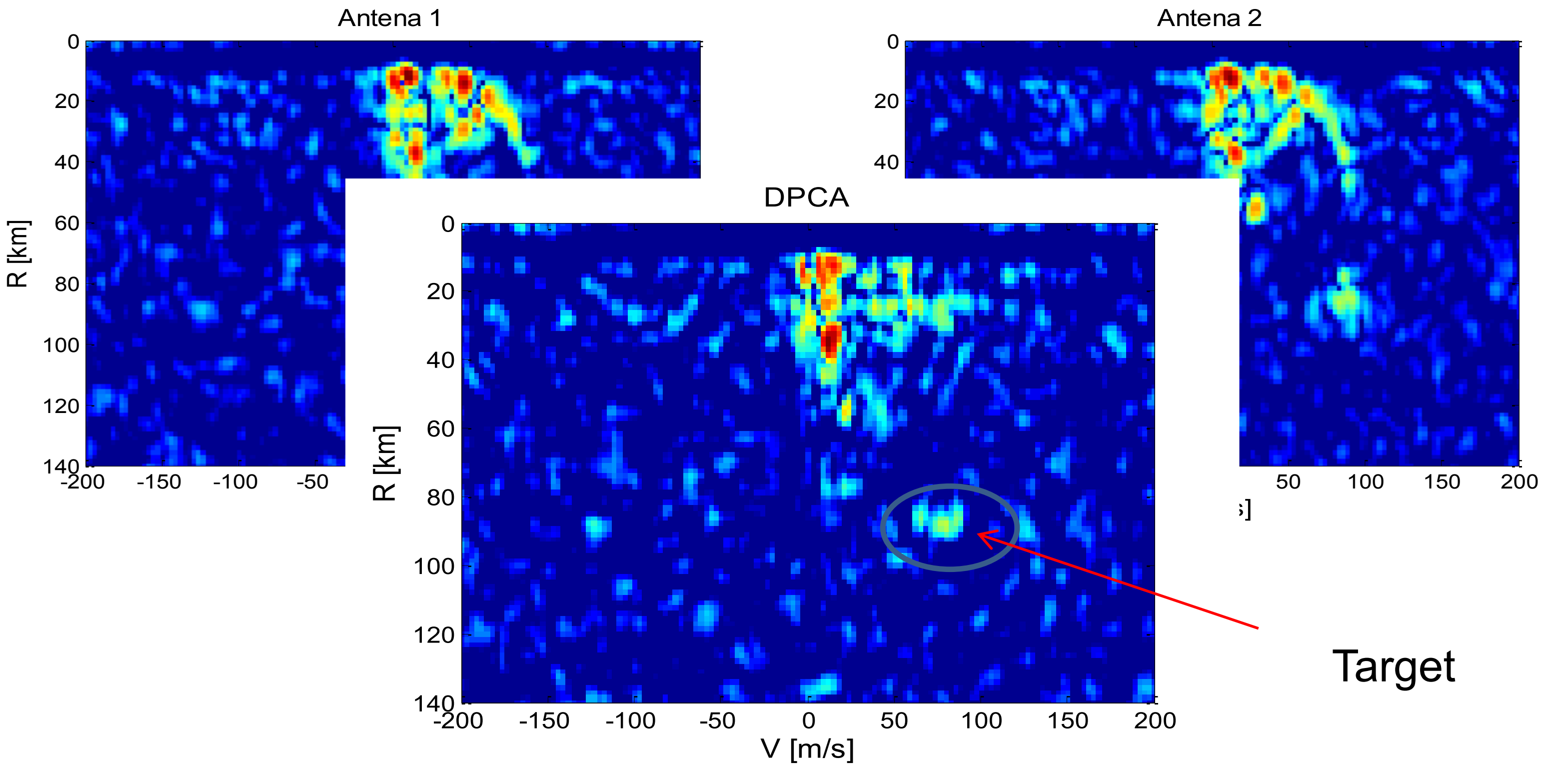
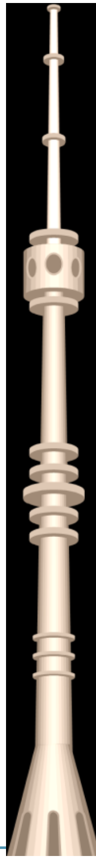
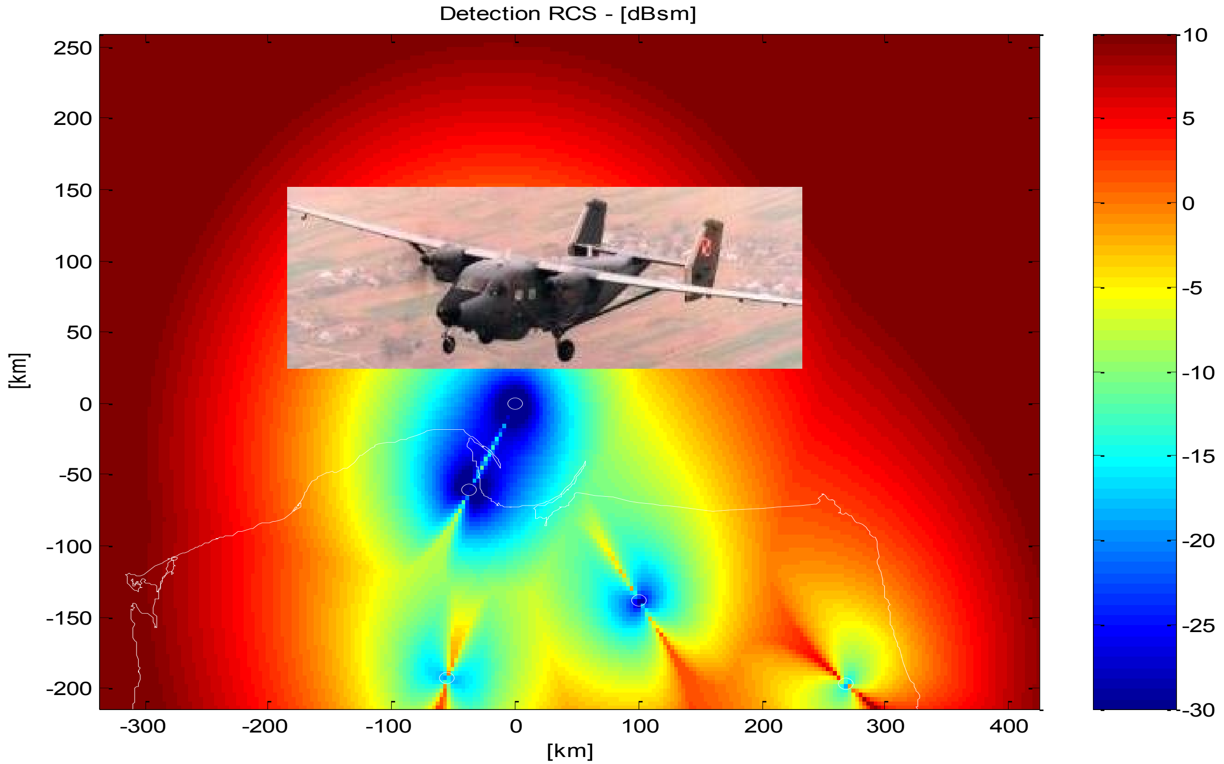
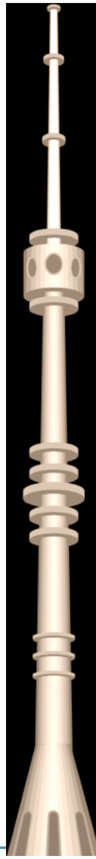




Coverage of APCL





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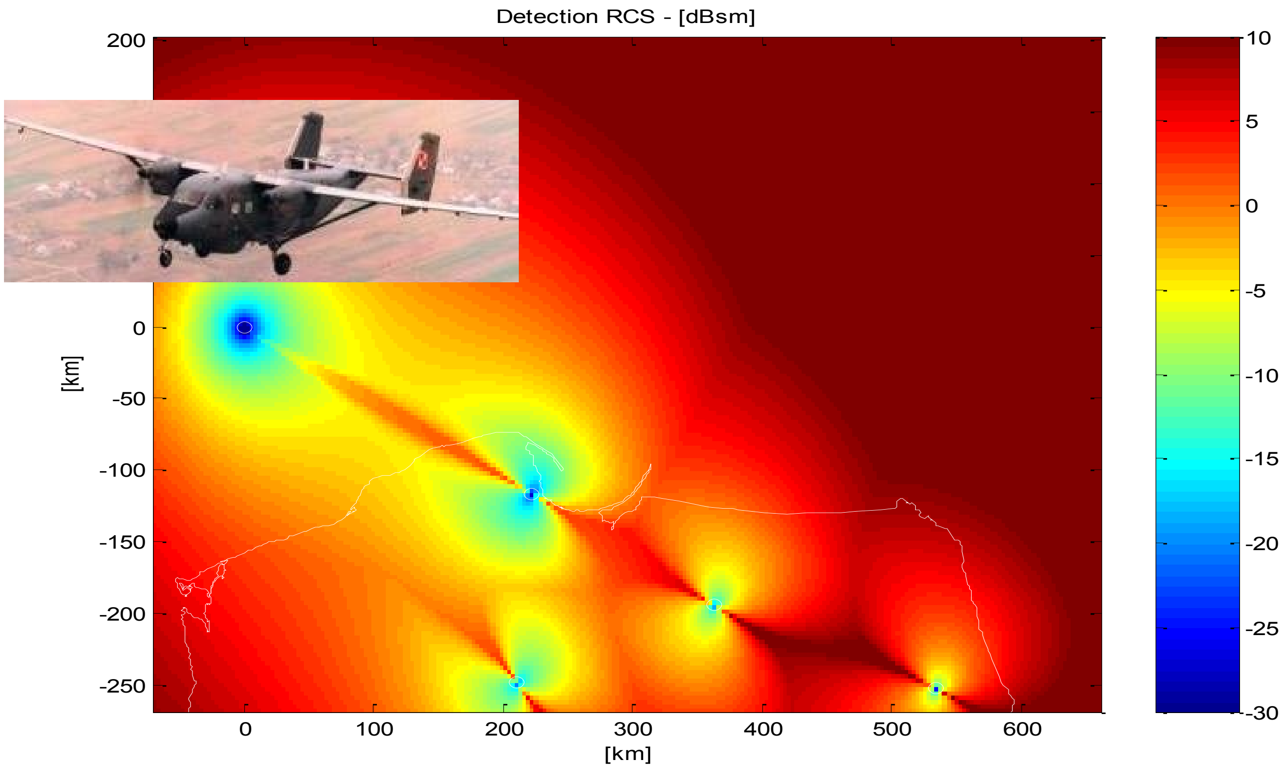
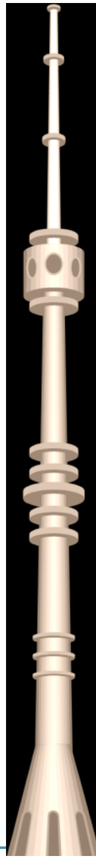
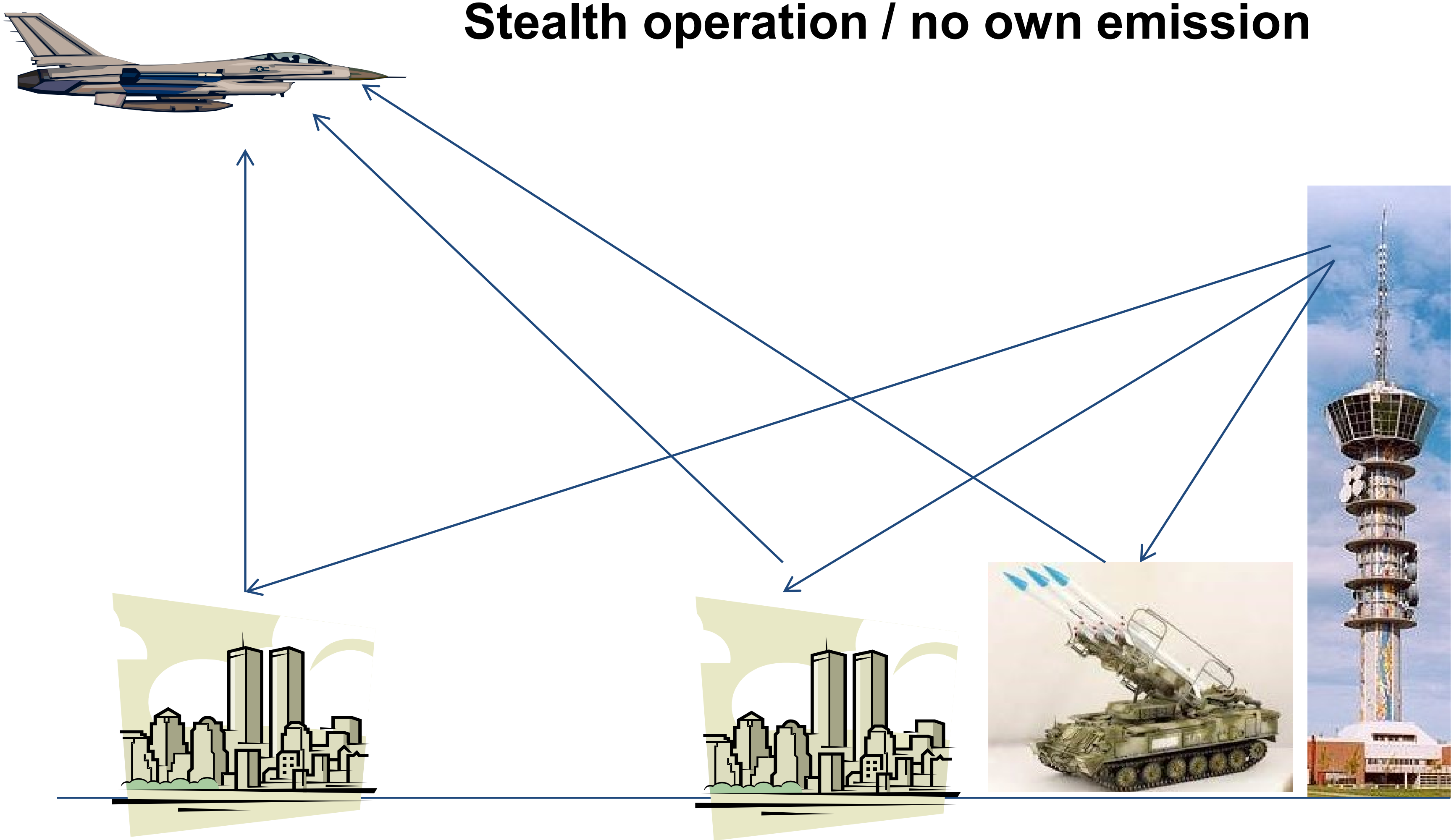




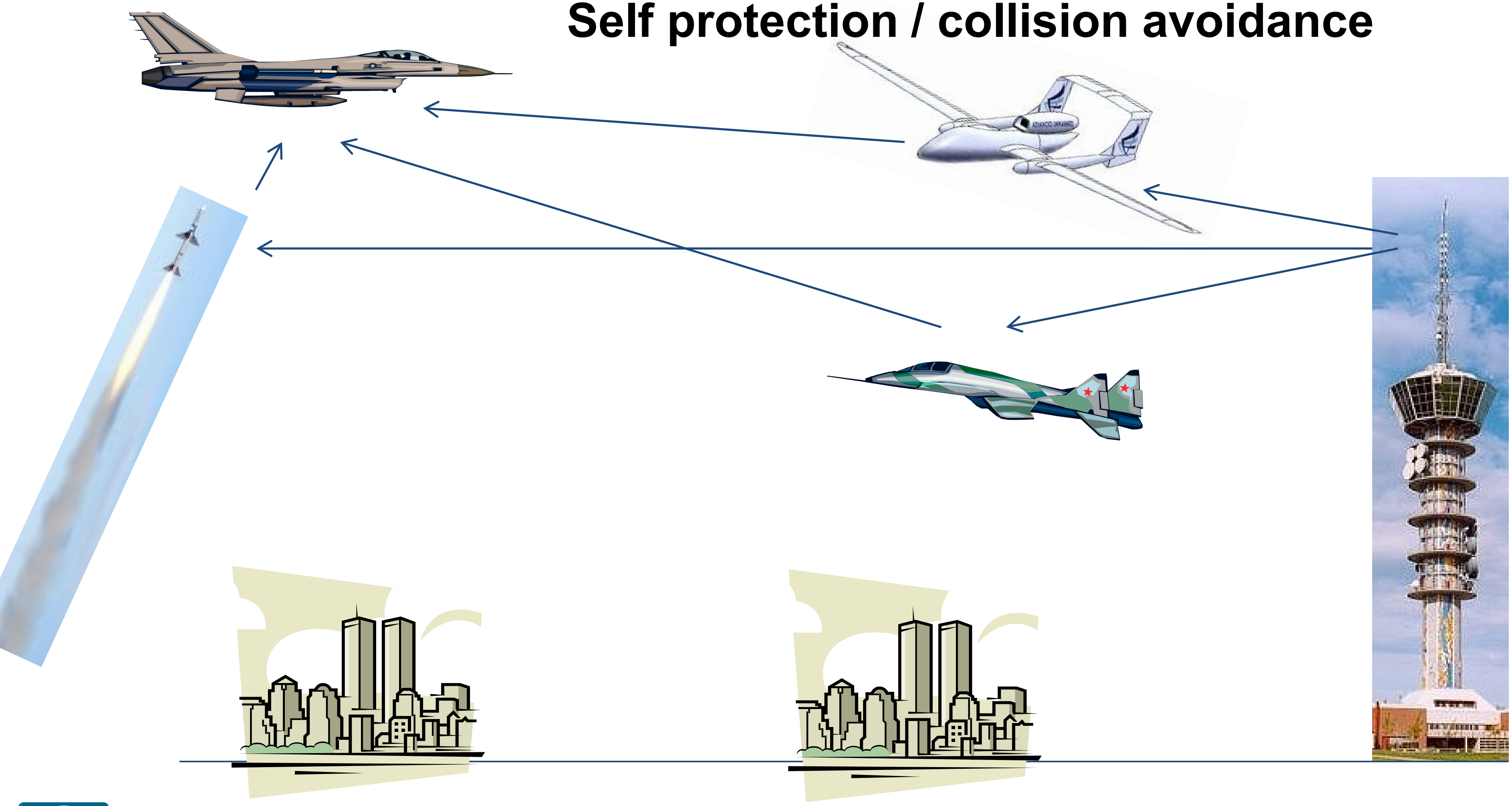
Applications

Stealth operation / no own emission



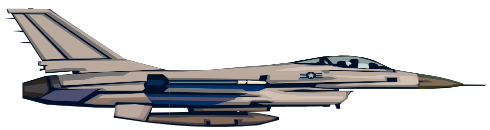
Applications

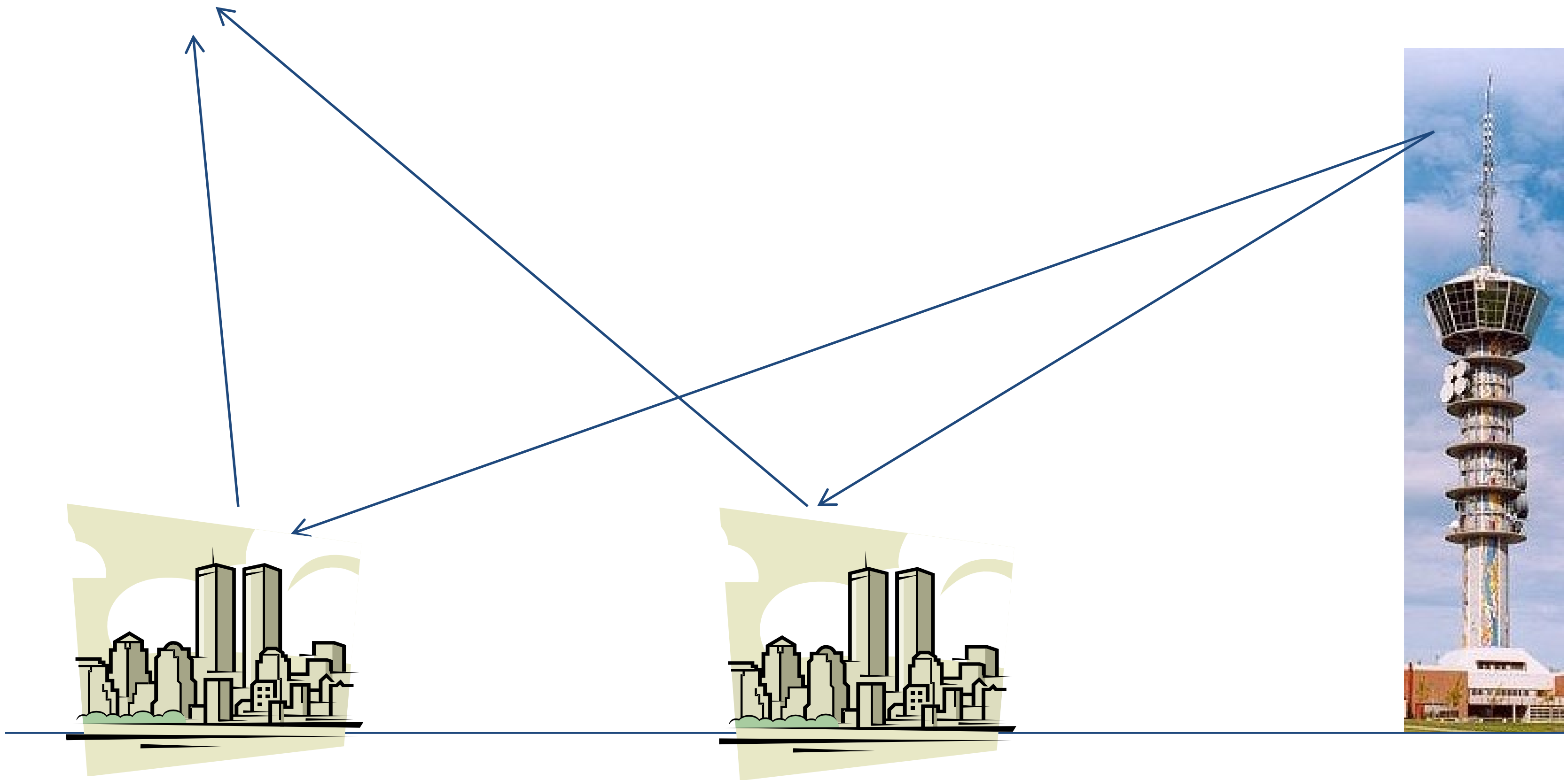
Self protection / collision avoidance



Applications

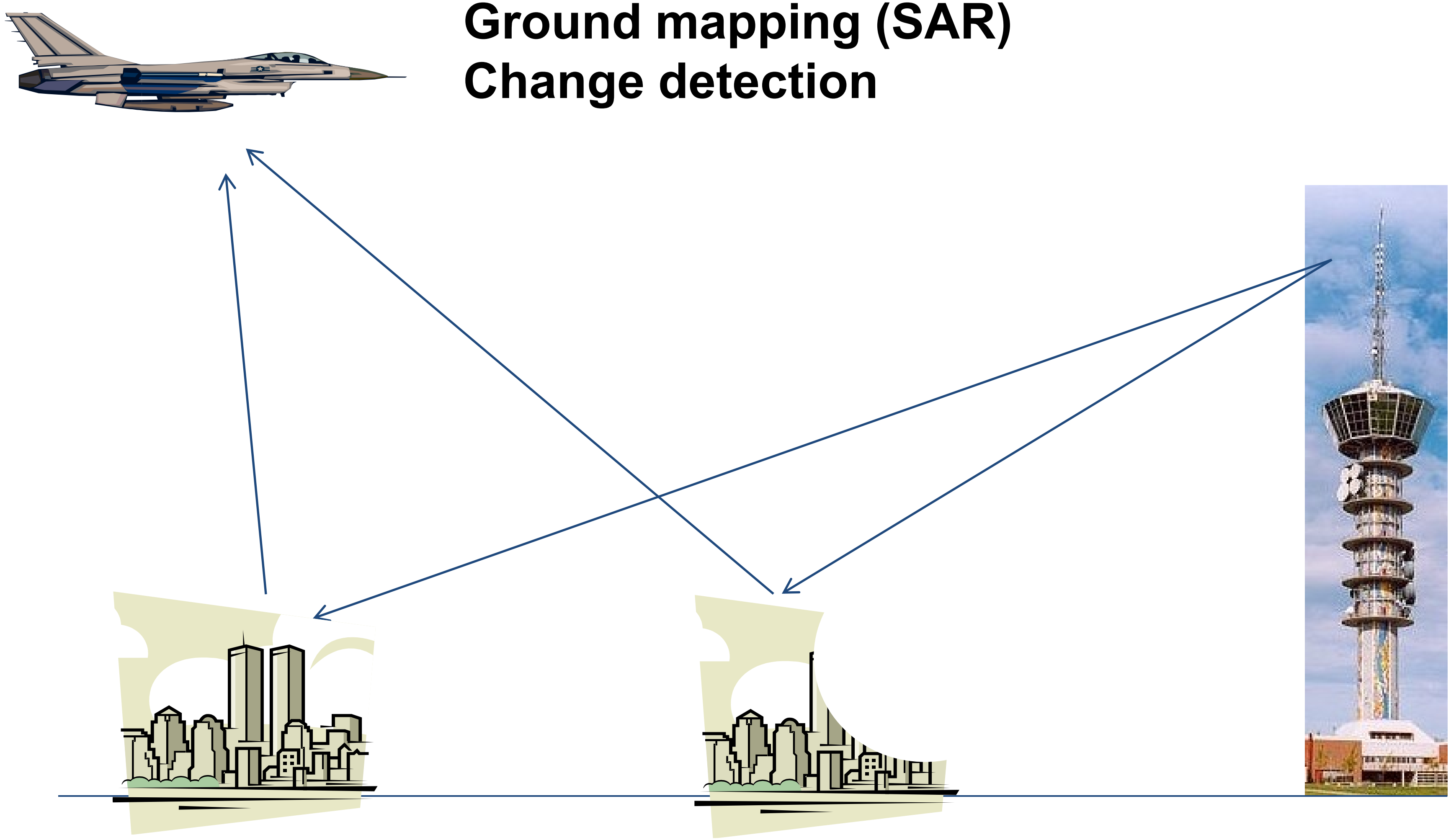
Ground mapping (SAR)





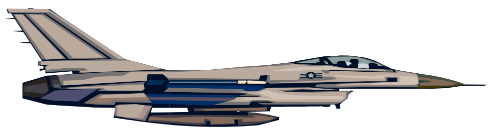
Applications

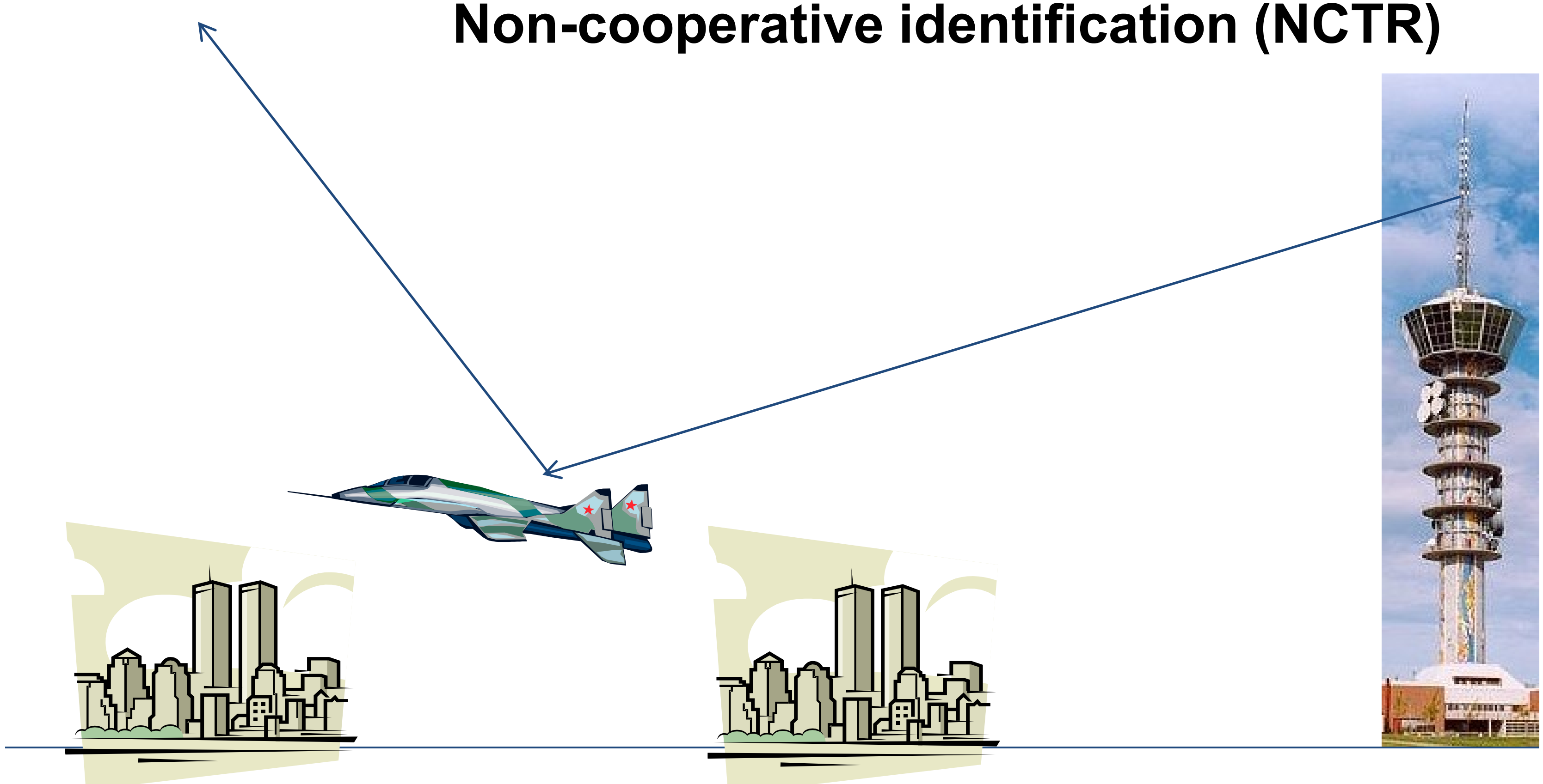
Ground mapping (SAR)
Change detection



Applications

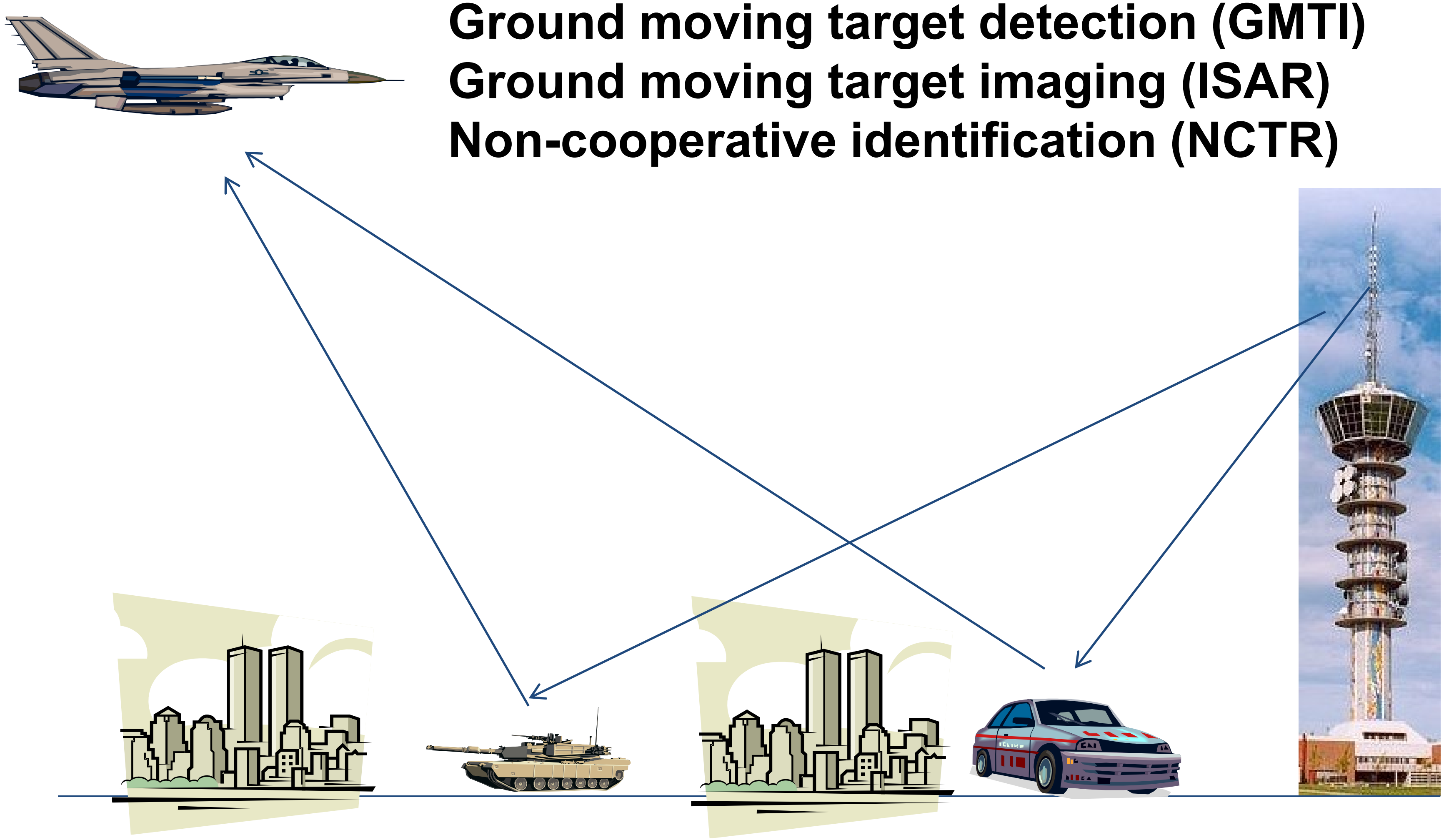
Low altitude flying target detection
moving target imaging (ISAR)
Non-cooperative identification (NCTR)



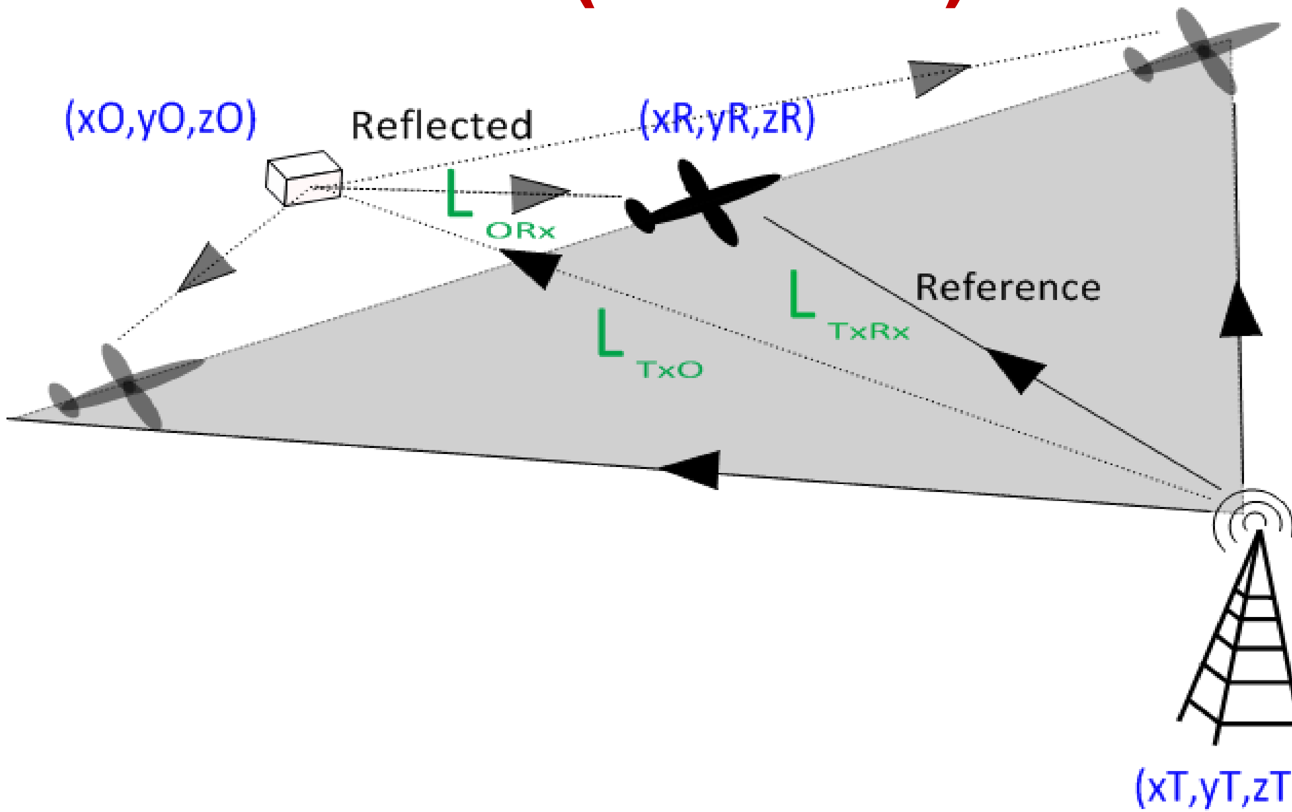


Applications

Ground moving target detection (GMTI)
Ground moving target imaging (ISAR)
Non-cooperative identification (NCTR)

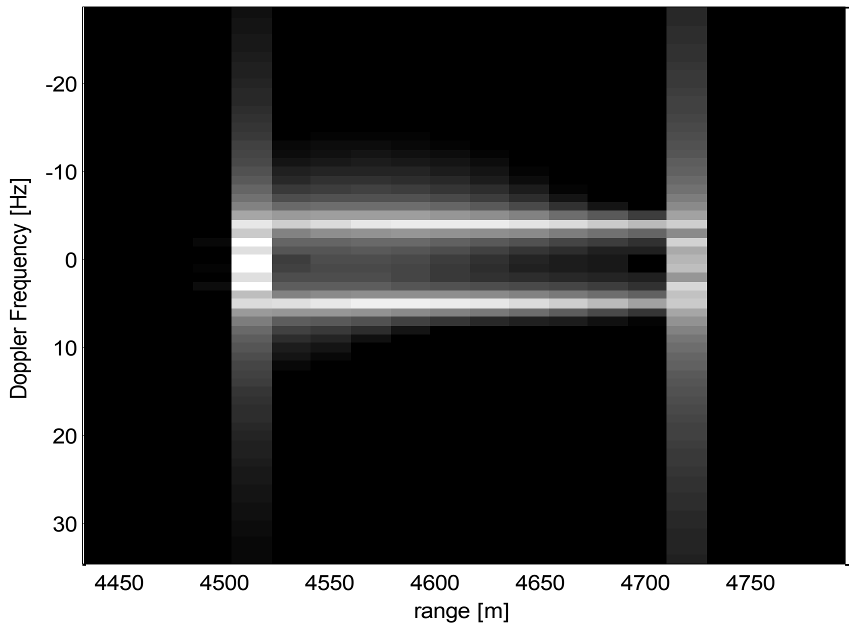


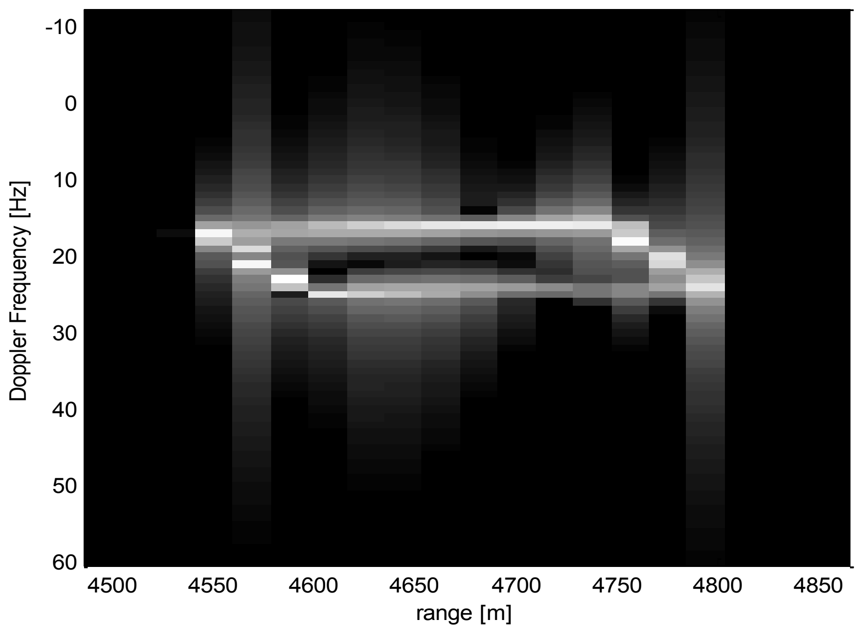
Passive SAR (PCSAR)



Illuminator: Ground based DVB-T transmitter

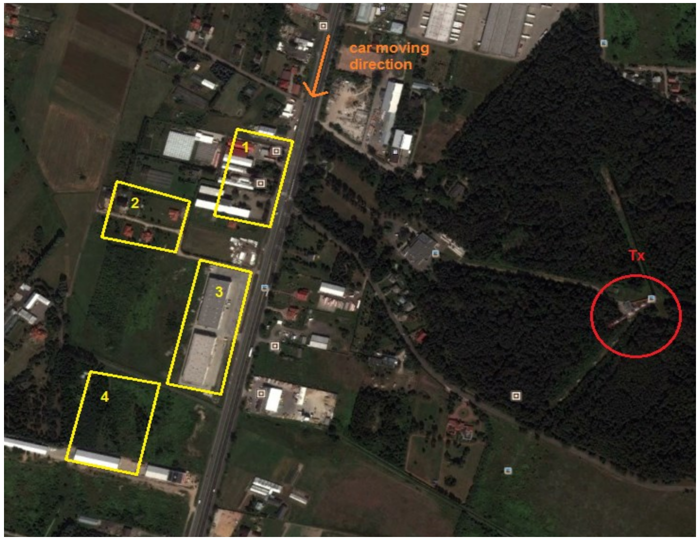
Verifications via simulations

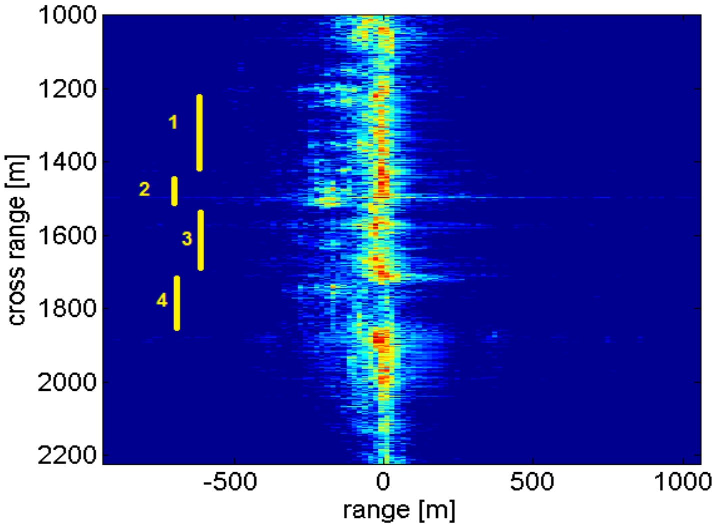




Verifications via experiments

Trial No 1

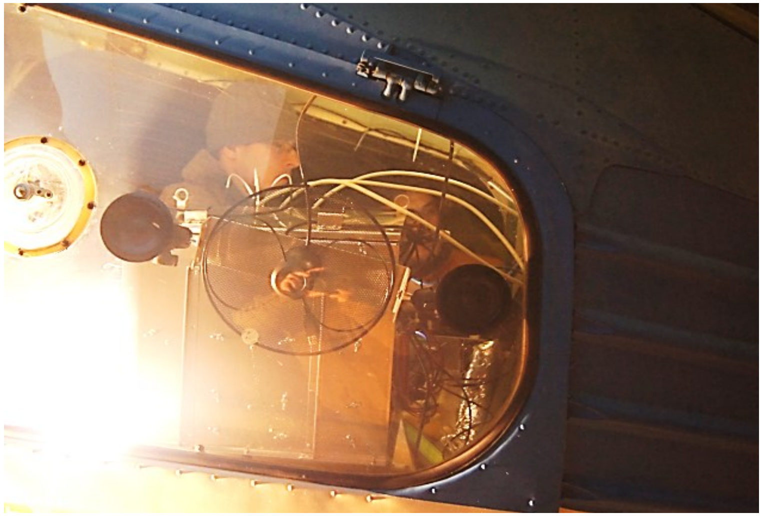




August 2013

Verifications via experiments

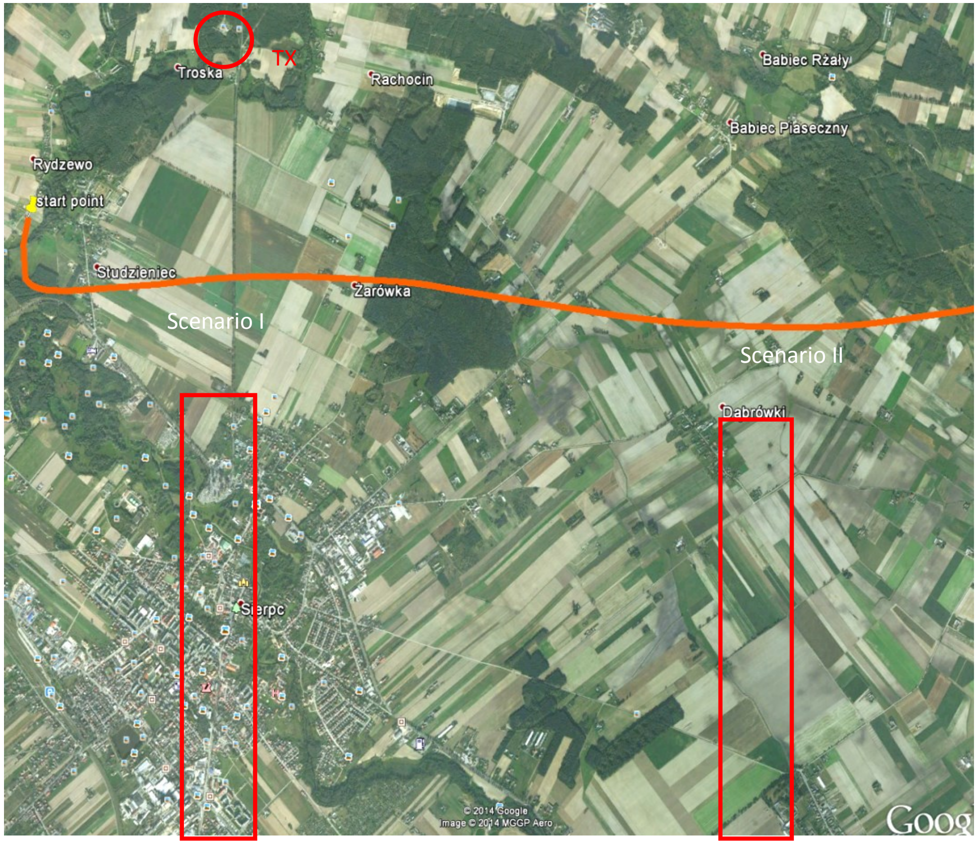
Trial No 2



October 2013

Verifications via experiments

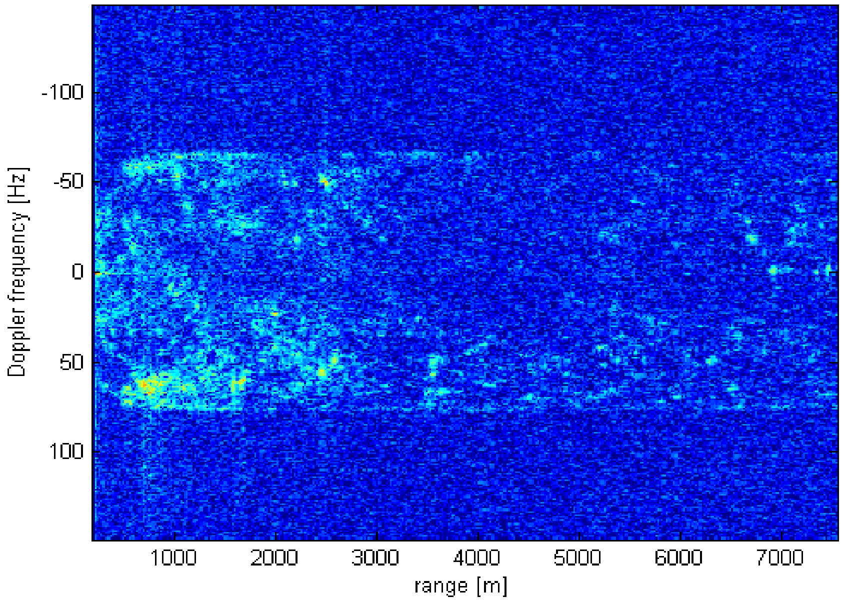
Trial No 2

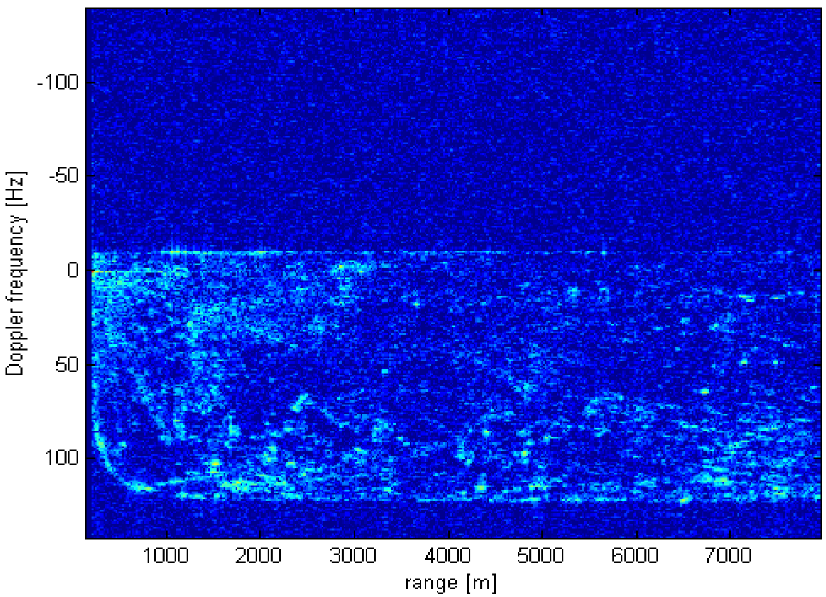


October 2013

Verifications via experiments

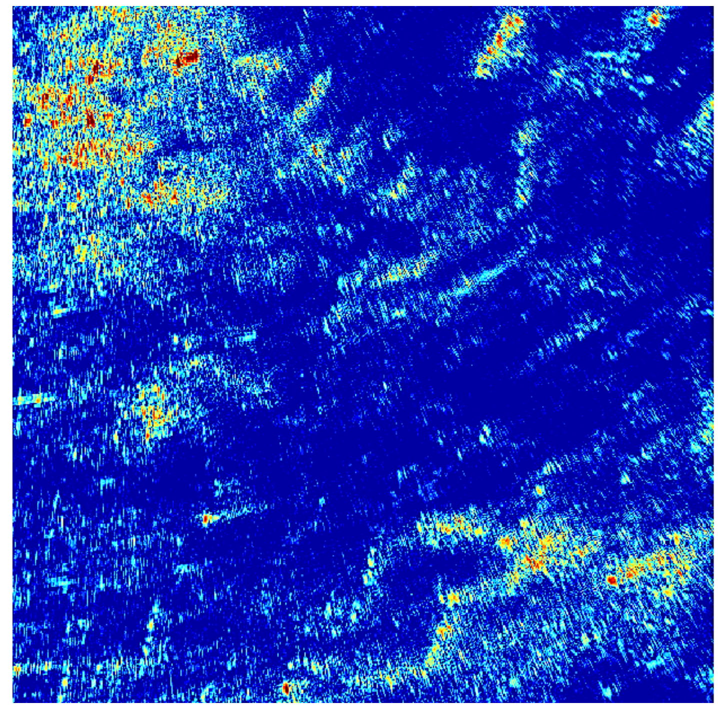
First infocused images





Verifications via experiments
PCSAR results

Focused images

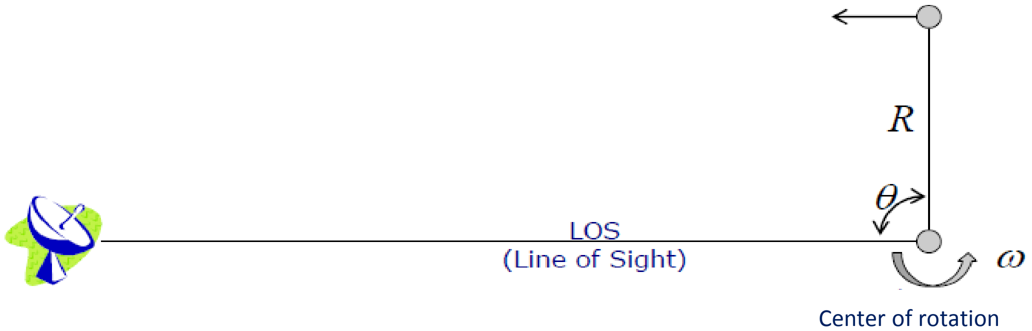


Passive ISAR imaging of air targets using DVB-T signals

ISAR - How does it work?

Geometry No. 1

$$V_r = V\sin(\theta) = \omega R\sin(\theta)$$



Doppler frequency

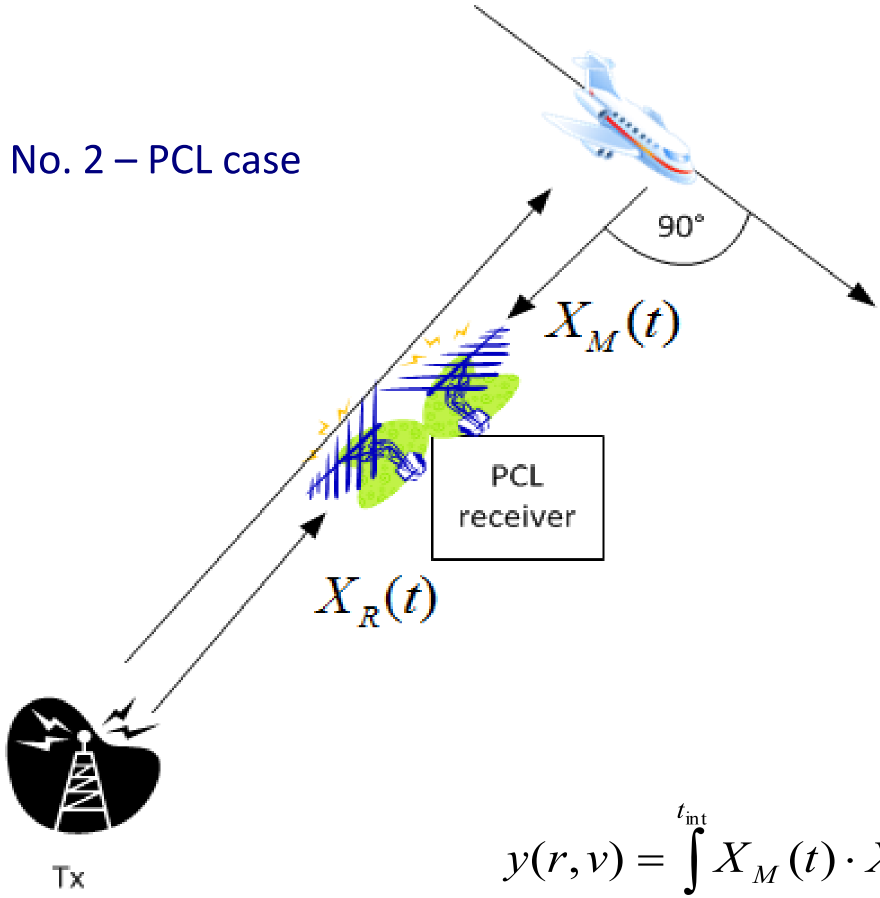
$$f_d = \frac{2V_r}{\lambda} = \frac{2\omega R\sin(\theta)}{\lambda}$$

Frequency resolution

$$\Delta f_d = \frac{1}{T}$$

System geometry

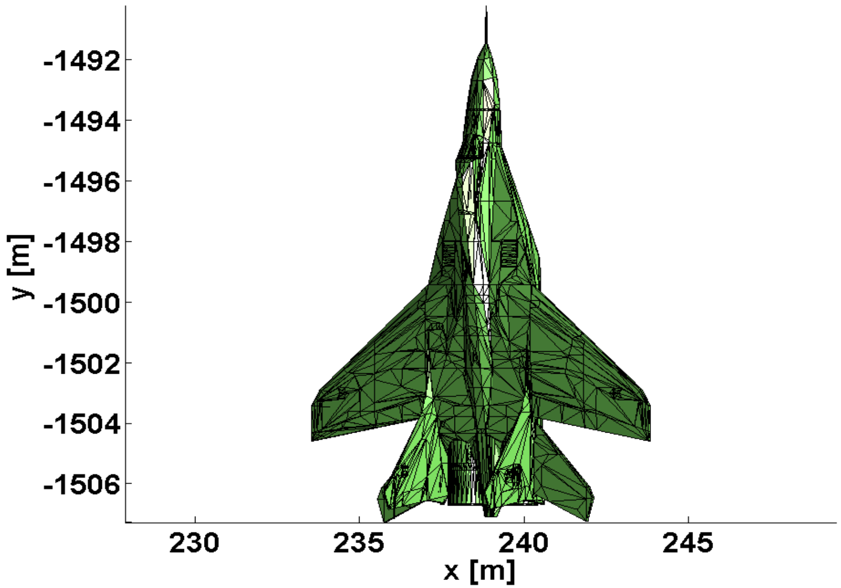
Geometry No. 2 – PCL case



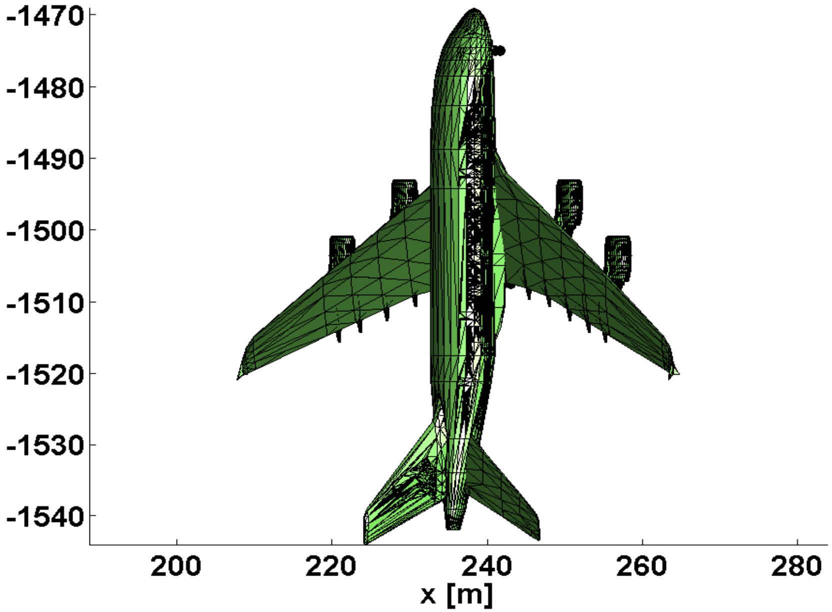
$$y(r,v)=\int_0^{t_{\text{int}}} X_M(t)\cdot X_R^*\left(t-\frac{r(t)}{c}\right)\cdot e^{2\pi\cdot f_C\frac{v}{c}\cdot t}\,dt$$

Verifications via simulations

Simulated targets



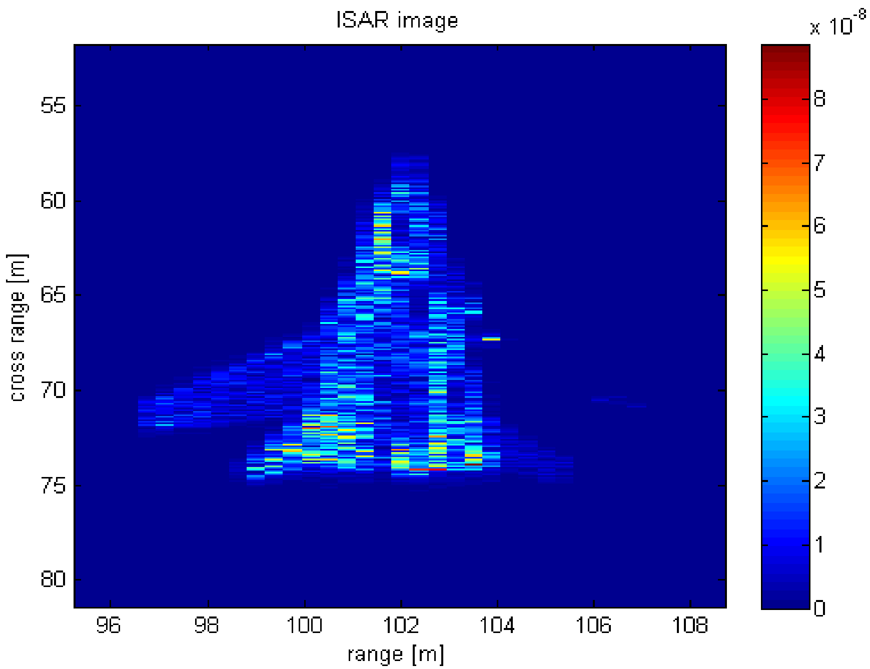
MIG-29



A-380

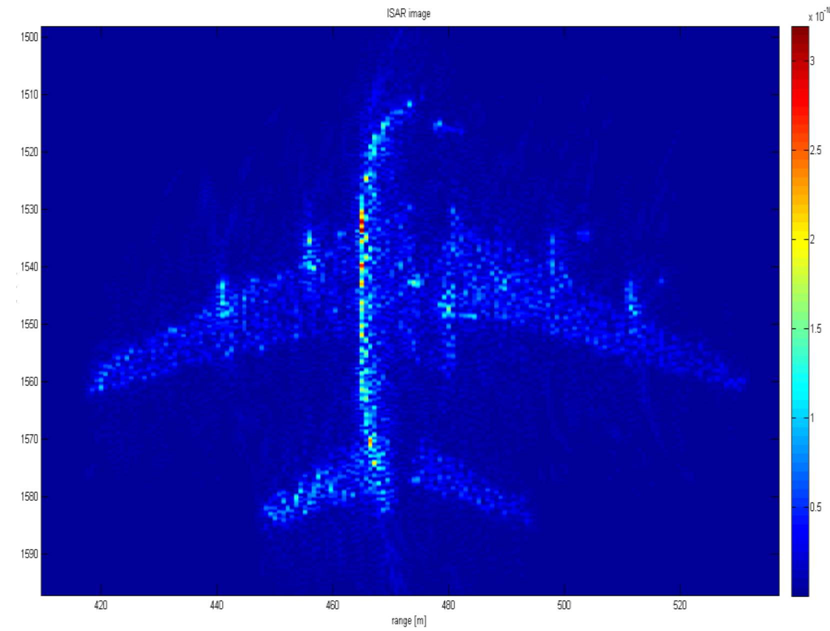
Verifications via simulations

Simulated targets



MIG-29

(B=400MHz)

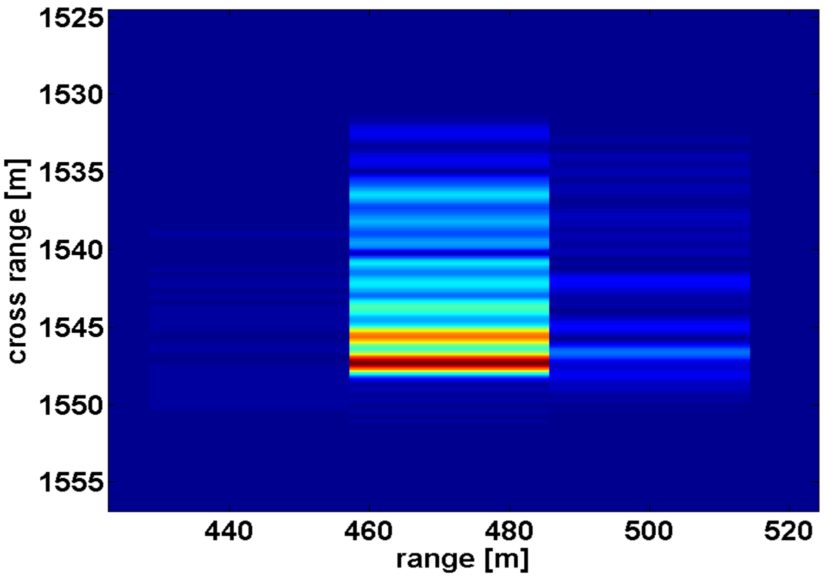


A-380

(B=400MHz)

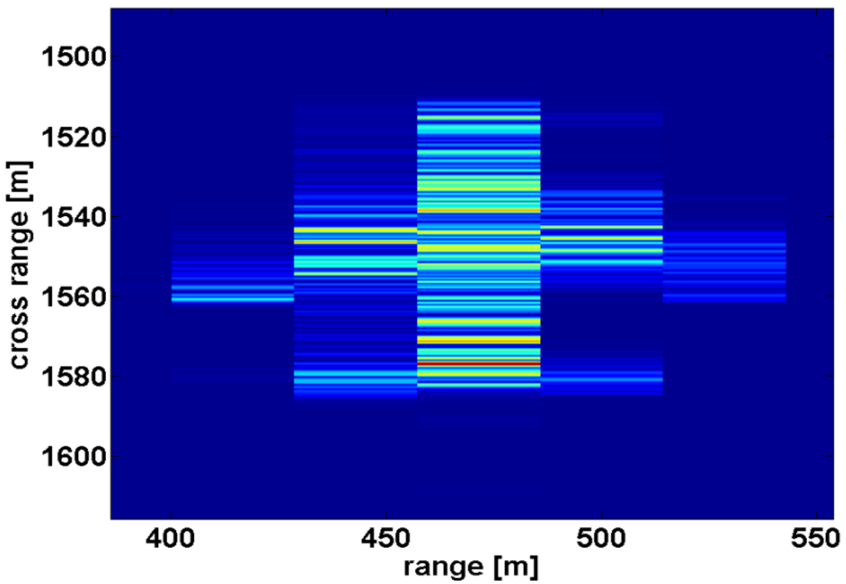
Verifications via simulations

Simulated targets



MIG-29

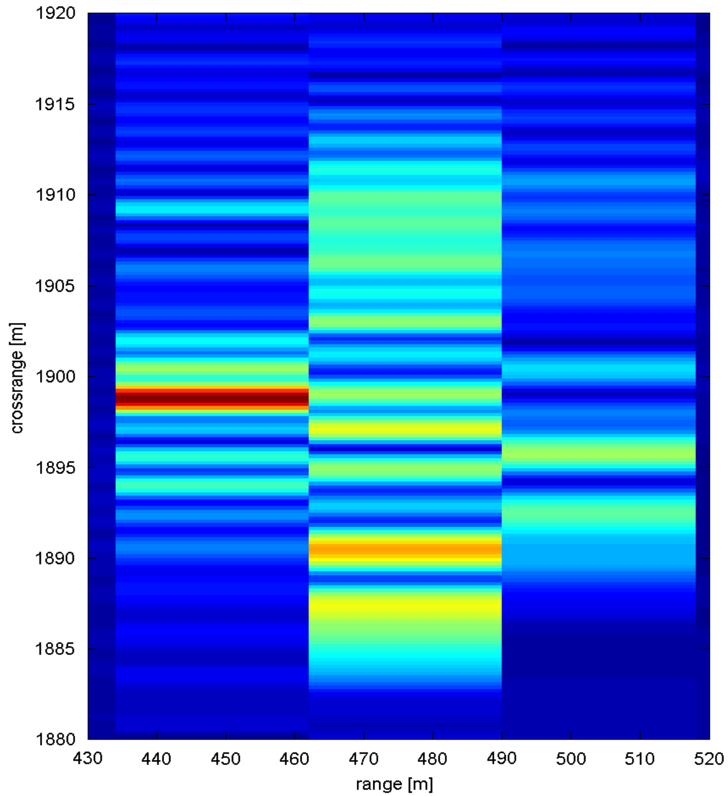
DVB-T illuminator (B=7.8MHz)



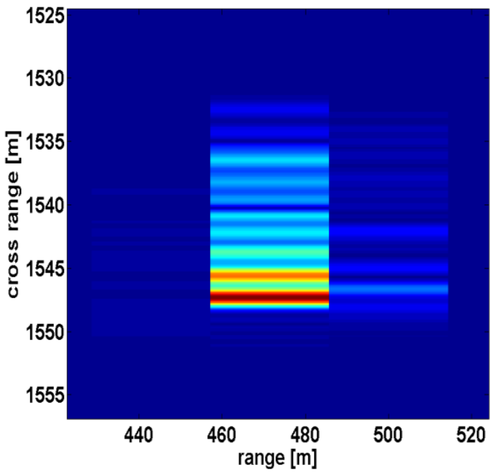
A-380

DVB-T illuminator (B=7.8MHz)

ISAR processing

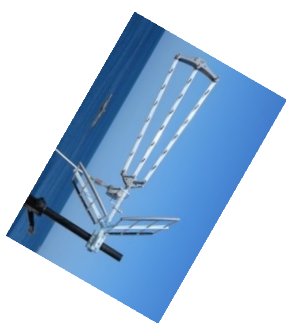


Passive ISAR image of MIG-29 (real data)

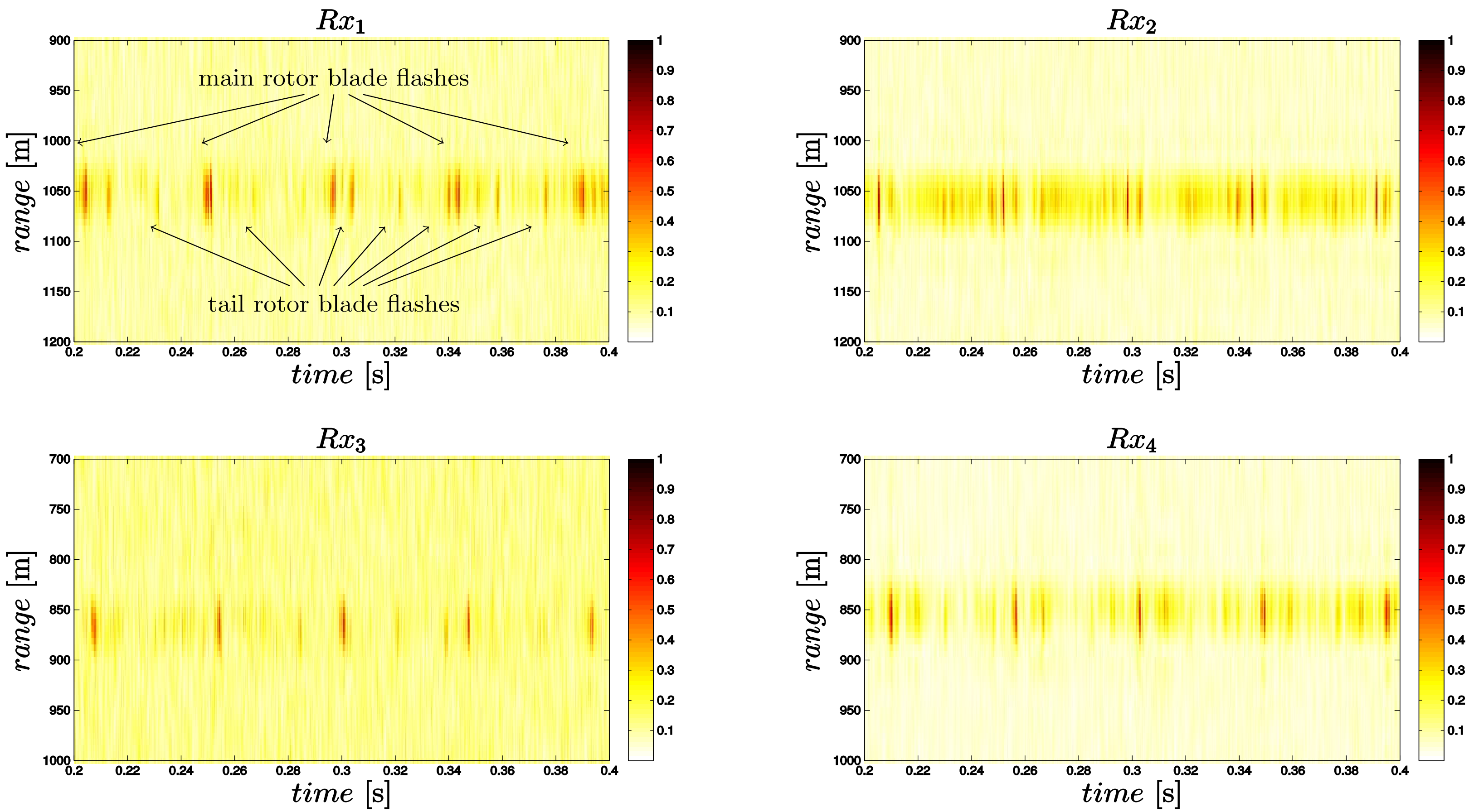


Passive ISAR image of MIG-29 (simulated data)

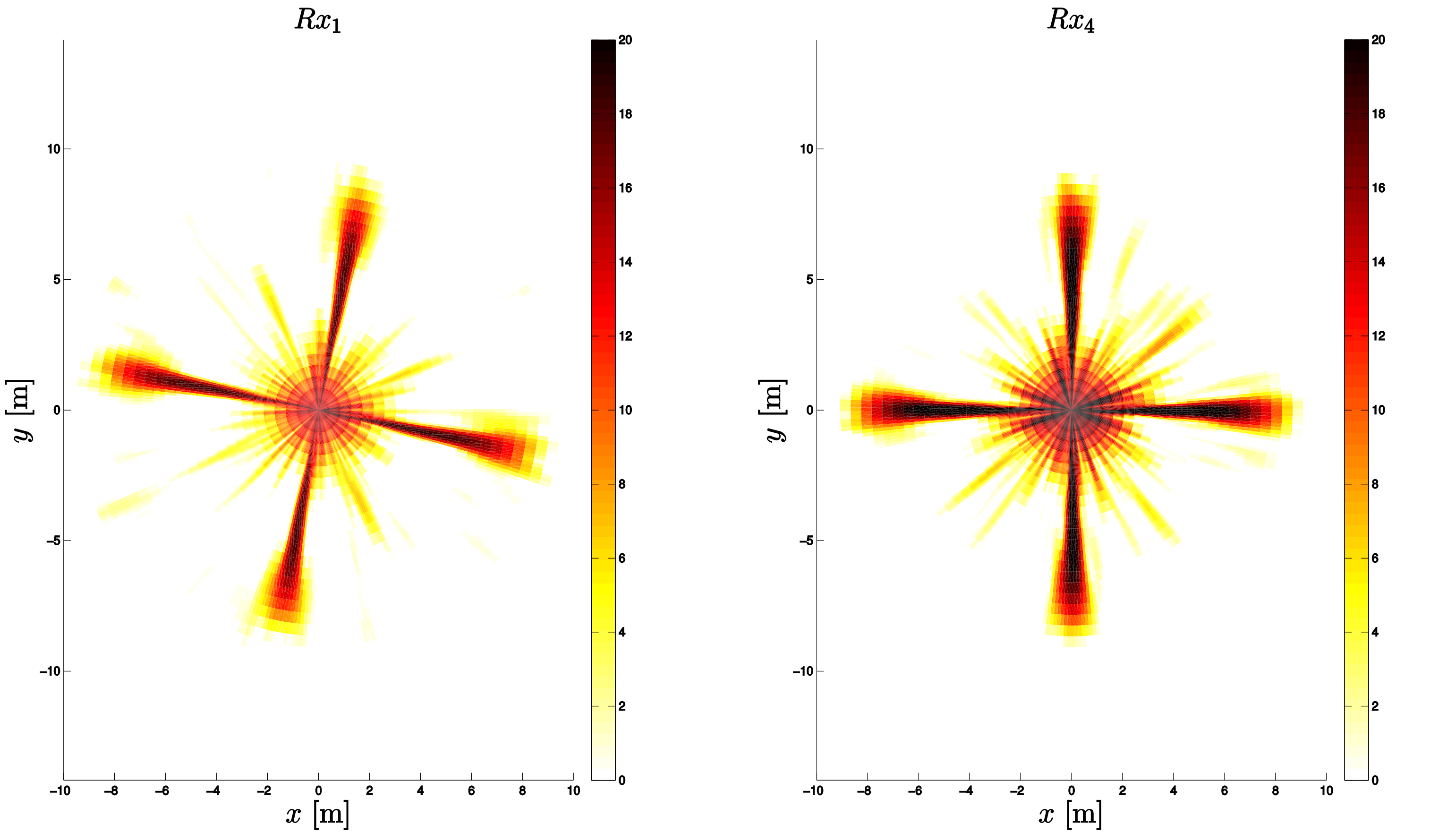
Helicopter identification
Using multistatic DVB-T PCL



Helicopter identification Using multistatic DVB-T PCL



Helicopter identification Using multistatic DVB-T PCL



PET-PCL project

GUNICA ⇔ PCL

PIT-RADWAR POLAND
+ Warsaw University of Technology

Conclusions

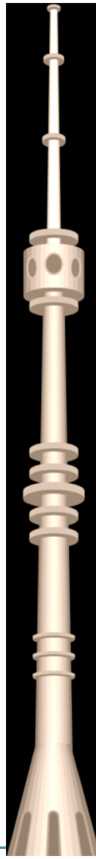
Passive radar can be used on airborne/space-borne platform

Pro

- covert detection of airborne/terrestrial targets
- situation awareness and self protection
- light, cheap system, low power consumption
- mountable on small platform (UAV in the future)
- gap filler
- alternative to expensive AWAX systems
- enhance functionality - cooperation of active and passive sensors

Contra

- sensitive to availability and coverage of transmitters of opportunity
- complicated signal processing
- coverage, sensitivity and accuracy depending in the scenario



Publication

- B. Dawidowicz, K. Kulpa, Airborne Passive Radar System - First Study International Radar Symposium IRS-2007, 05 - 07 September 2007, Cologne, Germany
- Krzysztof Kulpa, Mateusz Malanowski, Jacek Misiurewicz, Maj Mordzonek, Piotr Samczynski, Maciej Smolarczyk: Airborne PCL Radar: the Concept and Primary Results, Military Radar 2008, Amsterdam,
- B. Dawidowicz, K. S. Kulpa, M. Malanowski, Suppression of the Ground Clutter in Airborne PCL Radar Using DPCA technique, (w: EuRAD 2009. Radar Conference, European). 2009. ss. 306 - 309;
- P. Samczyński, K. Kulpa, M. Malanowski, J. Misiurewicz, „Advance Processing for Airborne Passive/Active Radars", IQPC Military Sensors 2010 Conference, 29-30 November 2010, Londyn, Wielka Brytania, ss. CD.
- Kulpa Krzysztof, Malanowski Mateusz Piotr, Samczyński Piotr Jerzy, Misiurewicz Jacek: On-board PCL systems for airborne platform protection, w: Proceedings of the Tyrrhenian International Workshop on Digital Communications, Enhanced Surveillance of Aircraft and Vehicles / Galati Gaspare , Genderen Piet van (red.), 2011, Centro Vito Vilterra - Tor Vergata University, ISBN 978-88-903482-3-5, ss. 119-122
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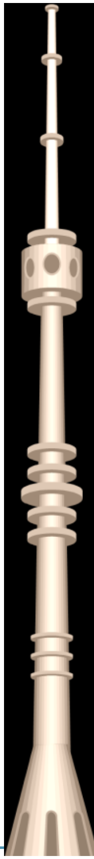
- K Kulpa, M. Malanowski, P. Samczyński, J. Misiurewicz, B. Dawidowicz,"Passive Radar for Airborne Platform Protection", in International Journal of Microwave and Wireless Technologies, Vol. 4, Special Issue 02, April 2012, Cambridge University Press, University Printing House, Shaftesbury Road, Cambridge, CB2 8BS, UK, pp 137-145
- Gromek Damian, Samczyński Piotr Jerzy, Misiurewicz Jacek, Malanowski Mateusz Piotr, Kulpa Krzysztof, Gromek Artur, Gadoś Andrzej, Jarzębska Anna, Smolarczyk Maciej: New high resolution SAR modes for an airborne maritime patrol radar — Implementation and results , w: 2013 Signal Processing Symposium (SPS) / Kulpa Krzysztof *[i in.]* (*red.*), 2013, ISBN 978-1-4673-6319-8, ss. 1-4, DOI:10.1109/SPS.2013.6623571



Thanks