# Passive Coherent Locator on Moving Platforms

**Krzysztof Kulpa, Mateusz Malanowski, Piotr Samczyński**

Institute of Electronic Systems

Warsaw University of Technology

Nowowiejska 15/19, 00-665 Warszawa

k.kulpa@elka.pw.edu.pl, m.malanowski@ elka.pw.edu.pl

***ABSTRACT***

*Passive radar is mainly aimed for detection and tracking of airborne targets using emitters of opportunity for target illumination. As they multistatic in nature, the main problem is that the measurements are based on bistatic range and range velocity estimation and main problem is in data fusion, while it is necessary to fuse the data from different pairs of transmitter-receiver to form and update tracks. In most cases the measurement provide only range Doppler information and no angular information, so in such a case target position can be estimated solving nonlinear set of equations and finding best possible association. In the notes the fundamentals of positioning and tracking are presented. Theoretical considerations are illustrated with selected simulation results.*

## 1.0 INTRODUCTION

Passive Radar has been one of the most rapidly developing fields in radar technology in recent years. The low cost nature of passive radar, known also as Passive Coherent Location (PCL), has resulted in strong interest from a significant number of companies and research institutions. As a result of this research, many passive radar demonstrators and commercial products have been developed [1, 2, 3, 4, 5, 6, 7].

Existing passive radar systems utilize various different types of signals for target illumination [8]. The most popular signals used by modern passive demonstrators are: FM radio [2,6,4,6], DAB radio [3, 9, 10, 11, 12], analog and digital television (DVB-T) [13, 14, 15, 16], GSM networks [17, 18, 19], and WiFi signals [20, 21, 22, 23, 24, 25].

Most of the known variants of passive radar are stationary, ground-based systems dedicated to the detection and tracking of airborne targets. The last decade of PCL systems development has led this technology toward a state of relative maturity for ground-based operation. These developments have prompted the research conducted for this study, which will focus specifically on passive radar on a moving platform. In the literature available on this subject, initial analyses devoted to PCL mounted on ground moving vehicles and airborne platforms can be found [26, 27, 28, 29, 30, 31, 32, 33].

At the present moment 4 different platform types are being analyzed: surface platforms (vehicles), sea platform (ships, patrolling boats, submarines) airborne platform (aerostats, aircrafts, helicopters, UAV) and space platforms (satellites).

As it was in the radar history, the active radars ware firstly diploid on the ground, and shortly ware adapted to many moving platforms. So in the near future we can predict, that the passive radars will be also adapted to the moving platforms and will play an important role for self-

protection, surveillance and reconnaissance.
Placing passive radar on moving platforms provide many challenges to the radar designers, but also provide new perspectives and new capabilities.
The use of mobile PCL systems can provides extended functionality to the passive radar. In case of placing it on airborne or satellite platform horizon limitation of using far illuminators of opportunity is removed and it would be possible to detect low flying target. The platform motion can be also exploit to perform passive imaging of the ground and create the passive SAR images [42, 43, 44], detect the slowly moving objects using Ground Moving Target Indication (GMTI) techniques [35, 36], and produced images of detected moving targets using Inverse Synthetic Aperture Radar (ISAR) mode [45, 46].
But it also bring the new challenges to the radar designers. In classical ground based passive radar the scene is illuminated by a stationary transmitter and the ground returns (ground clutter) have almost zero Doppler frequency. As the Doppler components originates from the target motion, only small motion or vibration of tree branches or leaves can introduces same little Doppler spread of the clutter, which can be easily removed by appropriate filtration. As most of targets of interest have significant Doppler shift due to its motion, the detection losses caused by zero or near zero Doppler clutter cancelation are negligible. In case of moving platform PCL the echo coming from no-moving ground objects (ground clutter) possess no-zero Doppler frequency due to the platform motion. And as the ground clutter signals arrive from different angles, one can observed the wide Doppler spread of the clutter. That Doppler frequency shift and its change as a function of time can be exploited in passive synthetic aperture imaging of the ground. But for slow target detection such clutter Doppler spread is a challenge, while the echoes of targets slower than are within the Doppler spread of the clutter and it is more difficult now to distinguish useful echoes form the clutter. Of course in case when only fast targets are of interest, it is possible to cancel all clutter using extended Doppler CLEAN technique and detect the targets on clutter-free region.
The objective of the signal processing in moving platform PCL is to suppress ground clutter, while preserving the echoes from moving objects. This problem is well known in the classic airborne pulse Doppler radars, for which the there are many solutions based on STAP or DPCA algorithms.
Such algorithms for active radars have been derived using assumption that all pulses send by radar are this some – have this some power and waveform. It is of course not true in passive radar, when we do not have pulses, and illuminating signal is not stationary. Both power and waveforms of illuminating signal are function of time and thus more elaborate methods have to be developed.

The concept of Passive radar placed on airborne platform is presented in Fig, 1

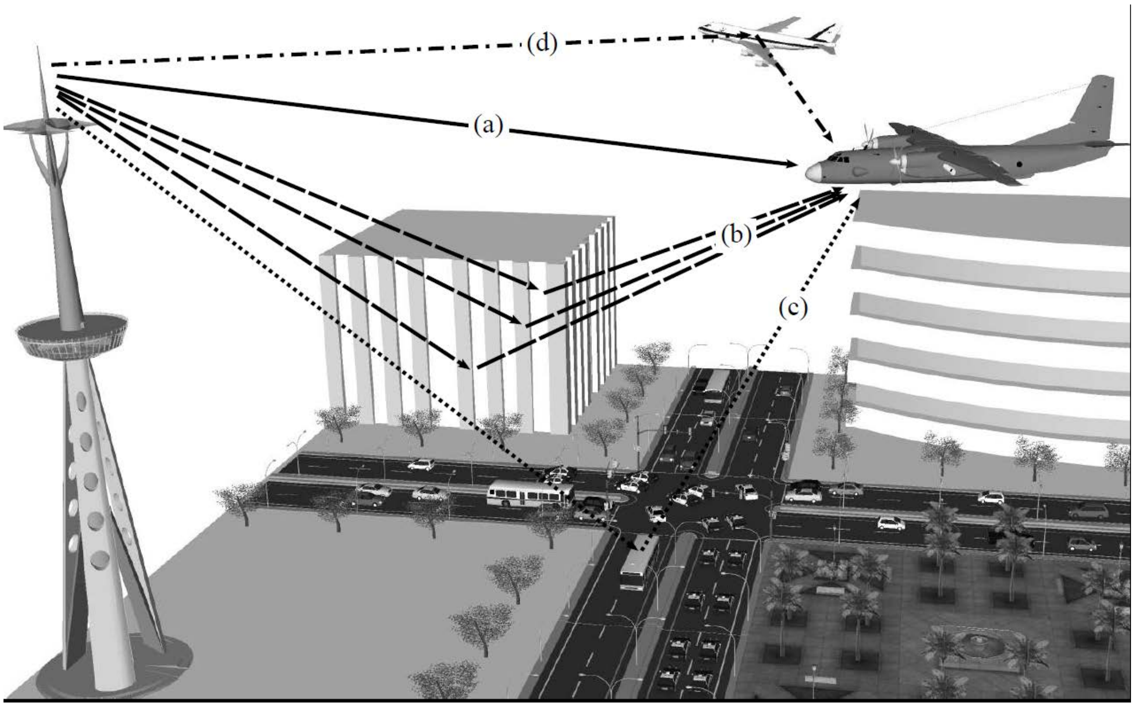


Fig. 1.Concept of Passive Radar placed on airborne platform.

The aircraft is equipped with the passive radar receiving several signals. The main important is the direct signal (a) used as the reference. Except of this the several indirect signals (echoes) are received from ground objects (b), ground traffic (c) and airborne targets (d). In practical case airborne passive radar will observed several transmitters and many moving targets, so the scene presented in Fig 1 is simplified one.

To resolve all those signals an advanced antenna array have to be used, equipped with several elementary antennas and digital receivers. The digital processing will then form several beams. One (or more) will be used as reference signal beam, while others will be used for surveillance and imaging purpose.

One of the most important problem is selection of transmitters. The PCL system can exploit the existing FM radio, analogue (in selected countries) or digital TV, Cellular phone base-station signals and many others. They can also exploit illumination from other radars
Their main characteristics are compared in the Tab 1.

Table 1. Signals that cen be used for PCL on mobile platform.

| Signal Type | Frequency [MHz] | Modulation Type, Bandwidth $\Delta f$ | EIRP [W] | Power Density (dBWm$^{-2}$) $\phi = (P_t G_t)/4\pi r_1^2$ |
|---|---|---|---|---|
| HF broadcast | 10-30 | DSB AM, 9kHz | 50e6 | -67 to -53 * |
| VHF FM (analog) | ~100 | FM, 50 kHz | 250e3 | -57 * |
| UHF TV (analog) | ~550 | AM (video), FM (audio), 5.5MHz | 1e6 | -51 * |
| Digital Audio Broadcast | ~220 | Digital, OFDM 220kHz | 10e3 | -71 * |
| Digital TV (DVB) | ~750 | Digital, 6 MHz | 8e3 | -72 * |
| Cellphone basestation (GSM) | 900,1800 | GMSK,FDM/TDMA/FDD 200kHz | 100 | -81 ** |
| Cellphone basestation (3G) | 2000 | CDMA 5MHz | 100 | -81 ** |

* @ $r_1$ = 100km, **@ $r_2$ = 10km

The choice of the most proper signal depends greatly on the application. The maximal range detection depends, like in traditional radar, on the transmitted power and the antenna gains. The range resolution (in this case bistatic range resolution) depends on the bandwidth of the received signal. The range resolution can be improved by the usage of the signal from the several TV channels or radio station simultaneously (bandwidth summation).

In general the effective bandwidth of the FM modulated signals depends on the type of the transmission (music, speech). This influence on the radar parameters (e.g. range resolution) during its work. The stable radar performance can be supported by the usage of the digital TV and 3G or 4G telecommunication signals.

## 2. PCL signal modeling

The main assumptions of the airborne PCL radar situation modelling are as follows: the objects on the radar scene are reflecting points, the received radar signal is disturbed by the Gaussian noise, during the so called integration time the object is moving with a constant velocity and heading. The classical detection process in PCL radar is based on the calculation of the range–Doppler cross-correlation function between the measurement and reference signal

$$y_r(r,v) = \int_{t=0}^{t_i} x(t)x_{ref}^*(t-\frac{r}{c})e^{-j2\pi(-\frac{2vF}{c})t}dt \tag{1}$$

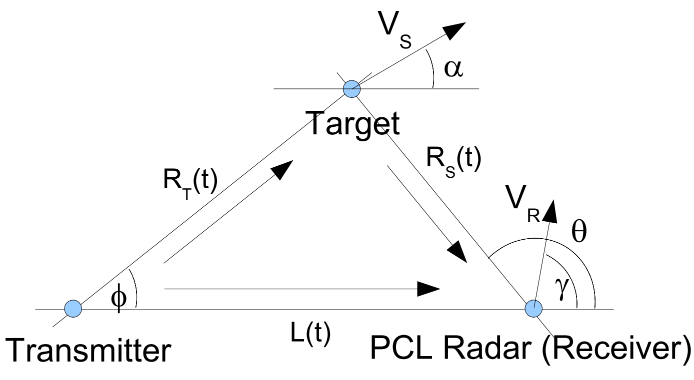


Fig. 2. PCL Radar situation model

In general case the radar situation is three-dimensional, but for the simplicity of the calculations the two dimensional model can be used (see Fig 1.). In this case where transmitter and the receiver are moving

The signal at the measurement receiver output, after quadrature detection, can be written in the form (1):

$$x_R(t) = \xi(t) + A_R x_T(t - \frac{r}{c}) e^{-j2\pi \frac{F_T v_R}{c} t} = \xi(t) + A_R x_T(t - \frac{r}{c}) e^{-j2\pi \cdot f_d t} \quad (1)$$

where $\xi(t)$ is the receiver noise component, $A_R$ is the amplitude of the target echo signal, $x_T$ is the reference signal at the PCL radar site (a delayed copy of the transmitted signal), $r$ is the range difference between the indirect signal path (sum of illuminator-target and target-receiver distances) and direct signal path (illuminator-receiver distance), $c$ is the velocity of light, $F_T$ is the transmitter carrier frequency (central frequency for wide-band transmission) and $v_R = \frac{dr}{dt} = \frac{d(R_T(t) + R_S(t))}{dt}$ is the PCL radar (receiver) and target relative radial velocity. For the sake of simplicity the noise component will be modelled by equivalent system thermal noise of the power $p_\xi = kT_{\mathrm{Re}}B$ generated by an equivalent receiver heated to the effective temperature $T_{Re}$ ($k$ is Boltzmann's constant). The Doppler shift $f_d$ of the received signal can be written in the form (2):

$$f_d = -\frac{1}{\lambda}\left(2V_S \cos\frac{\Theta + \phi - 2\alpha}{2}\cos\frac{\phi - \Theta}{2} + V_R\cos(\Theta - \gamma)\right) \quad (2)$$

The bandwidth of the received ground clutter Doppler frequency can be written in the form (3):

$$\Delta f_d \approx \frac{2}{\lambda}\left(V_R \sin\frac{\alpha}{2}\right) \quad (3)$$

where $\alpha$ is the antenna beamwidth. As on moving platform it is hard to install the big antennas, antenna beamwidth are supposed to be wide (10-90$^{o}$).

The Doppler frequency of the stationary objects and moving targets may overlap because there are always several stationary objects on different angles in the antenna beam during integration time.

To present the effect of clutter spectrum widening the simulation result is presented in the paper for simplified radar scene as presented in Fig. 3. All object on the radar scene are modelled by the reflecting points.

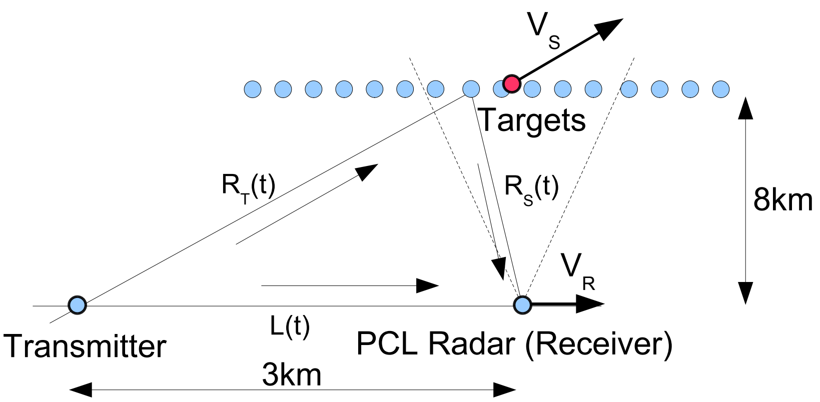


Fig 3. PCL radar simulation geometry

The computer simulations were performed for two general cases. In the first case both transmitter and PCL radar (receiver) were stationary ($V_R$=0). Apart of the few stationary objects there were two moving targets: fast (20m/s) and slow (5 m/s). It can be clearly seen that the detection of both slow and fast moving targets is quite easy. The moving and stationary objects are well separated (Fig. 4) so ground clutter can be easily suppressed using simple adaptive filtering [34].

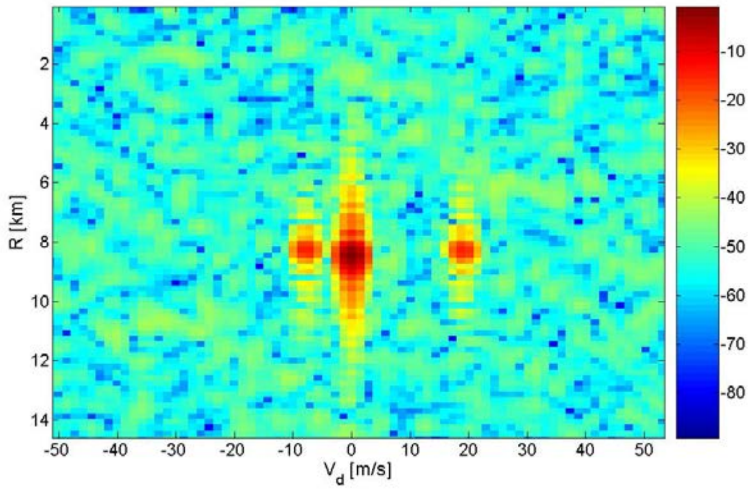


Fig. 4. PCL Range-Doppler correlation function - stationary case, color coded in dB; the fast and slow moving objects are separated from the ground clutter.

In the second case the receiver was placed on the moving platform. It was assumed that radar platform is moving with a velocity $V_{Ry}$=70 m/s and the antenna beam was directed perpendicular to the flight path. (beamwidth is equal to 30°).

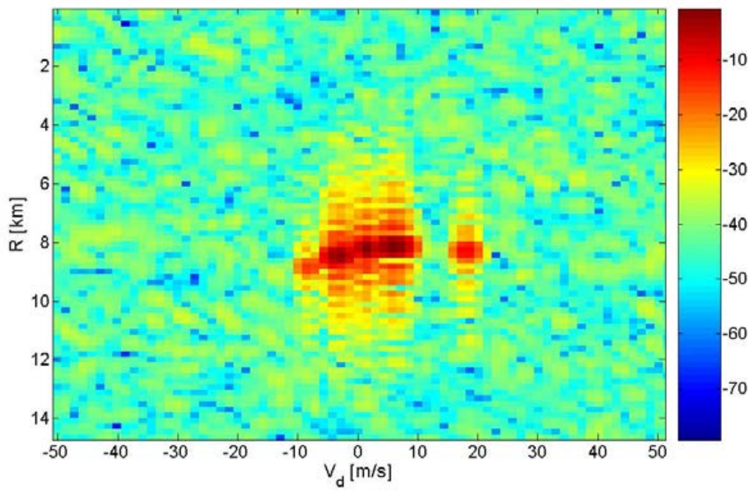


Fig. 5. PCL Range-Doppler correlation function – radar on the moving platform, color coded in dB; only the fast moving object is clearly seen while slow-moving object is hidden in the ground clutter.

According to the equation (2) the Doppler shift of the received signal depends on the directions of the signal arrival. Because there are several stationary objects in the received antenna beam on different angles the Doppler spectrum of the stationary clutter is wide ( $\Delta f_d \approx (2V_{Rv} \sin\frac{\alpha}{2})/\lambda$ - what corresponds for the modeled case to over 10 m/s). Thus the ground clutter Doppler spectrum can overlap the Doppler frequency of the slow moving target. Such a situation is shown in Fig. 5. Only the fast moving target (20m/s) can be detected in this case. However the presence of strong ground clutter can mask also the weak fast moving targets (Fig. 6). In such case the ground clutter suppresion methods based on the lattice filtering [35-39] are not effective, because in this case they do not suppress clutter sidelobes.

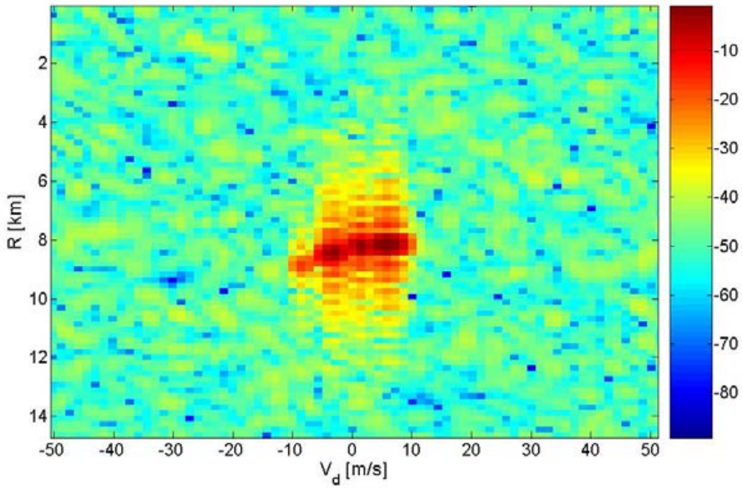


Fig. 5. PCL Range-Doppler correlation function – radar on the moving platform, color coded in dB; only the fast moving object masked by the strong ground clutter.

The detection of useful targets in ground Doppler spread region is possible only when the the clutter will be canceled without cancelling the target echoe. This can be done using modified STAP or DPCA method. The simper is the DCPA one. DPCA processing is a technique for countering the platform motion induced clutter spectrum spreading. This technology was invented originally for the pulsed radars. However after some modifications it can be utilized by passive radar. The basic concept of DPCA technology is to make the antenna appear stationary even though the platform is moving forward. This is performed by electronically shifting the receive aperture backwards during the operation as depicted in Fig. 6. The idea is that in consecutive time instance signal is received (and transmit in active radar case) by different antennas to produces such effect that receiving (and transmitting) point is not moving with the time. It needs of course time synchronisation between platform velocity and the pulse repetition frequency.

Similar effect can be obtained in case of passive radars, where integrating interval for each antenna is shifting in time equal to time being the division of distance between antennas and the platform velocity. In such a case the antennas position and motion within integration time are the same, so the ground clutter signal (after integration) will be exactly this some.

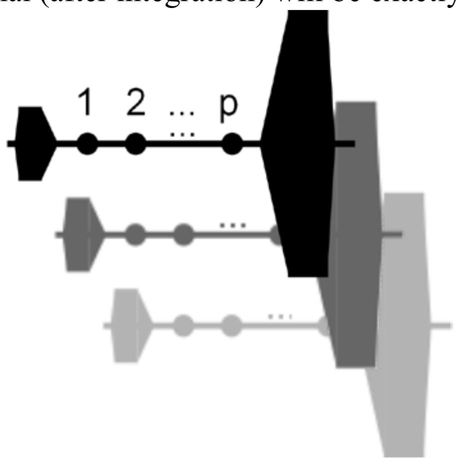


Fig. 6. Passive radar DPCA Processing Scheme

The suppression gain for PCL DPCA is a bistatic range invariant. For a PCL system with a fixed antennas configuration DPCA filter suppression characteristics depends only on velocity of the radar platform and bistatic velocity of the object on the scene.

The cancelation process is not perfect while the integration intervals are different and the illuminating signal is not stationary.

The idea of cancelation process for PCL DPCA, described above is illustrated in Fig. .

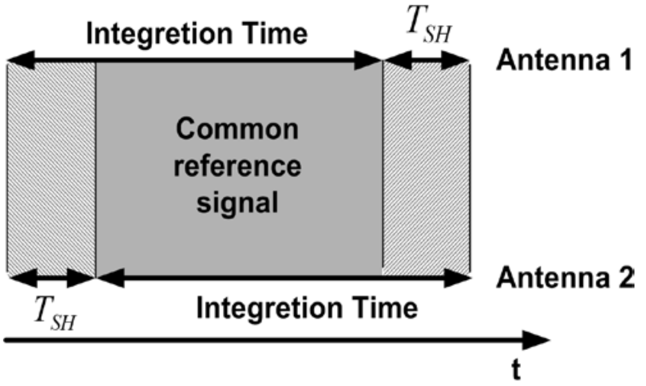


Fig. 7. Temporal decorelation in PCL DPCA

Suppose that the PCL system utilizes 100MHz carrier frequency signal with 50kHz bandwidth, sampled at 200kHz. The integration time is about 1s and the distance between the antennas phase centres is 2/3 of the wavelength. The results of the calculations of PCL DPCA filter is presented in Fig. 8.

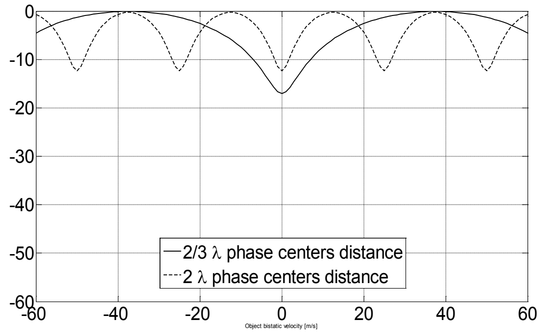


Fig. 8. Velocity characteristics if different PCL DPCA

The processing results are based on the assumption that the receiving antennas have exactly the same beam characteristic. This might be not true in the real situation.

For the longer distances between the antennas we are getting into well known 'blind speeds' problem. To show the efficiency of DPCA processing algorithm was tested using computer simulations. The geometry of the radar scene is presented in Fig. 3. Lets assume that PCL radar system is installed on the mobile platform flying *100 m/s* along X axis. The simulations were performed for the system utilizing FM radio based signals of a carrier frequency equal to the $f_0 = 100MHz$ and bandwidth $\Delta f = 50kHz$ The sampling frequency of the system is equal to $f_s = 200kHz$ . The integration time is equal to 1s and the distance between antennas phase centers is 1m. The initial distance between the transmitter and receiver is equal to 10km The initial bistatic range to the moving objects is about 8km.

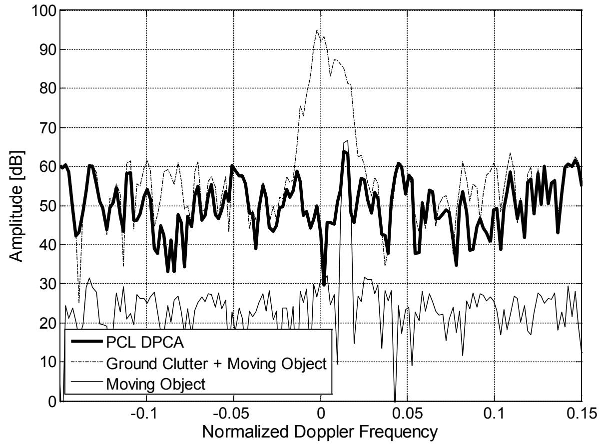


Fig. 9. DPCA PCL simulation results

The simulation results of DPCL PCL processing is shown in Fig. 9. The plot is showing the processing results for three following cases: only the signal from moving target is present in the received data (standard PCL range-Doppler processing is applied), signal from slow moving target is received in the presence of stationary ground clutter (standard PCL range-Doppler processing is applied) and finally the signal from slow moving target is received in the presence of stationary ground clutter (PCL DPCA processing). It can be seen that the suppression of the moving target not significant, clutter signal was suppressed almost fully, but side lobes of ground clutter returns at higher frequency remains. It means that more advanced algorythms are still needed.

The verification of presented concept was done in years 2006 - 2008 using both ground and airborne platform. The PCL The first measurement campaign has been carried out on the ground using car platform as depicted in the 10. The car have been equipped with 6 FM antennas and travel with speed of 30 m/s at the road near the landing path to Warsaw airport, observing landing planes at distance of 5-20 km. The DPCA PCL algorithm was used for data processing. The results are presented in Fig. 11. The plane echo is visible at distance 10 km with speed 200 m/s and ground clutter residues are visible in velocity range +- 30 m/s, as it can be predicted.

Fig. 10. Passive radar mounted on car platform

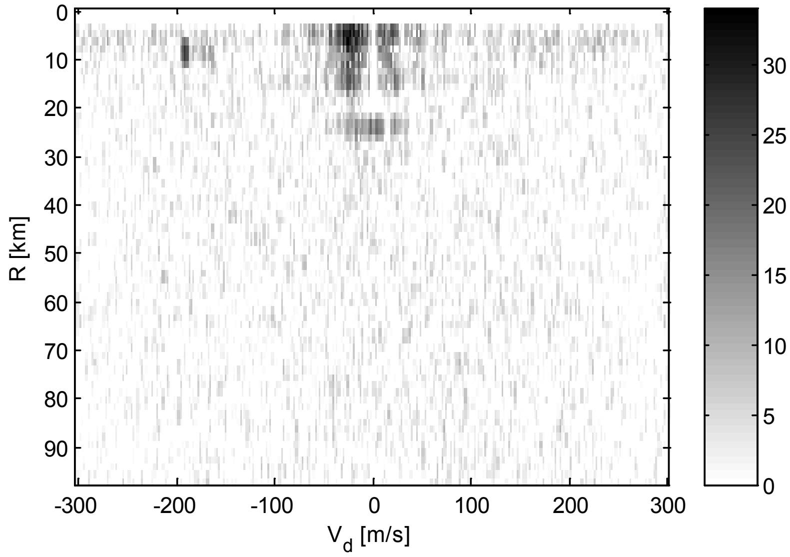


Fig. 11. Result of processing car PCL data

The second trial campaign has been carried out in the air. The flight campaign was done using *Skytruck* aircraft, as a moving platform, as presented in Fig 12. Six antennas were mounted in the airpplane windows as presented in Fig 13.


Fig. 12. Passive radar mounted on airborne platform

Fig. 13. PCL antenna mounted at the airplane window

The results shows that it is possible to use the PCL radar on moving platforms. Fig 14 shows prediction of PCL coverage (detected target RCS in dBsm) when polish FM transmitters are being used.

It can be clearly seen, that the detection range for medium size targets are handred of km, and PCL radar can also be used for platform protection, as it can detect very small targets (-20 dBsm) at distances to 20 km.

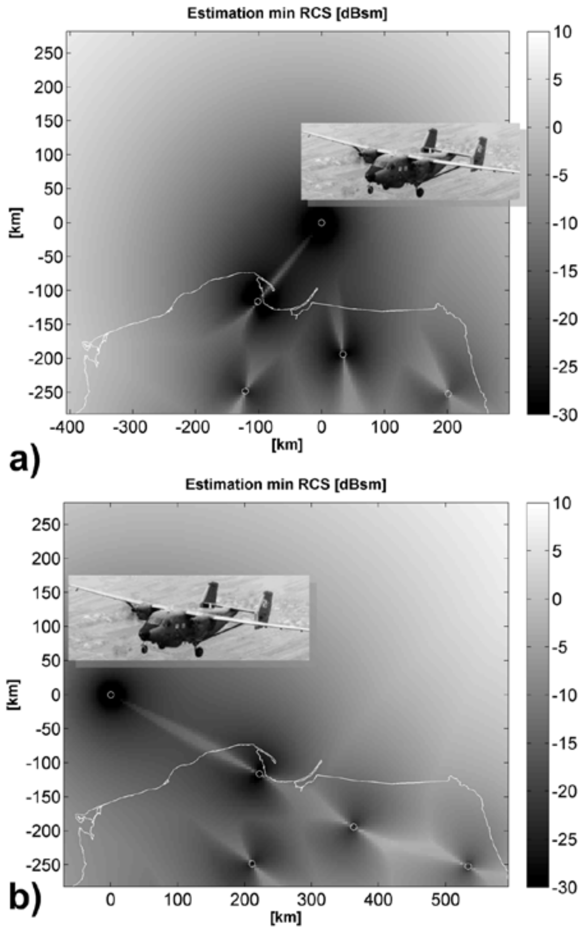


Fig. 14. Example of the PCL coverage for the trials carried out on the Polish coast - moving platforms coordinates in longitude and latitude (x, y): a) (20°, 55.5°); b) (15°, 55.5° ).

The airborne Passive radar can also be used for passive SAR imaging. Passive SAR scenario is presented in Fig. 15. In such a case the illuminator od chais id DVB-T transmitter, due to its power (up to 100 kW) and bandwidth (7.8 MHz for single channel, multiple channels are available in many locations)

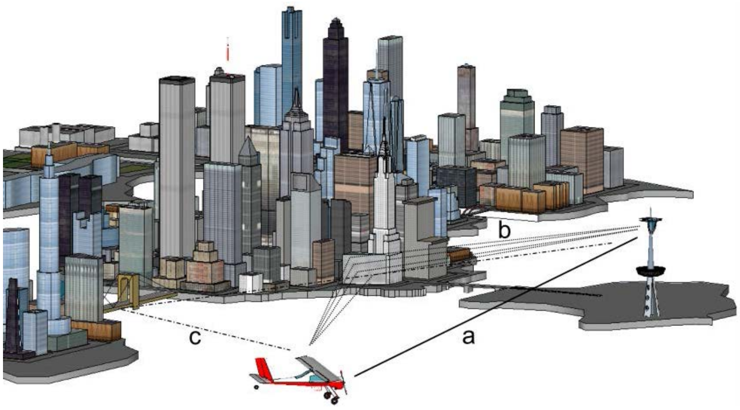


Fig. 15 DVB-T passive SAR scenario

The measurement campaign took place in December 2014. Measurements were made in Sierpc where the DVB-T transmitter is. As a mobile platform on which was mounted passive receiver was Polish plane

PZL-104 “Wilga” which is presented on Fig. 16.

Fig. 16 PZL-104 “Wilga aircraft used as an airborne passive SAR radar carrier and the measurement equipment place on board


**Fig. 17 Commecial DVB-T antennas used in experiment**

Fig. 16 shows hardware used in the experiment: DVB-T channel amplifiers, USRP N210 as a ADC and

PC for data recording. To the PC was connected also GPS/INS platform. Fig. 17 presents DVB-T antennas used in the experiment and Fig 18 – obrained SAR images.

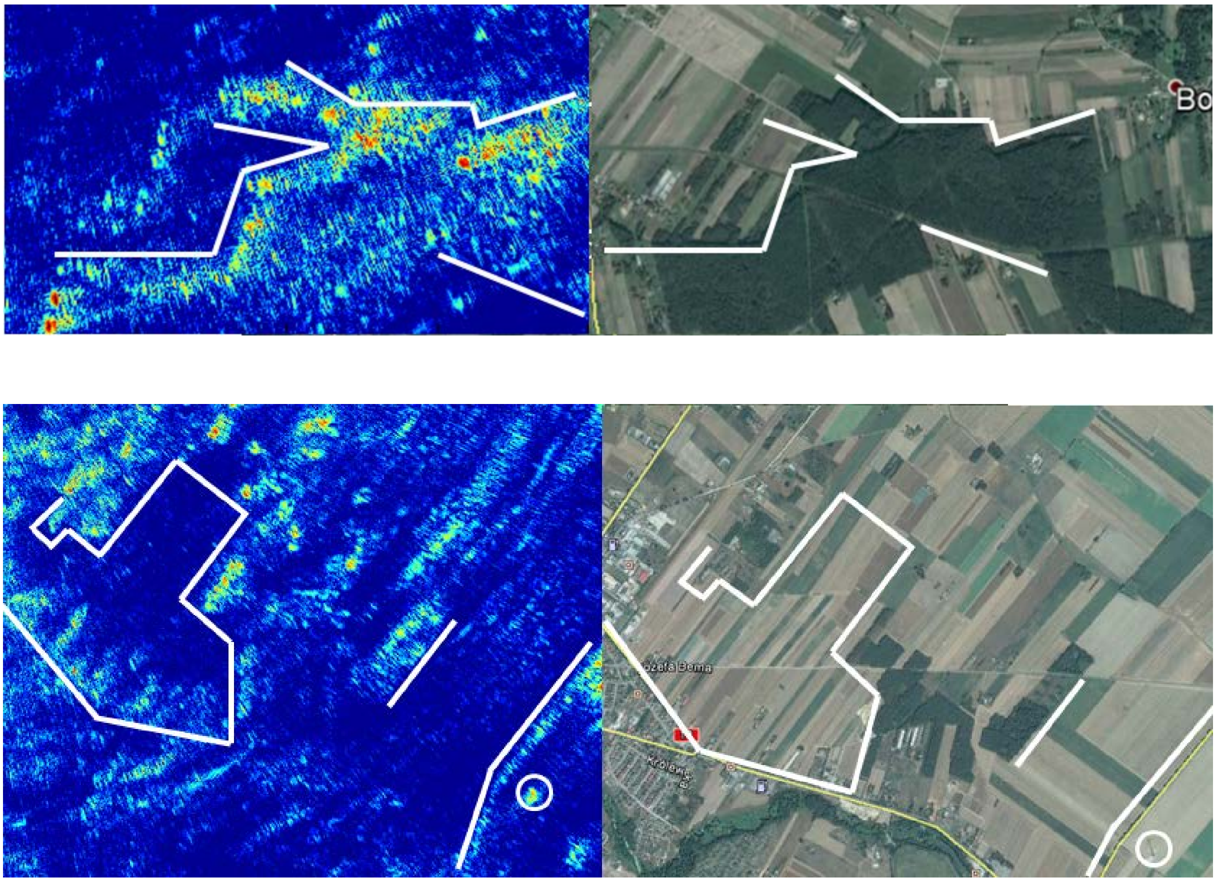

Fig. 18. Example of Passive SAR images obtained during experiment and the optical image of the observed area – characteristic elements highlighted (white line).

# Conclusions

# References

[1] D. Gould, R. Pollard, C. Sarno, And P. Tittenso. A Multiband Passive Radar Demonstrator. In Proc. International Radar Symposium 2006, Pages 657–660, Cracow, Poland, 24–26 May 2006.

[2] P. E. Howland, D. Maksimiuk, And G. Reitsma. Fm Radio Based Bistatic Radar. Iee Proc. Radar, Sonar And Navigation, 152(3):107–115, June 2005.

[3] H. Kuschel, M. Glende, J. Heckenbach, S. Müller, J. Schell, And C. Schumacher. Experimental Passive Radar Systems Using Digital Illuminators(Dab/Dvb). In Proc. International Radar Symposium 2007,

Pages 411– 417, Cologne, Germany, 5–7 September 2007.

[4] A. Di Lallo, A. Farina, R. Fulcoli, P. Genovesi, R. Lalli, And R. Mancinelli. Design, Development And Test On Real Data Of An Fm Based Prototypical Passive Radar. In Proc. Radarcon, Page Cd, Rome, Italy, 26–30 May 2008.

[5] M. Malanowski, K. Kulpa, And J. Misiurewicz. Parade – Passive Radar Demonstrator Family Development At Warsaw University Of Technology. In Proc. Microwaves, Radar And Remote Sensing, Page Cd, Kiev, Ukraine, 22–24 September 2008.

[6] B. D. Nordwall. 'Silent Sentry' A New Type Of Radar. Aviation Week And Space Technology, (30):70–71, 1998.

[7] D. Poullin And M. Flecheux. Recent Progress In Passive Coherent Location (Pcl) Concepts And Techniques In France. In Proc. Radarcon, Page Cd, Rome, Italy, 26–30 May 2008.

[8] H. Griffiths And C. Baker. The Signal And Interference Environment In Passive Bistatic Radar. In Information, Decision And Control, 2007. Idc '07, Pages 1 –10, 2007.

[9] C.R. Berger, B. Demissie, J. Heckenbach, P. Willett, And Shengli Zhou. Signal Processing For Passive Radar Using Ofdm Waveforms. Selected Topics In Signal Processing, Ieee Journal Of, 4(1):226 –238, 2010.

[10] C. Coleman And H. Yardley. Dab Based Passive Radar: Performance Calculations And Trials. In Radar, 2008 International Conference On, Pages 691 –694, 2008.

[11] C. Coleman And H. Yardley. Passive Bistatic Radar Based On Target Illuminations By Digital Audio Broadcasting. Iee Proc. Radar, Sonar And Navigation, 2(5):366–375, October 2008.

[12] C.J. Coleman, R.A. Watson, And H. Yardley. A Practical Bistatic Passive Radar System For Use With Dab And Drm Illuminators. In Radar Conference, 2008. Radar '08. Ieee, Pages 1 –6, May 2008.

[13] P. E. Howland. Target Tracking Using Television-Based Bistatic Radar. Iee Proc. Radar, Sonar And Navigation, 146(3):166–174, June 1999.

[14] D. Feng, H. Xie, D. An And X. Huang, "A Fast Back-Projection Algorithm For Bistatic Forward-Looking Low Frequency Uwb Sar Imaging," 2015 16th International Radar Symposium (Irs), Dresden, 2015, Pp. 1135-1140.

[15] Cai Miaohong, He Feng, And Wu Lenan. Application Of Ukf Algorithm For Target Tracking In Dtv-Based Passive Radar. In Image And Signal Processing, 2009. Cisp '09. 2nd International Congress

[16] R. Saini And M. Cherniakov. Dtv Signal Ambiguity Function Analysis For Radar Application. Iee Proc. Radar, Sonar And Navigation, 152(3):133– 142, June 2005.

[17] H. Guo, S. Coetzee, D. Mason, K. Woodbridge, And C. Baker. Passive Radar Detection Using Wireless Networks. In Radar Systems, 2007 Iet International Conference On, Pages 1 –4, 2007.

[18] Hongbo Sun, D.K.P. Tan, Yilong Lu, And M. Lesturgie. Applications Of Passive Surveillance Radar System Using Cell Phone Base Station Illuminators. Aerospace And Electronic Systems Magazine, Ieee, 25(3):10 –18, 2010.

[19] D. K. P. Tan, H. Sun, Y. Lu, M. Lesturgie, And H. L. Chan. Passive Radar Using Global System For Mobile Communication Signal: Theory, Implementation And Measurements. Iee Proc. Radar, Sonar And Navigation, 152(3):116–123, June 2005.

[20] K. Chetty, G. Smith, Hui Guo, And K. Woodbridge. Target Detection In High Clutter Using Passive Bistatic Wifi Radar. In Radar Conference, 2009 Ieee, Pages 1 –5, May 2009

[21] C. J. Baker, H. D. Griffiths, And I. Papoutsis. Passive Coherent Location Radar Systems. Part 2: Waveform Properties. Iee Proc. Radar, Sonar And Navigation, 152(3):160–168, June 2005.

[22] S. Rzewuski, M. Wielgo, K. Kulpa, M. Malanowski And J. Kulpa, "Multistatic Passive Radar Based On Wifi - Results Of The Experiment," 2013 International Conference On Radar, Adelaide, Sa, 2013, Pp. 230-234

[23] P. Maechler, N. Felber And H. Kaeslin, "Compressive Sensing For Wifi-Based Passive Bistatic Radar," 2012 Proceedings Of The 20th European Signal Processing Conference (Eusipco), Bucharest, 2012, Pp. 1444-1448.

[24] P. Falcone, F. Colone And P. Lombardo, "Localization Of Moving Targets With A Passive Radar System Based On Wifi Transmissions," Iet International Conference On Radar Systems (Radar 2012), Glasgow, Uk, 2012, Pp. 1-6.

[25] P. Falcone, F. Colone And P. Lombardo, "Potentialities And Challenges Of Wifi-Based Passive Radar," In Ieee Aerospace And Electronic Systems Magazine, Vol. 27, No. 11, Pp. 15-26, November 2012

[26] J. Brown, K. Woodbridge, A. Stove, And S. Watts. Air Target Detection Using Airborne Passive Bistatic Radar. Electronics Letters, 46(20), September 2010

[27] B. Dawidowicz And K. Kulpa. Experimental Results From Pcl Radar On Moving Platform. In Proc. International Radar Symposium 2008, Pages 305–308, Wroclaw, Poland, 21–23 May 2008.

[28] K. Kulpa, M. Malanowski, J. Misiurewicz, M. Mordzonek, P. Samczyñski, And M. Smolarczyk. Airborne Pcl Radar: The Concept And Primary Results. In Proc. Military Radar 2008, Page Cd, Amsterdam, The Netherlands, 27–29 October 2008.

[29] Danny Kai Pin Tan; Marc Lesturgie; Hongbo Sun; Yilong Lu, “Target Detection Performance Analysis For Airborne Passive Bistatic Radar”, 2010 Ieee International Geoscience And Remote Sensing Symposium, Year: 2010, Pages: 3553 – 3556

[30] Wuming, Hu And Wang Jun. “Airborne Sar Passive Radar Imaging Algorithm Based On External Illuminator”. Synthetic Aperture Radar, 2007. Apsar 2007. 1st Asian And Pacific Conference On, 642 –645. 2007.

[31] Gutierrez Del Arroyo, J. And J. A. Jackson. “Passive Sar Imaging Using Commercial Ofdm Networks”. 2011 Mss Tri-Service Radar Symposium. 2011.

[32] Cetin, M. And A. D. Lanterman. “Region-Enhanced Passive Radar Imaging”. Radar, Sonar And Navigation, Iee Proceedings -, 152(3):185–194, 2005.

[33] Qisong Wu; Yimin D. Zhang; Moeness G. Amin; Braham Himed, “High-Resolution Passive Sar Imaging Exploiting Structured Bayesian Compressive Sensing”, Ieee Journal Of Selected Topics In

Signal Processing, Year: 2015, Volume: 9, Issue: 8, Pages: 1484 - 1497, Doi: 10.1109/Jstsp.2015.2479190

[34] Willis, Nicholas J. “Bistatic Radar” 2005 Scitech Publishing©

[35] B. Dawidowicz, K. S. Kulpa And M. Malanowski, "Suppression Of The Ground Clutter In Airborne Pcl Radar Using Dpca Technique," 2009 European Radar Conference (Eurad), Rome, 2009, Pp. 306-309

[36] K. Kulpa. Adaptive Clutter Rejection In Bi-Static Cw Radar. In Proc. International Radar Symposium 2004, Pages 61–66, Warsaw, Poland, 19– 21 May 2004

[37] [132] K. Kulpa. Ground Clutter Suppression In Noise Radar. In Proc. International Conference On Radar, Page Cd, Tuluse, France, 18–22 October 2004.

[38] [133] K. Kulpa. Simple Sea Clutter Canceller For Noise Radar. In Proc. International Radar Symposium 2006, Pages 299–302, Cracow, Poland, 24–26 May 2006.

[39] [134] M. Malanowski. Comparison Of Adaptive Methods For Clutter Removal In Pcl Radar. In Radar Symposium, 2006. Irs 2006. International, Pages 1 –4, May 2006