DVB-T Passive Radar Dual Polarization Measurements in the Presence of Strong Direct Signal Interference

Kyrre Strøm*, **Øystein Lie-Svendsen***, **Erlend Finden***, **Idar Norheim-Næss***, **Terje Johnsen***, **Aurora Baruzzi****

*Norwegian Defence Research Establishment (FFI)
P.O. Box 25, NO–2027 Kjeller, Norway
email: {Kyrre.Strom, Oystein.Lie-Svendsen, Erlend.Finden, Idar.Norheim-Nass, Terje.Johnsen}@ffi.no

**Fraunhofer Institut für Hochfrequenzphysik und Radartechnik FHR
Fraunhoferstr. 20, 53343 Wachtberg, Germany
email: aurora.baruzzi@fhr.fraunhofer.de

Abstract: *A dual-polarization passive bistatic radar is used to evaluate the potential benefit of cross-polarized measurements for the suppression of strong direct signal interference in the DVB-T band. The linear array antenna consists of 10 bowtie elements, 5 of which measuring horizontal and 5 vertical polarization. Two small GPS-equipped aircraft were used as targets, flying prescribed patterns. Two antenna locations were used, one in which the broadcasting transmitter was only* $20°$ *from the antenna boresight, causing strong direct signal interference, and one in which the antenna was partially shielded from the transmitter. In both polarization channels, reconstruction of the reference signal and reciprocal filtering was used to suppress interference. GPS data from the aircraft was used to find the bistatic range, Doppler, and azimuth location, and the signal to interference pluss noise ratio (SINR) at this location was measured. In addition, the azimuth inferred from GPS was compared with the direction derived from the radar measurements. We find no advantage using cross polarization, even in the case with strong direct signal interference: On average there is no significant difference between co- and crosspolarized SINR, and the co-polarized channel is slightly better predicting the correct azimuth.*

1. Introduction

The detection range achievable with passive bistatic radar (PBR) is limited not only by the low power level illuminating the target, but also by the pervasive interference from the continuously transmitted broadcast signal, causing direct signal interference as well as clutter. Several techniques have been proposed to mitigate the problem: A direct signal cancellation method may be used to subtract the direct signal interference, as well as stationary clutter, from the surveillance signal before cross correlation [1]. In digital transmissions, such as DVB-T, orthogonality of the transmitted signal may be exploited, applying mismatched filtering of the surveillance signal with a reconstructed reference signal so that interference and clutter from stationary sources

978-3-7369-9343-3

DOI til publisert versjon / DOI to published version: 10.23919/IRS.2017.8008102

will only contribute to the range-Doppler matrix at zero Doppler [8]. Both methods are limited by the quality of the reference signal. Moreover, they will not prevent a strong interference from limiting the dynamic range of the receiver as they only affect the signal after sampling. For an array receiving antenna, a third method is to place an antenna “null” in the direction of the strong interference [6]. However, if digital beamforming is used, this method as well will not improve the dynamic range as it takes place after sampling.

If the interference is so strong that the dynamic range of the receiver is affected, interference must be filtered out before sampling. The most straightforward method is simply to shield the receiving antenna from the direct signal, e.g., by terrain shielding or absorbing elements in the direction of the transmitter. However, that may not always be feasible: Using a PBR as gap filler in a valley, say, it may not be possible to shield in the direction of the transmitter without also damping the echo signal from potential targets. And in a single frequency DVB-T network it may become impractical to shield from many transmitters simultaneously. Finally, if it is required to detect and track targets close to the base line between receiver and transmitter, it is impossible to shield the antenna from the transmitter.

Exploiting the cross-polarized component of the echo signal is another possibility that has gained interest recently, both in the FM-band [2] and in the DVB-T band [3]. Using antenna elements that are cross polarized relative to the transmitter polarization, the direct signal as well as co-polarized clutter can be strongly damped before sampling, potentially increasing the SINR of targets. The target cross-polarized radar cross section (RCS) must be sufficiently large if this gain is to be realized, and cross-polarized clutter cannot be too strong. In a recent study [5] using DVB-T transmissions, we found that both PBR measurements and RCS calculations showed that the co-polarized RCS of a small Cessna aircraft was substantially higher than the cross-polarized RCS, so that the SINR in most cases was not higher in the cross-polarized channel. However, those measurements were carried out when the transmitter was located approximately 90° from the antenna boresight. The direct signal interference was thus strongly damped by the antenna ground plane.

In this new study of DVB-T PBR, we have instead positioned the dual-polarized linear antenna so that the transmitter is only 20° from the antenna boresight (see Fig. 1). In this, less than ideal, configuration, the transmitter interference is expected to be maximized, and the possible benefit of cross polarzied measurements should also be maximum.

In this preliminary study, we shall not make a full analysis of the detection performance in the co- and cross-polarized channels. Instead we use GPS information from the participating aircraft to measure the SINR at their known range, azimuth and Doppler location in both the co- and cross-polarized channels. In addition, at the known target range and Doppler frequency, the co- and cross-polarized sections of the antenna are scanned digitally in azimuth, identifying the target at the azimuth of maximum signal strength. The discrepancy between this observed target direction and the GPS-inferred direction is then taken as another measure of the quality of the co-polarized and cross-polarized measurements.

Dette er en postprint-versjon / This is a postprint version.
DOI til publisert versjon / DOI to published version: 10.23919/IRS.2017.8008102

2. Equipment and experiment setup

The PBR system used during the measurement campaign is developed at Fraunhofer FHR [7], with exception of the receiver antenna which is developed at FFI [5].The antenna is a linear array of crossed bow-tie elements with ground plane reflector. The planar crossed bow-tie element consists of two orthogonally oriented triangular dipole bow-tie elements, allowing both horizontal and vertical polarization to be measured with better than 20 dB isolation. For the experiment, 5 crossed bow-tie elements are used making two uniform linear arrays with 5 triangular dipole elements each, for co-polarized and cross-polarized measurements respectively. The triangular dipole is manufactured as a printed circuit board with a triangle flare angle of 56°. The horizontal and vertical bow-ties are 134 mm and 142 mm in length, respectively. The bow-tie element is fed by a coaxial balun of length 130 mm. The antenna response has been measured in an anechoic chamber. For both H- and V-polarized input signals the directivity of the antenna elements co-polarized with the signal appears almost constant when azimuth and elevation is in the range [-45°,45°] from boresight. In this range the normalized radiation intensity varies less than 3dB when the signal frequency is 650-700 MHz.

Two experiements have been conducted. In the first experiment, at Ramberg, the antenna is exposed to strong transmitter interference, while in the second, at Vealøs, the transmitter interference is strongly reduced by the antenna ground plane. The geometry is shown in Fig 1. During both experiments the H-pol DVBT transmitter at Halden with carrier frequency 666 MHz is used as illuminator of opportunity (IOO).

Ramberg setup
One of the H-pol elements in the linear array also functioned as the PBR reference antenna for the direct signal from the H-pol IOO, which is located about 21° off boresight at 74 km distance with 63 kW EIRP. Two aircraft targets, a Cessna 172 S and a smaller Vervoorst FV-3 Delphin microlight, with GPS reference recording, were flying specified trajectories during the trial. The two aircraft both traced out an oval loop within the range 3–10 km from the receiver about 2.5 times, and thereafter another loop in the range 8–15 km from the receiver about three times. See left panel of Fig. 1 for the Cessna trajectory. The Delphin trajectory is almost identical, but at a higher altitude. The first loop appeared within azimuth -40° to 30° relative to antenna boresight, while the second loop appeared within azimuth -10° to 20°. The outer trajectory loop has an elevation angle from the PBR of about 1° and 2°, for the Cessna and the Delphin respectively. For the inner loop these elevation angles are in the range 1°-3° and 2°-7°.

Vealøs setup
In the Vealøs experiment the IOO was located more than 90° off boresight, at approximately 61 km distance. A separate log-periodic antenna was used for acquiring the reference signal. In this experiment there was only the Cessna participating as a GPS carrying target. The right hand panel of Fig. 1 shows the PBR location and aircraft trajectory. The elevation angle from the PBR antenna is 1°-2°.

Dette er en postprint-versjon / This is a postprint version.
DOI til publisert versjon / DOI to published version: 10.23919/IRS.2017.8008102

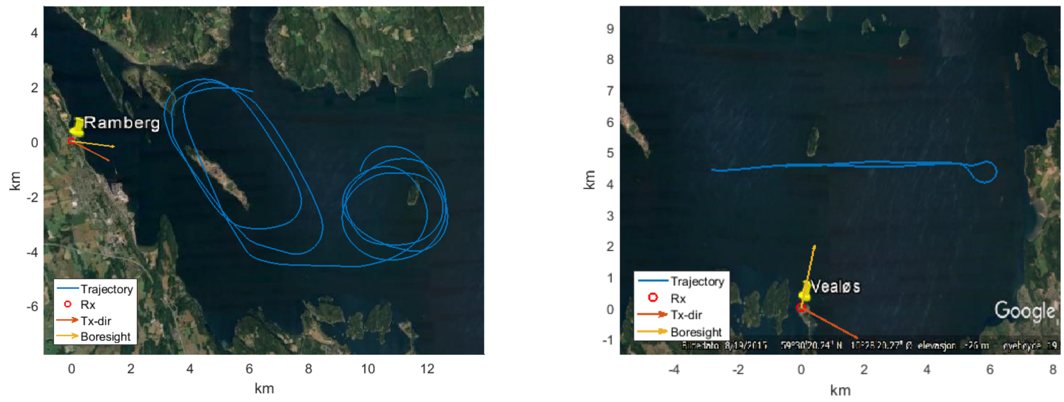

Figure 1: Aircraft trajectories in the two experiments. The receiving PBR antenna is indicated with a yellow thumbtack, the antenna boresight is shown with a yellow arrow and the direction towards the Halden DVBT-transmitter is indicated with a red arrow. Left plot shows the Ramberg setup, Vealøs setup to the right

3. Signal processing and detection

In the Ramberg experiment the input signal acquired by the H-polarized antenna elements was attenuated by 10-15 dB to assure optimum input level for the 16 bit analog-to-digital converter of the PBR. No attenuation was necessary for the V-polarized channel.

The PBR software forms a range-Doppler(rD) map for each of the antenna elements in the H-pol and V-pol arrays by means of reciprocal filtering, a mismatched filtering of surveillance signal with IOO reference signal. Before reciprocal filtering the reference signal is reconstructed according to the DVB-T standard [4]. When reference signal quality is good, the method is reported to suppress direct signal interference well, [8]. The PBR software estimates the reference signal quality by considering the carriers in the DVB-T symbol spectrum. The reference spectrum is adjusted so that the pilot tone carriers match the specifications of the DVB-T standard, and thereafter the mean square distance to the 64QAM constellation diagram as given by the DVB-T standard is calculated. The mean square distance is normalized to the interval (0,0.5), where zero distance means perfect signal quality. From experience, a distance of 0.2 is known to indicate sufficient quality for good reconstruction. In our experiments it was approximately 0.1.

From the aircraft GPS data we calculate bistatic range and Doppler at any given time. The GPS rD-coordinate is used as starting point when searching for the target echo signal in the rD-map. We apply beam-scan to improve gain and locate the target at a given time instance by forming rD-maps of squinted beams as coherent sums of the elementwise rD-maps. For a set of beams in the scan interval $\pm 45°$ we search the rD-maps for a local maximum SINR value close to the aircraft GPS rD-coordinate. The rD cell of maximum SINR over all the beams is taken as the candidate detection. To determine the azimuth direction of arrival we find the direction of maximum signal intensity for the candidate rD-cell. When the direct signal interference is substantial, this direction is likely to deviate from the direction of maximum SINR. The size

Dette er en postprint-versjon / This is a postprint version.
DOI til publisert versjon / DOI to published version: 10.23919/IRS.2017.8008102

of the rD-map neighbourhood search rectangle in the Ramberg setup is 7×5 cells, covering ± 100 m and ± 4 Hz relative to the GPS rD-coordinate. In the Vealøs setup the search rectangle is 13×8 cells, covering ± 200 m and ± 6 Hz. For GPS rD-coordinates close to zero Doppler, the zero Doppler line is excluded from the search rectangle as well as cells of opposite Doppler sign. The noise pluss interference power in the SINR is taken as the average squared amplitude of cells at far range Doppler corners in the global rD-map of the current beam. Figure 2 shows the noise pluss interference level for the H-pol and the V-pol channels as function of scan angle at a typical time instance. Noise levels at other time instances look similar. A substantial peak at

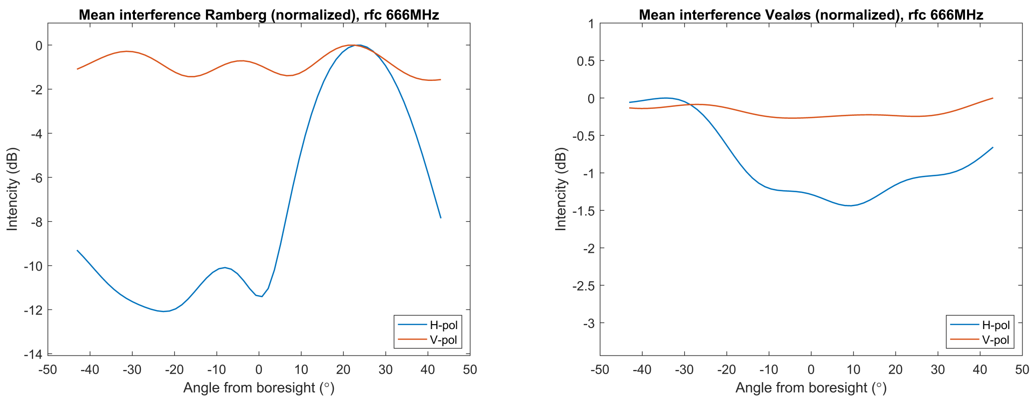

Figure 2: Interference normalized by maximum value as a function of scan angle for H-polarized and V-polarized arrays at a typical time instance. Left panel shows Ramberg setup, right panel the Vealøs setup

about 22° in direction of the IOO appears for the H-pol antenna in the Ramberg setup, showing that the noise level read off the H-pol rD-map has a substantial interference contribution from the IOO at Halden. This shows that the direct signal is not completely suppressed by the signal processing algorithm applied. The peak at 22° also indicates that maximum SINR for target echo acquired by the H-pol antenna will not appear in the same direction as the maximum target signal intensity when the target appears between boresight and the DOA of the reference signal. By contrast, for the V-pol antenna no distinct peak in averaged noise pluss interference level appears. In the Vealøs setup where the IOO is located partly in a backward direction from the surveillance antenna, the interference level varies by only 1.5 dB or less with scan angle, and no distinct peak appears.

With only 5 elements, beamscan is performed without tapering the antenna elements. The element spacing of our antenna is 0.26 m, with a 3 dB half beam width of 9° at 660MHz. Grating lobes appear when scanned to approximately 48°.

Data from the H-pol and V-pol arrays are recorded in parallel. During a coherent processing interval (CPI) of 0.5 s an rD-map is produced for each of the two polarizations. Thus, at any of the instances in a discrete set of times during the target trajectory, there is a an associated H-pol candidate detection of the aircraft and a V-pol candidate detection. The following criteria are used to determine whether a candidate detection found during beamscan is a proper detection.

DOI til publisert versjon / DOI to published version: 10.23919/IRS.2017.8008102

- The estimated azimuth direction of arrival for the candidate should not deviate more than $5°$ from the direction to the aircraft given by the GPS data.
- The bistatic Doppler should not be less than 2 Hz.
- The SINR should be greater than 12 dB.

4. Observations

Data recorded from half an hour of the aircraft trajectories in the Ramberg setup is analysed and presented in this section, together with five minutes from the Vealøs setup. The left panel of Fig. 3 shows SINR from Ramberg of the Cessna aircraft during 6.5 minutes of the trajectory. During this period the Cessna traced out one circulation of the trajectory loop closest to Ramberg shown in left panel of Fig. 1. We have added a dotted line for minimum acceptable SINR. H-pol and V-pol candidate detections are shown in the same figure. Also, candidates that do not fulfill the angle criterion or the Doppler criterion are replaced by straight line interpolation of SINR values between closest valid candidates. The right panel shows the estimated azimuth relative to boresight for the same candidate detections, both the valid and invalid ones. We note that the candidates of invalid azimuth and low Doppler appearing in the time interval 200-280 s of the right panel are represented by straight line interpolation values in the left panel. Fig. 4

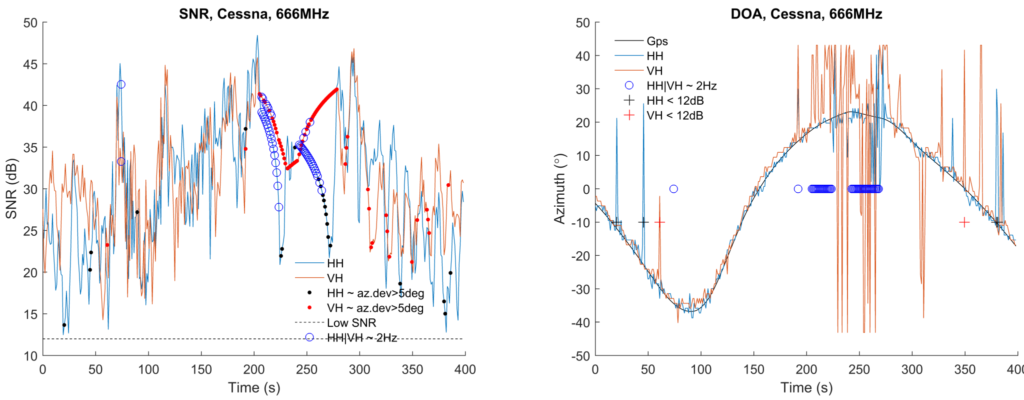

Figure 3: SINR (left) and estimated azimuth DOA (right) for the Cessna aircraft echo as function of time in the Ramberg setup. SINR for invalid candiates are replaced by straight line interpolation values; red and black dots for angle violation, blue circles for low Doppler. Right panel: Red and black cross mark location for low SINR, blue circle for low Doppler.

shows SINR and azimuth estimation of candidate detections during 335 s of the Cessna trajectory in the Vealøs setup, see right panel of Fig. 1. The figure is previously presented in [5].

Fig. 3 from the Ramberg setup indicates there is little difference in SINR and quality of DOA extracted from the data acquired by the two polarization channels, whereas in the Vealøs setup the SINR for the co-pol channel is notably higher, Fig. 4.

Dette er en postprint-versjon / This is a postprint version.
DOI til publisert versjon / DOI to published version: 10.23919/IRS.2017.8008102

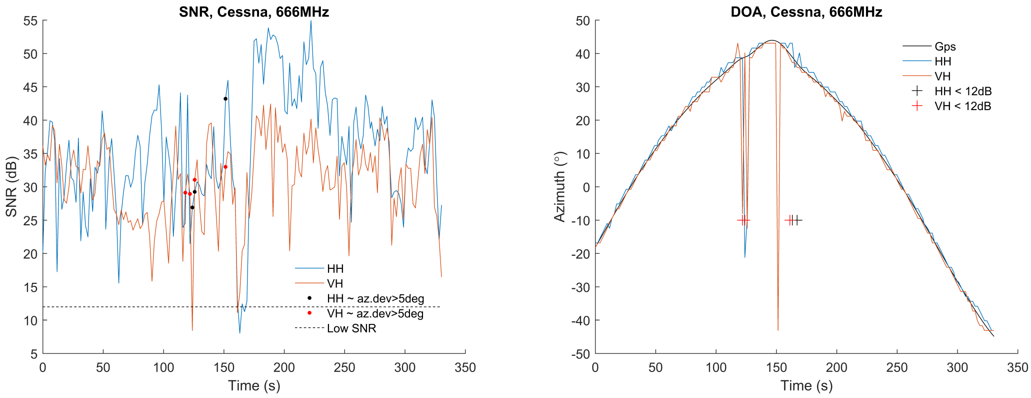

Figure 4: SINR (left) and estimated azimuth direction of arrival (right) for the target echo of the trajectory in the Vealos setup shown in right panel of Fig. 1.

The results are summarized in Table 1. Columns 3 and 4 list percentage of valid candidate detections acquired by the H-pol antenna and the V-pol antenna, respectively. The fifth column lists the percentage of time instances where candidates for both H-pol and V-pol are valid. The last column gives percentages of H-pol SINR larger than V-pol SINR in the subset of time instances where both polarizations have valid candidates. The two first rows list data for the

Target	Trajectory (time)	H-pol ok	V-pol ok	H-V ok	SINR H>V
Cessna (R)	0–940	83	74	72	54
Delphin (R)	0–890	82	76	71	45
Cessna (R)	940–1770	80	76	66	48
Delphin (R)	890–1770	68	66	53	58
Cessna (V)	0-335	97	96	95	76

Table 1: Percentage of valid candidate detections for different periods of the aircraft trajectories. Targets are marked (R) and (V) for Ramberg and Vealøs setups respectively. See text for explanation of the columns.

aircrafts while traversing the loop closest to Ramberg, and the next two rows list data for the more distant trajectory loop. Transition from the closer to the farther loop in the Ramberg setup occurs approximately at 940 s for the Cessna and at 890 s for the Delphin, see Figure 1.

The table indicates that the H-pol channel has a sligthly better performance in the Ramberg setup. In the Vealøs setup the difference in performance is more profound. For the distant trajectory loop of the Ramberg setup we see that in more than 20% of the time instances the candidate for one of the polarizations is valid but not for the other. Moreover, the V-polarization, with slightly fewer valid candidates, has valid candidates in quite some percentages where the H-polarization is not valid. A study of the FM-radio based PBR system [2] observed that combining detections made by co-pol and cross-pol antennas had a notable effect on the detection probability in the FM-band.

Dette er en postprint-versjon / This is a postprint version.
DOI til publisert versjon / DOI to published version: 10.23919/IRS.2017.8008102

5. Conclusion

The results shown here indicate that there is little to gain from using cross polarization to suppress direct signal interference. This is the case even when interference is very strong, and there is substantial residual interference despite reconstruction of the reference signal and reciprocal filtering. The interference is indeed substantially suppressed in the cross-polarized channel, but this reduction seems to be insufficient to compensate for the reduced echo power from the small aircraft targets in the cross-polarized channel. Hence these measurements seem to be in qualitative agreement with RCS-calculations of a Cessna aircraft, showing that the co-polarized RCS is generally somewhat higher than the cross-polarized RCS at DVB-T frequencies [5].

The SINR obtained in this study was based on beamscan. Because of the anistropic interference in the co-polarized channel, the direction to the target often deviates from the direction of maximum SINR. Hence the DOA had to be estimated in a two stage process. We note that more sophisticated methods for maximizing SINR should be investigated, [9]. Most likely, such methods will improve the obtained SINR more in the co-polarized than in the cross-polarized channel as long as the interference is more anistropic in the former.

We emphasize that these are preliminary results. We have not yet performed a thorough analysis of the detection performance in the co- and cross-polarized channels. It would also be of interest to study the potential advantage of using two polarization channels in a PBR system; since the RCS is expected to decorrelate between the two channels, this can possibly offer some advantage for Swerling I type target fluctuations compared with single channel coherent processing. And it is obviously necessary to carry out similar studies for other types of targets, where the target RCS may have a different polarization dependence.

References

[1] Cardinali, R, Colone, F, Ferretti, C & Lombardo, P 2007, Comparison of clutter and multipath cancellation techniques for passive radar. in *IEEE National Radar Conference - Proceedings., 4250356, pp. 469-474, IEEE 2007 Radar Conference*, Waltham, MA, United States, 17-20 April.

[2] F. Colone, and P. Lombardo, “Polarimetric passive coherent location,” *IEEE Trans. Aerosp. Electron. Syst.,* vol. 51, pp. 1079–1097, 2015.

[3] M. Conti, C. Moscardini, A. Capria, “Dual-polarization DVB-T passive radar: Experimental results”, in *Proc. IEEE Radar Conference 2016*, Philadelphia, USA, May 2016, pp. 1–5.

[4] Europeen Telecommunication Standard Institute. “Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for digital terrestial television”. ETSI EN 300 744 v1.5.1, 2004-11.

[5] E. Finden, K. Strøm, I. Norheim-Næss, M. Tømmer, Ø. Lie-Svendsen, F. Gulbrandsen and K. E. Olsen. “A Dual Polarized Crossed Bowtie Array Antenna for DVB-T Based Passive Radar.” in *Proc. 2016 IEEE International Conference on Antenna Measurements & Applications (CAMA).*, Syracuse, NY, 2016, pp. 1-4.

Dette er en postprint-versjon / This is a postprint version.
DOI til publisert versjon / DOI to published version: 10.23919/IRS.2017.8008102

[6] H. D. Griffiths, and N. R. W. Long, “Television-based bistatic radar,” *IEE Proc. F: Commun. Radar and Signal Process.,* vol. 133, pp. 649–657, Dec. 1986.

[7] J. Schell, J. Heckenbach, and H. Kuschel, ”ATLANTIS, a scalable, modular PCL receiver for OFDM signals,” *NATO SET-187 Specialist Meeting on Passive Radar, challenges concerning theory and practice in military application*, Szczecin, Poland, 13–14.05.2013.

[8] S. Searle, J. Palmer, L. Davis, D. O’Hagan, and M. Ummenhofer, “Evaluation of the Ambiguity Function for Passive Radar with OFDM Transmissions”, *Proc. 2014 IEEE Radar Conf.,* Cincinnati, OH, 2014, pp. 1040–1045.

[9] H. Van Trees, *Detection, Estimation, and Modulation Theory, Optimum Array Processing, (Part IV)*, John Wiley & Sons,Inc., New-York, USA, 2002, ISBN 0-471-09390-4

Dette er en postprint-versjon / This is a postprint version.
DOI til publisert versjon / DOI to published version: 10.23919/IRS.2017.8008102