Passive Coherent Locator Applications

Introduction

Passive radar concepts have been proposed for various applications, both military and civilian. Most of the proposed concepts are multi-static rather than bi-static and several are exploiting multiple transmitters of different type for diversity. Several such applications will be introduced in the following.

Multi-static PCL configuration can consist of various concepts, which may also require different signal processing approaches. The most general system concept is based on multiple netted receivers exploiting the illumination of multiple spatially distributed transmitters. Dependent on the complexity the receiver provider can master, each sensor can measure the time difference of arrival, direction and bi-static Doppler of echoes excited on one target by multiple transmitters. Thus an over determined target localization procedure can provide a high probability of detection by multiple simultaneous detections of the same target in a network. In reality, however, this is hardly affordable and thus more realistic multi-static system concepts either exploit multiple transmitters with one receiver, preferably featuring direction of arrival and time difference of arrival measurements, or consist of a network of omnidirectional passive receivers exploiting one dominant transmitter. In the latter case the localisation procedure is based on the calculation of intersecting ellipsoids, where the intersections indicate the location of targets. The focal points of the ellipsoids are the locations of the transmitter and the receiver. Here the target resolution depends on the signal bandwidth and multiple ellipsoid intersections lead to improved accuracy.

In the former case with the knowledge of the transmitter locations and the bearing measurement of the target echoes the location of targets can be determined by the intersection of the bearing vector with the time difference of arrival ellipsoid. The resolution here depends on the signal bandwidth and the beamwidth of the antenna providing the bearing information.

Multi-band PCL Systems with spectrally orthogonal illuminators

In the case of multi illuminator configurations it makes a huge difference if the transmitter signals are orthogonal in frequency, like different FM-broadcast channels, so that target echoes can unambiguously be assigned to a transmitter. Thus, also in such PCL systems, which exploit the emission of multiple, spectrally orthogonal transmitters an ellipsoid intersection procedure can be applied for target localization. This is the case when using FM-radio stations of different carrier frequencies as illuminators. It is more complex in the case of digital TV or digital radio where the broadcast signals are transmitted in single frequency networks, where all transmitters transmit coherently the same signal.

First a hybrid passive radar system concept will be presented, which can play the role of a gap filler or object protecting sensor for military applications followed by the description of a realized demonstrator.

A hybrid passive radar processing concept

The use of different types of illuminators, ranging from analogue FM-radio over digital broadcasters like DAB and DVB-T to cell-phone base stations, WiFi and satellite borne transmitters has been considered for short and medium range low level air target detection. They are characterised by individual strengths and weaknesses with respect to radar requirements. In addition to the signal modulation characteristics their elevation illumination coverage has been analysed. As technology has now reached a sufficient readiness level, a hybrid Passive Radar Concept for Medium Range Air Surveillance has been proposed combining the best properties of selected donor networks for extended range and improved target resolution.

The system concept comprises a low frequency target detection component (TDC) using FM-radio (88-108 MHz) emissions, a 'high' frequency target resolution component (TRC) exploiting DVB-T emissions (450-900 MHz) and an intermediate frequency component covering close-in high elevation airspace by utilising DAB or DMB signals.

The TRC and the high elevation component (HEC) are being cued by the TDC, which provides longer range at the cost of a coarse resolution and reduced accuracy. Both, the TRC and the HEC apply track-before-detect strategies and extended coherent integration with target motion compensation based on a high resolution target Doppler measurement provided by the TDC. All components are equipped with omni-directional array antennas for permanent volume surveillance with multiple beams. In addition, the antenna feeding the TRC, has elements spaced in two vertical planes to allow target elevation estimation. The signal processing front-end applies the software-defined radar principle, sampling the received signal according to the used bandwidth after band filtering in the radio frequency (RF) domain using fast A/D converters with high dynamic range. Target detection, tracking, cued tracking and height estimation are performed in a data processing component comprising clustered high performance off-the-shelf processors.

A circular array of vertical dipoles covering the frequency band of 88 to 240 MHz feeds the front-end units of the TDC and the HEC. Depending on the required degree of mobility/transportability, the chosen number of elements varies between 8 and 16. The TRC, using DVB-T emissions, is fed by two vertically stacked circular arrays of vertical broad band dipoles. The number of elements doubles that of the low-frequency array in both planes, thus leading to a number of elements ranging from 32 to 64. All three circular arrays are designed to have approximately the same diameter and can be mounted stacked on a common extendable mast. A scheme for the complete stacked antenna concept is depicted in Figure 1.

The principle signal processing concept of passive radar is based on the cross correlation of a reference which is a replica of the transmitted broadcast signal and a delayed echo signal, which is reflected by a target illuminated by the transmitter.

Both, the reference signal and the echo signal are obtained from the circular array by digital beam forming after direct RF sampling. After proper bandpass filtering and low-noise amplification sampling rates of up to 100 Msamp/s allow the digitization - by under sampling - of the whole FM-spectrum or several DAB or DVB-T channels, respectively, at a time. Parallel processing provides simultaneously a reference channel and target detection channels pointing in pre-determined directions.

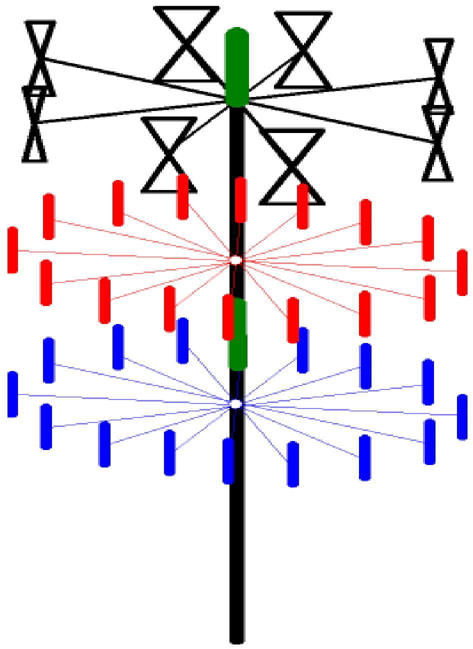

Figure 1: Layered multi-frequency antenna concept (black=88-249MHz, red and blue=450-900 MHz, green = Calibration elements)

The general difference between the TDC using FM-radio signals and the HEC and TRC using DAB and DVB-T signals, respectively, is the generation of the reference signal. In the TDC the reference signal is generated through a separate reference channel, which is directed towards the transmitter for optimum signal quality.

The digital waveforms, COFDM, used in the HEC and TRC contain - in contrast to FM-radio - synchronization information, which is required for proper demodulation. It can be exploited to reconstruct the transmitted signal from the received mix of direct signals and multi-path signals and generate a clean reference signal without multi-path interferences.

Cross correlation of the reference channel and the target echo channels and a Fourier transform of time-spaced cross correlations provide a detection matrix spread in bistatic range and bistatic range rate (Doppler). The range resolution is determined by the signal bandwidth and the Doppler resolution by the integration time. The detection threshold is determined by a range-CFAR (Constant False Alarm Rate), which moves an averaging window of range cells along with the cell under examination to adapt the detection threshold to the local noise floor. A detection is declared, if the threshold is exceeded in 3 or more neighbouring resolution cells. Such detection clusters are used as seeds for range/Doppler tracks.

As stated before, the range resolution is dependent on the signal bandwidth and determines the time, a target with a given radial velocity, where the term radial applies only to a quasi-mono-static geometry, stays within the range cell and thus the possible coherent integration time. Hence, the rather low bandwidth of FM-radio signals providing range resolutions in the order of several kilometres allows coherent integration times of up to 1 sec. In contrast, the comparably high bandwidths of DAB or DVB-T signals of 1.5 and 7.6 MHz, respectively, provide high range resolution but drastically reduced coherent integration times.

If the target motion is known, e.g. from detections in the FM-radio component of a system, procedures can be applied to compensate the motion dependent phase and range walk in the other (DAB, DVB-T) components and extend the coherent integration time beyond the time the target stays within the range cell. Such procedures have been developed e.g. for high range resolution radar applications like ISAR (Inverse Synthetic Aperture Radar) and SONAR applications. They, however, require the knowledge of the target's motion. In ISAR applications, where target super-resolution is attempted, a recommended solution is the tracking of a single scattering centre to determine the target motion. In passive radar a small resolution cell simply prevents coherent integration of sufficient echo energy to exceed the detection threshold.

With the comparably coarse range resolution FM-radio based passive radar provides, long integration time in the order of a second and more can be spent to increase the detection range. When cueing e. g. a DVB-T based passive radar (TRC) with detections from the FM-based TDC, the integration time, consistent with the resolution cell may be extended considerably, provided that motion compensation procedures and multi-hypothesis tracking can be applied for longer detection ranges and larger coverage.

A multi-hypothesis track before detect procedure has to be developed on the basis of the Doppler measurements performed in the TDC.

Let the carrier frequency of the transmitter providing the Doppler measurement be f1 and the measured Doppler frequency f_{D1}, the corresponding estimated target Doppler shift in the TRC will be

$$f_{D2} = f_{D1} \times \frac{f_2}{f_1} \qquad (1)$$

with f_2 being the carrier frequency of the DVB-T signal exploited in the TRC. Using (1) a Doppler matched cross-correlation can be processed and a track can be started in each TRC range cell falling into the larger TDC range cell. With the target motion the bistatic angle β and the target velocity angle ϑ vary and thus varies with the bistatic Doppler.

$$f_D = 2 \times \frac{v}{\lambda} \times \cos(\vartheta) \times \cos(\beta/2) \qquad (2)$$

Thus, knowing the position of the transmitter as well as that of the receiver the bistatic geometry is used to estimate the target Doppler in adjacent range cells under the assumption of a linear flight trajectory and thus allows range cell exceeding coherent integration. Thus, the number of track hypotheses equals the number of TRC range cells filling one TDC range cell. If the other flight trajectories - with varying Doppler e.g. - shall be allowed, the number of hypotheses will increase according to the allowed Doppler gradient. This has to be respected in the range/Doppler tracking.

Once a range/Doppler track has been established and confirmed, the track head is transformed into Cartesian coordinates and a Cartesian tracking algorithm is applied.

A multi illuminator passive radar system

A multi illuminator PCL demonstrator/prototype system, which bears the potential to apply the above described hybrid passive radar has been proposed by Airbus DS, Germany. All design considerations for the multi illuminator system of Airbus DS were directed towards a mature and fully mobile assembly. It therefore covers analogue FM broadcast as well as DAB and DVB-T waveforms with a single mast multiband antenna. The system is able to process multiple FM transmitters simultaneously as well as DAB SFNs and DVB-T SFNs in real-time. Electronic equipment and operator's workstations are integrated in a specific Passive Radar van which comprises the integrated, extendible antenna mast system. The innovative system design enables full mobility and flexible deployment in all kinds of terrain. Figure 2 shows the van in transport mode (left side) and operational mode (middle). For transportation the lifting arm is retracted and the antenna elements are removed by quick fasteners. On-site system installation can be realised within 30 minutes. An additional picture gives insight into the Passive Radar van and shows the operator's work environment with 3 independent work stations (right).

Figure 2: Passive Radar van and operator consoles (Courtesy of Hensoldt).

The system architecture of the multiband PR system is shown in Figure 3. The integrated multiband antenna system uses 21 elements distributed on three elevation levels. This antenna structure provides 360° azimuth coverage and enables 3D bearing detection. The antenna comprises an integrated calibration system for improved bearing accuracy. The FM and DAB subsystems use 7 antenna elements and 7 channel direct sampling and down conversion receivers. DVB-T is received and processed by direct down conversion in 14 channels with antennas on two elevation levels for additional elevation angle bearing detection. Real-time processing is implemented on commercial PC hardware based on standard quad core processors. An enhanced multi hypothesis tracking system resolves ambiguities resulting from the multi-illuminator situation for digital SFNs and fuses FM, DAB and DVB-T detections and range-rangerate-tracks to optimise spatial coverage and localisation performance. The MMI (Man-Machine Interface) consists of three separated displays. The signal processing engineering console allows the display of e.g. antenna amplitude levels, the frequency spectrum of the received signals as well as the processed range Doppler maps.In addition, a tracking engineering console is realised for the display of intermediate tracking results and further internal parameters. The fused output tracks are visualised on the professional and end-user oriented operator console ViSys (Visualisation System). ViSys is a modern air surveillance MMI which is based on a standard product for the German Improved Air Defence System (GIADS). For reference purposes, a commercial ADS-B receiver is part of the system. Its tracks can also be displayed on ViSys for real-time comparison between actual air picture and the Passive Radar performance.

To use existing infrastructures like the already mentioned GIADS the Passive Radar output data is mapped into standard ASTERIX protocol formats (so-called categories 'CAT' [16]). Active radars typically transfer their data in CAT048 (incl. CAT034) for plots respectively CAT062 for tracks.

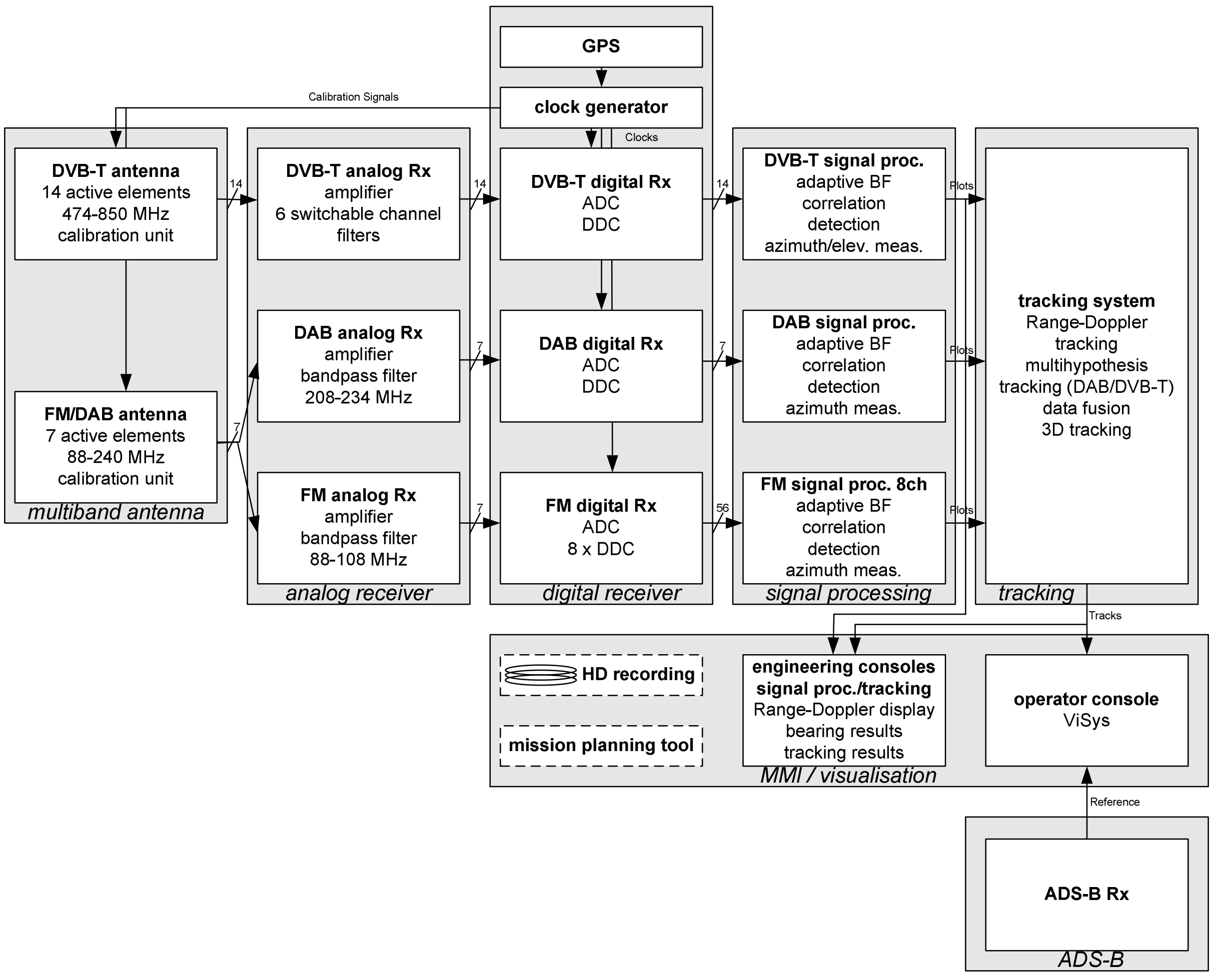

Figure 3: PR system architecture (Courtesy of Hensoldt).

Unlike active radar plots the individual bistatic PR plots consisting of bistatic range and Doppler depending on the transmitter do not allow a location of the target in 2D/3D. Thus the transmission of real PR plot data is meaningless to standard MST (Multi Sensor Tracking) systems and operators. Hence the same tracker output data is used for coding track positions as "pseudo plots" in CAT048 as well as track positions including velocity and heading as tracks in CAT062.

Since common visualisation tools do not provide track history information for CAT062, the additional parallel display of "pseudo plots" in CAT048 visualises both, the high update rate as well as the track behaviour including track attributes as heading and speed. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows the combined information on ViSys.

The Passive Radar is able to provide the ASTERIX data over a TCP/IP data link for the immediate vicinity of the system. For long distance data transfer a UMTS interface has been implemented to support mobile operation.

PCL-PET as Extended Passive Multi-Static System for Air Defence

A further military system, which combines passive radar with passive emitter tracking is proposed by PIT-RADWAR, Poland. The main configuration is composed of 4 stations. The characteristics of all stations are alike. The criteria for the choice of the master station are provision of the highest quality of detection and tracking and maintaining the best communication link with Command and Control Systems.

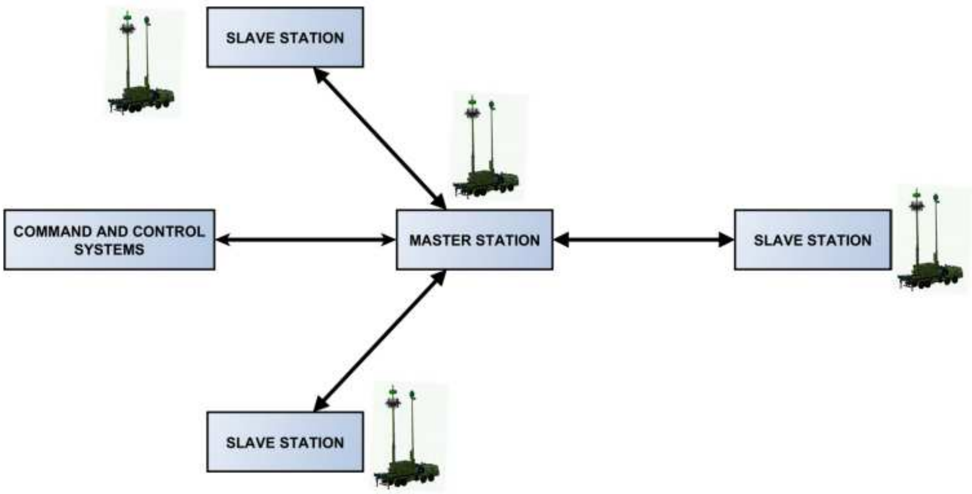

Figure 4: Main configuration of the system **(Courtesy of PIT-RADWAR).**

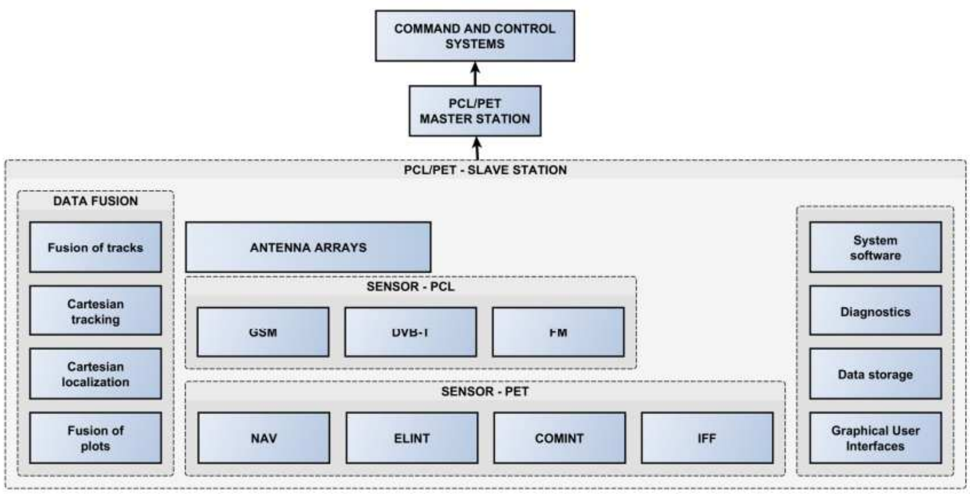

Figure 5: Functional structure of the system **(Courtesy of PIT-RADWAR).**

The PCL subsystem has the following features:

- Exploited emitters:
    - FM
    - DVB-T
    - GSM
    - Working with single or multiple stations
- Data fusion:
    - of signals from all bands (FM, DVB-T, GSM)
    - of signals from different stations
    - of data from PET subsystem (fusion module)
- Mission planning:
    - Evaluation of the coverage and accuracies
    - Assignment of optimal positions for stations to deploy and selection of exploited illuminators

The PET subsystem detects aircrafts on the basis on emissions of their on-board transmitters: radars (ELINT), communication (COMINT), navigation (NAF) and IFF (IFF) signals. It acquires aforementioned signals and evaluates time differences of signals' arrivals for system stations (TDoA method) or evaluates the angular direction for emissions' sources (DF method). These measurements create bi-static plots and angular bearings, on basis off are determined object localization (by multilateration and triangulation). Figure 6 shows the prototype and a laboratory station, which allow the system also to be installed on a vessel.

Figure 6: Prototype (left) and laboratory station (right) **(Courtesy of PIT-RADWAR).**

Ground based camp protection

The Thales Ground Alerter 100 radar (GA100) is a multi-static passive radar, which detects and localizes without being seen. The GA100 benefits from the inherent characteristics of the passive radars:

- It is fully silent/undetectable and is fully safe for people/environment as it does not transmit any electromagnetic signals (in opposition to conventional radars)

- It has inherent anti-stealth capacities due to the use of low frequencies (UHF/VHF) and due to its multi-static architecture.

The GA100 has an instantaneous 360° azimuth and 60° elevation coverage and ensures a fast information refresh to air situation display and/or to connected systems through its standard ASTERIX interface.

The GA100 relies on FM and DVB-T illuminators and can be deployed either as a standalone system (composed of one or several radar stations) or can be integrated in a command and control system through its ASTERIX interface. The GA100 relying on a modular design (COTS oriented) and on a flexible configuration is provided as a fixed or transportable configuration based on a combination of FM and DVB-T radar stations.

The GA100 includes an automatic tracking capacity and benefits from the coverage and tracking improvements brought by radar stations networking and by real time fusion of FM and DVB-T signals. GA100 deployment is made easy thanks to its comprehensive, ergonomic, multi-band deployment tool, which provides radar coverage simulation at different altitudes and for different target RCS taking into account the receivers/transmitters characteristics, the digital terrain map and the propagation models.

The GA100, particularly efficient for detection of all small targets, at low altitudes and low speed, is the perfect candidate for the following operational missions:

- Air surveillance : Gap filler, Border surveillance
- Site protection : Sensitive site protection, event protection , airport protection

The GA100 release for site protection has been enhanced to include detection and localization of micro-drones and includes an alert function upon intrusion of threats (drones/small aircrafts) in the controlled area. The GA100 is a field proven solution for air surveillance and site protection missions, which has been hardened and enhanced through 10 years of experimentations and evaluations in different environments and for different customers. The Thales passive radar is used operationally on 2 French MOD sites:

- Since 2015 for area sanitizing on a French MOD experimentation center
- Since 2016 for protection against drones and small aircrafts on a French military site

Figure 7: GA100 by Thales (Courtesy of Thales)..

SMARP Software-defined Multiband Array Passive Radar for maritime surveillance

The purpose of the project was to design and realize a technological demonstrator of a multiband array passive radar based on a software-defined solution for maritime and coastal surveillance applications. The processing, control and display unit implements the whole radar processing chain up to the tracker, it provides a GUI for controlling the main system parameters and presents the radar output on range-Doppler maps and georeferenced visualization.

The multiband receiving array antenna is working in UHF (470-790 MHz) and S-band (2100-2200 MHz) with dual polarization reception (H/V). The RF-Front-End is used to amplify and filter the desired signal with a limiting effect on the system noise figure. The multichannel receiver is based on versatile SDR boards from National Instruments, it can operate on a wide frequency band (i.e.: 400MHz-4.4GHz)

Single receiving element design and realization:

- The receiving element is a planar LPDA realized by means of printed circuit board (PCB) technology with a FR4 substrate. This choice leads to the following main advantages :
  - ✓ Very high element reproducibility (desirable when dealing with antenna arrays);
  - ✓ Reduced production cost;
  - ✓ Easy to protect against oxidation due to atmospheric exposure (Solder Mask protection layer);
  - ✓ Good wind resistance;
  - ✓ Compactness.

Surveillance array antenna:

- Multiband receiving array antenna: UHF (470-790 MHz), S-band (2100-2200 MHz) with dual polarization reception (H/V);
- Four linear arrays, two for each band, composed of 8 LPDA patch antennas;
- Two plane reflectors, one for each band (3.1x1.3x0.86m and 1.1x0.7x0.27m).

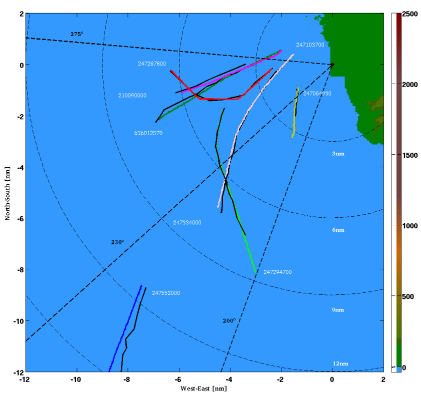

Figure 8: DVB-T tracks **(Courtesy of CNIT).**

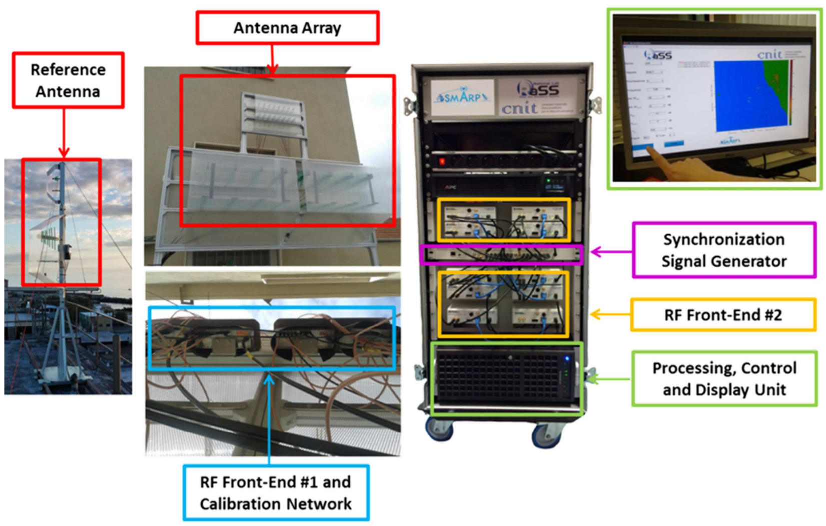

Figure 9: SMARP demonstrator architecture **(Courtesy of CNIT)**

WiFi-based PCL for monitoring private airfields

In the latest years, the potentialities of a WiFi-based passive coherent location (PCL) have been investigated for target detection, localization and imaging of vehicles and human beings. To this purpose, an experimental setup has been developed and fielded at Sapienza University of Rome and it has been extensively employed in many acquisition campaigns aimed at demonstrating the capabilities above.

In this work, the potential exploitation of WiFi-based PCL systems is investigated with reference to a real-world civil application. In particular, we consider the monitoring application of small private airstrips or airfields. With this terminology, we refer to open areas designated for the taking-off and landing of small aircrafts, but which, unlike an airport, have generally short and possibly unpaved runways (e.g. grass, dirt, sand, or gravel surfaces) and do not necessarily have terminals. More important, such areas usually are devoid of conventional technologies, equipment, or procedures adopted to guarantee safety and security in large aerodromes. The use of the runways is usually limited to the daylight hours and mostly controlled by dedicated operators equipped with radio transceivers in the HF/VHF band to communicate with the pilots of the aircrafts. Depending on the length of the runways and visibility conditions, it could be difficult to monitor the whole area of interest in order to avoid runway incursions by other aircrafts, vehicles, people, and even animals. In fact, it is possible that vehicles or beings intrude onto the runways either intentionally or accidentally. In addition, it would be desirable to monitor the airstrips and neighboring zones also when they are not being used by conventional users (i.e. night-hours, closing times, etc.) in order to avoid an illicit use by ill-intentioned persons. As is apparent, there is substantial scope for an improvement in situational awareness in such scenario. To this purpose, the use of WiFi-based PCL sensors should be considered since they in principle provide a reliable surveillance capability with low cost and limited impact on the airstrip users. In addition, the WiFi transmissions represent an attractive choice in the considered scenarios since they are a widely accessible source of opportunity. In fact, the WiFi connection is sometimes also adopted for preflight briefing. Therefore, based on the passive radar principle, the same WiFi access point might be exploited to provide the required radar surveillance capability in the area of interest. Different tests have been performed in a small airfield located near Rome, Italy. The employed WiFi-based PCL receiver and the adopted signal processing scheme are reported in. The obtained results have proved the capability of the conceived sensor to detect and accurately track typical users of the airfield, there including small or ultralight aircrafts, ground vehicles, and people. Therefore, it could be successfully employed as an automatic, low-cost, compact, and non-intrusive sensor to improve safety and security in such scenarios with limited impact on its users.

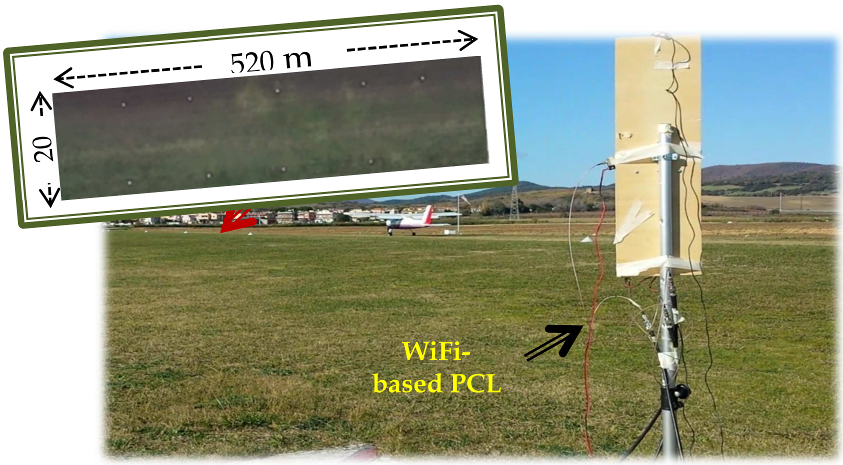

Figure 10: WiFi based air field monitoring (Courtesy of La Sapienza)

CommSense system by University of Capetown

The Concept: Radar systems retrieve the channel information assuming that the received signal is correct. Telecommunication systems focus on retrieving the received signal with least error while assuming that the channel is knows. For this assumption (that we know the channel) to hold true telecommunication systems have a set of blocks performing what is known as "channel equalization". For this known bit-sequences (called pilot signal), which can consist of as much as 10-12% of the data-packets, are sent while transmitting. These, in turn, are used to estimate the channel interference and later to equalize for the channel.

We proposed to use the channel equalization system responds to extract information about the channel. We call this system Communication based Sensing of environment or a CommSense system.
Challenges: There are two major challenges of this system.

1. This is not coherent. Even in the newer standards (like LTE-A) the time provided by the telecommunication systems is way coarse than what we need for a coherent radar system.
2. The second challenge is the fact that the sensing system is highly under-determined. In GSM we get around 48 readings per data frame and in LTE we get around 1004. This reflects the events happening in a very wide area covered by the whole communication cell.

To take care of these challenges we adopted a novel instrumentation scheme which we call Application Specific Instrumentation (ASIN) In this we have two major assumptions. 1) The environment is not dynamic (as might be expected from a combat situation). 2) And, we know what we looking for. In other words the application is knows. Then it becomes a task of finding how separable is the event of interest in the given scenario. To this effect we have tested both GSM and LTE based CommSense systems for various change detection tasks.

<u>In-house development: using GSM (2G) communication</u>

Figure 11 shows the h/w used to gather channel estimation filter's characteristics. This was collected from different scenes and Figure 12 shows how such data look clustered. The clustered nature of the data implies that the data we collect CAN BE used to distinguish different environments and events in them.

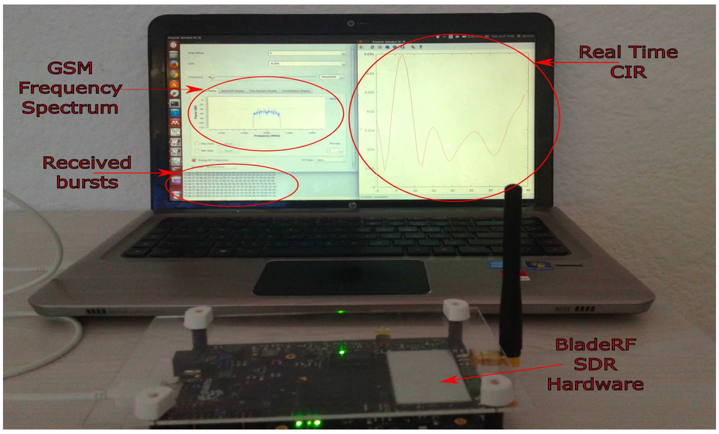

Figure 11: Laptop and BladeRFx40 based implementation of the system (Courtesy of UoC).

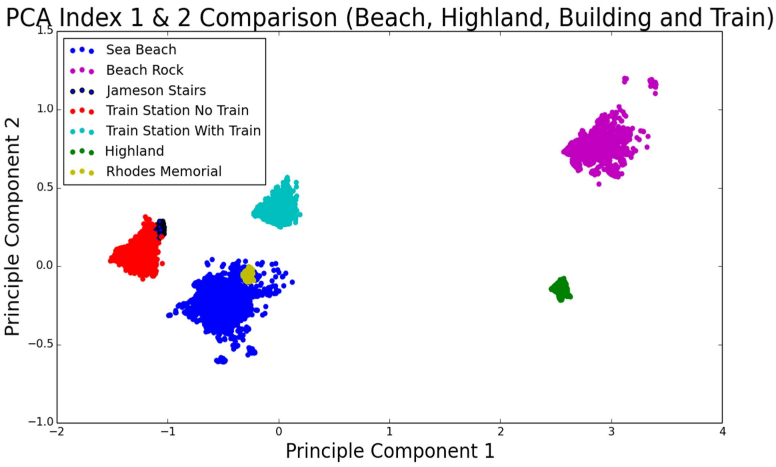

Figure 12: Data from different scenes and events (Courtesy of UoC).

<u>LTE-CommSense Development</u>

The UoC has also been investigating LTE-CommSense using LTE signal. Figure 13 shows the USRP based LTE-CommSense data collection system. Figure 14 shows the fractional Fourier transform representation of the channel impulse response (CIR) for two situations, one with human target in a room and the other with no human target in the room.

As can be seen from Figure 14, there seem to be visibly distinct signature of the FrFT for the presence of a human target. These initial results are highly encouraging and seem to suggest that a lot can be done using LTE-CommSense.

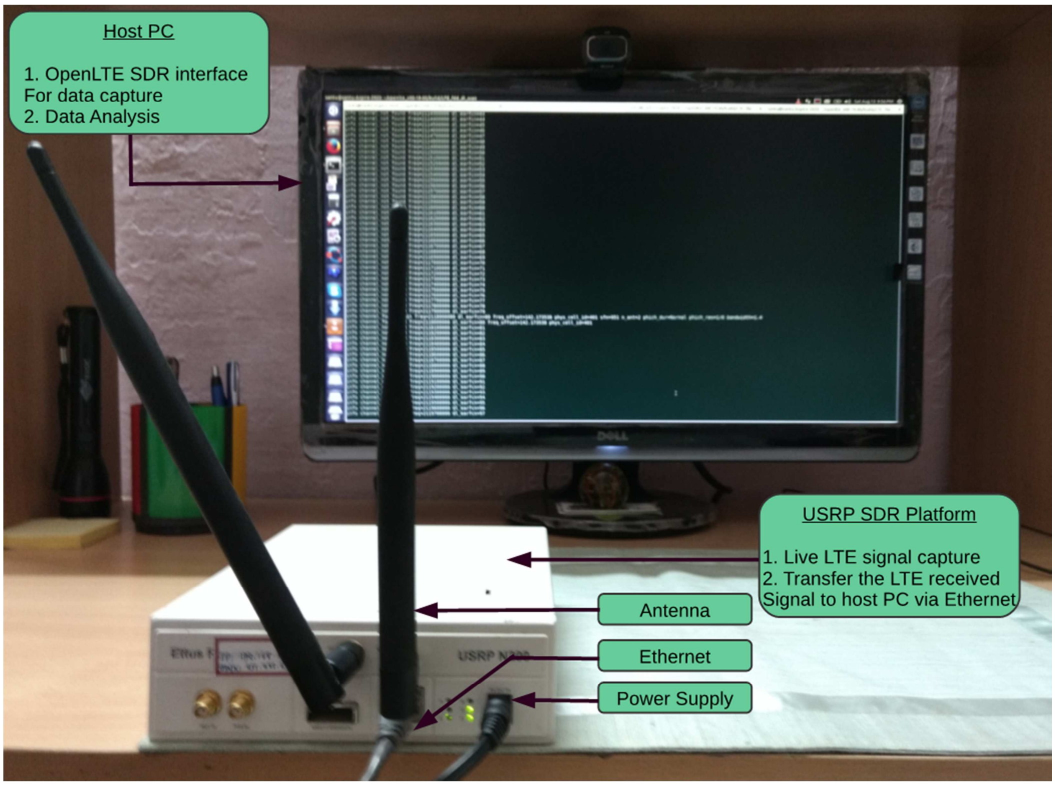

Figure 12: LTE-CommSense data collection system (Courtesy of UoC).

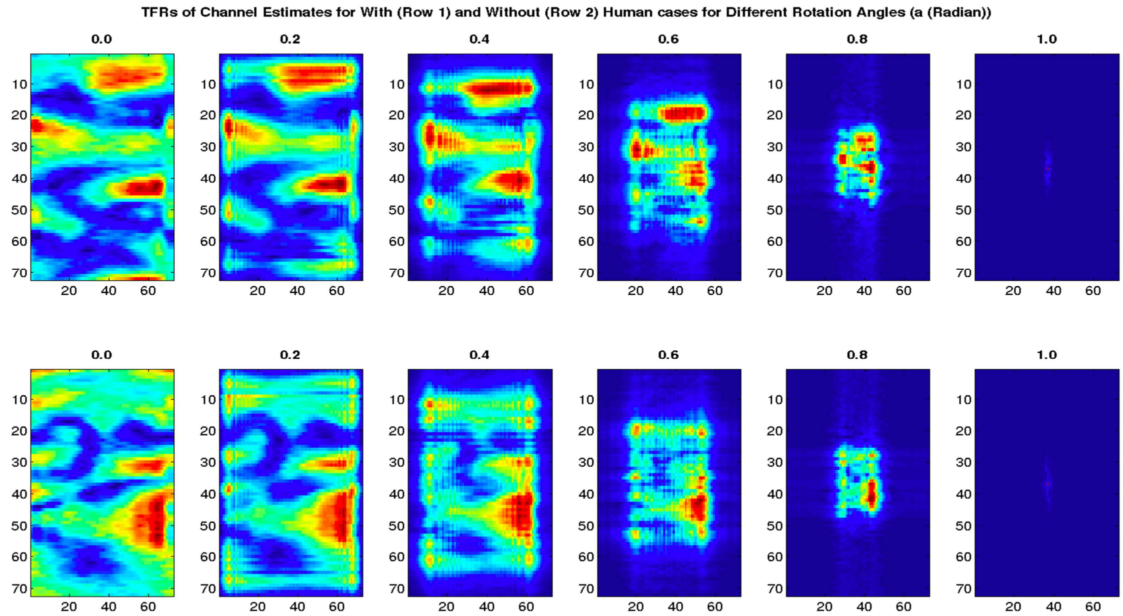

Figure 14. FrFT of CIR of scenario with (row 1) and without (row 2) a human targe (Courtesy of UoC).

Passive Radar Collision Warning System PARASOL

The passive radar based collision warning system for wind power plants PARASOL controls the switching of the warning lights on demand in order to increase acceptance of renewable energies in the population and avoid the attraction of birds by light emissions. The PARASOL system exploits the transmission of digital TV broadcast networks for passive detection and location of potential targets by the measurement of time-difference-of-arrival (TDOA) of direct and reflected echo signals and calculation of the TDOA ellipsoid intersections. The system consists of a minimum of three passive radar sensors, which are distributed in a wind park in order to provide sufficient coverage for warning of aircraft intruding in the protected space. This paper gives a complete description of the system, its installation and an example for the optimization of sensor locations within a wind park. It also includes a method of suppressing unwanted signal returns from wind turbine blades in passive radar systems. A signal processing procedure is proposed, which suppresses the returns of rotor echoes, while allowing the detection of target returns. The validity of this approach is demonstrated with data obtained from a PARASOL passive radar system. Figure 15 shows the antenna unit on a wind turbine mast and figure 16 an aircraft track in the range-Doppler plane.

Figure 15: PARASOL antenna

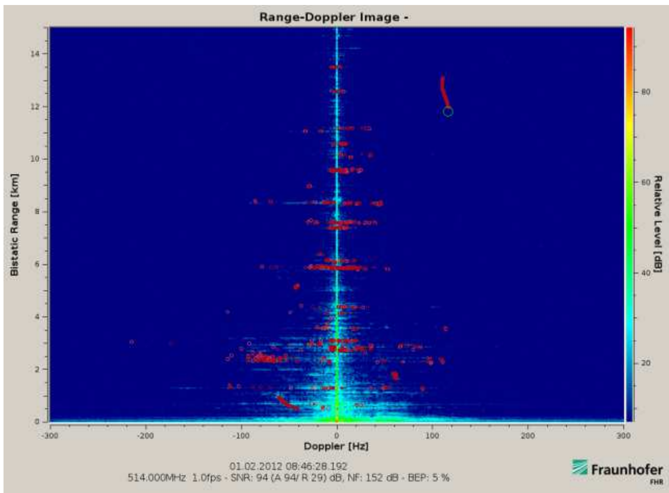

Figure 16: range Doppler map with target.

Passive Radar for traffic monitoring

The use of radar technology allows for precise velocity measurements and information generation not only on traffic density but also on traffic velocity. As the passive radar does not emit energy, there are fewer restrictions on the system deployment. However, proper deployment positions for passive radar sensors have to be selected because the sensors have to be able to observe the roads illuminated by selected transmitters of opportunity. As the shadowing effect is very common in cities, only parts of the road will be under surveillance. Using DVB-T illumination makes it possible to estimate the traffic in several distinct points of the road. Furthermore, by using the multiple receivers placed e.g. on the road crossings and observing different roads simultaneously, it is possible to receive an overall picture of traffic on road junctions.

According to the authors' knowledge this emerging technology has not yet been implemented in real life. But given the maturity of passive radar technology development, it should be possible to implement it in the near future. As passive radars consist only of commercial direction antennas, digital receivers and computational units, they can be as inexpensive as modern TV sets. Thus, they could be widely used in the future for traffic monitoring purposes, especially as the radar sites can be additionally equipped with TV cameras to enrich the information on traffic.

Although the topic of traffic monitoring still requires further research, it is anticipated that this 'green' technology, which does not require a spectrum allocation, will introduce new possibilities in the use of passive radars in civil applications in the future. Moreover, the passive radar technology can be also considered as an emerging technology for the car traffic density monitoring, especially if it is connected to the inter-active GPS navigation systems of the big cities.

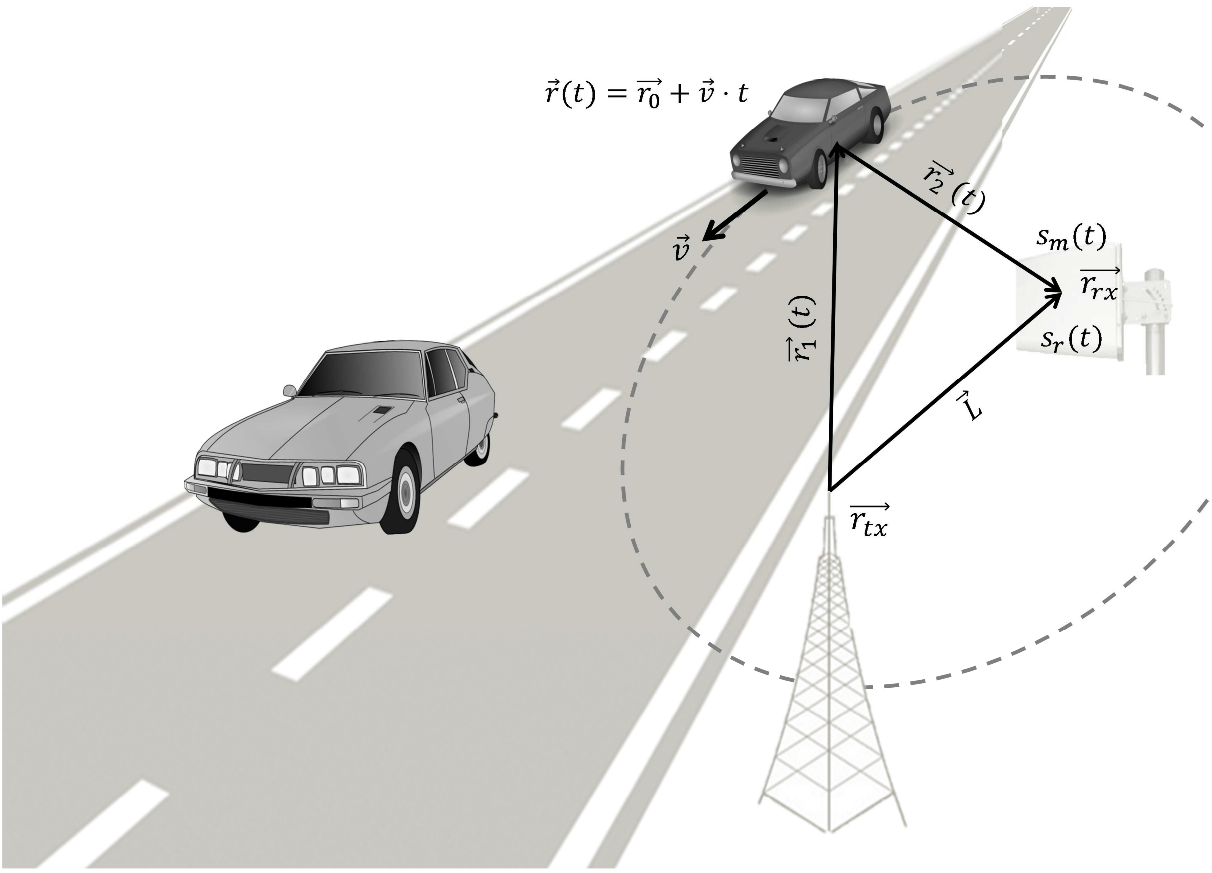

Figure 16: PCL for traffic monitoring