Approaching 80 Years of Passive Radar

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Abstract—The history of passive radar dates back to the early days of radar in 1935 when the Daventry experiment was conducted in the UK. It continues in WW II with the German Klein Heidelberg passive radar and receives new interest today, as passive covert radar (PCR) systems like Silent Sentry, Homeland Alerter 100, Aulos and PARADE are ready for operation. The future of PCR will strongly depend on the availability of transmitters of opportunity such as FM-radio and digital broadcast networks.

Keywords-PCR, anti-stealth, DAB, DVB-T, pulse chasing.

I. INTRODUCTION

Since radar had been recognized by the military as a means to detect enemy air or naval targets at extended ranges, its vulnerability to localisation due to the fact that it could not do without transmitting energy was well understood. Though at the beginning of the radar century there were no such threats as anti-radiation-missiles, a radar location could be determined by receiving the typical radar signals and using triangulation. The jamming and destruction of radar systems were threats that developed later.

The advantage of silent operation without revealing ones position was obvious and thus a seed for the desire for passive radar was already planted in the early days of radar.

The principle of passive radar, either using transmitters of opportunity or co-operative transmitters is based on cross-correlating a signal received directly from a transmitter with its reflections from a target. Knowing the geographical positions of the transmitter and the receiver allows spanning an ellipsoid with the two positions as foci. Target positions are obtained by either using multiple transmitters or receivers, respectively, to determine the ellipsoid intersections, or measuring the target direction and its intersection with the ellipsoid. The accuracy of the target position strongly depends on the bandwidth of the utilised signal and the receiver antenna beam-width and is often considered a criterion for determining the suitability of passive radar systems for particular applications.

II. PASSIVE RADAR BEFORE AND DURING WW2

The history of passive radar measurements with the aim of detecting aircraft targets dates back to 1935, when Sir Robert Watson-Watt conducted a bi-static experiment using the illumination from the shortwave (49 m wavelength) BBC Empire transmitter at Daventry to detect a Heyford bomber aircraft at short distance (8 km) [1, 2].

The Heyford was a slow aircraft that first flew in 1930. For the purposes of the test however, with a wing span of 75 feet, it did provide quite a large object to 'aim at' in the sky. Furthermore, the dimensions of the Hayford equated nearly to a ½ wavelength of the source signal.

The test was to be carried out in a field outside the town of Weedon, near Daventry. Figure 1 shows a sketch of the Daventry experiment. The Heyford was flown on a path between Weedon and the BBC transmitter at Daventry. The detection equipment consisted of a rather large receiver which

Figure 1. Sketch of Daventry experiment

was fitted with an oscilloscope, furnished by The National Physical Laboratory, and was tuned to the wavelength of the BBC Empire transmitter at Daventry.

The pilot of the Heyford took off from Farnborough, climbed to 6,000 feet and started to fly the course on his flight plan making passes at various altitudes.

Robert Watson - Watt and his assistant Arnold Wilkins tuned their radio receiver to the frequency of the BBC transmitter at Daventry. As the Heyford bomber flew overhead, the signal of the transmitter which was being received and displayed on the oscilloscope, began to fluctuate, indicating that a variable & measurable amount of radio signal was being reflected from the passing Heyford aircraft.

The men in the van watched as the signal indicated the aircraft in their vicinity; they were able to track it for some 8 miles.

Subsequent to the successful demonstration, a new radar research establishment, the Bawdsey Research Station, was
founded under the Air Ministry and Sir Robert Watson-Watt became its Superintendent in 1936.

Later, his research led to the installation of a chain of radars along the south and east coast of England, known as the Chain Home radars [3].

While the Chain Home radars were active radars operating with a transmitting power of 350 kW (later 750 kW) at a frequency of 20–30 MHz, on the German side passive radars were installed along the continental Channel coast.

Since 1943 the German ‘Klein Heidelberg’ receivers located near the Channel coast line exploited the emissions of the British ‘Chain Home’ radars to detect incoming aircraft [4]. These were the first operational passive radars. Resistance to the British jammers was the main advantage of the passive Klein Heidelberg receivers over the German active radars Freya, Mammut, Wasserman and Würzburg. After preliminary trials at ‘mount couple’ between Calais and Boulogne 4 Klein Heidelberg receivers were set into operation in summer 1944 at Oostvoorne, den Haan, Boulogne and Abbeville. Figure 2 shows the location of the Oostvoorne station and the illuminating Chain Home radars. A picture of the Klein Heidelberg antenna based on a 40 m Wasserman S tower is shown in Figure 3. The main antenna consisted of 18 dipole elements in front of a reflector plane positioned in 3 column arrays of 6 elements, each. It spanned a beam-width of 45° and provided an angular measurement accuracy of about 5°. An additional dipole antenna at 15 m height received the direct transmitted signal.

III. NEW INTEREST IN PASSIVE RADAR AFTER WW2

With the invention of the duplexer in 1936, which permitted the rapid development of the operationally more convenient, single-site, monostatic radar, interest in passive radar was temporarily lost. Radar development turned towards low probability of intercept (LPI) radars and the investigation of electronic counter counter measures (ECCM) to cope with jamming.

In the 1980s the several European countries developed interest in ‘passive location’, which primarily referred to passive emitter tracking (PET) and passive jammer location, but also included a passive radar receiver concept hitchhiking on the emission of a conventional airport surveillance radar (ASR). This concept included the so called pulse chasing principle, which requires the passive receiver to follow with its beam the pulse emitted through the rotating antenna of the active illuminator radar. As the transmitted pulse travels along the transmit beam direction at the speed of light, pulse chasing requires extremely fast beam steering on the receiver site, or, alternatively multiple receiver beams (fan beam, see figure 4), which can be steered at a somewhat slower speed. Though being very ambitious, the latter approach seemed more realistic at that time.

A further revival of passive covert radar (PCR) occurred in the 1990s, when the NATO defence research group (DRG) launched a study on passive and noise radar, which was concluded by a symposium [5]. In addition to the pulse-chasing principle, which applies to the exploitation of non-cooperative pulsed radar signals as illumination, broadcast transmitters were discovered as potential sources for PCR. The new motivation for passive radar was, in addition to its covertness, the system’s inherent anti-stealth capability.
Since stealth technology primarily aims at the reduction of an aircrafts radar cross section (RCS) with respect to monostatic radars at operational radar frequencies from L- to X-band, the bi- or multi-static geometry of passive radars and their predominant VHF/UHF illuminators successfully counter stealth.

PCL studies were conducted at UCL, where Griffith and Long investigated the use of analogue TV transmissions from Crystal Palace for the detection of aircraft targets. Additionally Howland utilised the analogue TV video carrier, again from the venerable Crystal Palace transmitter, to detect and track airliners to ranges of up to 260 km. These studies demonstrated the feasibility of the principle of PCL technology.

At the same time Thales in France obtained a patent on a method which exploits the spectral shift of the TV-carrier and the line synchronisation pulses of a moving target echo versus the direct signal for passive target detection ranging.

A demonstration of passive radar target detection using the illumination of a Russian type P18 VHF-surveillance radar was conducted under the name of PARADE (Passive Radar Demonstration) in 2001 by FGAN-FHR in co-operation with the Hungarian Technology agency.

As a further source of illumination being available in almost all parts of the world FM-radio signals were exploited in many PCR system designs. Typically, FM broadcast stations provide reasonable transmit power and a signal modulation, which allows detecting targets by cross-correlating the echo signal caused by target reflections with a reference signal received directly from the transmitter. However, the ever changing bandwidth of the FM-radio signal, which is dependent on the programme content is the reason for a largely varying range resolution and measurement quality. Rock music seems to be most advantageous due to a comparably large constant bandwidth, while oral contributions like news are the least favourable. Careful selection of the transmitter to be used is required for optimum performance.

In France, a small company C&T (Communication et Téléphonie) led by Jean-Philippe Brunet developed a system called Occiu [7], which consisted of an 8-element antenna array, an off-the-shelf computer, sophisticated signal processing and a mission planning software ‘Aneth’.

![Fig. 6: Thales HA100 antenna (Courtesy of Thales)](image)

![Fig. 7: Aulos PCL-System (Courtesy of SELEX)](image)

![Fig. 8: PARADE Multi-band PCL (Courtesy of Cassidian)](image)

![Fig. 9: PaRaDe antenna (Courtesy of WUT)](image)

The first commercial PCR prototype using FM-radio broadcast emissions was developed by Lockheed-Martin [6] and is referred to as ‘Silent Sentry’ (see figure 5), thus underlining the sensors covertness.

![Figure 5. Silent Sentry 3 set up (Courtesy of Lockheed-Martin [14])](image)

Other European industries like Thales and EADS among others became interested in the new sensor approach. In retrospect, Occia can be considered the predecessor to HA100 by Thales (see figure 6). The name HA100 standing for Homeland Alerter with about 100 km detection range suggests the role foreseen for this type of sensor. Later, other industries like SELEX (System AULOS, figure 7), Cassidian (System PARADE, figure 8), WUT (System PaRaDe, figure 9) and ERA joined in with experimental systems or demonstrators.

The handling of vast amounts of data at reasonable processing times was facilitated by technological development. Direct RF-signal digitisation, applying the ‘software defined radar’ principle further supported the applicability of passive radar for military and civil security purposes.

IV. PCR WITH DIGITAL WAVEFORMS

From the late 1990s on, with the advent of digital broadcast signals and the installation of digital broadcast networks (Digital audio broadcast DAB, Digital video broadcast-terrestrial DVB-T) in central Europe, concepts for the exploitation of such signals as illumination sources for PCR were developed, first by ONERA and starting in 1999 by FGAN-FHR. The first PCR-system to demonstrate air and maritime target detection in multi-national trials was the CORA system developed by FGAN-FHR (now Fraunhofer-FHR). Figure 10 shows the antenna, front-end and processing van of the DAB-DVB-T radar using the CORA system during the set-up for a measurement campaign in Germany in 2006. The digital waveforms employing OFDM modulation with noise-like, almost constant spectral amplitude within the band limits of 1.5 MHz (DAB) and 7.5 MHz (DVB-T), provides a constant measurement quality at range resolutions of about 100 m and 20 m, respectively. This exceeds by far the range resolution of some km, which can be achieved using FM-radio emission. On the other hand, DAB stations transmit at much lower power than FM-stations, while the DVB-T transmit power levels are comparable to those of FM-radio.

Currently DVB-T networks are operated either as multiple-frequency-networks, where each transmitter has its own frequency band and thus, target echoes can be unambiguously related to the illuminating transmitter, or as so called single-frequency-networks, where each transmitter in the net transmits coherently the same signal at the same time causing ambiguous receiver-transmitter-target relations.

Such ambiguities have to be solved by extensive track processing. Nevertheless, even with such demanding processing loads the application of advanced signal processing technology, fast A/D-conversion and powerful data processors makes the dimensions of passive radar sensors shrink with each passing year.

V. PCR FOR CIVILIAN APPLICATION

Advancing technology also enables the exploitation of passive radar technology for civilian applications. ARGUS 3D, a multinational EU-Project and PARASOL, a project sponsored by the German ministry of environmental affairs, are examples of such applications. ARGUS 3D aims at improving the air traffic security against terrorist attacks and technical failures by upgrading primary airport surveillance radars with a 3D capability and adding adjunct sensors like bistatic radar and passive radar to civilian air surveillance. PARASOL stands for collision warning illumination on demand of wind power plants and employs a passive radar system using DVB-T illuminations to detect aircraft approaching wind parks. It aims at improving the acceptance of wind energy plants and reducing the collision of birds, which are attracted by the collision warning lights.

VI. CONCLUSIONS AND PERSPECTIVES

Technology readiness of passive radar sensor development now reaches a level, where military as well as civilian users start considering the implementation of passive radar sensor networks in order to enhance the performance of active air surveillance, fill coverage gaps and provide object or border protection.

The radar community is reaching the understanding that passive radar is not to be considered as a replacement for active radar but rather as a different type of sensor with different limitations and different capabilities, which in many cases can complement those of active radar. It becomes clear that, if passive radar is used for purposes where it has it’s strengths, like low level coverage, anti-stealth, covertness and the avoidance of yet another source of “electromagnetic pollution”, it can expect a successful future.

While demonstrator-type passive radars are reaching a high maturity level, research in the field of passive radar is ongoing and currently extends also to short and very short range applications using emissions from cell-phone base stations and WiFi hot spots for moving target localisation. System concepts like Celldar by Roke Manor [9] and experiments by ONERA [10] and Fraunhofer-FKIE [11] using GSM signals may offer some additional fields of application for PCR.

A preliminary demonstration of the potential of a WiFi-based PBR for local area surveillance applications was presented at the 2nd FHR-PCR-focus day in November 2009 at Fraunhofer FHR in Wachtberg [12].
Very recently the idea of using airborne platforms as PCR receivers develops at PIT in Poland [13] and passive radars on naval platforms. Both, airborne PCR and naval PCR would require additional motion compensation techniques to minimise losses in target signal-to-noise ratio due to range and Doppler walk. It is expected that passive radar technology will advance with digital technology advances to keep it a priority for radar research establishments.

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