South African Passive Radar and Towards Its Characterisation

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Abstract– A passive or passive coherent location (PCL) radar does not have an own transmitter or require owning spectrum, making it a very cost effective instrument for tracking non-cooperative targets. The paper discusses achievements in FM-based passive radar developments in South Africa, including a brief summary of experimental results. The paper then introduces a project to characterise and quantify the passive radar's performance in a six radar nodes testbed being around the major South African airport near Johannesburg and intended to prove the technology and enable addressing the needs of air traffic control (ATC) in developing countries.

1.   INTRODUCTION

Radars [1] have become an important tool in civilian and military applications. South Africa has deep history in radar developments starting with first in-house radars developed, built and tested in 1938 and used in the Second World War [2,3]. South Africa has since then established strong radar industry, which until recent was mainly focussing on the advancing the traditional radars. This trend may be expected to shift with the development of much less expensive and nearly as versatile passive radar technologies.

A traditional monostatic radar has transmit and receive subsystems that are co-located at one site. The transmit subsystem is responsible to emit a radio wave. This wave travels to and reaches a target, e.g. an aircraft, reflects from it, travels back, and received at the receive subsystem. Subsequently, determining the time delay between the transmitted and received signals permits to estimate the propagation time and distance to the target. By also determining the bearing towards the target, the target is then located by estimating its position. This permits to detect and track non-cooperative targets, i.e. targets which for any reason do not respond to queries sent to them.

However, needing a powerful transmitter and requiring a spectrum license to generate emissions, places serious constraints on the traditional radars, as both factors lead to high costs, power requirements and a need for maintenance that demands a high skill level.

For example, several major airports in South Africa have primary radars, augmented with secondary radars and supported by the Automatic Dependant Surveillance-Broadcast (ADS-B) and other systems. At the same time, for most of the smaller airports, primary radars, the only radars able to deal with non-cooperative targets, are overly expensive. The situation is similar in many other locations in Africa and other developing regions.

Passive radar systems gained strong momentum over the last decade (e.g. [4-19]) thanks to its relatively low cost and absence of spectrum licensing requirements. These advantages together with highly promising preliminary results are envisioned to bring passive radars to serve Air Traffic Control (ATC) in areas with lack of ATC systems and to complement existing infrastructure. With the technology readiness nearing maturity, the performance characterisation and quantification of passive radars may be seen as the final step towards the adoption of this technology for ATC.

A passive radar system gains its advantages over the traditional radars by using/"borrowing" an external transmitter, referred to as an illuminator of opportunity. Instead of the radar emitting a radio wave, the wave is emitted by an already existing transmitter operated by another party. Whilst nearly any source of radio signal may serve this role, the most popular choices are FM radio, digital TV broadcasting and cellular communication towers. Of these, the FM usually offers the best long range (several 100's of kilometres)

detection coverage and, usually the best availability (especially in Africa), whilst higher frequencies used by TV broadcasting and cellular services normally offer more accurate target localization, but at short range (several 10's of kilometres).

Having eliminated the need for a dedicated transmitter, the hardware of passive radar only requires receiving a reference signal from the selected illuminator of opportunity and the signal reflected from the target, and then comparing them to determine the required parameters, such as distance/range to the target, the Doppler shifted frequency of the reflected signal in comparison to the reference signal etc. The recent developments in software defined radios (SDR), as well as advances in digital computing power, made these functions fairly affordable.

An entire passive radar system may be depicted with Figure 1, showing the mutual locations of a transmitter of opportunity, passive radar receiver, target, and distances between them. As seen from the figure, the passive radar is usually run in a bistatic configuration [20,21], where transmit and receive subsystems are geographically positioned at two different locations.
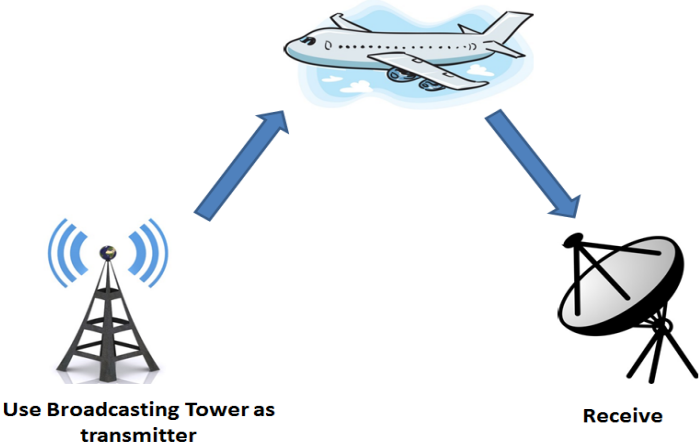

Use Broadcasting Tower as transmitter

Receive

Figure 1. Bistatic radar geometry

2.   PRESENT WORK ON PASSIVE RADAR IN SOUTH AFRICA

In South Africa, the work on passive radar was mainly focussed on using FM radio as the illuminator of opportunity, e.g [10,13,15-19]. A technology demonstrator was developed that consisted of hardware signal processing algorithms and software and used in several trials to verify target detection and tracking of the technology.

The present technology demonstrator uses proprietary receivers developed by the South African company Peralex Electronics. These receivers are able to coherently digitize 3 arbitrary 200 kHz wide channels and operate with the FM broadcasting band (88 MHz to 108 MHz). The signal processing is performed in real-time in which target detection is done using a General Purpose Graphics Processing Unit (GP-GPU) on a PC and target tracking on a multi-core CPU.

A number of tests have been carried out over the last few years. Setups used in these tests and some of the results are shown in Figure 2. A summary of the archived results includes:

- Single site based detection and tracking of a Cessna 208 in terms of range and angle, performed in 2013 using a setup shown in Figure 2a and with results shown in Figure 2b.

- Detection and ranging of a small low flying aircraft (Cessna 172 at 2000 ft Above Ground Level / AGL) and large (Boeings) aircrafts at 168 km and 400 km bistatic ranges respectively, and starting with target recognition (by accurately estimating the Revolutions Per Minute (RPM) of a Cessna 172 propeller, shown in Figure 2c), also done in 2013.

- Multistatic detection and tracking of Boeing like targets, performed in 2014 using setups shown in Figure 2d and 2e. Notice the excellent match between the passive radar estimated target position and ADS-B acquired results illustrated in Figure 2f.
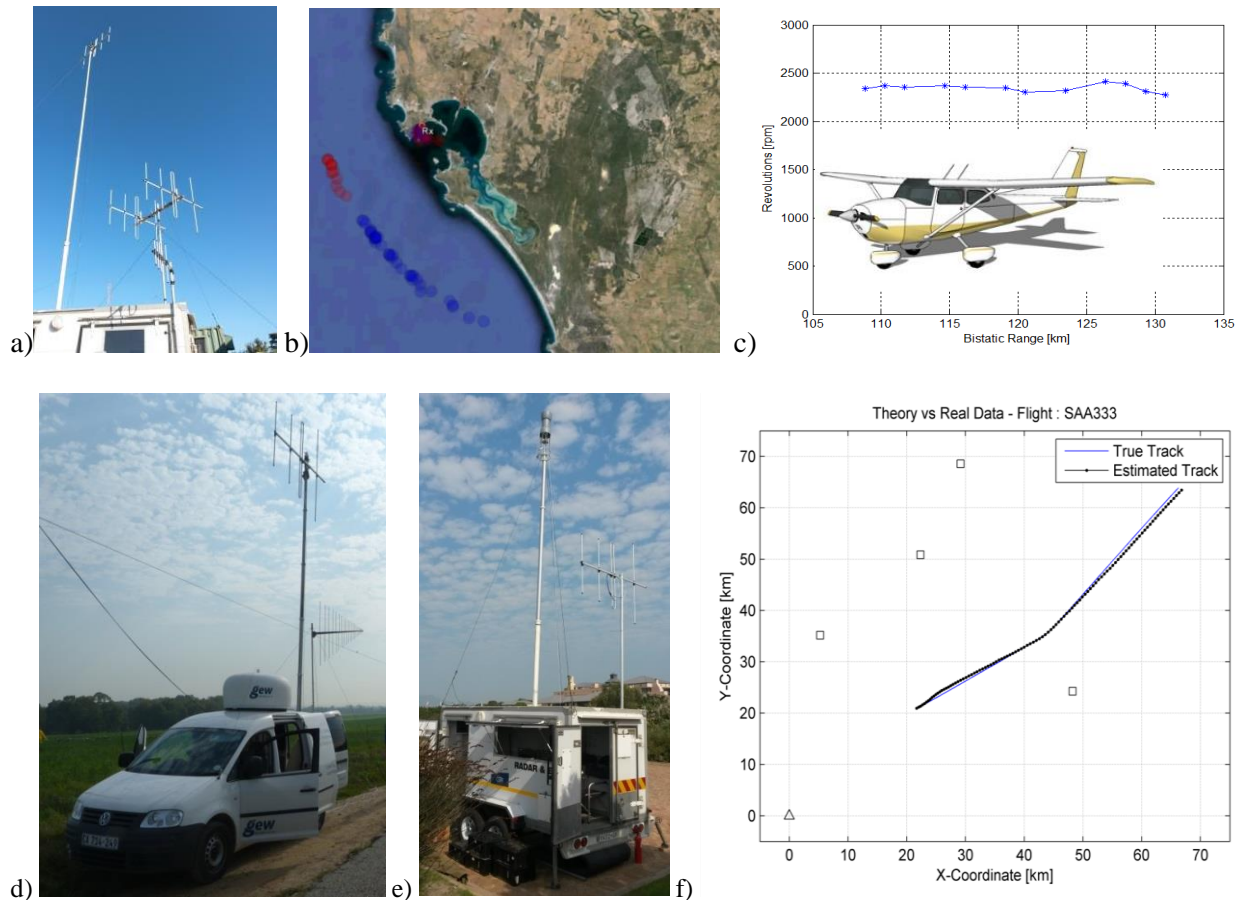

Figure 2. Setups used in various tests of passive radar systems and some of the results achieved.

3. CAN PASSIVE RADAR COVER ENTIRE SOUTH AFRICA?

Whilst traditional radar is self-sufficient, the passive radar depends on the availability of illuminators of opportunity. South Africa has a large number of FM transmitters spread across the land, as shown in Figure 3a. Assuming 80 km or 150 km coverage radius for an FM transmitter shows that the FM-based passive radars are able to cover entire South Africa, as shown in Figures 3b and 3c, respectively.

At present we are carrying additional research to characterise the coverage and optimal placement of passive radar setups more accurately. Provisionally, it is already possible to state that every airport in South Africa should be able to take some advantage of FM-based passive radars.
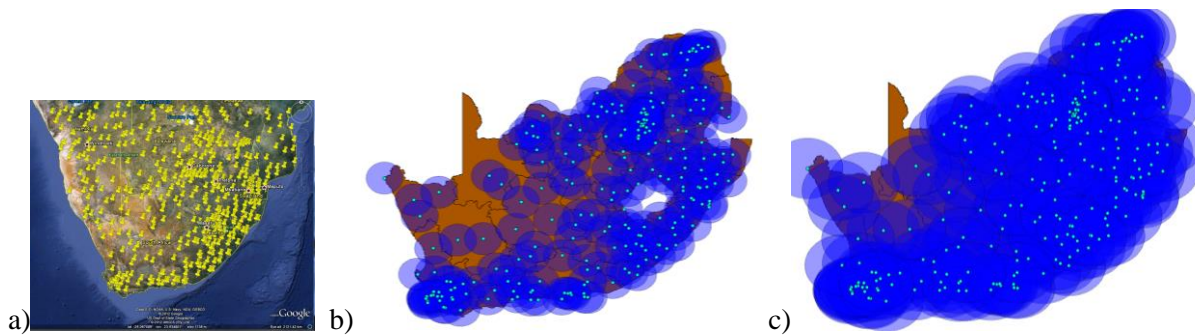
Figure 3. a) FM radio stations in South Africa; b) 80 km coverage for the same; c) 150 km coverage for the same.

4. PROJECT DESCRIPTION AND EXPECTED RESULTS

With the technology demonstrator showing promising results, the CSIR has started a 3 year project to characterise the performance of a FM radio passive radar system.

4.1 SETUP BEING DEVELOPED

A diagram of the large permanent testbed under development is shown in Figure 4. The final testbed will have six receiving nodes (Rx1-Rx6), feeding the data to a central processing node.

Each receiving node is planned to have several components. These include three antennas, one for receiving the reference FM broadcasting signal and the other two for receiving the signal reflected from the target and performing interferometry/direction-finding on the target. The antennas connect to a digitising receiver (supplied by Peralex Electronics), and a signal processing PC able to do target detections and possibly tracking. At present, we also plan to experiment with adding narrowband filtering in the Radio Frequency (RF) frontend to improve the signal to noise ratio against the out-of-band signals and thus enhance the robustness and accuracy of detection and tracking.

In addition, the receiving nodes shall include: precise time referencing (time-stamping recorded data) using the global navigation satellite system receivers to enable coherent data processing at the central node, a weather station to enable the performance characterisation of the passive radar over different weather conditions, as well as local intermediate storage to buffer possible breakages in connectivity with the central node.

The receiving nodes will pass the data to a central processing node. We intend to rely on the South African National Research Network (SANReN), which has over 400 nodes around South Africa connected with fibre and is providing up to 10 Gbps capacity per link. This should permit up to real-time data transfer and distributed detection and tracking capabilities.

In addition, the system will include other sensor inputs, such as ADS-B and primary and secondary radar data. This information will be used to provide references enabling comparison of passive radar estimated positions/velocities against the already trusted ADS-B and traditional radar data.

We are working together with South African Air Traffic Navigation Services (ATNS) to ensure availability of sufficient and trustworthy reference data and appropriateness of procedures to compare the performances.

In order to achieve this, the central processing will have a database collecting all of the above information. The collected information will be used to generate the statistics on the performance of the passive radar. We

anticipate that such metrics as probability of detection (versus distance to target), detection ranges for different types of aircrafts (in different weather conditions) are going to provide a sufficient wealth of proof to enable commercial installations of passive radars for ATC. We welcome a discussion and comments on the best ways to characterise the performance.
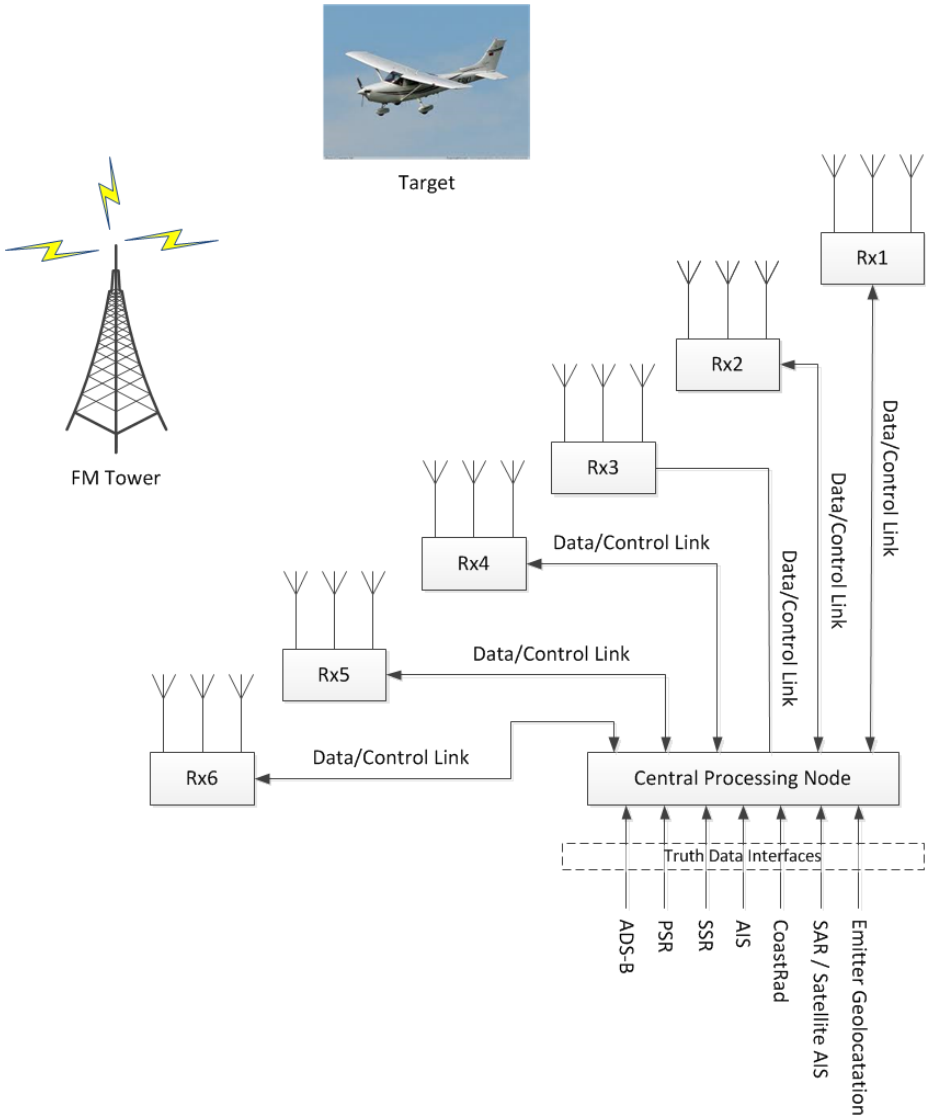

Figure 4. Large scale passive radar testbed under development

4.2   DRAFT PROJECT PLAN

In the first year of the 3-year-long project, we anticipate to have the first two nodes and a basic central processing node with a database operational. We have already identified 2 locations and are in process of setting them up. One node shall be located at the CSIR's main campus in Pretoria and the other location will be at the Gauteng site of the South African National Space Agency's (SANSA) space operations. These two sites are located at around 90 degrees with respect to the O.R. Tambo airport, the largest and busiest airport in South Africa, and so the observations made at the sites shall enable good quality and wide range two-dimensional localization of targets.

In the second year, we plan to add 2 more nodes to the setup, execute strategic trials to validate performance of the 4-node setup, extend the database to a web-based server to share data with international community, and expand the tracking capabilities.

The final 3rd year of the project will focus on adding two last nodes, making this a six-node setup, upgrades and optimisations based on the lessons learned through year 2, and continuing with the performance validations on the full six node passive radar. As mentioned in the previous section, each receiver node will be capable to detect and track targets individually (based on a single bistatic range, bistatic Doppler and angle measurement) and specifically applies to low flying targets. However, for large, high flying commercial airliners, the 6 receiver nodes would have common detections on these targets and subsequently be used to derive target accuracy statistic (based on a multiple bistatic range, bistatic Doppler and angle measurements) as a function of Geographic Dilution of Precision (GDOP), number of detection on target etc.

Throughout the duration of the project, we would also like to develop better understanding of planning and implementation aspects for passive radar installations. With this, we are actively working on the radio planning tooling and performance prediction capabilities based on modelling and simulation. Example of such problem may be illustrated with Figure 5. There, one may observe the airport and locations of possible receiver sites around it. Determining the optimum location of the passive radar nodes is yet an open problem.
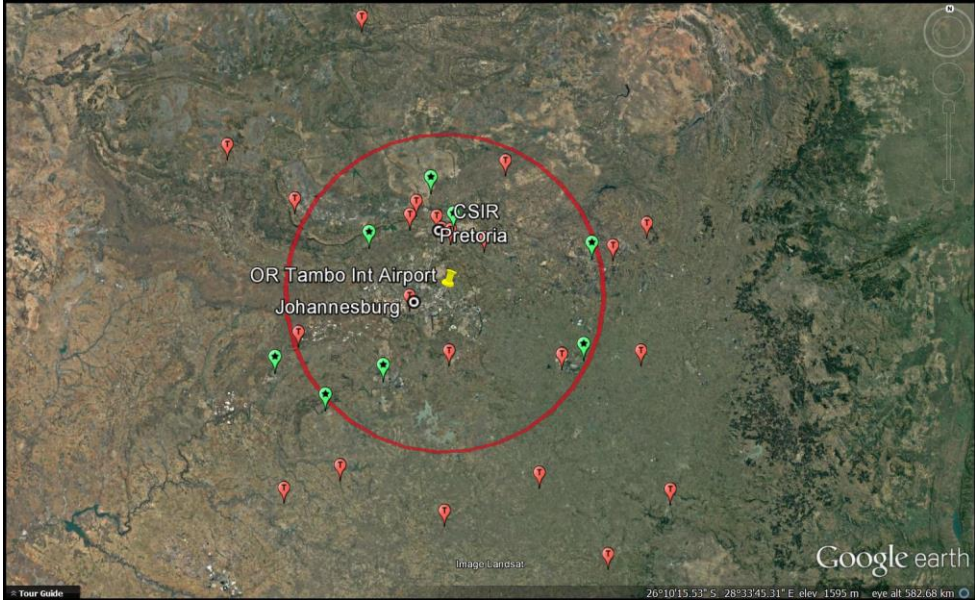

Figure 5. A view of the area where the long term testbed deployment is being conducted. O.R. Tambo International Airport is indicated as "OR Tambo Int Airport" and the airport's Primary Surveillance Radar's detection range of 110 km indicated by the red circle. FM Transmitters with unique frequencies are indicted by red place markers and the green place markers indicated SANReN connected sites where possible receiver nodes could be deployed. Lastly the CSIR is indicated in the figure as "CSIR" that would serve as the central processing node. Figure is courtesy of [19]

5. **CONCLUSION**

Obtaining acceptance of passive radars as a technology suitable for commercial air traffic control (ATC) and other uses, the passive radar requires a long term experimentally obtained data enabling comprehensive performance characterisation and comparison against existing technologies, such as primary radars and ADS-B. The 3-year long project started by the CSIR in South Africa in 2016 will establish a passive radar

testbed and perform a trial of the technology, operating the radar in various conditions, including seasonal changes, and observing the radar's outputs on various types of targets. In addition, the project will attempt to develop a performance prediction and radar site identification methods and tools, to aid in practical commercial implementations of the technology.

ACKNOWLEDGMENT

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