75 Years of Sparkling Achievements in Radar Research & Technology Development at the CSIR

1 The Birth of Radar in South Africa

The first radar echo in South Africa was received on the 16th of December 1939. It signalled the beginning of a field of science and technology that has since blossomed into a modern, strategically important radar capability in South Africa, with a scope and level of advancement unexpected for a developing country. It is increasingly being seen as a sovereign capability that should be valued and employed to not only help improve the country's defence and security but also to grow its knowledge-based industrial development and job creation through competitive, radar-based innovations.

Figure 1: The first experimental radar built in South Africa and tested on the roof of the Bernard Price Institute for Geophysical Research building on the Campus of the University of the Witwatersrand (Wits). The first radar echoes from the Northcliff hill were received here on 16 December 1939.

JB-0 was the first South African radar demonstrator developed by a team consisting of seven South African engineers and scientists from South African universities who, at the start of World War II, were drafted into the South African Army Corps of Signals to form the Special Signal Services, a wartime code name for the radar capability of the South African Defence Force (SADF). The team based their work on technology transferred from Britain.

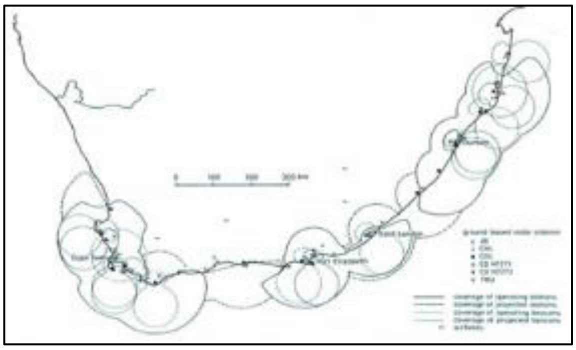

Figure 2: Locations and calculated coverage areas of the coastal radar network in South Africa during WWII.

During the war years, radar expertise in South Africa grew exponentially and, within a remarkably short time, mobile radars were developed, deployed, and operated in East Africa and near the Suez Canal. When British-manufactured radars remained unavailable for use in South Africa, locally produced radars were used to start the establishment of a coastal radar network to help protect the sea route around the South African coast. By the end of WW II, this network had grown to 30 coastal radar stations. The South African radar capability grew to consist of 60 radar professionals, 200 radar technicians and 500 female graduates who volunteered to be trained as radar operators.

2 Establishment of a Radar R&D Capability at the CSIR

In 1945, the South African Government established the CSIR through an act of Parliament with the mandate to develop and apply modern science and technology in support of the post-war reconstruction and growth of South Africa and its fledgling industrial base. In 1946, the CSIR established the Telecommunications Research Laboratory (TRL) as one of the founding institutions of the CSIR with nine core members seconded from the SA Army Special Signals Services (SSS) Radar Team.

Figure 3: The JB51 long range surveillance radar deployed at Pienaars River north of Pretoria.

The first president of the CSIR was the director of the SSS during WWII. He motivated for a continued defence R&D capability at the CSIR. The TRL subsequently supported the South African Air Force (SAAF) with propagation predictions in support of HF radio communications, as well as radar acquisition, site selection and data network planning for the new air defence surveillance radar network that was being established to help protect the industrial heartland of South Africa against air attack. 1951 saw the beginning of the CSIR's development of the JB51, a next-generation long-range surveillance radar that met the requirements of the SAAF. It was a 600 MHz, fully coherent radar with 200 kW peak power, low and high antenna beams and a moving target indicator (MTI) signal processor. By 1957, the technology had been developed, transferred to Marconi South Africa, and a pre-production model produced. It was deployed at Pienaars River, north of Pretoria, where it was used by the SAAF in the training of pilots and ground-controlled intercept (GCI) fighter controllers.

When selecting the long-range surveillance radars for the modernised SAAF air defence radar network in the early 1960s, the SAAF project team decided against the use of South African radar and opted for radars produced by the well-established British radar industry. This decision led to the end of the original radar team's work on military radars in South Africa. The TRL (renamed the National Institute for Telecommunications Research or NITR), continued building radar-based instruments in support of geophysical research for some years. These included ionosondes and even a Ka-band weather radar to study raindrops and hail. This radar was in use until the late 1970s.

3 Missile-related Radar R&D

Defence-related radar R&D at the CSIR, however, survived this setback. In the early 1960s, the military authorities in South Africa concluded that the country had a strategic need to follow the example of other militaries at the time by developing a sovereign design, development, test, and production capability for missile systems. They tasked the CSIR with establishing such a capability. Subsequently, the National Institute for Rocket Research was established at the CSIR in 1963, to be expanded into the National Institute for Defence Research (NIDR) in 1965.

The NIDR established R&D groups focussing on the understanding, design and development of missile systems and related subsystems. This included radars such as missile seekers, altimeters, and proximity fuses as well as surveillance and fire control radars for Ground-Based Air Defence Systems (GBADS).

The renewed radar capability at the CSIR was strengthened by another technology transfer, this time from France, as part of the acquisition of a low-level GBADS missile system for the SA Army. In March 1964, twenty NIDR engineers were sent to France to take part in the development of the Cactus system (later called the Crotale in France). It was later transferred from the SA Army to the SA Air Force. The target acquisition radar was an S-band pulse-Doppler radar while the target tracker used for command-to-line-of-sight missile guidance was a Ku-band monopulse tracking radar.

During the early 1970s, the NIDR radar team designed, built, and tested technology demonstrators of missile-related radars including an X-band seeker and radar altimeter for a sea skimmer missile, and an X-band, coherent pulse compression surveillance radar intended for the modernisation of the Super Fledermaus air defence gunnery system of the SA Army. While these technology demonstrators were not industrialised, their development grew the South African radar R&D capability and took it to the state-of-the-art level of radar theory and techniques of the 1970s.

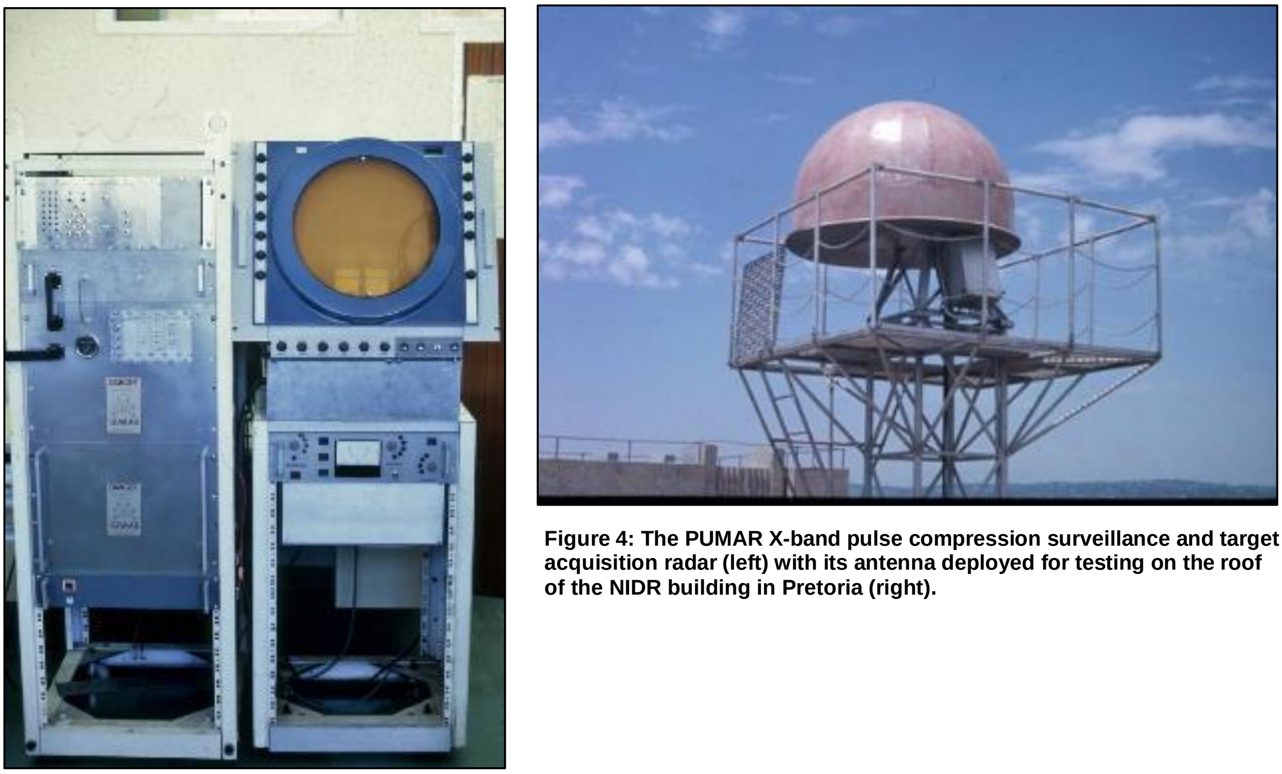

Figure 4: The PUMAR X-band pulse compression surveillance and target acquisition radar (left) with its antenna deployed for testing on the roof of the NIDR building in Pretoria (right).

4 Expansion into other types of Defence Radar and Radar Countermeasures

Figure 5: UHF Foliage Penetration Radar Test Facility.

During the early to mid-1970s, requirements for detecting armed insurgents in bushy savannah foliage on the northern borders of South Africa and Namibia led to experiments and, eventually, the development of early versions of UHF and VHF pulse-Doppler foliage penetration radars. Based on these, the CSIR specified a small, man-portable VHF version that was built by Barcom in Durban, utilising existing VHF radio technology. The SADF never contracted production versions of this radar as, by this time, the threat to South Africa's territorial integrity had escalated to the level of conventional warfare.

Given the greatly increased threat perception caused by the introduction of Soviet weapons systems into Southern Africa from the mid-1970s onwards, the CSIR was tasked to develop and industrialise an Electronic Warfare (EW) capability for the Defence Force. It included microwave Electronic Support Measures (ESM), electronic countermeasures (ECMs) against radars and electronic counter-countermeasures (ECCMs) to protect radars against ECMs. During the next decade, a range of locally designed microwave and antenna components and first-generation digital processors were developed from first principles in support of EW-related capability development for the SAAF and SA Navy (SAN). Increasingly capable radar warning receivers, self-protection chaff and flare dispensers and ELINT receivers were developed and industrialised for use on South African aircraft and ships.

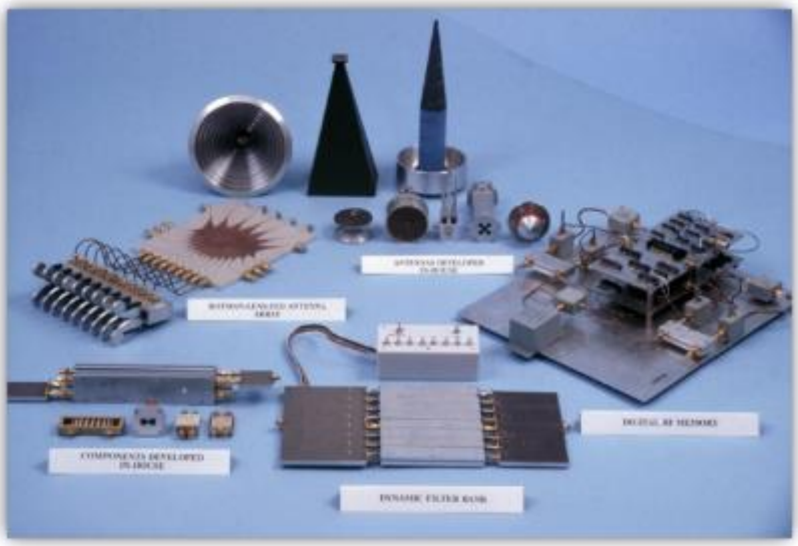

Figure 6: EW-related components developed at the CSIR during the late 1970s.

Towards the end of the '70s, the technological basis of the South African missile industry had been established. Missile R&D, production facilities and staff were transferred from the CSIR to form Kentron (Pty) Ltd, a new company established by Armscor. It later became Denel Dynamics, a business division of Denel, which went on to design and develop missiles, including radar-based missile seekers and proximity fuses, for local use and export. Meanwhile, National Defence Research, Development Test and Evaluation (RDT&E) capabilities remained at the CSIR with a continued focus on the Department of Defence's (DOD) technology development tasks and on providing technological support to the Defence Force's force design, force acquisition, force preparation and force application.

5 Establishment of Digital Monopulse Tracking Radar Technology

The 1980s saw an escalation in the requirements for the modernisation of both the SA Army and SA Air Force GBADS. The radar team at the CSIR utilised some of the latest developments in Ka-band (35 GHz) technology along with the first generation of Intel single-chip digital signal processors and microprocessors to realise an experimental development model of a range-only tracking radar called NIMBUS. It was closely followed by the FYNKYK pseudo-coherent monopulse tracking radar. FYNKYK became quite famous in the SADF when, deployed as part of the Red Forces during force preparation exercises, it defeated existing SAAF countermeasures and flying tactics at the time and was credited with as many as 27 "kills" of ground-attack fighter aircraft during a single week of intensive "operations". This demonstrated the value of its modern technologies and the danger this holds should similar technologies be deployed by the enemy. It motivated the development of improved flying tactics and updated requirement definitions for self-protection equipment against such threats. FYNKYK digital monopulse tracking radar technology was transferred to the industry during the late 1980s and formed the basis of the newly-created tracking radar division at ESD, a private company formed by Reunert with the support of Armscor. ESD later became part of Reutech Radar Systems (RRS) who based their first industrialized tracking radar on this technology transfer.

Figure 7: The NIMBUS Ka-band range-only radar, integrated with the technology demonstrator of a 20 mm GBADS Gunnery System also developed at the NIDR, during field testing at the St Lucia test range.

Figure 8: The FYNKYK Ka-Band Monopulse Tracking Radar in its mobile laboratory during field testing against a Mirage F1 fighter aircraft outside Irene, near Pretoria.

6 Expansion into Digital Pulsed Doppler Tracking, Surveillance and Multifunction Radars

Starting with training courses conducted by international experts in their fields in the 1980s, digital Pulse-Doppler (PD) radar know-how was established in South Africa throughout the 1980s and 1990s. In 1989, the MECCANO pulsed Doppler tracking radar technology development programme was contracted to the CSIR. It included the development of a new generation of wideband, low side lobe level, monopulse antennas, coherent Travelling Wave Tube (TWT) transmitters, frequency-agile receivers and high performance, FPGA and firmware-based, pulse-Doppler processors. These were integrated into the MECCANO radar technology demonstrator. By the late 1990s, the programme culminated in the technology transfer to RRS of high-performance PD tracking radar technology along with a high-level design that satisfied the stringent requirements defined by the SA Navy (SAN) for operations in the challenging maritime conditions around the South African coast. These included high sea states, high winds, heavy rain and modern enemy ECMs.

Figure 9: The MECCANO wide band monopulse tracking radar antenna being tested on the rooftop of Building 44 at the CSIR in Pretoria.

Figure 10: The Reutech Radar Systems RTS 6400 Optronic Radar Tracker installed on the SA Navy frigate SAS Spioenkop.

RRS used the MECCANO technology and concept design in the detailed design and development of the Optronic Radar Trackers (ORTs) that they eventually manufactured and integrated on the new Valour Class Frigates of the South African Navy. To meet the stringent timelines for the integration of these radars on the ships, RRS contracted the CSIR to design and produce the advanced pulsed Doppler radar signal processors and the wideband, monopulse antennae used in the ORT as well as provide system-level support such as the waveform design. The ORT became operational in 2006 as part of the proudly South African air defence fire control system of the Navy's new frigates.

During the early 2000s, the CSIR Radar team continued to focus on enhancements of the tracking radar technology base in support of RRS' integration, testing and evaluation of the ORTs on the frigates along with carrying out performance improvements that were required by the SAN. One of these was to improve the tracking accuracy of the radar when tracking extremely low flying targets, such as sea-skimming missiles. This required some fundamental research into radar propagation over smooth, highly reflective surfaces such as a calm sea. Based on measurements made with the MecORT facility, a new tracking radar technique called Synthetic Height Profiling (SHP) was developed. After nearly 10 years, and many sea trials on board the frigates, the SHP algorithm was refined and qualified to meet its challenging performance specifications over a broad range of maritime conditions. The SHP algorithm was accepted and deployed to all the operational ORTs in the SAN.

In reaction to technology planning inputs from both Director Technology Development (DTD) in the South African National Defence Force (SANDF) and the Radar Division at Armscor during the early 1990s, the CSIR radar team investigated the latest international trends towards electronically steered, phased array antennas and their applications in multifunction radars. In 1995, Armscor accepted a CSIR proposal to develop a passive phased array radar antenna in a joint R&D project between the CSIR and Tellumat. It was specified for use along with technologies developed under project MECCANO to realise a technology demonstrator of a networked, multifunction target acquisition and tracking radar system for use in a modernized SA Army GBADS capability with robust ECCMs and the ability to defend against multiple simultaneous air attacks. The project was called SAFARI. While the CSIR team was developing the specifications and design of the rest of the SAFARI radar, Tellumat designed, built and tested the first modules of the experimental phased array antenna. This work soon proved that the relative phase stability and inter-channel phase calibration of such an antenna was a major challenge with the technology available at the time. Considerably more funding would be required to overcome these challenges.

At the CSIR, the Pulse-Doppler radar knowledge base was utilised not only in developing the tracking radar for the SAN but also to provide technical support to the SAAF and Armscor during the acquisition of the airborne, multifunction radar for the Cheetah C fighter aircraft upgrade program in the 1990s and the Gripen fighter with its advanced radar in the 2000s.

During the late 1990s, the SANDF cut funding for the SAFARI project as part of the suspension of several advanced technology programmes in the national defence industry. It was a major blow to the careers of many experienced professionals and even whole companies in the defence industry and resulted in the resignation of a significant part of the CSIR's experienced radar team.

7 Wide Area Persistent Surveillance Radar Technology

In 2003, first the SAN, and later the Defence Capability Planners at Joint Operations Division (J Ops) of the SANDF defined wide-area, persistent surveillance sensors for use as force multipliers in border safeguarding and peace support operations as high-priority requirements. Radar was identified as the primary sensor technology with the potential to satisfy asymmetric military and security-related requirements when considering the vast areas that need safeguarding in Southern Africa (including land and maritime border zones), the small and slow-moving objects of interest and the need for all-weather, day-and-night operations. In many applications, the radar's data would need to be fused with those from other sensors, such as electro-optical cameras, RF intercept receivers and direction finders. The data would need processing, distribution, display and recording to convert it into actionable intelligence. This is commonly referred to as a Command, Control, Communications, Computers, Information, Intelligence, Surveillance and Reconnaissance (C^4I^2SR) system of systems.

The CSIR Radar team soon realised that detecting objects of interest on the surface as well as low-flying aircraft over wide areas would require long-range sensors with a look-down capability located on high sites. In the absence of sites with enough height to provide line-of-sight conditions to low-level targets at the required ranges, a form of aerial platform would be required. Following the lead of the USA and their allies who were using aerostats operationally in Iraq and Afghanistan for similar requirements at the time, the CSIR team identified these cost-effective airborne C^4I^2SR platforms as a possible solution. Aerostats could be flown for uninterrupted periods of 30 days or longer at a much lower cost than aircraft and satellites

This was the start of a major R&D programme at the CSIR to develop such a long-range airborne C^4I^2SR system integrated on an aerostat. The programme, called AwareNet, started in 2004 and by 2011, with the support of the then Minister of Science and Technology, the proposal to develop an AwareNet system of systems as a national flagship programme was accepted by the Joint Crime Prevention and Security (JCPS) cluster of government departments. In parallel, South Africa signed a bi-national agreement with another country to participate in several joint defence-related R&D projects. The largest of these was agreed to be AwareNet.

Figure 11: The MecORT PD Radar Laboratory deployed in Simons Town in Sept 2010 to collect data and test AwareNet radar signal processing algorithms under realistic maritime conditions. This was part of a comprehensive C^4I^2SR field trial involving a team of 35 people, including a number of international collaborators.

These successes unlocked significant funding for the local development of C^4I^2SR concepts and advanced technology over 10 years. It also formed the basis of the thinking and the technology underpinning a new generation of surveillance radar technologies at the CSIR. Some of these were advanced pulse-Doppler radar detection, tracking, classification, and data fusion technologies. These were required to automatically sense small objects of interest on the surface of the earth or at low levels above it, distinguish them from the reflections received from the natural environment and classify them using radar-based, non-cooperative target recognition techniques. This information was intended to be fused with the information from other sensors and used as a near real-time source of intelligence and as a force multiplier for the command and control of defence and security forces. Based on the rapidly growing body of knowledge at the subsystem level, the system engineering work to select the aerostat and define the integrated C^4I^2SR system to be flown on it progressed well.

In 2013/14, economic conditions in both South Africa and its international partners' country took a turn for the worst. The main sponsors of the programme failed to attract the required funding from their respective governments. The AwareNet programme had to be suspended after a decade of exciting technical progress, growing international interest and recognition and the revitalization of the radar capability at the CSIR.

While AwareNet itself came to a halt, the CSIR radar team managed to attract funding for both new technology development as well as radar support services from several institutions and companies, both locally and internationally. A major local programme that was supported, was the Dual X- and L-Band Radar (DBR-X/L), a 3-D missile designation radar for an integrated GBADS concept proposed by RRS in 2005. The CSIR supported Armscor in the technical steering of the programme and took part in the development of its innovative 3-D sensing algorithms as well as some advanced ECCMs. In support of this work, the CSIR developed a detailed digital simulation of the DBR-X/L and took part in the technical steering workshops organized by RRS. In the period 2013 – 2015, the concept demonstration phase was concluded with some highly successful field demonstrations of DBR-X/L by itself and integrated with the land version of the Denel Umkhonto short-range air defence missile system. However, in 2016 the DOD implemented another round of funding cuts that put the SA Army's GBADS renewal project on ice and, with it, the product development of DBR-XL.

Other important initiatives in the period 2005 to 2015 in which the CSIR played important roles, included:

- The establishment of a post-graduate programme in radar engineering at the University of Cape Town (UCT) in 2011. A significant number of young, talented engineers received their post-graduate education in radar in this programme, which is still ongoing.
- The establishment of the South African Radar Interest Group (SARIG) in 2008. Its membership includes South African individuals and organizations with an interest in radar and who wish to foster radar as an industrial sector in South Africa on the one hand, and the use of radar in South Africa on the other. SARIG meets regularly and organises national level radar events such as the 2014 South

African Radar Conference to celebrate the 75th anniversary of radar in South Africa and the IEEE South African Radar Conference in 2015.

8 Integrated Wide Area Surveillance Sensors Systems

When security forces need to safeguard large areas against a threat that can occur anytime and anywhere in the area, using conventional armed patrols would entail large numbers of people and equipment, making it prohibitively expensive.

In 2012, rangers in the Kruger National Park (KNP) faced such a problem when rhino poachers were killing an average of 3 rhinos per day within a total area of 1.2 million hectares. Scientists estimated that should the killing rate increase any further, it could cause the extinction of rhinos in the KNP. By 2015, this number had already escalated to 5 per day. Senior security staff from the SA National Parks Board (SANParks) approached the CSIR to study the problem and urgently identify technological solutions that would be effective in the challenging environmental conditions and wide expanses of the KNP.

CSIR engineers and scientists concluded that a layered C^4I^2SR system, well-integrated with existing KNP systems, would act as a major force multiplier for the rangers in the park, similarly to how such systems supported modern military forces. It would require a wide-area surveillance sensor system (WASS) to detect, geo-locate, track, and classify poachers before they kill rhinos. It needed to be fully self-contained, re-deployable to remote high sites providing line-of-sight to the entry routes used by poachers and available for 24/7 operations while surviving the harsh temperatures, high winds, rain and lightning occurring at such sites in the KNP.

Using the insights and some of the technology already developed over the previous 12 years as part of the AwareNet programme, the CSIR radar team defined an integrated WASS based on radar for the detection, geo-location and tracking functions and a long-range, day-and-night camera system for the target classification function. They took responsibility for the design, integration, deployment, and testing of the integrated system – dubbed *Postcode Meerkat* by SANParks and the funders of the project, the Peace Parks Foundation who received donations from the Postcode lotteries in the Netherlands and Britain.

Due to the increasing poaching rate in the KNP, the Meerkat development project had to be executed in the shortest possible time. As far as possible, the team, therefore, used mature building blocks that could be integrated and modified to achieve the required functions and performance. They choose the RSR 904 Stealthrad surveillance radar produced by RRS and a long-range day-and-night camera system, custom-designed and developed by the CSIR's Optronic Systems team as the main sensors that could cost-effectively satisfy the stringent requirements.

Figure 12: The Meerkat integrated WASS deployed during its launch in the KNP in December 2016.

In December 2016, the first Meerkat concept demonstrator was officially launched in the KNP. Testing quickly proved that the sensors worked well, but that the rangers needed new concepts of operation (CONOPS) to effectively utilise the wealth of information provided by Meerkat. A technical operations manager (TOM) was appointed to work with the CSIR technical team to develop such CONOPS while conducting anti-poaching operations. Having access to the local technology and its original developers, source code and detail designs, Meerkat could be modified rapidly to support the evolving CONOPS. By mid-2017, the system was declared operational. It was deployed at a poaching hotspot in the KNP where, over the next two years, operations proved that it detected virtually all poachers in its 20 000ha coverage area and helped rangers carry out their optimised CONOPS effectively. SANParks was delighted with the results and presented the CSIR team with their 2018 Kudu Innovation Award.

During the optimisation phase of Meerkat, CSIR engineers identified several emerging requirements that could be addressed using the latest radar technology developments at the CSIR. This included Active Electronically Scanned Array (AESA) antennas, multichannel receivers, digital beamforming, software-defined signal and data processors, and the latest version of the GIS-based radar display, control and recording technology. By combining all of these with artificial intelligence technology, non-cooperative, radar-based target classification (NCTR) could be performed, and an automatically recognised situation picture produced. The first technology demonstrator of this new generation surveillance radar was implemented on the Ground Surveillance and Classification Radar (GSCR) development platform and showed promising results in its first tests in the KNP in early 2021. It doubled the area over which effective classification of humans could be performed compared to a high-performance optical classification system. Being radar-based, and not constrained by optical propagation conditions, it operated day and night and under most weather conditions as was demonstrated in February 2021 when testing was done under conditions of green foliage, strong winds and rain. When fully developed and industrialised, such a radar-only WASS can be used in more available, easily deployable, and cost-effective integrated surveillance sensor systems covering even larger areas. Systems based on GSCR technologies are expected to prove effective in land and coastal border safeguarding operations, in rural industrial areas, national key points and farming district protection, as well as in traditional military applications.

Figure 13: The GSCR with its separate transmit and receive AESA antennas deployed in the KNP for its first set of field trials in February 2021.

9 Modular AESA Radar Technology

The loss of funding for the SAFARI phased array radar development program in the late 1990s, together with the resulting belief that South Africa could not afford phased array radars, meant South African radar development continued to be based on mechanically scanned antennas for the next 17 years.

However, by 2015 a new generation of low-cost C-band microwave components had come on the market as a result of huge investments by civilian component manufacturers in the cellular phone and Wi-Fi markets. RF and radar engineers at the CSIR believed that by using these components along with some innovations at the microwave and digital assembly levels, affordable and modularly extendable, AESA antennas could be realised cost-effectively in South Africa. In this type of array antenna, the radar’s transmitter amplifier is distributed across the array in the form of many small, low-cost, solid-state amplifiers. This saves cost and greatly improves the mean-time-between-critical-failures (MTBCF) of the radar’s transmitter. Moreover, these arrays could be realised without using export-controlled components, thereby broadening the potential overseas market for future products.

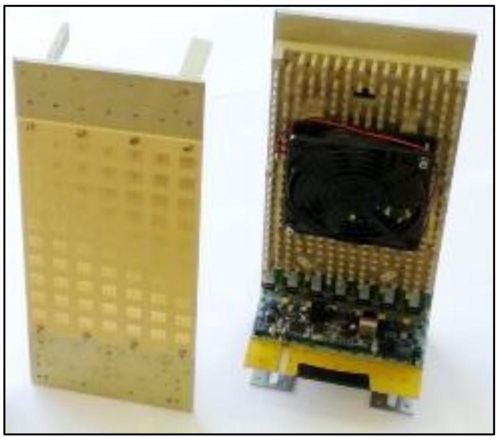

Figure 14: C-band AESA panels developed for the transmitter node of the SAMURAI multi-static drone surveillance radar.

An opportunity to demonstrate this innovation arose when armasuisse, the Swiss Federal Office for Defence Procurement, contracted the CSIR for a technology development facility for drone surveillance radars, called SAMURAI. They required a multi-static radar configuration and agreed to the use of the AESA antenna in the transmitting node.

The success of the transmitter panel, and its lower price compared to similar products worldwide, led to further CSIR investment to first mature the receive antenna version of this technology, and later, also the combined transmit/receive (T/R) panel technology as required for monostatic radars.

The C-band AESA panel technology enables the realization of different types and sizes of radar faster and at a lower cost than ever before. Radars are being designed using a single 16 x 9 cm panel, all the way to a design using 380 panels in a 5.5m x 1m array. As newer, high-power amplifier modules and different antenna panel sizes become available, it is becoming increasingly possible to design bespoke solutions for specific problems, while optimising for radar size, weight, power and cost, or a subset of these parameters.

Figure 15: An integrated C-band phased array antenna consisting of three 7 channel AESA T/R panels.

During the period 2015 to 2020, the C-band phased array technology was used in the definition of several new radar concepts, including the SAMURAI drone detection radar, the Ground Surveillance and Classification Radar (GSCR), several UAV SARs, a medium-range surveillance radar with naval and land-based variants and a spaceborne C-band SAR with a foldable 5.5m x 1 m array antenna.

10 Radar Sensors for Aircraft Self Protection

Jumping to a different type of radar, already in 2007, the South African Air Force (SAAF) identified a future requirement to replace the ultra-violet (UV) missile approach warning (MAW) sensors on their aircraft with radar sensors to counter advances in missile technology that reduce their UV signatures. The CSIR was tasked with assessing the feasibility of building radar-based MAW systems for SAAF helicopters locally. The major challenge was to develop radar sensors that can operate in the harsh on-board conditions, and within the allowable size, weight, and power consumption (SWaP) constraints to fit into the small spaces available on existing aircraft. Such radars need to detect small, fast-approaching missiles in the presence of large reflections off the ground and in the proximity of moving elements such as a helicopter’s rotor blades. Detection ranges must be long enough to allow sufficient reaction time for the MAW sensor to trigger the automated missile countermeasure systems timeously and effectively.

The radar MAW technology development programme at the CSIR was funded by the Department of Defence (DOD) and was undertaken from 2007 to 2014. Two radar sensor systems were developed. The first took the form of an airborne radar laboratory which was flown on multiple missions on board a SAAF ORYX helicopter to characterise the conditions under which a radar missile approach warning radar would need to operate. Engineering data collected with this system enabled CSIR engineers, in collaboration with Saab Grintek Defence (SGD), to realise a second radar sensor, shown in Figure 16. This compact radar sensor satisfied the SWaP requirements of the airborne platforms, whilst providing the required missile detection, localisation, tracking and clutter suppression performance. It proved the feasibility of a future product based on technology that can potentially be industrialised in South Africa and delivered to the SAAF when required.

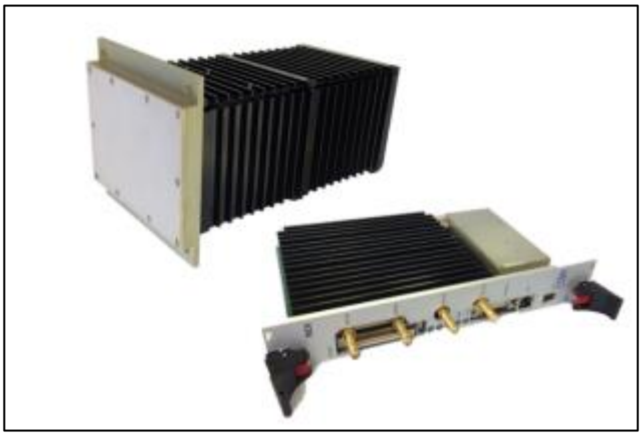

Figure 16: The final hardware of the sensor demonstrator developed under the radar missile approach warning program, conforming closely to the size, weight and power requirements of a final product system.

In 2016 SGD identified a frequent client requirement for a hostile fire indication sensor (HOSFIN) for helicopters. Such a sensor needed to alert the crew to the presence and origin of bullets from small arms fired at the aircraft, in time for the pilot to perform effective avoidance manoeuvres.

Radar technology was identified as a potentially attractive solution, since, in principle, a radar's performance should be unaffected by muzzle flash suppressors on rifles, platform noise, the sun, temperature, time of day, atmospheric conditions, dust, fog, and even rain. Using radar, the bullet's location, speed, and trajectory can be measured, thus allowing for both miss distance and shooter location to be estimated and communicated to the crew.

In partnership with SGD, the CSIR developed a compact proof-of-concept radar sensor demonstrator for helicopter use, which exhibits the required functional and performance characteristics. Practical field testing of this demonstrator on a hovering helicopter successfully demonstrated small arms fire detection and trajectory tracking during live bullet firing tests, as shown in Figure 17. Development is planned to continue in 2021 to develop a South African product for peace support operations worldwide.

Figure 17: Live bullet firing tests with the hostile fire indicator hardware demonstrator mounted on an Alouette II helicopter.

11 Synthetic Aperture Radar

Most people know radar for its ability to detect and track aircraft. However, an American mathematician and engineer, Carl Wiley, first demonstrated in 1951 that radar can also be used to map and image the earth, and more recently, even other planets at long standoff ranges, at incredibly high resolution and through clouds, smoke and dust. This is accomplished by a class of airborne and spaceborne radars known as Synthetic Aperture Radar (SAR). SAR makes radar images by using the time delay of the reflections of objects on the ground to resolve and measure their locations in range. Simultaneously it measures the Doppler frequencies in each range resolution cell. From the way that these change as the radar flies past the scene, cross-range resolution and localisation data can be obtained. This process produces 2D images that appear similar to airborne photography. The intensity of each 2D pixel in the radar image represents the magnitude of the radar reflections from the corresponding resolution cell on the ground.

The CSIR entered the world of SAR in 1995 through a joint project with the University of Cape Town and funded by the SANDF, for the development of an experimental SAR called SASAR. It was developed as a fully polarimetric SAR, operating around 100 MHz. The low carrier frequency had the advantage of penetrating

Figure 18: SASAR system installed on a SAAF C-47TP Turbo Dakota. Notice the VHF Antennas protruding from the aircraft skin aft of the rear windows.

Figure 19: 12m resolution Fully Polarimetric SAR image of the the Botriver lagoon area and its northern surrounds produced in late 1999

through foliage and even the upper soil layer in dry areas. The technology was tested on a SAAF C-47TP Turbo Dakota aircraft in several flight campaigns in the late 1990s and early 2000s. These showed significant promise for both military (finding targets obscured by foliage at long stand-off ranges) and civilian applications (e.g. geology and mining by penetrating to sub-surface levels and uncovering structures).

Unfortunately, in the early 2000s, the SANDF opted for international SARs rather than locally developed systems and sold the SASAR aircraft. However, the SAR technology base lived on during the 2000s through R&D in high-resolution radar cross-section (RCS) measurement techniques as well as inverse SAR (ISAR) target recognition techniques in support of the AwareNet programme (see above).

Figure 20: The DSI SAR airborne facility installed in an Atlas Angel aircraft ready for flight tests.

As a follow-up to the SASAR system, an X-Band SAR was developed in the early 2000s to find a means to generate higher resolution SAR images. An early experimental demonstrator developed as a rooftop testbed at the CSIR used stepped frequency techniques developed in conjunction with UCT that allowed imaging with bandwidths greater than 1GHz. It produced imagery with an astounding 15cm resolution. This was a unique achievement at the time.

Figure 21: C-band SAR image of an agricultural area near the Hartbeespoort dam, produced with the DSI SAR facility in 2017.

Around 2014, it became clear that SAR technology was a game-changer in many areas and without access to airborne and spaceborne SAR capability, South African industry would be left behind. Also, the burgeoning Unmanned Aerial Vehicle (UAV) industry in South Africa needed a locally-produced SAR sensor to allow access to developing international markets. Efforts were further fuelled by the advent of the so-called ‘spaceborne SAR wars’ in which several international commercial companies were competing as producers of constellation-based SAR imagery covering any spot on earth every day. This prompted a strategy to develop the first locally-produced satellite SAR, starting in 2015.

Figure 22: Looking forward, this image shows a CAD rendering of the design for a satellite SAR payload and bus, jointly being developed with a South African micro-satellite manufacturer.

The market pull, together with funding from the then Department of Science and Technology (now Department of Science and Innovation), enabled the development of a new generation airborne SAR technology development facility as a first step to re-establish SAR capability in South Africa. It operates in the C- and L-bands and can produce multi-frequency, multi-polarisation, high resolution (60cm) imagery. Thus far, some SAR processing techniques, several UAV SAR concepts and a Spaceborne SAR concept had been developed. All of these concepts make use of the CSIR C-Band phased array panel technology.

12 Radar Simulation, Measurement and Development Facilities

Over the years, the CSIR has built, maintained and operated a range of radar-related facilities to support ongoing national radar development, testing and evaluation. In addition to specialised microwave, RF, digital and radar integration laboratories at the CSIR Pretoria campus, these include a national antenna measurement range at Paardefontein, a transportable wideband dynamic radar cross-section (RCS) measurement radar called FYNMEET, a reference tracking radar based on the FYNKYK technology demonstrator, the STATIC inverse synthetic aperture RCS measurement facility at Air Force Base Waterkloof and a continuously-refined range of digital RF memory-based EW T&E facilities called ENIGMA. In the 2000s, these facilities were extended to include the transportable MecORT pulse-Doppler tracking and measurement radar facility, its outdoor integration and testing environment on the CSIR campus and a transportable sensor RDT&E command centre.

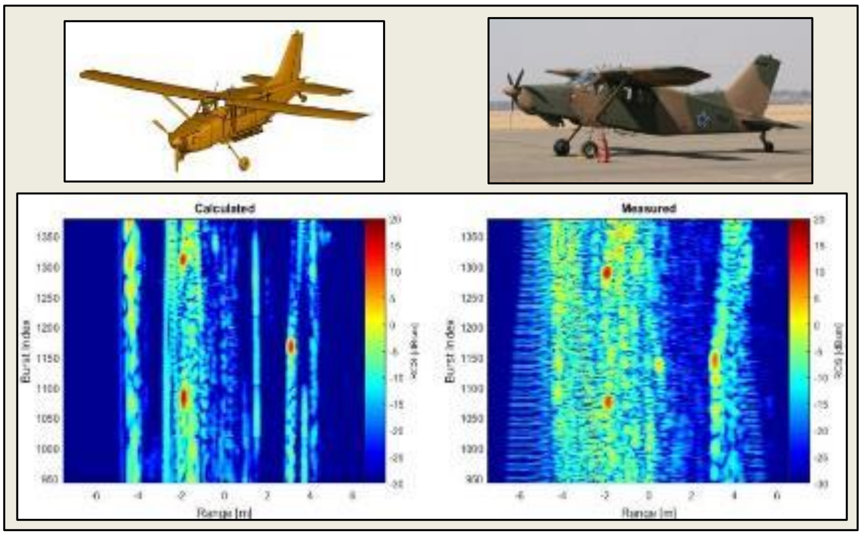

Figure 23: High Range Resolution (HRR) RCS calculated with SigmaHat on a CAD model constructed from laser measurements (left) vs HRR RCS measured with MecORT on the actual aircraft in flight (right). The regular modulation on the left of the measured data is caused by the rotating propeller.

In the 2000s, it became apparent that an integral part of understanding radar cross-section (RCS) measurements, is the ability to predict RCS characteristics using computer modelling. Commercial, off-the-shelf EM modelling suites were either very costly, export restricted, or simply lacked performance when trying to model electromagnetically complex targets such as aircraft or ships. The CSIR team developed a highly successful in-house EM code named SigmaHat, which allowed efficient and sufficiently accurate modelling of targets. They successfully verified and validated this code against measurements made with FYNMEET and MecORT.

13 University Research and Education, and International Networking

As a member of the South African system of innovation, the CSIR radar team played a significant role to foster and grow radar education in South Africa and to support international collaboration in radar R&D. In collaboration with UCT and international partners, the CSIR was instrumental in the establishment of the UCT Master of Engineering Programme specializing in radar. It is a taught MEng in radar where students are exposed to top radar researchers from around the world, each lecturing in block weeks. They can also perform their own research and submit it as part of a dissertation or research report for degree purposes.

Over the years, members of the CSIR radar team have been playing an active role in the international radar community, publishing papers at international conferences, and, since 1980, attending the series of International IEEE Radar Conferences that rotates between the USA, France, China, Australia and the UK in a 5-year cycle. Utilising this network, the CSIR invited international radar experts to present short courses on advanced radar topics in South Africa and, thereby, exposed many more South Africans to these learning opportunities. This is ongoing, with several of the CSIR research staff currently serving on IEEE committees, NATO SET panels, and other international fora to further the cause of radar globally.

These interactions have elevated the international stature of South African radar and contributed to the IEEE's decision to allocate to South Africa the hosting of the first IEEE Radar Conference to be conducted in Africa. It was held in Johannesburg in October 2015 as part of the commemoration of 75 years of radar in South Africa (and 80 years in Britain) and was attended by 250 delegates from 24 countries, of which close to 40% were from overseas.

14 Conclusion

Looking back over the long history of Radar RDT&E at the CSIR, what stands out is the passion, dedication and teamwork of successive generations of electronic engineers, scientists and technicians who continued to maintain and grow the radar profession in South Africa despite changing political decisions and economic fortunes. They made it their business to become professionals in radar and its multitude of sub-disciplines with the single-minded aim to employ their talents and enthusiasm to serve South Africa and its needs for defence, peace, safety and security on the one hand, and industrial growth on the other. Combining the exponential growth in radar knowledge in the world with the explosion in new materials, components and tools with which to implement new radar innovations, they continue to achieve new heights of functions, performance and impact while guiding new generations of talented young people into exciting and fulfilling careers.

15 Acknowledgments

Information and photos used in the Introduction are based on B. A. Austin, “On the Development of Radar in South Africa and Its Use in the Second World War,” URSI Radio Science Bulletin, No. 358, September 2016, pp. 69-81. The rest of the information and photos are from CSIR archives.

.