Does the CSIR have the sensor capabilities to put South Africa on the radar screen?

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Abstract

Through many years of research and development into radar sensors, the CSIR has made a significant contribution to the strategic and industrial capabilities of South Africa. The continued national investment into radar research and development enables a growing number of scientific and technological breakthroughs as well as test and evaluation capabilities that positions CSIR at the forefront of new radar sensing capabilities.
The impact and quality of the research and development work will be demonstrated by reviewing the following:

1. Technological support to the South African National Defence Force (SANDF),
2. Contributing to the national human capital development effort by providing opportunities for engineering skills development opportunities,
3. Supporting the SA defence-related industry to grow its international competitiveness,
4. International Research and Development (R&D) partnerships and global bench-marking.

1. Introduction

1.1 What is radar?

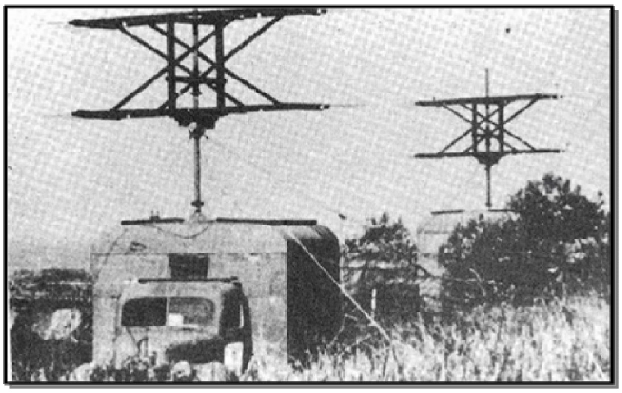
RADAR is a system that uses radio waves to detect, determine the direction and distance and/or speed of objects such as aircraft, ships, terrain or rain and map them. A transmitter generates and amplifies radio waves, an antenna focuses and radiates them, they travel to the target where they are reflected, the same or another antenna receives the reflection and a receiver detects it. Although the radio signal returned is usually very weak, radio signals can easily be amplified, so radar can detect objects at ranges where other emission, such as sound or visible light, would be too weak to detect.

The term *RADAR* was coined in 1941 as an acronym for **Ra**dio **D**etection **a**nd **R**anging. This acronym of American origin replaced the previously used British abbreviation *RDF* (*Radio Direction Finding*).
Radar functions and applications include search and detection, target tracking, reconnaissance and surveillance, air traffic control and navigation, space and range instrumentation and weather sensing.

1.2 History and context

Some of the historical highlights of radar at the CSIR are:

- In 1939, top secret radar technology was transferred to South Africa as part of the Allied war effort. Dr Basil Schonland, founder and first president of the CSIR, led a team who built the first South African radar, the JB1 (after Johannesburg) based on this technology.



- After the war, this team was transferred to the CSIR and built the JB51 for the South African Air Force (SAAF). The SAAF used it for many years in Force Preparation exercises.

- During the 1960s South Africa received another technology transfer, this time from France as part of the joint development of the Cactus radar guided air defence system.

- Throughout the 1970s radar technology at the component and subsystem levels were developed and used to upgrade operational radar systems. Breadboard demonstrators of a missile seeker and a pulse compression target acquisition radar were also developed and tested during this period.

- During 1983 a contract was placed on the CSIR to design and develop a full monopulse tracking radar technology demonstrator. It was to operate at an extremely high radar frequency and utilize the latest digital signal processor and microprocessor technology. The Fynkyk radar, as it became known, was completed in 1988 and integrated in a mobile laboratory for field trials and demonstrations. During the past decade, Fynkyk was extensively deployed in support of engineering measurements and South African Air Force and Army force preparation exercises.

Figure 1 Fynkyk radar

- The Meccano breadboard radar technology demonstrator was contracted in 1990. The aim was to establish a variety of modern radar technologies in support of the new generation of radar applications. These included modern flexible waveform generation, digital pulse compression, pulsed Doppler processing and advanced Electronic Counter-Countermeasures (ECCMs). This radar technology was transferred to a South African radar company, Reutech Radar Systems, who utilised it in the development of the Optronic Radar Tracker (ORT), now fully integrated on the SA Navy's Valour class Frigates.

- In Oct 2005 CSIR received the MecORT X-band monopulse pulse-Doppler radar and electro-optical tracking laboratory.

2. Radar capability

A capability must be evaluated in the context of the organisation in which it exists and in relation to the functions and the roles of such an organisation. In this case, the type of organisation is a "Defence Evaluation and Research Institute" (DERI). The definition of such an organisation, including its roles and functions are briefly explored in this section.

2.1 Definition of a DERI

The term Defence Evaluation and Research (DER) generally refers to "*the whole field of Science and Engineering in which Technology is generated and applied through the performance of Research and/or Development, Test and/or Evaluation, or Operational Research in Defence applications*". [1]

2.2 Roles of a DERI

In general, the following roles were found to be common in DERI-like organizations worldwide [1]:

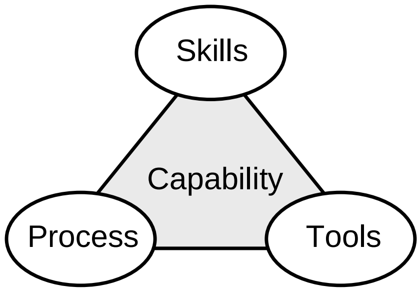
1. Provide scientific and technological (S&T) support to the Department of Defence (DoD) to enable them to be knowledgeable buyers of equipment (on acquisition projects).

2. Provide S&T support to the DoD (specifically the Defence Force) to enable them to be knowledgeable users of equipment (operational test and evaluation, training, force preparation, intelligence gathering and interpretation and operations).
3. Ensure continued effectiveness of military systems while minimizing the cost of ownership by performing the DER part of pre-planned maintenance, logistic support, and modifications to improve reliability.
4. Maintain the winning edge through the performance of some of the DER part of the development of equipment with unique capabilities or, when conditions or doctrines change or equipment becomes obsolete, by supporting the continued product improvements and/or upgrades.
5. Provide equipment to satisfy unique requirements in cases where the Defence Industry cannot do so.
6. Provide strategic independence in some niche areas by enabling independent indigenous military product development, manufacturing and commissioning, thereby reducing supply vulnerability and improving the probability that special, differentiating features that may ensure a winning edge in battle remain secret.

If these are the roles of a DERI, then what are the capabilities which are required by such an organisation to enable it to perform these roles efficiently through activities such as research, development, test and evaluation?

2.3 Definition of a capability

A capability is commonly defined as an integrated combination of three components [2]:



1. **Skills:** (people and the knowledge that they have) form the basic building blocks of a capability.
2. **Process:** (routines, procedures, structures, responsibilities, accountabilities, etc.) enable the collaboration between individuals.
3. **Tools:** (models, computer programs, laboratory equipment, prototypes, fieldable concept demonstrators, etc.) allow humans to interface more effectively with their environment and enable them to capture and manipulate knowledge.

2.4 The shape and size of the capability today

CSIR Defence, Peace, Safety and Security consists of seven competency areas. The Radar capability is represented by the Radar and Electronic Warfare (EW) competency area. The Radar & EW competence provides DERI related offerings such as contract research and technology development, operational test and evaluation support, acquisition support, performance requirement studies, expert consultation and training to the South African National Defence Force (SANDF), other international DERI-like institutes, local industry and international industry.

Skills:

The competency’s personnel complement of 80 people (90% of them electronic engineers), are organised into four groups that work in close cooperation, to provide offerings in the areas of platform self-protection, air defence, test and evaluation facilities and the emerging area of persistent real-time surveillance.

Each of the major capabilities is supported by people, facilities and processes in the different groups, and the capabilities are in many cases established across research groups. For this reason the competency has a strong culture of collaboration.

The ***Radar Research and Applications group*** *and the* ***EW Research and Applications group*** mostly provide contract research and operational test and evaluation support, acquisition support and training to the local SANDF client and local Radar and EW industry. The excellent relationships with the South African Navy (SAN), the South African Air Force (SAAF), the SA Army, DoD Technology Acquisition groups and Armscor allow these groups to make an impact in the local user community. The group also collaborates with the local universities, an activity supported by funding under the LEDGER contract from the SANDF.

The ***Experimental EW Systems group*** *and the* ***Experimental Radar Systems group*** are responsible for the design and development of technology demonstrators, test and evaluation facilities and simulators. These groups have most of the skills required for experimental development work. The skills include system engineering, signal analysis, high speed digital hardware design and implementation and radio frequency design and implementation. The direction of the technology in this group is purposefully aligned with the requirements of the local SANDF clients to impact on the local client sector.

Tools:

The competency's most important tools are the ***key research facilities*** they operate, maintain and upgrade to provide measurement, interpretation and system evaluation services:

Fynmeet is a microwave measurement sensor, capable of performing radar cross section (RCS), Chaff and Jammer power measurements over the frequency range of 6,5 to 17,5 GHz on aircraft, decoys and emitters, under dynamic conditions (i.e. flying or sailing).

MecORT is an X-band monopulse pulse-Doppler radar and electro-optical tracking laboratory. The system is built into a number of containers that can be deployed in the field. Its advanced data display, capture and analysis capability makes it ideal for advanced radar and electro-optical research.

Enigma is an electronic warfare hardware-in-the-loop simulator system. The simulator is based on high resolution digital frequency memory (DRFM) technology developed at the CSIR. The Enigma system is a radar stimulator able to capture a radar pulse, modify it and play it back to the radar, thus emulating various aircraft manoeuvres as well as typically employed Electronic Countermeasures (ECMs).

Modelling & simulation and analysis also play a key role in providing services to predict and analyse the performance and behaviour of radar & EW systems.

Processes:

The ***processes*** that form an integral part of the competence's capabilities include research processes, teaming processes, system engineer processes, hardware, firmware and software development processes, modelling and simulation processes and field trial processes. The current division of the research groups is largely due to the significantly different processes that have to be followed in applications research (spiral process with quick turn-around and significant redirection) versus technology research and development processes (where requirements are more clearly defined and driven directly by client needs).

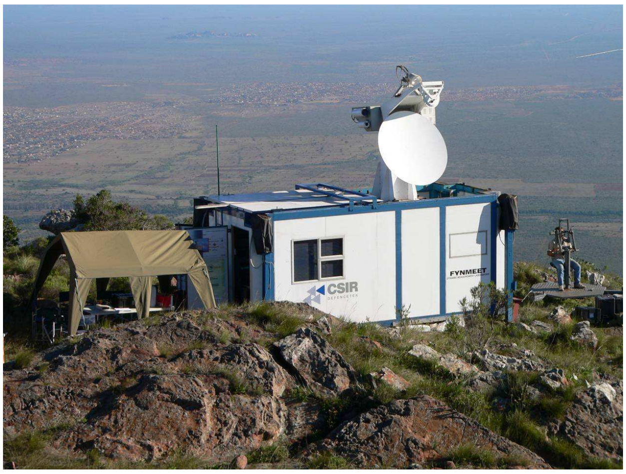


Figure 2 Fynmeet deployed in support of the South African Air Force

3. Technological support to the South African National Defence Force (SANDF)

3.1 Evaluating a radar system on the Navy's Frigates in pursuit of watertight defence

The CSIR evaluated the effectiveness of the electronic counter-countermeasures (ECCMs) of the optronic radar tracker (ORT) on South Africa's new Navy Frigates. The ORT is a key component of the Frigate's defensive systems against attack from incoming missiles and aircraft. A recent strike on a USA warship off the Syrian coast by a shore-launched missile demonstrated the vulnerability of such Navy assets when operating close to the shore, as would be required when the Frigates are employed to support African peace support operations.

The CSIR undertook the project using the knowledge and test infrastructure (Enigma) built up at the CSIR over a 15-year period. Tests had been conducted at the Simon's Town Naval base and results were analysed to evaluate the system's ECCM effectiveness. This has demonstrated the value of having a local capability to perform tests too sensitive to outsource.

3.2 Providing Acquisition Support on the Gripen Aircraft Radar

The primary sensor on the Gripen fighter aircraft is a state-of-the-art multifunction radar system. In support of the Gripen aircraft acquisition project, the South African Department of Defence (DoD) established an office at SAAB in Linköping, Sweden in 2000, manned by personnel from the South African Air Force (SAAF) and Armscor. DPSS has been providing specialist technical support to the Gripen acquisition project and this office during the past decade.

The support involves impartial systems modeling and performance prediction, comparing own performance predictions with that of the supplier, resolving differences, signing off on acceptance test procedures and results at different levels in the systems hierarchy, reviewing specifications, designs and test results, and participating in technical negotiations. In addition Electronic Counter-Countermeasures (ECCM) requirements were defined, its implementation by the supplier were studied and accepted.

As a result the SAAF is receiving a radar that is cost effective, maintainable, testable and that meets the SAAF's requirements. The radar was tailored to South African needs and is suitable for deployment in the region (which is very different from the European environment).

3.3 Ensuring that naval radars do not lose their sense of direction

The propagation of electromagnetic waves in the vicinity of the earth's surface is always affected by reflections of these waves from the surface and objects on the surface. This induces extra propagation paths for the electromagnetic waves which are referred to as "multipath propagation". Multipath propagation leads to constructive and destructive interference of the waves, thus causing the received signal to fluctuate in an unpredictable manner. (This same phenomenon causes cellular phones to drop calls.) Multipath can also degrade the accuracy with which a radar can measure the height of a target above the surface of the earth. This is especially true for low-flying targets over the surface of the ocean.

A project was established at DPSS in 2004 to address this internationally recognised challenge for naval radar. During the subsequent years, mathematical and simulation models of the multipath phenomenon have been developed by researchers at DPSS. The development of these models has been underpinned by regular tests on South African radar systems in conjunction with the South African radar manufacturer, Reutech Radar Systems. The models allowed the researchers to develop an algorithm which counteracts the effect of multipath propagation. The algorithm was then tested on data captured using the MecORT system. The results of these tests enabled the implementation of the algorithm in MecORT as a technology demonstrator. In May 2008 the algorithm was tested under closed-loop tracking conditions in False Bay near Simon's Town using the MecORT system. The deployment culminated with a demonstration of the algorithm against a Hawker Hunter jet at low level over False Bay. The maximum speed the jet obtained was 950 km/h. These tests demonstrated that the algorithm significantly improved the measurement accuracy of the radar under operational conditions.

Figure 3 MecORT deployed near Simon's Town to evaluate anti-multipath technology

4. Contributing to the national human capital development effort by providing opportunities for engineering skills development

The following was clear from an investigation into the status of the existing engineering population and pipeline in South Africa:

- “The capacity problem in engineering is a world-wide phenomenon, but equity issues and migration further complicate the matter in South Africa. Engineering employment declined over the period 1995 to 2004”. [5]

- Although there was an improvement in engineering graduations in some disciplines between 2000 and 2004, this was still not enough to address the shortages of engineering professionals overall. The ratio of engineers to population is very low in South Africa with only 1 engineer for every 3166 people, compared to Brazil (1:227) and India (1:157) [5]

- Of the 351 503 successful matriculants in 2006, 25 217 (7.1 %) passed Higher Grade Mathematics and 29 781 (8.5%) passed Higher Grade Physical Science - an entry requirement for a graduate degree in engineering. There is unfortunately not an increasing tendency in the number of matriculants fulfilling this requirement.

The challenges associated with this reality were acknowledged by the South African government and several initiatives have already been launched to address it. The question we considered during our strategic discussions and work sessions was: *We are a significant entity in the South African engineering community and a recipient of substantial SA government R&D funding. How can we make a contribution towards addressing this national human capital development challenge?* We decided to undertake the following initiatives in close collaboration and with guidance from the DPSS Human Resources Manager:

- To retain intrinsically motivated R&D engineers, attention has to be given to motivators beyond the hygiene factors (e.g. salaries), such as:

1) creating an exciting and challenging work environment where everybody can develop to their full potential irrespective of race, gender or culture and increasing the number of black and female engineers to well above the national engineering population demographics. As part of the national drive to increase the number of females in engineering our female engineers took part in national conferences. Three of our female engineers also shared their positive experiences during a recently screened SABC programme on “Women in Science”.

2) Providing opportunities for contributing to a common good, such as mentorship or 'giving back'.

3) Competing successfully in the international arena.

- To increase the number of graduates, we are:

1) Investing a third of the Radar & EW Competency Area’s parliamentary grant (R1.5 M) in post-graduate studies and continued education of our permanent personnel in order to increase our competitiveness in the global engineering market.

2) Initiating a vacation work programme aimed at providing engineering students with an opportunity to gain experience in a high-technology research and development environment. During the past three years more than a 100 students took part in R&D projects in Radar & EW under the guidance of experienced CSIR researchers.

Figure 4 One of the vacation work groups with their mentors

3) Initiating a studentship programme that provides engineers an opportunity to, as an integrated member of a strategic research team, obtain a MSc or PhD degree on research performed in close collaboration with a local university. Studentship engineers are mentored by internationally recognised CSIR researchers and have access to data recorded using world-class radar measurement facilities. The success of this new programme was demonstrated by the number of best paper awards the studentship engineers received at local and international conferences.

4) Launching an internship programme in response to the identified need for recently qualified engineers from Academic and Technical Universities to gain work experience. The aim of this initiative is to provide an accredited training programme under the leadership of an engineer with more than 35 years of experience in engineering research and development.

- To increase the amount of engineering students, we are establishing an interactive exploratorium and are taking part in Scifest and Sasol Techno X initiatives to stimulate learner's interest in science and engineering as well as programmes supporting teachers of science and mathematics.

Figure 5 Learner arriving during Sasol Techno X, August 2008

5. Supporting the SA defence related industries to be internationally competitive

The South African Navy's new Valour class frigates are considered to be among the most advanced of their kind internationally. The sensors are the eyes of the ship and the radar technology on board is of a high quality, relative to international standards. By developing the tracking radars in South Africa, R350 million was kept in the country and provided the local scientific and engineering community with R&D opportunities. This enabled scientists and engineers to apply and grow their knowledge through real-world experiences in developing and optimising a radar for uniquely South African conditions. It also contributed towards positioning the local industry for international export contracts such as the R150 million contract that was recently awarded to Reutech Radar Systems, in conjunction with Norway's Electronicon. This four-year contract will cover the supply of radar equipment for five ships in the Royal Norwegian Navy. CSIR and Reutech Radar Systems are contributing to the international competitiveness of the national radar cluster through the development of radar technology that will have applications in air defence and maritime surveillance.

Figure 6 A South African Navy Valour Class Frigate

6. International R&D partnerships and global benchmarking

6.1 Countering a serious threat with home-grown technology

During the 1980s advances in electronics technology resulted in major progress in the development of radar technology. The same advances in digital electronics that enabled the development of personal computers were utilised to develop custom-designed digital electronic computers or so-called radar digital signal processors. The digital signal processors and advances in other radar building blocks led to the development of a new generation of radar systems called coherent pulse Doppler radar. These radar systems with their powerful signal processors could utilise coded and highly agile waveforms that greatly enhanced their capability to detect and track aircraft and other objects of interest. It also gave them the ability to suppress signals generated by the platform self-protection systems that existed at the time.

Platform self-protection systems are designed to protect military platforms such as aircraft and their associated military personnel against weapon systems that are guided by radar and/or optronic sensors. Engineers in the USA took the lead in the development of a new device that could counter the threat posed by pulse Doppler radar technology. This device, which utilises very high-speed digital electronic hardware, has the capability to receive, modify and retransmit radar pulses in a way that creates false targets which are, for the radar, almost indistinguishable from real targets that result from the reflection of electromagnetic energy from aircraft or other platforms.

When it became clear by 1988 that Digital Radio Frequency Memory (DRFM) technology would not be available for export to SA, the DoD decided to contract the CSIR to initiate a local development programme. This programme had two major aims namely to develop know-how to firstly **design the advanced electronic hardware** required for these devices and secondly the know-how **to program** these devices **to generate effective countermeasures** against specific pulse Doppler radar systems. This programme became one of the most successful technology development programmes conducted at the CSIR and resulted in a number of unique benefits for South Africa:

- The development of the Enigma Radar target and Electronic Counter Measure (ECM) simulator that is utilised to evaluate the level of protection SA radar systems have against electronic attack.

- Wide-spread international recognition for the CSIR's expertise in this area which resulted in several contracts for the supply of DRFM-based test systems. These contracts facilitated the continuous improvement of the DRFM technology. A recent benchmarking opportunity in the USA indicated that the CSIR's fourth generation DRFM hardware is a world leader with respect to its real-time digital signal processing capabilities.

- Know-how on the utilisation of DRFMs to protect the personnel and platforms of the South African National Defence Force during operation where they have to face the threat of pulse Doppler radar guided weapon systems. This is know-how that cannot be acquired from overseas.

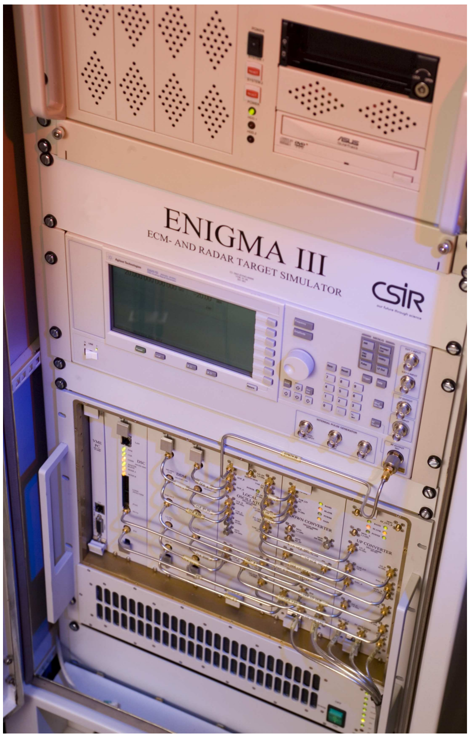


Figure 7 Enigma radar target en Electronic Countermeasure Simulator

6.2 Positioning South Africa on the international radar screen

The CSIR's aim to enhance its scientific, engineering and technological (SET) excellence resulted in a strong drive to increase collaboration with the international radar & EW community. Some of the highlights of the last two years that resulted from this drive are:

- Completion of a post-doctoral study in collaboration with the University College of London on the detection of small boats in sea clutter.
- The launch of a website that made a unique dataset of Fynmeet radar measurements of sea clutter and small boats available for international research. SA received strong recognition during a recent radar conference for the contribution this data set is making to the international research effort.
- Publishing of *5* peer reviewed journal articles
- Presentation of *17* Conference papers
- Presentation of DRFM professional development courses on invitation in the USA and Brazil
- Very favourable response received from reviews of the radar capability and research outputs by a panel of local and international radar research experts
- Substantial increase in the number of international collaborative contract R&D projects and significant progress made towards establishing long-term strategic R&D partnerships

7. Conclusion

This paper investigated the progress made with establishing a radar capability at the CSIR in terms of the impact made in relation to technological support to the SANDF, contribution to the Defence related industry and international R&D partnerships and benchmarking. From the recognition the competency received we are of the opinion that CSIR's radar capability has appeared on the world's radar screen. It is however clear from the aspects that were investigated that this progress was highly dependent on close collaboration and partnerships with the SA DoD and SANDF, local and international universities, local industry and international strategic R&D partners. In light of this reality and the challenges we face as an organisation and country it is by no means guaranteed that this "blip" on the world's radar screen will remain there. If we want to continue to grow the radar echo (in radar terms the "radar cross section") of the return the world sees on their radar coming from South Africa, we will need to continue to work strategically and with dedication towards a well defined vision for the future of this radar sensor capability.

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