On the Development of Radar in South Africa and Its Use in the Second World War

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Abstract

The first radar echo was received in South Africa on December 16, 1939. The apparatus used in that first trial was designed at the University of Witwatersrand in Johannesburg, by a team led by Basil Schonland, Professor of Geophysics at the university, based on information supplied by Britain. With its designers soon in uniform as soldiers, the equipment operated in many theaters of war in Africa, the Sinai, and in Italy.

1. Introduction

South Africa declared war on Germany on December 6, 1939. It was a close-run thing, because the divisions within parliament were stark. The Nationalists favored neutrality, with some even openly sympathetic to Hitler. The Unionists, under Jan Smuts, a hero of the Boer War against Britain but a post-war anglophile dedicated to uniting his country's European peoples, rallied to the cause of supporting Britain in her hour of greatest need.

The country was ill-equipped to go to war. Not only were there serious divisions amongst the electorate, but the military forces had been allowed to run down to minimal levels during the 1930s, mainly (but not exclusively) as a result of the Great Depression. The army numbered fewer than 6000 regular soldiers. The air force had but a handful of military aircraft, while the naval service, of almost insignificant strength, was disbanded in 1934. Despite these shortcomings, South Africa's geographic position made her the guardian of the sea-route around the Cape. This was a region of major strategic importance, especially if the Suez Canal was to fall into German hands, or into those of its Axis allies in Europe, who were then positioning themselves.

In Britain, there was little doubt that support from their kith and kin within the Dominions of Australia, Canada, New Zealand, and South Africa would not only be forthcoming, but it would be crucial to the defense of the "mother country," even if only in terms of the manpower it could provide. This had been the case in the previous global conflict that had ended just twenty years before. Such an allied response to Nazi aggression was naturally expected again. As then, British military resources were spread thin in terms of resources, but their technical expertise was immediately made available to assist those key allies in their preparations for war. So it was that the government in London announced in February, 1939, at a secret conference of the High Commissioners of those Dominion countries, that [1]

> It has been found that wireless waves are reflected by aircraft in flight, and a technique of causing and measuring such echoes has been developed by means of which it is possible to determine the position and height of distant aircraft.

The disclosure went on to describe in some detail how this highly secret new technology, then known as RDF in England, could be used to provide early warning against attack from the air as well as well as defense against ship-borne actions by means of both coastal defensive radars as well as airborne equipment. South Africa's High Commissioner in London immediately communicated this information to his government. He also informed the responsible minister that Britain had offered to inform a "technical representative from the Dominion Governments" of the workings of the system, and therefore a suitably qualified physicist should be sent to London for a period of three to four months.

It was with this background information that South Africa became aware of what soon became known as radar, when Britain dispensed with the term RDF in favor of the concise and expressive name adopted in America in November 1940.

2. The RDF Secret

South Africa chose not to send a scientist to London, but rather sent a soldier, Brigadier General F. R. G. Hoare, the Director of Technical Services of the Union Defense Force (the UDF). He went to England to attend the technical briefings at Bawdsey Manor on the coast, near Ipswich. Bawdsey had become the home of British radar development shortly after the original discovery, made in February 1935, by Robert Watson-Watt and his colleague Arnold Wilkins, that radio waves from a suitable transmitter would be reflected with sufficient intensity by a metal-skinned aircraft such that they could be detected on the ground. This remarkable discovery – assumed in England for quite some time afterwards to be unique – has since become known as the Daventry experiment. It was named after the BBC transmitter at Daventry, which was used to transmit the signal that was reflected from a bomber aircraft of the RAF. Hoare was accompanied by an officer from the South African Air Force, a Major Willmott, who happened to be serving at that time in England. Needless to say, these two military men were soon out of their technical depth at Bawdsey. However, their visit was not in vain, because it enabled the British Air Ministry to establish what South Africa's defense needs might be around its very long and unprotected coastline, and especially at the country's major ports. Hoare immediately informed his Defense Headquarters (DHQ) in Pretoria that arrangements should be made to send a scientist to England.

As it transpired, the New Zealand scientist, Dr. Ernest Marsden, who was present at Bawdsey along with his scientific colleagues from Australia and Canada, was about to set sail for home. It was then realized that he could pass on to the South Africans all the technical information he had acquired whilst at Bawdsey, but that required a change of ship to one that would be calling at Cape Town. Marsden duly sailed on the *Winchester Castle* on September 2, 1939. Two weeks later, he met Basil Schonland, hastily dispatched to South Africa's mother city from his seat of learning in Johannesburg.

3. Enter Schonland

Basil Schonland (1896-1972) was a professor of geophysics at the University of the Witwatersrand, known as Wits, in Johannesburg. For much of the previous decade, he had established an international reputation as an expert on the physical processes involved in lightning discharges. By 1937, he had named most of them in the international literature. His terms such as the return stroke, the leader, the dart leader, and the pilot streamer were in common usage by lightning researchers elsewhere. The following year, he received Britain's highest scientific accolade when he was elected a Fellow of the Royal Society. Schonland's reputation as a physicist was therefore well established. Some had even dubbed him Benjamin Franklin's natural successor [2, p. 422] (Figure 1 is a photo of Schonland).

Figure 1. B. F. J. Schonland, the father of South African radar.

As well as photographing lightning with high-speed cameras, Schonland and his colleagues at the Bernard Price Institute of Geophysical Research (the BPI, as it was always known) at the university had also made considerable use of radio-based methods to delineate the details of the lightning process. Probably the most important of these techniques was radio direction finding. In this, a network of receivers tuned to some appropriate very low frequency where lightning emissions were most readily observable was used, with rotatable loop antennas to determine the direction of the lightning stroke. By means of triangulation among the various stations, the approximate position of the lightning strike was then fixed. This involved not only the design of suitable radio equipment, but, crucially, the use of the cathode-ray oscilloscope to display the lightning waveform. In doing this, Schonland followed the work pioneered in England by Watson-Watt and Edward Appleton at the Radio Research Station at Slough, near London.

The three men knew each other well. Appleton and Schonland had been research students together at the Cavendish Laboratory at Cambridge. Watson-Watt and Schonland first met at a conference of the British Association for the Advancement of Science, in London, in 1931. Schonland, who was born in Grahamstown, South Africa, and educated there at Rhodes University, spent the years of the First World War as a signals officer in the British army's Corps of Royal Engineers. He interrupted his post-graduate studies at the Cavendish in order to do so. It was during this time that he first met Appleton, a fellow signals officer and already a physicist of some repute. After obtaining his PhD at Cambridge in 1922, Schonland accepted an appointment as Senior Lecturer in Physics at the University of Cape Town.

Figure 2. Schonland, Hodges, and Phillips in Durban in 1939.

By 1937, he had come to the notice of many people, both at home and abroad. This was particularly true when his field of research changed from atomic physics, under Lord Rutherford in Cambridge, to the study of lightning in South Africa. The change came about because Cape Town was so far from the center of gravity of research on atomic physics that Schonland quite rightly felt that no meaningful progress could be made working entirely on his own, at the southern tip of Africa. He therefore looked for a new field, and found it in lightning. However, it was in Johannesburg, almost 1500 km from Cape Town, where lightning was really active during the summer months. It was there that Schonland made lightning research almost his own and particularly at the BPI, the institute that had been founded by its generous benefactor in order that Schonland could pursue his research there. It was with this background that South Africa's foremost physicist came to meet Dr. Marsden in Cape Town, in mid-September 1939, with both their countries now allied to Britain in the war against the Third Reich.

4.The RDF Manual

Schonland and Marsden traveled together on the next leg of Marsden's onward journey. The *Winchester Castle* docked in Durban harbor three days later. During that voyage, they locked themselves in the New Zealander's cabin while they studied in detail the *RDF Manual*, a copy of which had been given to each of the three Dominion scientists who had been briefed by Watson-Watt and his colleagues at Bawdsey. Immediately on their arrival in Durban, the two men made for the physics laboratory at Natal University College. The man in charge there was one of Schonland's former PhD students from the University of Cape Town, David Hodges, who was now actively participating with Schonland's team in Johannesburg in tracking lightning by radio. Hodges was assisted in this by an electrical engineer, Eric Phillips. Figure 2 shows Schonland, Hodges, and Phillips. There, after Schonland had sworn both Hodges and Phillips to secrecy – since they were soon to become party to details of Britain's greatest wartime secret, as solemnly communicated to them all by Marsden – the four men proceeded to make glass photographic slides of the pages of the top-secret manual. Once complete, the New Zealander returned to his ship for the journey home, while Schonland left immediately, by air, for Johannesburg.

5. Tracking Lightning

Tracking lightning storms across southern Africa by means of their radio emissions occupied Schonland's team throughout the years 1937 and 1938. Naturally, the longer the baseline of the direction-finding system, the better the accuracy. A second station was therefore set up in Hodges's laboratory in Durban, some 500 km from Johannesburg, on South Africa's east coast. There, Hodges and Phillips had constructed a DF system, based on the principles outlined by Schonland. In order to coordinate the task of identifying the source of a single lightning stroke from the multiplicity of such things at the height of a storm, careful coordination was required between the Johannesburg and Durban teams. This was made possible by means of a dedicated telephone circuit between the two cities, provided by the Postmaster General's office in Pretoria. The man who authorized this was the Under-Secretary for Telegraphs, Mr. Freddie Collins. He also served, in a part-time capacity, as the Assistant Director of Signals in the South African army. Lt. Col. Collins thus became a key player in the development of radio direction finding in South Africa. Along with all of those mentioned so far, he was to be part of the first South African venture into radar.

The two lightning-monitoring stations were given the identifying letters of JB, for Johannesburg, and D, for Durban. By this means, communications between the two, and especially the recording of key information, was considerably speeded up. However, soon those letters would take on a completely and far more significant meaning: JB would become the letters that designated South Africa's first radar.

Schonland reported to General Hoare and thereafter, word soon reached the South African Prime Minister, Gen. J. C. Smuts. Smuts was well aware of the secret briefings that had taken place in England following the visit to Bawdsey by Hoare and Willmott, just a short while before. Moreover, Smuts knew Schonland well. In fact, they were distantly related by marriage, and Smuts was also much interested in science, especially botany. The fact that Schonland's father was a renowned botanist at the university in Grahamstown meant that he and Smuts had occasional contact. This allowed South Africa's Prime Minister, now serving in that role for the second time, to keep a close eye on the career of the younger Schonland. Smuts had followed with interest Schonland's school days as something of a prodigy to his time as an undergraduate at university in Grahamstown, and from there to his doctoral studies under Rutherford in Cambridge. More recently, after

Schonland's great contributions to the study of lightning, it was Smuts who formally opened the new BPI building in Johannesburg, when it came into being in October 1938. It therefore followed that Smuts well knew when a South African physicist was needed to help his country join forces with its British and Dominion allies in the radar war, who that person should be.

Britain's initial intention, when releasing the information about RDF to its Dominions, was that they should become conversant with its operation, so that as soon as British equipment became available, they would be able to set it up and use it in the defense of their respective countries. However, the exigencies of war were such that British resources were stretched to their limits in simply meeting British needs. It was soon evident that no equipment would be forthcoming for the Dominions in the immediate future. As soon as Schonland realized this, he persuaded Smuts to allow him to go ahead with the development of a radar set that would at least enable South African forces likely to use the equipment to gain some useful practical experience. Smuts agreed.

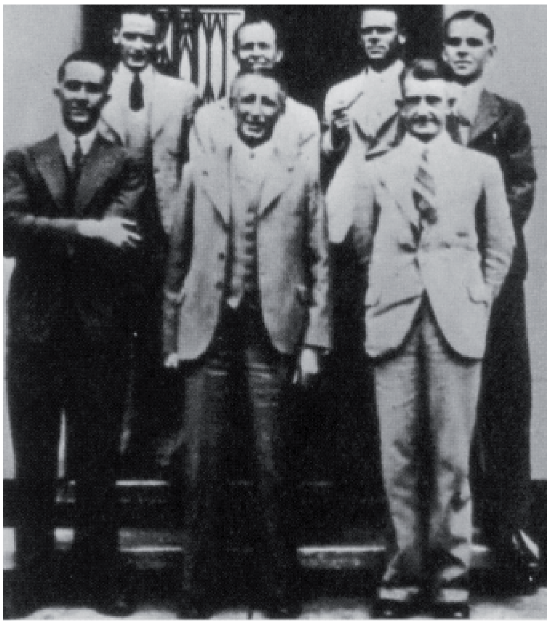

Figure 3. The radar design team at the BPI. (back) Keiller, Anderson, Gane, Hewitt; (front) Bozzoli, Schonland, Roberts.

6. Engineers to the Fore

Until now, the research carried out at the BPI had been the domain of physicists. However, Schonland immediately knew when he saw the details of the British Chain Home radar system – as described in the Marsden's *RDF Manual* – that he needed the assistance of electrical engineers with specific skills in the art of radio engineering to both effectively and quickly do the job. Intriguingly, this was not the thinking of Watson-Watt in England, when he embarked on the design of that original British RDF equipment. It was Watson-Watt's peculiar view that physicists without industrial experience should design the hardware [3, pp. 13-16]. What made this all the more surprising was the fact that Watson-Watt himself was an engineer!

Schonland immediately enlisted the support of three electrical engineers, all of whom were senior lecturers at their particular universities, and all who were well-versed in what to some was the black art of radio-frequency engineering Figure 3. From the University of the Witwatersrand, the home of the BPI, came G. R. Bozzoli, the son of Italian immigrants to South Africa, although he himself was born in Pretoria. Before becoming an academic at his alma mater, Bozzoli had been a broadcast engineer at the African Broadcasting Company, the predecessor of the South African Broadcasting Corporation. From Natal, Schonland asked for the services of W. E. Phillips, the same man who had assisted Hodges, Marsden, and himself to make the glass photographic slides of the *RDF Manual*. Phillips, as noted above, was also familiar with the direction-finding equipment used for tracking lightning activity. The third engineer to be recruited was N. H. Roberts from the University of Cape Town. Dr. P. G. Gane, who was Schonland's deputy at the BPI, was a physicist, but one who was particularly talented as a designer of circuits using thermionic valves (or tubes). Such expertise was then of considerable importance.

The immediate problem that faced Schonland's team was the lack of suitable transmitting valves. South Africa was not at that stage producing any transmitting equipment: the broadcasting company of Bozzoli's immediate past imported all its equipment from England. What was more, careful study of the *RDF Manual* had suggested South Africa's radar needs would be best served by using the so-called searchlight principle. In this, the radar beam from the transmitting antenna would be regularly swept across a region of space and then received, preferably by using the same antenna when switched to the receiver. This was akin to the coastal defense (CD) radars then presently under development at Bawdsey. This was in contrast to the earlier Chain Home (CH) radar, which worked on the flood-lightning principle of "illuminating" a wide swath ahead of the transmitting antenna, and using a separate highly directional receiving antenna to determine a target's bearing. Technologically, the two systems were very different from one another. The searchlight system required a considerably higher radio frequency than the 20 MHz to 30 MHz (then called Mc/s) used by the CH radar. The higher frequency meant that the antenna size could be made small enough to be easily rotated, while still producing a beam of sufficiently narrow width. The British CD radars therefore operated at a frequency of about 200 MHz. That same frequency would also be used in the radar that evolved from this, intended specifically for the detection of low-flying aircraft, called the Chain Home Low, or CHL [4].

7. The Design Challenge

Bozzoli and his colleagues turned to the suppliers of radio equipment, and especially the components, used by the country's amateur-radio community. Along with their colleagues elsewhere in the world, South African "Hams" were keen (and competent) designers of much of their own equipment, particularly transmitters. In addition, they sought to operate at the highest frequencies available to the amateur-radio service. As a result, the dealers in such equipment in Johannesburg kept stocks of appropriate components. As discreetly as possible, the BPI placed orders for as many high-power transmitting valves capable of operating at the highest frequencies that the radio dealers could supply. The costs were all borne by a special account managed by DHQ in Pretoria, because by now the BPI had been officially handed over by the university to the UDF for the duration of the war. Lt. Col. Collins was now officially in charge, with Schonland reporting directly to him.

However, technical information was scarce, especially in South Africa. There were few engineering textbooks at that time that covered the design principles underlying high-power amplifiers intended for operation at frequencies much above 50 MHz in any detailed way. Other than the relevant pages of the *RDF Manual*, the two books that served the circuit designers well at the BPI were F. E. Terman's *Radio Engineering*, and the 1936 edition of *The Radio Amateur's Handbook*, published by the American Radio Relay League. There was also a dearth of suitable measurement and test equipment. They had no suitable signal generator, nor even an oscilloscope capable of making accurate measurements at frequencies above a few megahertz. Once again, they were in good company. Before moving to Bawdsey, Watson-Watt's team had set themselves up on a fairly isolated strip of land, almost

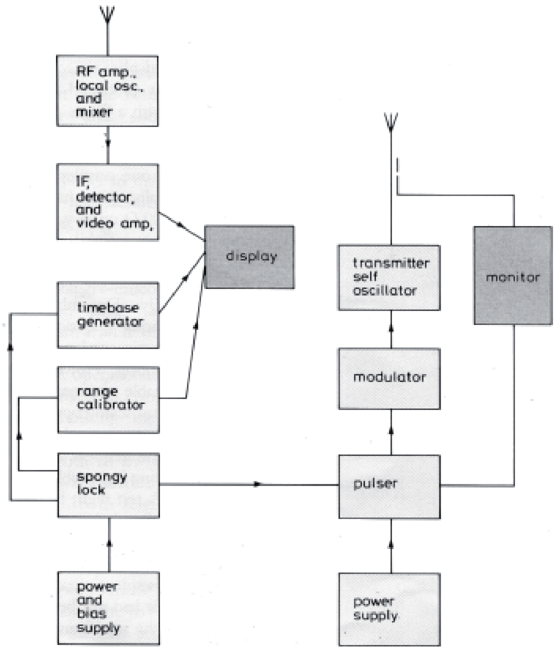

Figure 4. A block diagram of the JB radar system.

completely surrounded by water, called Orfordness on the south-east coast of England. Over many years, it had been used by the Ministry of Defense for a variety of tests and experiments of a secret nature. It was therefore most appropriate to design Britain's early RDF equipment at such a remote place. However, the British scientists also suffered from a distinct shortage of suitable test gear. There was no signal generator, and all they had was a wavemeter, an old double-beam oscilloscope of doubtful bandwidth, and a multi-meter. In addition, they suffered at the hands of the hidebound and extremely cumbersome stores system operated by the military, which required forms to be filled out (always in triplicate) for even the most mundane of items [3, p. 12].

8. The JB0 Prototype

Schonland's team of three engineers and a physicist were assisted by J. A. Keiller. From its inception, the BPI had a well-equipped workshop, and Jock Keiller was the man who ran it. His part in the mechanical construction of South Africa's own radar equipment would be crucial. The design of the various elements of the radar transmitter, the receiver, the timing and display units, as well as the necessary power supplies, and the antenna, was decided by the team members themselves (Figure 4). Their objective was to produce a radar that would operate at the highest frequency they could achieve, given the limitations of the available transmitting valves. Each played to their particular strengths, with Bozzoli handling the RF, mixer, and local-oscillator stages of the receiver; Phillips took on the IF amplifier; Roberts looked after the timing and display circuits; while Gane handled the transmitter, and he would also design the antennas. In its prototype form, the first South African radar became known as the JB0. It would be classified today as a bistatic radar, because the transmitter and receiver had their own antennas, which could be separated from each other by some distance. Their rotation in synchronism was handled by a bicycle-chain arrangement, with the motive power provided by the legs of the radar operator.

Although all members of this very secret group of individuals then occupying the BPI were nominally still civilians, they soon fell under the jurisdiction of the South African Corps of Signals, and hence of Col. Collins. Nevertheless, Collins gave Schonland complete freedom to operate as he saw fit, while remaining as his interlocutor to the military high command, which obviously held sway over South Africa's slowly evolving war machine. However, it soon would be necessary to turn Schonland's men into soldiers of a sort, because it was they who would take their radars into the field of action. They naturally would become very much part of the military once there. Schonland himself made the transition into uniform very easily, since he had had experienced almost four years of soldiering during the First World War. For the others, it took some adjusting. Informally, they were known as the

Figure 5. A group photo of the SSS. Schonland is in the center of the front row, with Bozzoli on his left, and Roberts on his right. Second from the left in the back row is T. L. Wadley.

Special Wireless Section. Within time, as their numbers substantially increased, they became the Special Signals Services (SSS) of the South African Corps of Signals (SACS) (Figure 5).

By December 1939, the JB0 was complete and was ready for testing. This was quite remarkable, given that work on it had only commenced less than three months before. Its circuitry was conventional, except perhaps for Gane's transmitter. As far as they could be measured or estimated, the radar's characteristics were as follows. The transmitter operated at a wavelength between 3 m and 3.5 m (or about 86 MHz to 100 MHz). Its peak power output could only be estimated, but since the pulse width controlled by the modulator was initially about 20 µsec at a pulse repetition frequency (PRF) of 20 msec, it was about 30 dB greater than the average power developed by the two type 250 TH triodes used as a high-power pulsed oscillator. They were subsequently replaced by the type 354E triodes, which produced better performance. Their frequency of operation was determined by two short-circuited copper transmission lines, each nominally one-quarter wavelength long, which were the only tuned elements of that pulsed oscillator. Fine-tuning was accomplished by a small, widely spaced variable capacitor, associated with each line (Figure 6).

Bozzoli's radio-frequency sections of the receiver made use of the new "acorn" tubes, manufactured by RCA. These were claimed in the advertising literature as being suitable for ultra-high frequencies of 450 MHz, and even higher. He used the type 956 pentodes for both the RF amplifier and mixer, with the 955 triode as the local oscillator. The IF amplifier, designed by Phillips, followed the techniques used by the manufacturers of British television receivers at that time, while Roberts was much influenced by the ideas contained in the *RDF Manual*. His timing and control circuits included the "spongy lock" circuit that was used in Britain's CH radar system. Its purpose was to act as an electronic shock absorber to smooth out variations in the 50 Hz mains supply to which all the radars in the CH system were locked, thus ensuring that they all operated in synchronism. Such sophistication, though vital to the success of the earliest RDF equipment in England, would soon lead to problems when the JB radar went "up north" with the country's troops.

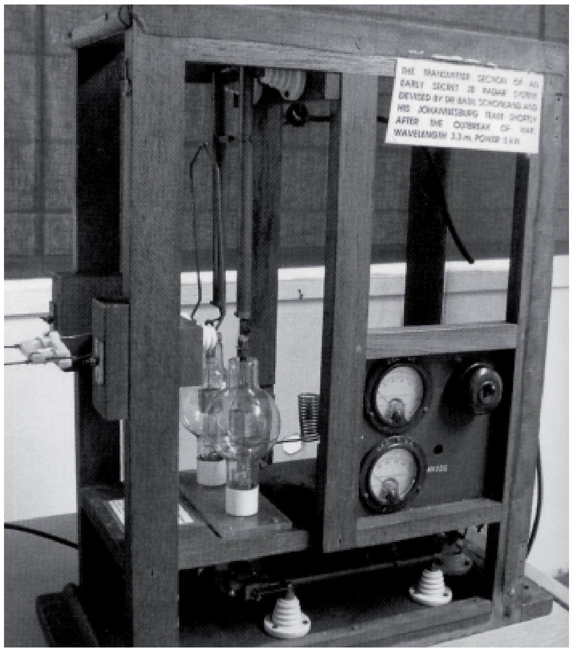

Figure 6. The JB1 radar transmitter in its wood-framed enclosure, showing the triode valves and the tuned lines.

Figure 7. The BPI building, with a radar antenna on the roof.

9. The First Radar Echo

December 16 was a public holiday in South Africa. The BPI was therefore closed. However, with the JB0 showing signs of functioning, Schonland and Bozzoli decided to go in to see if they could get the complete system to operate, and perhaps even detect a reflected signal from some object in the vicinity. Previous attempts to do this had been made, but none had been successful. The first test involved a mesh of copper wires, lifted to some appreciable altitude by hydrogen-filled balloons, which they hoped would act as a suitable radar reflector, but the JB0 registered nothing meaningful on its cathode-ray tube. The next test, arranged with the cooperation of the South African Air Force, involved a flight by a single-engine aircraft along a carefully planned route. The pilot was briefed, but no information was given to him as to the purpose of his strange mission. On the appointed day, with five pairs of eyes anxiously watching the radar screen at the BPI, no sign of the aircraft appeared. This was most disappointing, until it was discovered that the pilot had decided that the exercise seemed pointless, so he had detoured over his girlfriend's house instead!

The JB0's antennas, which were both dipole arrays backed by reflectors, were positioned on the roofs of two nearby university buildings. The transmitting antenna was situated on the roof of Central Block, the main university administrative building, while the receiving array was on the roof of the BPI (Figure 7). The equipment connected to each was housed in rooms immediately below the two antennas. The two radar "operators" – Bozzoli attended to the transmitter, while Schonland watched the cathode-ray tube of the receiver – were in direct communication with each other via the university's telephone exchange. This was reminiscent of JB and D again, between Johannesburg and Durban. They slowly steered their respective antennas from north to northwest, with Schonland keeping a close eye on the CRT screen. Then it happened: he shouted down the phone to Bozzoli that there was a reflection! Bozzoli dashed across from one building to the other, taking the stairs three at a time. Sure enough, there was a definite "blip" on the screen, so, together, he and Schonland moved the receiving antenna back towards north. The blip disappeared. Turning the antenna back to its previous heading restored the reflected signal to the center of the screen. The two men rushed up to the BPI roof, and looked northwest. There, some 10 km away, was a well-known Johannesburg landmark, the Northcliff water tower, atop a hill known as Aasvoelskop. One or the other was clearly the radar target, the first ever seen in South Africa that day in December, 1939 [2, p. 182].

10.The JB1: An Operational Radar

Schonland informed Col. Collins of their success, and also indicated that the ranks of the SSS were increasing by one. A very young Frank Hewitt, with a freshly minted master's degree in Physics under his belt, from Schonland's own university in Grahamstown, had recently joined the BPI. He had been offered a position there by Schonland some while before, with the intention that he would join the lightning research group. By the time he arrived, the face of the BPI and the work they were now involved with had significantly changed. Hewitt was not immediately admitted to the inner circle. As he mentioned in his correspondence with me many years later, he was given something to read about lightning, while his colleagues took time to get to know him. Once he had apparently passed whatever scrutiny was required – and had demonstrated that he was more than handy with a soldering iron, having been an enthusiastic designer and builder of radio receivers from his schooldays – he was put in the picture by Bozzoli, and immediately given the task of designing a monitor for Gane's transmitter.

Now that they had a target – and a fixed one, at that – that they could use to make measurements, Schonland's team set about peaking up their equipment. They soon were able to detect aircraft targets at a distance of 15 km and, within a month, they had increased the range to 80 km. Word then reached the BPI that the British equipment which they were expecting would be delayed indefinitely. This was a major blow, but Schonland, confident that the SSS now had the ability to do more than just learn the techniques of radar and could actually construct a setup themselves, proposed to Collins that they should go ahead and design a radar suitable for use in the field. Collins readily agreed, and the team switched all its efforts into producing their first operational radar, the JB1.

The design team was soon depleted, because Phillips and Roberts had to return to their universities, as the new academic year had begun and their services were required in their teaching roles. However, Hewitt was fast proving his worth. He was next given the task of designing an indicator using a so-called magic-eye tube, which would show when the spongy lock was actually locked. Bozzoli now assumed the mantle as chief radar design engineer. He immediately redesigned many aspects of the system, including Gane's

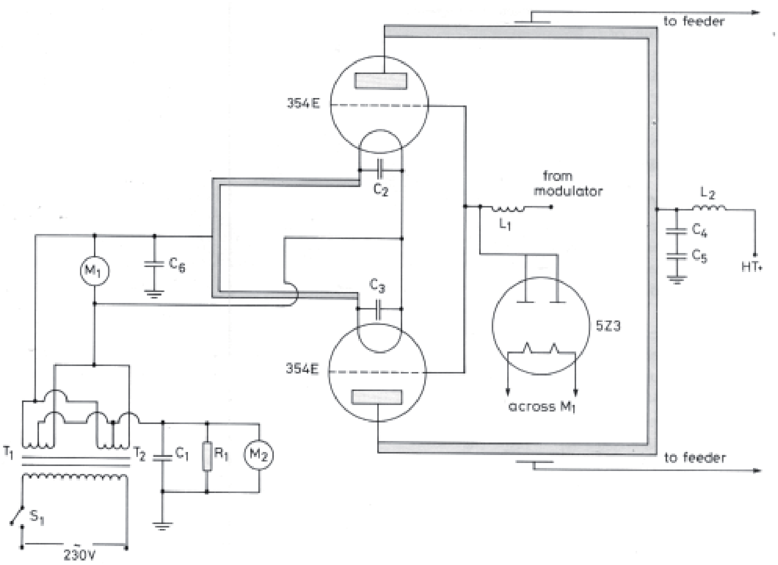

Figure 8. The JB1 transmitter schematic.

rather temperamental transmitter. It still used two triodes in a push-pull shock-excited oscillating amplifier (Figure 8) but now included a clamp circuit provided by the 5Z3 diodes on the two grids. Its purpose was to prevent the grids from going positive, and so causing the amplifier to break into uncontrolled oscillation, which it had been prone to do. Bozzoli also altered the IF amplifier of the receiver, considerably simplifying it while increasing both its gain and its bandwidth, making the latter more appropriate to the pulse width of the transmitter. However, for some inexplicable reason, he decided to leave the spongy lock in place, even though there was no apparent need for it. Hewitt soon mastered the theory underlying this strange circuit, and his lock indicator worked well. This was very fortuitous, for in the not too distant future, he would have to carry out a redesign of that circuit under far from ideal circumstances, when the JB1 was in service near Mombasa, in Kenya, performing its first operational role.

The JB0 had been a crude laboratory "lash-up." By comparison, the JB1 had the appearance of a solidly-constructed piece of broadcasting equipment, as might have been expected given Bozzoli's pedigree. Rack and panel construction was the order of the day. The receiver, the modulator and timing circuits, and their power supplies all occupied solid steel racks, about 1.5 m high and of the standard 19 in (48 cm) width (Figure 9). However, the transmitter remained very different. It was housed in a stout wooden cabinet, with all four sides being made of separated, fine metal gauze, such that the inner workings were all visible. This was done so as not to de-Q those two copper tuned lines that determined the operating frequency of the radar. However, the impression given to any uninformed observer was more akin to a birdcage than a rather special piece of electronic equipment!

A trial of the JB1 was immediately called for over the sea, because its first operational role was to be in providing cover against air attacks off the coast of Kenya. This was all driven by the fact that the Italian campaign in Abyssinia (the present-day Ethiopia) was showing signs of advancing further south. South Africa was about to send an infantry brigade to defend the British colony of Kenya from attack by Mussolini's army, and to then drive the Italians out of East Africa altogether.

The radar trial took place in June 1940, just north of Durban, at a place called Avoca. The SSS were now in uniform. Major Schonland was accompanied by Captain Gane and Lieutenant Hewitt, and a recently-recruited Post Office technician by the name of Anderson, rapidly promoted to Staff Sergeant. There were very few regular flights by aircraft on which to test the JB1. However, the roadstead off Durban was extremely busy with shipping, thereby

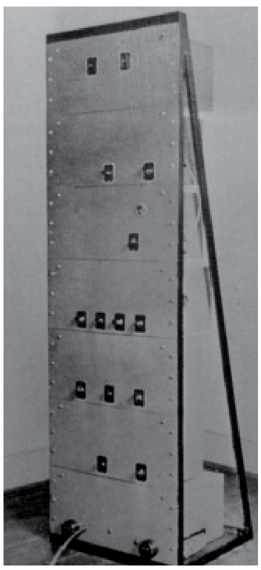

Figure 9. The JB1 receiver, showing the rack and panel construction.

providing excellent targets as well as a new role for the South African radar. It performed very well, and enabled the operators to gain considerable experience in using the equipment. A strange and rather surprising phenomenon was noticed, as well. Numerous target echoes appeared when no ships were visible at all. Hewitt and Gane believed they were ships beyond the horizon, but Schonland was skeptical. To settle this, he promised them all a meal at Durban's best hotel if the ships actually came into view. Eventually, they did. The explanation was anomalous propagation caused by atmospheric ducting. The experience turned out to be very useful, for it was to occur many times in the future. Schonland's men duly got their promised meal [2, p. 189].

11. The SSS at War

On June 16, 1940, a convoy of three ships left Durban, bound for Mombasa, in Kenya. Onboard were troops of the 1st South African Division, and with them was the JB1 radar with its SSS radar operators: the same three men who had tested the equipment in Durban just a couple of weeks before. Their commanding officer, Major Schonland, would be flying to Mombasa on an aircraft of the South African Air Force (SAAF) to meet them there in a week's time. The radar was to be set up near the village of Mambrui, just north of Mombasa, on a site selected for it by the gunners of the South African Anti-Aircraft Brigade, whose task was to defend the nearby airfield from air attack by the Italians. Expectations were high, and all eyes were on the SSS and its equipment.

They immediately ran into problems. Electrical power to operate the JB1 was provided by a diesel generator purchased in Mombasa. Unfortunately, when under load, both the voltage and the frequency were most unstable, and they exceeded the range of the JB1's spongy lock. The result was that the various timing pulses of the radar were all awry. The spongy lock, despite its intended purpose, was unable to stabilize the system. It was at this point that the young Frank Hewitt really showed his mettle, by effectively redesigning that part of the timing system, and making the necessary circuit alterations under anything but ideal laboratory conditions. The fact that Schonland had drummed into the SSS the need for absolute secrecy, so that they could never be accused of betraying the secrets of British radar to a living soul, meant that they had taken no circuit information with them. However, Hewitt's construction efforts in Johannesburg now bore multiple fruit. He had committed the spongy-lock circuit to memory, and he also knew the placement of all its components on the chassis. While Schonland anxiously watched, his young colleague produced a solution that stabilized the JB1's display on the screen, and the radar was in operation.

The JB1 was calibrated by tracking the daily flight of an aged Junkers J 86 aircraft of the SAAF that had been pressed into military service from its usual role as a transporter of civilian passengers around South Africa. Back at the BPI in Johannesburg, Bozzoli, who was in charge of the production of a series of JB1s while also beginning to work on new developments, was anxiously awaiting news of the radar's performance in Kenya. This soon arrived by way of a suitably enciphered telegram from Schonland. In order to deceive the enemy should the missive be intercepted, Schonland had devised a code whereby the maximum range achieved by the JB1 – a figure of much interest to all at the BPI – was added to Schonland's age. It was received, decoded, and then read with considerable satisfaction.

In the six months that the JB1 was in service in Kenya, it tracked enemy targets just once, for enemy aircraft appeared just once! The Italians had been expected to mount their attack on Mombasa's airfield by approaching from over the sea, and that was where the radar was watching. However, on the only occasion when they came, two aircraft approached from exactly the opposite direction. They flew in from behind the JB1's antenna, dropped their two bombs, and then continued on out to sea. It was then that the radar tracked them for about 55 km before the two blips on the screen eventually disappeared into the noise. The fact that the open-wire feed lines to the antenna wound themselves around the mast if 360° rotation was tried posed an operational problem. This encounter with the enemy coming from behind led to a special request being made to the BPI for a solution.

12. An Encounter with the RAF

The SSS had been sent to Mombasa to provide radar cover because there was none at all in Kenya. Quite unbeknown to the South Africans, the Royal Air Force was concerned about this, and had dispatched an officer to assess the situation, and report back to his headquarters in Cairo. He was Flt. Lt. J. F. Atherton who, in civilian life, had been a member of Watson-Watt's radar entourage in England. On his arrival in Mombasa, Atherton was surprised to discover that the South Africans had already set up a radar station in the country, with more to follow. However, his report was rather condescending about what he had seen. He said the South Africans were already operating their "elementary homemade RD/F [sic] in the area." He said the sets were of little practical value in view of their limited performance [2, p. 192-193]. Worse was to follow.

In his discussions with Schonland, Atherton had learnt of the political divisions between government and opposition in South Africa, and the presence of some in the country who had decidedly anti-British views. Schonland had emphasized to him that the SSS therefore treated the existence of radar as a matter of great secrecy, even to the extent of not divulging its existence to anyone beyond the very privileged few. Certainly excluded were many within Defense Headquarters in Pretoria, who would not accept that South Africans should be expected to fight beyond the borders of their country, while some even believed they should not be fighting for the Allied cause, at all.

However, Atherton completely misconstrued this. He reported to the RAF HQ in Cairo that Schonland's own headquarters – in other words, the SSS at the BPI – could not be trusted with the secret of British radar! The SSS had thus suffered ignominy on two fronts: their equipment was considered inadequate, and their trustworthiness was doubtful. The complexities of South Africa's politics looked like it was scuppering the country's involvement with one of Britain's most important wartime developments. Thankfully, better-informed minds in London soon prevailed. A cipher telegram was sent from the Air Ministry to Cairo. This informed those concerned that Britain had made a full and frank disclosure on RDF to all its Dominions, and as a result, there would be no possibility of discouraging any of them from conducting research or operating RDF systems.

13. The Suez Canal

By the end of 1940, the war in the Middle East was at a critical point. The British army, with some of its Dominion allies alongside, was now fighting in the Western Desert against the German Afrika Korps, soon to be under the command of Gen. Erwin Rommel. The Suez Canal was a prime target for attack from the air, with both German and Italian bombers seeking to close it. Radar cover was therefore urgently needed, especially as the British radars in the vicinity were required elsewhere as matters came to a head in the eastern Mediterranean, and especially in Greece. Schonland, now a Lieutenant Colonel, was asked to fly to Cairo for discussions with the RAF. The outcome was a request that the SSS and their radars should move from East Africa to the Sinai without delay, and take over the protective duties previously performed there by the radars of the RAF. Given recent events, this was a remarkable about-face by the British, and a particular boost for the South Africans.

Production of further JB1s was immediately stepped up at the BPI. There had also been a flurry of military promotions in the SSS. The four original members of the radar design team were all promoted to the rank of Major. In addition, Bozzoli was also designated Chief Technical Officer, and as such, was in effective command at the BPI, even though David Hodges from Durban, who had also joined the SSS, was appointed as Schonland's second-in-command. Recruiting of other technically qualified personnel was now in full swing, with special radar training courses having been set up at the three participating universities.

On January 8, 1941, a complete JB1 left Durban bound for Cairo, where it and its accompanying operators were met by Phillip Gane, who had flown there directly from Mombasa. The radar was immediately demonstrated to officers of the RAF, who were impressed. It was considerably smaller and hence more mobile than any British radar. Given its performance, which was keenly observed, it was deemed to be well-suited to its new role in providing radar cover of the Suez Canal zone. By mid-July, three JB1s were in operation along the Sinai coast at El Arish, Rafa, and El Ma'Aden. They initially had been used in parallel with a British radar, no doubt to compare their performance, and the outcome caused many a wry smile amongst the SSS. The JB1, appropriately sited with the sea ahead of it, outperformed the longer-wavelength (40 MHz) British MRU radar, operating right alongside it. The JB1s regularly tracked aircraft at distances of 120 km. They even had the occasional sighting of the island of Cyprus, some 400 km to the north: yet another example of the anomalous propagation first noted near Durban more than a year before. The South African radars were soon accorded official designations as SSS1, SSS2, and SSS3 in the RAF's list of radars operating in the Middle East [1, p. 564].

14. Coastal Radars Around South Africa

It had always been the intention that the radars designed in South Africa, as well as any of the British equipment that Schonland was able to muster, would be employed in the defense of South Africa's 2000 km coastline, and especially its major seaports of Cape Town, Durban, Port Elizabeth, and East London. It was feared that German armed raiders, posing as merchant ships, as well as the German U-boats, would be a significant threat to shipping around both the Atlantic and Indian Ocean seaboards. Later, after Japan had come into the war, both Japanese submarines and ship-borne aircraft were considered to be likely threats, as well.

The first JB1 radar to go into service in South Africa was at Signal Hill in Cape Town on May 22, 1941. However, it was not the first radar to be operationally used in the country. That honor belonged to the British ASV (Air-to-Surface-Vessel) radar, operating at 200 MHz. That was installed not in an aircraft, but on the Bluff in Durban, two months before. The much-promised British radars had thus finally begun to arrive in South Africa, but in very small numbers, and they were frequently incomplete. In June, an order was given for the BPI to construct 25 JB1s for use both in the Middle East and in South Africa. This was a task that Bozzoli efficiently organized, while also being personally involved in establishing the first coastal installations (Figure 10). This task was not without its problems. The insistence on complete secrecy about anything to do with radar (and, as a result, the SSS) introduced no end of administrative problems, which required careful handling. Bozzoli became very adept at this [5, pp. 42-44].

Schonland left Cape Town for England in March 1941. The purpose of his visit was to speed up the supply of radars, as there was clearly an urgent need for the more-sophisticated British equipment, which, by that stage of the war, already included the microwave radars using the cavity magnetron. Equipment began to arrive. These included the CHL (and its tropicalized version, the COL), both of

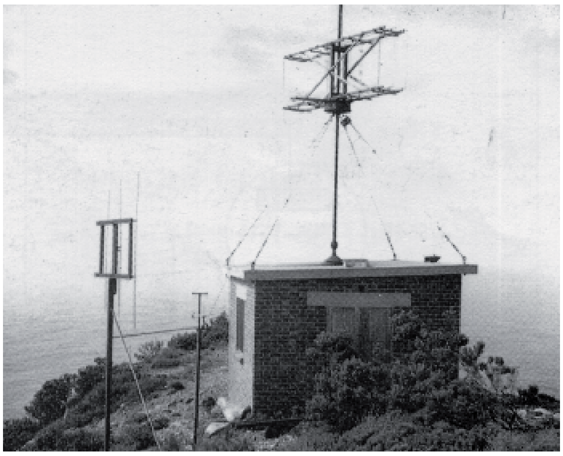

Figure 10. The JB1 radar situated at Cape Point.

which operated at 200 MHz; and the TRU, a scaled-down version of the CH radar, which worked at about 40 MHz. In addition, there were a few ASV and SLC radars, also 200 MHz equipment. The former was intended for use in aircraft, but was actually used on the ground in South Africa (as mentioned above). The SLC (known as Elsie) used five Yagi antennas mounted on a searchlight for accurate target acquisition and tracking.

The SSS had actually embarked on designing their own version of Elsie, when Major Noel Roberts was asked to provide such a radar for use by the South African artillery guarding the port of Mombasa, in Kenya. Roberts produced a complicated system, using a spiral time-base for the display, as well as air-blast cooling of the VT 58 pulsed triodes in the transmitter. It was called the JB2. However, its development was too rushed. On delivery to Mombasa, it proved unreliable, as well as being too complicated to set up in the field. It was thus abandoned [5, p. 27].

Virtually all the South-African-designed radars deployed around the coast were of the type soon to be designated the JB3. This was essentially a mobile radar (Figure 11), with the transmitter and its rotatable antenna in one vehicle, and the receiver plus its antenna in another.

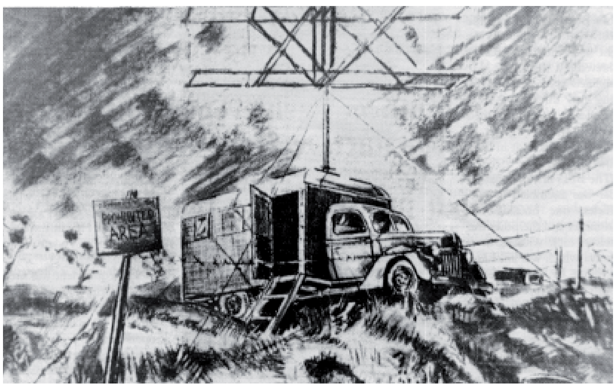

Figure 11. The JB3 mobile radar, from a charcoal drawing by the war artist, Geoffrey Long.

However, most JB3s were operated as fixed installations, once they had been driven to their sites. The first such unit was completed in April 1941. The antennas used are of some interest. The earlier dipole arrays had been superseded by a fully rotatable Sterba array backed by a similar group of reflectors, all mounted on a sturdy wooden frame. The problem referred to earlier of the feeders being wound around the supporting pole when the antenna rotated was solved at the BPI by using a magnetic coupler that allowed 360° rotation. Just a single such Sterba antenna was subsequently used for both transmitting and receiving. This was made possible by the inclusion of a transmit-receive (T-R) switch, consisting of two spark gaps at the appropriate points on a transmission-line stub that fired when the transmitter pulsed, thereby effectively isolating the receiver from its companion transmitter. This new radar was named the JB4. When in its mobile configuration, it became the JB5 [5, p. 34].

In all, by the end of the war in 1945, more than 30 radar stations of various types were operating around South Africa's very long coastline (Figure 12). Remarkably, given its inauspicious beginnings, the SSS had designed and built 31 JB radars in all, beginning with the JB0 prototype, which started it all in late 1939, to the JB5 of 1944. These would then be augmented by a variety of British radars, with the microwave equipment in the form of the British types NT 271, 273, and 277 – which began arriving in South Africa in 1942 for use by the coastal artillery – representing the pinnacle of technical development. The step change in electronic sophistication, from that earliest JB "lash-up" to those British-designed 10 cm (and, ultimately, the 3 cm) radars, clearly showed how the pressures of war undoubtedly determined the exceptional rate of progress that had been made.

15. Radar Training at the BPI

It soon became apparent that the need for competent and well-motivated radar operators would place severe strains on the available skilled manpower in South Africa. Just as had occurred in Britain, the decision was taken to use women, most of whom had a variety of university degrees. All underwent a course of military training, as well as dedicated instruction in the art of operating the radars, and in communicating the information to the filter rooms situated in the four major port cities. Their training took place mainly at the BPI. These women became members of the Women's Auxiliary Army Service (WAAS). They were then posted to radar stations around the country, where they were under the command of an SSS technical officer, whose function was to run the station while keeping the radar equipment "on the air" (Figure 13). By 1945, more than 500 female radar operators had been trained. They carried out by far the bulk of the operating and monitoring of those radars around the country. In addition, around 300 male technicians were trained at the three participating

Figure 12. A map showing the position and the predicted coverage from the radar stations around the South African coast.

universities around the country to be able to service and maintain all the various radar types [6].

The strength of the SSS when the war ended in Europe in May 1945 had doubled in size from the numbers serving at the end of December 1941. There were then 145 officers, of whom 28 were women, and 1407 other ranks (507 women). As well as those serving throughout South Africa, two SSS contingents were posted to Italy as part of the Allied invasion, the purpose of which was to drive out the Germans following the Italian surrender in September 1943. The SSS set up two Field Radar Stations (Nos. 70 and 71 FRS) near Naples and Milan, respectively. There, they operated a variety of British and American equipment, including the radio navigation systems Gee and SHORAN. In addition, the SSS provided a contingent to the South African Force squadron that was based at Takoradi on the Gold Coast (now Ghana) in West Africa, from where it carried out anti-submarine patrols. The Wellington aircraft involved were fitted with the British ASV MkII radar, as well as IFF which, by then, was a standard feature on most Allied aircraft. It was the responsibility of the SSS to install and maintain it all, a task made even more challenging by the intense humidity of the tropical environment. In addition, they provided blind-landing aids, known as Babs (Blind Approach Beacon System), on the aerodrome.

16. The Personalities

In concluding this account of the little-known South African involvement in the wartime radar story, it is perhaps worth just mentioning the subsequent careers of some of the major players.

Basil Schonland never returned to South Africa after going to England in 1941, because his services were immediately required there. Initially, he became the deputy to Prof. John Cockcroft at the Air Defense Research and Development Establishment (ADRDE). He soon succeeded Cockcroft when the organization expanded, and was renamed the Army Operational Research Group (AORG). Schonland became its first Superintendent. The AORG was responsible for the radar activities of the British Army, as well as myriad other issues related to the interplay between science and soldiering. Along with the operational research section established by the RAF, Schonland's AORG was the pioneer in the field of scientific soldiering. One of its most important contributions to Britain's war effort was the marked improvement in radar-controlled anti-aircraft gunnery brought about by operational research [2, p. 231]. Just prior to the invasion of northwest Europe by the massed US, British, and Canadian armies in June 1944, Schonland was appointed scientific advisor to General (later Field Marshal) Bernard Montgomery's 21 Army Group. By now a Brigadier, Schonland served throughout that campaign until December 1944. At that point, when it appeared to many that the war would soon be over, he was recalled to South Africa by his Prime Minister, Field Marshal Smuts, for the specific purpose of drawing up plans for the establishment of the Council for Scientific and Industrial Research (CSIR). Schonland served as the CSIR's first President for five years, before returning briefly

Figure 13. Women operators using the COL radar in South Africa.

to the BPI and lightning research. However, his presence was soon required in England (and elsewhere too, judging by the many offers he received). In 1954, he again joined his old Cambridge colleague, John Cockcroft, this time at Harwell, the home of Britain's Atomic Energy Research Establishment. Schonland served as Cockcroft's deputy for four years, before taking over from him as Director in 1958. He retired in 1960, and was knighted by the Queen for his services to British and Commonwealth science. In 2000, some thirty years after his death, Schonland was elected as South Africa's scientist of the 20th century [2, p. 579].

"Boz" Bozzoli became Head of the Department of Electrical Engineering at Wits, Dean of the Faculty of Engineering, and, in 1969, Vice-Chancellor, the senior academic and administrative position at the university.

Frank Hewitt established the Telecommunications Research Laboratory (TRL) at the CSIR. Amongst his senior staff were six other members of the wartime SSS. He then became Deputy President of the CSIR. Two of those TRL personalities – whose names haven't appeared in this account, although their technical expertise was highly valued – were T. L. Wadley and J. A. Fejer. Both made major contributions to post-war radio science. In 1957, Wadley invented the Tellurometer, a microwave distance-measuring instrument that revolutionized land surveying. Before that, in 1954, he designed the HF radio receiver that set new standards in the performance of such equipment. It soon became the mainstay of the Royal Navy's HF communications when Wadley's technique was adopted by the Racal, a UK electronics company, who turned it into their famous RA17 continuously-tunable receiver. Jules Fejer was a brilliant theoretician who provided the mathematical back-up at the TRL when Wadley was developing the Tellurometer. He then moved to Canada and from there to the USA, where he made very significant contributions at the University of California to the science of ionospheric backscatter.

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Introducing the Author

Brian Austin was born in Johannesburg, South Africa. He completed his electrical engineering degree at the University of the Witwatersrand in 1969, and subsequently obtained his MSc (Eng) and PhD from the same university. He spent a decade in industry, working for the Chamber of Mines Research Laboratory. There, he led the team that developed a hand-held medium-frequency SSB transceiver for direct-through-rock communications in deep-level gold mines. He then became an academic, first at his alma mater, and then at the University of Liverpool in the UK. His research interests covered the fields of antennas and radio propagation, mainly at HF, as well as the history of radio and radar technology. He published widely in all those areas. He is a Fellow of the IEE (now the IET), a Senior Member of the IEEE, and was also the UK representative to URSI in the area of Fields and Waves. He has been retired