Chapter 2

Frontier Life at the Field Stations

2.1 Introduction

Between October 1945 and March 1946 Radiophysics staff took advantage of the facilities at radar stations located at Collaroy Plateau and Dover Heights in suburban Sydney to follow up the British and New Zealand solar observations mentioned earlier, and this effectively marked the launch of radio astronomy in Australia. The equipment used at these field stations included radar antennas connected to 200 MHz receivers. In 1947 Ruby Payne-Scott (1912–1981) described the Royal Australian Air Force Radar 54 antenna at Collaroy as a

... broadside array of four horizontal rows each of ten half-wave dipoles with a reflector, having a gain of 80 relative to a half-wave dipole (i.e. $g = 130$) and a horizontal beam (to the half-power points) of 10° . (Payne-Scott, 1947b)

This COL (chain overseas low-flying) radar at Collaroy and a similar antenna at Dover Heights (see Fig. 2.1) were mounted vertically, and could only rotate in azimuth. In this configuration, they functioned as sea interferometers (Fig. 2.2), and because of the locations of the sites could only observe the Sun as it rose above the eastern horizon.

From early 1946, Radiophysics began setting up radio astronomy field stations in the general Sydney area (see Fig. 1.14), where small groups of scientists and engineers developed new instrumentation and used this in a multi-faceted assault on radio astronomy (see Orchiston and Slee, 2017). One of these pioneers was W.N. ('Chris') Christiansen (1913–2007), who wrote about the field stations:

The field work had a pioneering appearance. Each morning people set off in open trucks to the field stations where their equipment, mainly salvaged and modified from radar installations, had been installed in ex-army and navy huts. At the field stations the atmosphere was completely informal and egalitarian, with dirty jobs shared by all. Thermionic valves were in frequent need of replacement and old and well-used co-axial connectors were a constant source of trouble. All receivers suffered from drifts in gain and "system-noise" of hundreds or thousands of degrees represented the state of the art. During this period there was no place for observers who were incapable of repairing and maintaining the equipment. (Christiansen, 1984)

Fig. 2.1 (right) The 200 MHz COL Mk V radar and control room at Collaroy Plateau in early 1946. The COL radar was a British design with the tower structure built by the NSW Government Railways (after Dillett, 2000: 48). (below) The Dover Heights radar station in 1943 looking north towards the entrance to Sydney Harbour [courtesy: CSIRO Radio Astronomy Image Archive (CRAIA)]

Fig. 2.2 Illustrating the principle of the sea interferometer. The cliff-top aerial combines the direct signal from a radio source with the signal reflected from the sea to create an interference pattern. As the radio source rises above the eastern horizon, the interference pattern goes through a series of maxima and minima. The reflected signal simulates an imaginary aerial, spaced from the real aerial at a distance equal to twice the height of the aerial above sea level (courtesy: CRAIA)

In a document dated 12 October 1956, the head of the Radio Astronomy group at RP, Joe Pawsey (1908–1962), outlined his philosophy regarding field station research:

A major point of policy in directing the Group over the past years has been that the outstanding individual research workers should have their own distinct fields of interest and should have facilities appropriate to the work. In the event of one failing to make good progress ... facilities should not be taken from the others to bolster him up. (Pawsey, 1956)

Meanwhile, a letter written to a US colleague in 1960 reveals more about Pawsey's thoughts on effective research: "So my advice [to you] is to encourage radical ideas and not be afraid of a "damn fool" experiment, provided you can do it quickly and get rid of it quickly if it does not work." (Pawsey, 1960a). But, as Jim Hindman (1919–1999; 1978) has reminded us, the chance of success at the RP field stations was high, for "In those days, you could pick almost any field [of radio astronomy] and make a discovery." Yet Frank Gardner (1924–2002; 1986) was firmly convinced that without Pawsey's influence radio astronomy would have died at Radiophysics: "Personal hostilities and lack of appreciation of fundamentals would have led to chaos, and within a few years the Executive would have encouraged research in radio astronomy, an anomaly within CSIRO, to taper off." Thus, Pawsey played a key role in the success of the research and in the viability of the field stations.

Those of us (like the first author of this book) who were lucky enough to have lived through the 'field station era' remember the field stations with genuine affection. There was a freedom not experienced by those back at the 'Lab' (as the Radiophysics Laboratory was known): the pervading sunshine, the clean fresh air, those incident-packed trips from home to field station (during the 1950s Commonwealth cars replaced the open trucks mentioned above), and the sense that we were somehow making history. There were also snakes to contend with, wet days when antennas still had to be aligned and observations made, floods that had to be negotiated, and those times – fortunately few and far between – when vehicles became bogged and had to be rescued by local farmers (Fig. 2.3). Brunsviga calculators (Fig. 2.4) and slide rules were the norm, and personal computers but a future dream. Signal generators, not sources, provided calibrations, and results were displayed in real time on Esterline Angus and other all-too-familiar chart recorders (Fig. 2.5). These were pioneering days!

At one time or another between 1946 and 1961, ten different field stations existed in the Sydney area and near Wollongong (Figs 2.6 and 2.7), and the development of each of these is discussed in this chapter. In addition, the Collaroy and North Head radar stations were used briefly for solar radio astronomy projects in 1945–46, and during the 1950s and 1960s a number of short-lived 'remote' sites were used in conjunction with the regular field stations (e.g., see Research Activities ..., 1960). In all, research by RP staff was carried out at 21 different sites in the general Newcastle–Sydney–Wollongong area during the early days of Australian radio astronomy, as well as at two solar eclipse sites in Victoria, two solar eclipse sites in Tasmania (see Fig. 2.8) and two temporary field stations on the North Island of New Zealand. In addition, during the 1940s RP staff were closely associated with the

Fig. 2.3 Life on the field stations sometimes had its downsides. A farmer comes to the aid of the mobile lab, affectionately known as ‘Flo’, and four of the RP staff: Bruce Slee (left), Alec Little, Les Clague and Kevin Sheridan. The poles form part of the Shain Cross, one of the major radio telescopes of the 1950s (see Fig. 2.63) (courtesy: CRAIA)

Fig. 2.4 Solar radio astronomer Steve Smerd with one of the Brunsviga calculators (courtesy: Sullivan collection and CRAIA)

solar and Galactic radio astronomy that was conducted at Mt Stromlo Observatory near Canberra.

Staff based at the ten ‘regular’ RP field stations often enjoyed unheralded visits from Joe Pawsey (Fig. 1.13), head of the Radio Astronomy Group within the Division, the undisputed “... father of radio astronomy in Australia ...” (Kerr, 1971). Joe “... had a remarkable physical insight and an almost boyish enthusiasm for just ‘suck it and see’ sort of attitude, and this really was the key thing in the whole early days of radio astronomy.” (Lehany, 1978). He liked to turn up at field

Fig. 2.5 Dick Mullaly at the Fleurs field station examines the chart recorder as the Chris Cross generates a strip scan of the Sun (courtesy: CRAIA)

Fig. 2.6 The locations of ten RP field stations in and near Sydney and Wollongong discussed in this chapter (see also Fig. 1.14): 1 = Badgery's Creek, 2 = Dover Heights, 3 = Fleurs, 4 = Georges Heights, 5 = Hornsby Valley, 6 = Murraybank, 7 = Penrith, 8 = Potts Hill, 9 = Dapto, 10 = Bankstown Aerodrome (*map* Wayne Orchiston)

stations at morning or afternoon tea time, armed with a supply of 'lamingtons', cubes of sponge cake coated in chocolate icing and desiccated coconut, which he found totally irresistible! Frank Gardner (1973) remembers how Joe was "... very good at getting the best out of people. He had this method whereby when you came to talk to him about some problem, he'd often propose some other way of doing it ... he took an interest in everything ...". The downside of Joe's unbridled enthusiasm was that "... you were lucky to get home for dinner when he showed up at the end of the day." (Payne-Scott, 1978). Yet through these flying visits, Joe was able to keep track of progress at the field stations, and provide feedback to their staff when there were problems to be discussed.

Fig. 2.7 Sketch map of the Sydney area showing the locations of five of the ten RP field stations in Fig. 2.6. The airports at Kingsford Smith and Richmond were used for the rainmaking experiments and for radio applications to air navigation (courtesy: CRAIA)

Fig. 2.8 The locations of some other radio astronomy sites mentioned in the text (map Wayne Orchiston)

Field station staff mainly heard of developments at other field stations only when they attended occasional seminars and meetings at Radiophysics. Their frequency varied considerably during the early years:

There were times when these meetings were held very regularly and other times when they seemed to be forgotten altogether ... [When they were held] it was a time when one sorted out people treading on each other's toes or pressing each other's borders ... (Wild, 1978).

At these times field station staff also could access the Lab's excellent research and reference library, and liaise with the engineers and technicians involved in designing, developing, and overseeing the fabrication of new antennas and receivers. Later, they would make occasional use of the computing facilities offered by the Lab, which built Australia's first home-grown computer and which was appropriately christened CSIRAC (Fig. 1.11).

While most of the early observational work was carried out at the field stations, in 1948 and 1949 some important research was carried out using a small antenna mounted on the 'Eagle's Nest', a small room and associated flat-roofed area located at the very top of the RP Lab. The 1.1 m (44 inch) equatorially-mounted dish – a recycled WWII searchlight mirror – was used by Jack Piddington (1910–1997) and Harry Minnett (1917–2003) in mid 1948 for observations of the Sun and the Moon at 24 GHz (Fig. 2.9). Then between October 1948 and March 1949, Harry Minnett and Norman Labrum (1921–2011) used this same antenna for solar monitoring at 9.4 GHz. A slight interruption to this program occurred on 1 November 1948 when they used the small dish to observe a partial solar eclipse, in collaboration with RP colleagues at the Potts Hill field station and at remote sites in Victoria and Tasmania. This dish was then transferred to Potts Hill.

Fig. 2.9 The 'Eagle's Nest' was a small flat-roofed room at the very top of the Radiophysics Lab that was used for research and to test new equipment. Piddington and Minnett used the 1.1 m antenna to observe the Sun and Moon in 1948 (courtesy: CRAIA)

Fig. 2.10 Graham Smith with one of the 7.5 m diameter Würzburg dishes used in the interferometer at Cambridge for accurate measurements of radio source positions (courtesy: Robertson collection)

It is interesting to note that Radiophysics made an attempt to obtain one of the large Würzburg radar dishes, abandoned by the retreating German forces after the D-Day invasion in June 1944 (see Fig. 2.10). These dishes were fundamental to the early post-war development of radio astronomy in a number of countries, particularly in Europe (e.g. see Orchiston et al., 2007; Radhakrishnan, 2006; Sullivan, 2009: 78; Van Woerden and Strom, 2006). In November 1945 John N. Briton (ca. 1908–1965), then the acting Chief of the RP Lab, wrote to a colleague in London:

“We understand that there is a good possibility of sidetracking one of the German Würzburg equipments from the Royal Air Force. We would be very glad indeed to acquire one of these. We would set it up at our new field testing site at Georges Heights, Sydney, where it would be very useful for a number of purposes ...” (Briton, 1945).

Unfortunately, nothing came of the idea.

2.2 Dover Heights

The Dover Heights field station was at the site of a WWII Australian Army radar station, on the cliff edge some 79 m above the Tasman Sea and 5 km south of the entrance to Sydney Harbour (Figs 2.1 and 2.6). In the immediate post-war years, it was undoubtedly the most significant of all RP field stations. It was here that Ruby Payne-Scott (see Biobox 2.1) became known internationally for her solar work and John Bolton (1922–1993; Biobox 2.2), Gordon Stanley (1921–2001) and Bruce Slee (1924–2016) for their pioneering studies of the enigmatic ‘radio stars’. It was also here that Dick McGee (1921–2012) would conduct his first research project, ideal training for his future involvement in hydrogen-line astronomy at Potts Hill, Murraybank and Parkes (Sim, 2013).

Biobox 2.1: Ruby Payne-Scott

Ruby Violet Payne-Scott (Fig. 2.11) was born in Grafton, New South Wales, on 28 May 1912 and died in Sydney on 25 May 1981. She graduated from the University of Sydney with a BSc (First Class Honours) in Physics and Mathematics and an MSc in 1933 and 1936 respectively, one of very few women to study science at this time, and in 1938 was awarded a Diploma of Education. From 1936 to 1939 she worked as a physicist for the Cancer Research Department at the University of Sydney and for a year as Science Mistress at Woodlands Church of England Girls Grammar School in Glenelg, South Australia. Between 1939 and 1941 she was a radio engineer at Amalgamated Wireless Australasia, before joining the Radiophysics Lab.

Ruby worked on wartime radar technology at Radiophysics and then carried out pioneering solar radio astronomy at Dover Heights, Hornsby Valley and Potts Hill before leaving CSIRO in 1951 to start a family. Because Commonwealth regulations prevented the permanent employment of married women, she had kept secret her marriage in 1944 to Bill Hall from the CSIRO hierarchy during her years at Radiophysics. Ruby enjoyed one brief return to the astronomical fold when she attended the 1952 URSI Congress, held in Sydney, and she is conspicuous in Fig. 1.31 as the sole female radio astronomer present.

After raising two children, Ruby took up teaching again in 1963, and over the next 13 years successive classes of girls at Danebank Anglican School for Girls in Sydney received their initial training in physics from her. Ruby held strong left-wing political views, was a champion of women's rights, and a keen bush-walker. One of her co-workers, Gordon Stanley (1997), later reminisced: "She was part of my early education on women's issues, and despite early insensitivities on my part, I grew to have a great respect and liking for her."

In 2008 CSIRO established the Payne-Scott Award to support researchers who take extended career breaks to be the primary family carer. In 2021 the Australian Academy of Science established the Ruby Payne-Scott Medal, recognising outstanding career achievements by a woman in the physical or biological sciences. See the full-length biography of Ruby by Goss and McGee (2009) and the abridged version by Goss (2013).

Fig. 2.11 Ruby Payne-Scott (1912–1981) was Australia's first female radio astronomer (courtesy: Bill Hall family; all rights reserved)

Biobox 2.2: John Bolton

John Gatenby Bolton (Fig. 2.12) was born in Sheffield, England, on 5 June 1922. After completing a BA degree at Cambridge University he served as a radio officer on the aircraft carrier HMS *Unicorn*, which was stationed in Sydney at the end of WWII. John stayed on and in September 1946 was appointed a research officer in the Radiophysics Lab. Initially he worked closely with Gordon Stanley and Bruce Slee at Dover Heights, where he “... isolated the first known discrete radio sources, measured their positions and radio spectra, placed upper limits on their angular sizes, recognised the non-thermal nature of the radio emission, and made the first identifications ... of radio sources with optical counterparts.” (Kellermann, 1996: 729). The discovery of these discrete radio sources marked the beginning of a new branch of astronomy – extragalactic radio astronomy.

Bolton then transferred briefly to the Lab’s rainmaking group before accepting a fellowship at the California Institute of Technology in 1955. With colleague Gordon Stanley he established the Owens Valley Radio Observatory (see Fig. 1.22) in the northern Californian mountains, the first major observatory for radio astronomy in the US. At the end of 1960 John returned to Australia as Director of the new Parkes Radio Telescope, where he and his many colleagues carried out two extensive surveys of the southern sky, first at 408 MHz (over 2100 radio sources) and then at 2700 MHz (over 8000 sources). Bolton’s principal role was to make optical identifications of these sources, most of which were either radio galaxies or quasars, and this involved extended visits to optical observatories in the US.

Bolton was the PhD supervisor and mentor to many of the next generation of radio astronomers. He was a Fellow of the Australian Academy of Science (1969) and of the Royal Society of London (1973). Among the many honours John received were the Inaugural Karl Jansky Lectureship (1967, US National Radio Astronomy Observatory), the Gold Medal of the Royal Astronomical Society (1977) and the Bruce Medal (1988, Astronomical Society of the Pacific). Following a heart attack in 1979, John retired to the coastal town of Buderim in Queensland, where he died on 6 July 1993. See Robertson (2017) for a full-length biography; see also Wild and Radhakrishnan (1995), Kellermann (1996) and Orchiston and Kellermann (2008).

Fig. 2.12 John Bolton (1922–1993) and the group at the Dover Heights field station discovered the first discrete Galactic and extragalactic radio sources (courtesy: Letty Bolton)

Fig. 2.13 The 4-Yagi antenna installed at Dover Heights in 1946 and operated at 200 MHz. Note the simple equatorial mounting that allowed the antenna to track the Sun and other celestial objects (courtesy: CRAIA)

Payne-Scott's initial solar work at Dover Heights had been carried out with the 200 MHz WWII radar antenna (see Fig. 1.19), but this was not designed for radio astronomy. All it could do was record the Sun as it rose above the horizon; it could not track the Sun throughout the day. This rather serious problem was overcome in early 1946 when RP staff installed a 4-element 200 MHz Yagi antenna (Fig. 2.13) on the roof of the second blockhouse at Dover Heights, about 50 m north-west of the cliff-side blockhouse with the radar antenna. At about the same time, similar 200 MHz Yagi antennas were also installed at the North Head radar station (at the northern entrance to Sydney Harbour) and at Mount Stromlo Observatory, near Canberra.

The first Dover Heights Yagi antenna was soon followed by twin-Yagis operating at 60 and 85 MHz, attached to improved receivers built by Stanley, and in November 1946 a 100 MHz twin-Yagi replaced the 85 MHz antenna. By May 1947, the three Yagi antennas had been transferred to the roof of the seaward blockhouse (see Fig. 2.14). Bolton (1986) later recounted in a letter to one of us (WS) that by February 1947 the rusting old WWII radar antenna "... had been almost destroyed by vandals and only the basic framework was left ... [so] Stanley and I cut it up with an oxy torch and dropped the bits over the cliff ..."!

Although the simple Yagi antennas were designed initially for solar research, they were soon turned to good account in the search for 'radio stars'. As part of this project, between late 1947 and early 1948, Bolton, Stanley and Slee conducted what was probably the world's first spaced-antenna experiment, using the Yagi aerials at Dover Heights and similar antennas set up at Long Reef and briefly at West Head, about

Fig. 2.14 John Bolton and the cliff-side blockhouse at Dover Heights in May 1947, with the 60 and 100 MHz twin-Yagis on the roof. The 200 MHz antenna was on the far corner and is not visible. Note the wartime camouflage paint (courtesy: Stanley family)

15 km and 35 km away and to the north of Sydney Harbour, to simultaneously measure the intensity variations exhibited by the source in the Cygnus constellation. A further extension of the radio stars project occurred in 1948 when the Dover Heights 100 MHz antenna was used in conjunction with a 4-Yagi mobile radio telescope (Fig. 2.15) that was transported to New Zealand and between June and August was used at two different sites near Auckland (Fig. 2.16) (Orchiston, 1994). Pakiri Hill, near Leigh, on the east coast, allowed observations of sources as they rose above the horizon, while the cliffs above Piha, a famous surf beach to the west of Auckland, permitted observations of these same sources as they set below the western horizon. The cliffs at both Pakiri Hill and Piha were about three times higher than at Dover Heights, which meant that the resolution of their sea interferometer aerial was three times better. While Bolton and Stanley took care of these observations at RP's most distant temporary field stations, Slee continued to conduct parallel observations at Dover Heights.

In order to improve the instrumentation at Dover Heights, in early 1949 a 9-Yagi array was constructed by RP workshop staff and mounted on the blockhouse. This had a novel mounting which allowed it to operate as an equatorial (permitting easy tracking of objects as they moved across the sky), or as an alt-azimuth instrument so that it could function as a traditional sea interferometer and record sources rising over the eastern horizon (see Fig. 2.17). It was Stanley who suggested introducing a

Fig. 2.15 The ex-Army radar trailer in the grounds of the Radiophysics Lab, shortly before it was shipped to Auckland, New Zealand. This mobile sea interferometer featured four Yagi aerials, a new 100 MHz receiver, recorders, chronometers, weather recording instruments and all the tools and backup equipment needed to operate reliably at a remote location (courtesy: CRAIA)

Fig. 2.16 The locations of Pakiri Hill and Piha in relation to the city of Auckland. The observations carried out at these two temporary field stations in the winter of 1948 marked the start of non-solar radio astronomy in New Zealand (after Orchiston, 1994: 542)

Fig. 2.17 The 9-Yagi array under construction early in 1949, with two of the Yagis leaning against the blockhouse. The array with its equatorial mount was used to carry out the first survey of the southern sky (courtesy: Stanley family)

third axis that in effect converted the declination axis to an azimuth axis for sea interferometry. Bolton and new recruit Kevin Westfold (1921–2001) used this antenna with a 100 MHz receiver to carry out the first systematic survey of the southern sky. At the same time, Stanley and Slee temporarily installed new 2-element Yagis operating at 40 and 160 MHz on the roof of the blockhouse, in order to examine a number of strong discrete sources over a wider range of frequencies.

In 1950 Stanley was largely responsible for constructing a new radio telescope at Dover Heights, a 3.9 m (16 ft) parabolic antenna. Although dishes had been used for some time at the RP Lab and at the Potts Hill field station, this was the first dish to be used at Dover Heights. Initially it was mounted on the back of an old WWII trailer and used as a sea interferometer (Fig. 2.18), but eventually it was attached to the equatorial mounting on the blockhouse roof used formerly by the 9-Yagi antenna (Fig. 2.19). This dish was intended mainly as a test bed for low-noise receivers between 190 and 400 MHz, although it was also used to study some of the stronger discrete sources.

With the dish installed on the roof of the blockhouse, in mid-1951 Bolton, Stanley and Slee began constructing another radio telescope. By using elements of the now-surplus 9-Yagi antenna, they soon assembled near the cliff edge a new sea interferometer that was set up on an azimuthal mounting. This was briefly an 8-Yagi array (Fig. 2.20), but was soon converted to a 12-Yagi array, arranged in two widely-spaced banks of six Yagis (see Fig. 2.21), and was used for yet another all-sky source survey at 100 MHz.

Fig. 2.18 The 3.9 m dish mounted in sea-interferometer mode on the back of an ex-Army truck (courtesy: CRAIA)

Fig. 2.19 Star trails and the 3.9 m parabolic dish on the roof of the Dover Heights blockhouse (courtesy: CRAIA)

The last radio telescope to be built at Dover Heights was an ingenious design, and used typical Australian initiative to overcome funding shortfalls at RP at this time (Orchiston and Slee, 2002a). It represents what Christiansen (1986) referred to as the tendency “... to beat poverty with brains ...”. By 1951 several different RP staff members were competing for the limited funds available in order to construct innovative new radio telescopes. Bolton, Stanley and Slee wanted to build a very large two-element interferometer at Dover Heights but were unsuccessful in their funding bid, so they decided to take the initiative and build a giant new radio telescope themselves. The idea for the telescope most probably came from Bolton who

Fig. 2.20 The 8-Yagi antenna was built at the end of 1951 and installed on an old wartime mount a little to the south of the blockhouse and close to the cliff edge (courtesy: CRAIA)

Fig. 2.21 The 12-Yagi array, looking south, was used at 100 MHz to carry out a sky survey and detected 104 discrete sources (see Table 4.3) (courtesy: CRAIA)

had spent most of 1950 touring radio astronomy centres in Europe and North America. He visited the Jodrell Bank field station in Cheshire and was impressed by a fixed above-ground parabolic dish, consisting of a spider's web of wires suspended on upright tubular supports. Its huge size (67 m diameter) enabled Robert Hanbury Brown and Cyril Hazard to detect faint radio emission from the giant Andromeda galaxy.

The Dover Heights group realised they could build a similar dish by excavating a dish-shaped depression in the sand and furnishing this with a reflecting surface and a long mast supporting a dipole. Despite the dish being stationary, different sections of the sky could be surveyed by using the Earth's rotation and by altering the angle of tilt of the antenna mast. Sydney's latitude was ideal, for it meant that the

Galactic Centre – a region of great interest to astronomers – would pass nearly overhead. They chose a site about 150 m to the north of the blockhouse, and during a three-month period in 1951 spent their lunch breaks shifting enough sand to create a 22 m paraboloidal shape, dumping the spoil around the rim of the depression. When the hole neared completion, Stanley drove a truck to the Bunnerong Power Station and collected several loads of ash, which were worked into the sandy surface to help stabilise the shape. He then collected many metres of steel strip from packing cases at the shipping terminal in Botany Bay, and these were laid in close parallel bands across the depression to form a crude reflecting surface. A guyed aluminium mast with a 160 MHz dipole at its top was erected at the centre of the dish, and a low-noise preamplifier was installed in a waterproof box at the base of the mast. From there, the signal was fed to a nearby mobile laboratory (Fig. 2.22).

Initial observations proved successful and in 1952, with Pawsey's blessing, funds were assigned for an upgrade (Fig. 2.23). Over the next three months the dish diameter was extended to 24.4 m, the surface was coated with a layer of concrete in which a small-mesh chicken wire reflecting surface was imbedded (Fig. 2.24). The outer part of the antenna consisted of a 'skirt' formed out of 25 mm aluminium

Fig. 2.22 The original 22 m 'hole-in-ground antenna', one of the largest radio telescopes in the world, was built by the Dover Heights staff as a lunchtime project in 1951. The catwalk provided access to the centre of the dish, the aerial mast and dipole, and the instrument box at the base of the mast that contained part of the 160 MHz receiver (courtesy: CRAIA)

Fig. 2.23 Upgrading the hole-in-the-ground in February 1953 – a concrete surface was added and the diameter extended from 22 to 24.4 m. The rotating parabolic template was used to position formwork for the concrete and also to finish the surface (courtesy: CRAIA)

Fig. 2.24 The upgraded hole-in-the-ground antenna could survey consecutive strips of the sky by altering the position of the aerial mast. Here Gordon Stanley uses a theodolite to measure the mast's angle of tilt (courtesy: CRAIA)

tubes spaced at intervals of 1.8 m which were set in the concrete and constrained by fencing wire to the correct shape. As noted by Arthur Higgs, a senior member of the RP staff: “The actual reflecting surface ... tolerance is within $\pm\frac{1}{2}$ inch, so that the aerial is usable at all wavelengths down to 10 centimetres” (Higgs, 1953). Meanwhile, Stanley designed a new receiver, parts of which were housed in waterproof boxes at the base of the mast. The refurbished antenna was used to study 400 MHz emission from along the plane of the Galaxy and to survey for new radio sources. By this time, Dick McGee had become a vital member of the research team, as Bolton, Stanley and Slee also had to spend much of their time on the 12-Yagi array sky survey.

Upon thinking back on his Dover Heights experience, Bruce Slee (1978) felt that in general the equipment that he and other RP staff built was pretty reliable, but “After the War we had a lot of coal shortages and strikes – [so] for several years there we often had blackouts.” Meanwhile, Gordon Stanley (1986) had more romantic views of those halcyon days in the late 1940s and early 1950s:

In later years, we [he and John Bolton] regretted the ‘loss of innocence’ in the approach to research, compared to the business-like attitude that pervades radio astronomy today. Despite our later success at Owens Valley and Parkes, we never again experienced the exhilaration of those early years.

The remarkable hole-in-the-ground antenna was the last radio telescope built at Dover Heights, and from 1954 the field station was used briefly by the RP Cloud Physics group before being handed back to the Commonwealth Government in 1956. By this time, the Division’s radio astronomical focus had shifted to the Potts Hill field station, and a new field station at Fleurs (Sections 2.6 and 2.10).

For further details on the role of the Dover Heights field station see Orchiston and Robertson (2017). For their personal reminiscences on the Dover Heights years see Bolton (1982), Slee (1994), Stanley (1994) and Westfold (1994).

2.3 Georges Heights

The Georges Heights radar station occupied an attractive strategic position on Middle Head, overlooking the entrance to Sydney Harbour (see Fig. 2.6), and during the war was home to a number of different radar antennas (Fig. 2.25). In 1947 and 1948, this site was used by RP as a short-lived field station (Orchiston, 2004a; Orchiston and Wendt, 2017; Wendt and Orchiston, 2018).

One of the wartime radar antennas at Georges Heights was an experimental unit featuring a 4.3×4.8 m section of a parabola and a cumbersome alt-azimuth mounting (Fig. 2.26), and this was used for early solar radio astronomy. The only way it could be used effectively was to place the antenna ahead of the Sun, let the Sun drift through the beam, hand-crank the antenna ahead of the Sun again, and repeat the process throughout the day. This procedure produced a distinctive ‘picket fence’ chart record. At this time, Payne-Scott and her collaborators were monitoring solar activity from

Fig. 2.25 The Georges Heights radar station and the view towards the entrance to Sydney Harbour (courtesy: CRAIA)

Fig. 2.26 Joe Pawsey (left) and Don Yabsley with the ex-radar antenna at Georges Heights. Yabsley and Fred Lehany used the antenna for solar observations at 600 and 1200 MHz (courtesy: CRAIA)

Fig. 2.27 One of the American 3.05 m AN/TPS-3 radar dishes undergoing testing at Georges Heights in August 1948. Two of these simple radio telescopes were transported to remote sites in Victoria and Tasmania to observe solar eclipses in 1948 and 1949 (courtesy: CRAIA)

Dover Heights, using 60, 100 and 200 MHz Yagis, and the Georges Heights antenna allowed the frequency coverage to be extended from 200 MHz to 600 and 1200 MHz.

Assigned to the Georges Heights antenna were two young RP radio engineers, Fred Lehany (1915–1980) and Don Yabsley (1923–2003). Lehany (1978) related that his involvement with this short-lived project “... came about in a typical ‘Pawseyian way’, before I knew what was happening ... there was an observing program and ... Yabsley and I were a suitable pair to share not only the week days but also the weekend duty ...”. This was Lehany’s sole foray into radio astronomy, and soon afterwards he transferred to another CSIRO Division. In contrast, this proved the perfect radio astronomy training ground for a youthful Don Yabsley who later spent a decade working in the RP air navigation group, but returned to radio astronomy with the commissioning of the Parkes Radio Telescope. For a few months in 1947, Lehany and Yabsley were assisted by Bruce Slee, before he was re-assigned to Dover Heights.

In mid-1948, the Georges Heights field station was used as a test-base for two portable American ex-WWII 3.05 m dishes (Wendt and Orchiston, 2018) that were assembled in order to observe the 1 November 1948 partial solar eclipse from Rockbank (Victoria) and Strahan (Tasmania) (Fig. 2.27). Ironically, this eclipse was the death-knell for Georges Heights as a radio astronomy facility, for a decision was made to transfer the ex-radar antenna to the Potts Hill field station, where it could be used to monitor the eclipse. After less than two years as a field station, Georges Heights was closed down.

2.4 Hornsby Valley

Few if any residents now living in Hornsby would be aware that Hornsby Valley – Old Man Valley, as locals call it – was at one time an important astronomical site. Located on the northern outskirts of Sydney (Fig. 2.6) in a closed valley on

farmland to the west of the Pacific Highway and near a quarry site, between 1947 and 1952 this RP field station was home to a number of unusual radio telescopes. Under the auspices of Frank Kerr (1918–2000), Ruby Payne-Scott, Alex Shain

Biobox 2.3: Alex Shain

Charles Alexander Shain (Fig. 2.28) was born in Sandringham, Victoria, on 6 February 1922. He completed a BSc (Second Class Honours) at the University of Melbourne in 1942. Following a brief stint of military service, Alex joined the Radiophysics Lab in November 1943 and worked on radar.

After the War, Shain was the leading ‘low frequency’ practitioner in the radio astronomy group and, assisted by Charlie Higgins, carried out Galactic observations at 9.15 MHz and 18.3 MHz from the Hornsby Valley field station. In 1956 Alex was responsible for the construction of the 19.7 MHz Shain Cross radio telescope at the Fleurs field station and used this to survey the Galactic Plane and to derive isophote plots of the strong discrete sources Centaurus A and Fornax A. Shain “... pioneered the study of two features peculiar to this range of radio astronomy: absorption in ionised interstellar hydrogen (HII regions), and absorption and refraction in the ionosphere” (Pawsey, 1960b: 244). Following the 1955 report by the Americans Bernard Burke (1928–2018) and Kenneth Franklin (1923–2007) of decametric emission from Jupiter, Alex revisited the 18.3 MHz ‘static’ recorded at Hornsby Valley in 1950–51, and to his chagrin discovered that some of these events were indeed Jupiter bursts! This was surely a missed research opportunity for Australian radio astronomy. When Alex Shain died from cancer on 11 February 1960, aged only 38, a promising career was cut short.

Fig. 2.28 Alex Shain (1922–1960) pioneered very low frequency radio astronomy, first at Hornsby Valley and then at the Fleurs field station (courtesy: CRAIA)

Fig. 2.29 The Hornsby Valley field station showing the antennas, transmission lines and instrument huts used by Kerr, Shain and Higgins in the 1948 Moon-bounce experiment. Radar signals at 17.84 and 21.54 MHz were transmitted from Shepparton (Victoria), bounced off the Moon, and received at Hornsby Valley (courtesy: CRAIA)

(1922–1960) and Charlie Higgins these were used to carry out pioneering studies in lunar, solar and Galactic astronomy (Orchiston and Slee, 2005; Orchiston et al., 2015a, 2015b).

In 1947 Frank Kerr and Alex Shain (Biobox 2.3) decided to study the structure of the upper part of the Earth's ionosphere with a simple rhombic antenna and modified communications receiver at the Hornsby Valley field station (Fig. 2.29). They succeeded in receiving radio signals broadcast at 17.84 and 21.54 MHz by Radio Australia (at Shepparton, Victoria) that had bounced off the Moon. This project lasted about one year, and was to be Kerr's sole foray into radar astronomy as he soon transferred to Potts Hill where he went on to make a name for himself through his hydrogen-line work.

Ruby Payne-Scott was keen to expand the solar work she had begun at Dover Heights, and towards the end of 1947 she moved to the Hornsby Valley field station and set up simple Yagi antennas for observations at 60, 65 and 85 MHz, together with an 18.3 MHz broadside array. She also made use of Kerr's 'Moon-bounce' rhombic antenna, operating at 19.8 MHz. Circular polarisation was investigated with the 85 MHz antennas, which consisted of a pair of crossed Yagis. This study ran from January through to September 1948, when Payne-Scott transferred to the Potts Hill field station (Goss and McGee, 2009).

After Kerr's departure to Potts Hill, Shain stayed on at Hornsby Valley, and he eventually became an acknowledged authority on low frequency radio astronomy, assisted throughout by Charlie Higgins. Up to this time, that region of the electromagnetic spectrum had been largely neglected because of the detrimental impact of

the ionosphere on the incoming radio waves. Countering this problem was the simplicity of low frequency radio telescopes, where the ground itself could serve as a reflector. All that was required were posts to support the dipoles.

This simplicity was typical of the various arrays built at Hornsby Valley in 1949 and the early 1950s. For example, in 1949 Shain erected an array of eight half-wave dipoles strung between four rows of telegraph poles in order to investigate Galactic radiation at 18.3 MHz. The antenna system was attached to a standard communications receiver, and observations were carried out between May and November 1949.

The success of these early observations led Shain to expand the array to 30 horizontal half-wave dipoles, so that a more detailed survey could be carried out with a smaller beam. Although the antenna was stationary it was possible to move the beam electronically, and this meant that a wide strip of sky from declination -12° to -50° could be surveyed. The observations were carried out between June 1950 and June 1951, and only about 10% of all records were lost through interference or atmospheric effects.

In June 1951 the 18.3 MHz radio telescope was replaced by a network of 12 fixed horizontal half-wave dipoles, operating at 9.15 MHz. The network utilised some of the original telegraph poles, in four parallel banks of three antennas (Figs 2.30 and 2.31). The dipoles were attached to a standard communications receiver. Like its predecessor, this was a transit instrument which relied on the Earth's rotation in order to record radio emission from different strips of the sky (but this time without directing the beam). And once again, Sydney's fortuitous latitude meant that the celestial region of greatest interest, the Galactic Plane and centre of the Galaxy, would pass almost directly overhead. Between July 1951 and September 1952 this radio telescope was used by Shain to scan a strip of sky centred on declination -32° . Because of the prevalence of interference caused by the atmosphere and by radio stations, the most favourable time for observations was between midnight and half an hour before sunrise. It

Fig. 2.30 Some of the 9.15 MHz aerials at Hornsby Valley used in the low frequency sky survey centred on declination -32° (courtesy: CRAIA)

Fig. 2.31 Inside one of the receiver huts showing the chart recorders used for the 9.15 MHz sky survey in 1951–52 (courtesy: CRAIA)

Fig. 2.32 Radio astronomers attending the URSI General Assembly at the Hornsby Valley field station, in discussion with Alex Shain (far left) (courtesy: CRAIA)

was in August 1952, during this research project, that some of the delegates from the International Union of Radio Science Congress, which was meeting in Sydney, visited Hornsby Valley where they were given a guided tour of the site by Shain (Fig. 2.32).

As early as February 1952, Shain was having reservations about the future of the Hornsby Valley field station. The 9.15 MHz survey was underway, but interferometric observations planned at 18.3 MHz had been terminated prematurely when the equipment used was destroyed in a bush fire. After completion of the 9.15 MHz survey, Shain (1952) planned to embark on a major new low frequency project, but he concluded that “The Hornsby station will not be satisfactory for [this due to] ... lack of adequate open level space ... Hence we should plan to progressively evacuate Hornsby – breaking down the gear now in use after October 1952.” While Shain suggested Badgery’s Creek as a suitable site for the new low frequency work, it was in fact Fleurs that benefited from the eventual closure of the Hornsby Valley field station.

2.5 Bankstown Aerodrome

This was the last of the post-WWII RP field stations to be documented, and its very existence was only identified during doctoral research by Harry Wendt (2008). For about one year, during 1947–1948 Radiophysics maintained a field station at Bankstown Aerodrome, about 20 km south-west of the Sydney central business district. The aerodrome was set up in 1940 as a Royal Australian Air Force base, and after WWII some of the 18 hangars and 16 huts there “... were hired out to a range of enterprises, including the CSIR. This is how RP’s little-known Bankstown Aerodrome field station was formed ...” (Wendt and Orchiston, 2019: 267–268).

By June 1947, RP had established a blossoming line of research in both solar (Orchiston et al., 2006) and cosmic noise investigations (Robertson et al., 2014) using sea-interferometry, but this technique could not locate the positions of short-duration sources, such as those associated with solar bursts. It was the task of Ross Fredrind Treharne (1919–1982; Treharne, 1983: 153), assisted by Alec Little (1925–1985; Mills, 1985), to develop a new type of interferometer that could detect these short-lived solar bursts.

By 20 February 1948 Treharne reported that he and Little had built a prototype 100 MHz two-element interferometer, and would soon start making solar observations, but shortly after the field station was vandalised and some of the equipment stolen. RP then decided to transfer the new interferometer to the secure and nearby much larger Potts Hill field station and the small Bankstown Aerodrome facility was closed down in July 1948. Treharne ended his brief flirtation with radio astronomy and went on to build a successful career in military research. The final development of what became known as the swept-lobe interferometer was then transferred to Ruby Payne-Scott and Little. As we will see in the next section, this unique radio telescope was used very effectively for daytime observations of the Sun, and of an evening by Bernie Mills to investigate discrete radio sources.

2.6 Potts Hill

The Potts Hill field station was located 17 km west–southwest of central Sydney (Fig. 2.6), at the radio-quiet site of the city’s main water storage facility (Fig. 2.33). Begun in 1948 as a centre for solar radio astronomy, its role soon expanded to include important developments in non-solar radio astronomy (see Fig. 2.34 for site map). Radio astronomers associated at one time or another with Potts Hill included Chris Christiansen, Rod Davies (1930–2015), Jim Hindman, Frank Kerr, Alec Little, Don Mathewson (b. 1929), Bernie Mills (1920–2011), Harry Minnett, John Murray (b. ca. 1927), Ruby Payne-Scott, Jack Piddington, and a youthful Brian Robinson (1930–2004). The earliest radio telescopes on this site date from 1948, including a simple equatorially-mounted Yagi antenna used by Alec Little (Fig. 2.35) to monitor the Sun at 62 MHz. Another was a 3.05 m diameter dish (Fig. 2.27) with which Piddington and Minnett surveyed radiation from the region of the Galactic Centre at 1210 MHz (with a beam width of 2.9° at this frequency).

In the second half of 1948 the 4.3×4.8 m radar antenna at Georges Heights was relocated to Potts Hill (Orchiston and Wendt, 2017) and installed on an equatorial

Fig. 2.33 Aerial view of the eastern reservoir at Potts Hill from the north, site of one of RP’s most productive field stations. Part of the larger, western water reservoir can be seen in the distance. The two 1420 MHz solar grating arrays are shown, with the original 32-element array in the background and the later 16-element array in the foreground (courtesy: CRAIA)

Fig. 2.34 Layout of the Potts Hill site showing the variety of radio telescopes in operation in the early 1950s (courtesy: Harry Wendt)

mounting (Fig. 2.36), after this was designated the station responsible for Sydney-based observations of the partial solar eclipse of 1 November. These observations were carried out at 600 MHz by Christiansen (Biobox 2.4), Yabsley and Mills. Other observations of this eclipse were made at Potts Hill by Piddington and Hindman at 3000 MHz, using an equatorially-mounted 1.7 m dish, which later was used with a distinctive full-aperture polarisation screen (Fig. 2.38). In addition, portable 3.05 m dishes operating at 600 MHz (see Fig. 2.27) were assembled and tested at Georges Heights and then transported to Rockbank, near Melbourne, and Strahan, on the west coast of Tasmania, to be used in conjunction with the ex-Georges Heights antenna at Potts Hill (Wendt and Orchiston, 2018). Following the celebrated New Zealand ‘radio stars’ field trip of June–August 1948, this eclipse therefore continued a tradition of establishing radio telescopes at temporary remote sites for special projects.

Fig. 2.35 At the Potts Hill field station in 1949 (from left): Ruby Payne-Scott, Alec Little and Chris Christiansen (courtesy: CRAIA)

Fig. 2.36 After it was relocated to Potts Hill in 1948, the ex-Georges Heights radar antenna was installed on an equatorial mounting and used for a wide range of research projects. In 1951 it was the first Australian radio telescope to observe the newly-discovered hydrogen line (courtesy: CRAIA)

Biobox 2.4: ‘Chris’ Christiansen

Wilbur Norman (‘Chris’) Christiansen (Fig. 2.37) was born in Melbourne on 9 August 1913 and died in Sydney on 26 April 2007. He studied mathematics and physics at the University of Melbourne, graduating with BSc and MSc (First Class Honours) degrees in 1934 and 1935 respectively. In 1953 the University awarded him a DSc, and he subsequently received an honorary DSc (Engineering) from the University of Sydney in 1980 and an honorary DEng from his *alma mater* in 1982. Immediately after completing his Masters, Chris worked for the Commonwealth X-ray and Radium Laboratory, before joining Amalgamated Wireless (Australasia) Ltd in 1937.

In 1948 Chris joined the Radiophysics Lab, rising to Senior Principal Research Scientist, before leaving in 1960 to accept a chair and head the Department of Electrical Engineering at the University of Sydney. After retiring in 1978, he was appointed a Visiting Fellow at Mount Stromlo and Siding Spring Observatories in Canberra. One of the pioneers of radio astronomy, Chris invented the solar grating interferometer at Potts Hill and the crossed grating interferometer at Fleurs, and also developed the innovative Fleurs Synthesis Telescope (Fig. 1.25). He was the first to use Earth rotation synthesis to produce a map of a celestial object, and provided confirmation of the existence of the 21 cm hydrogen line. He also carried out design work on radio telescopes in a number of overseas countries. A former President of URSI and Vice-President of the International Astronomical Union, Chris was a Fellow of the Australian Academy of Science, and was a recipient of the Syme Medal (University of Melbourne), the Russell Medal (Institution of Engineers Australia), the Fleming Award (Institution of Electrical Engineers) and the Adion Medal (Observatoire de Nice).

Apart from his many research papers, Chris was known for the textbook *Radiotelescopes* (CUP, 1969), co-authored by Jan Högbom (b. 1929). “Physicist, engineer, astronomer, teacher, administrator ... Christiansen has in his times played many parts, and all of them with distinction” (Labrum, 1976; cf. data in Christiansen, 1976). For more on Christiansen’s career see Swarup (2008), Davies (2009), Orchiston and Mathewson (2009), Wendt et al. (2011c), Frater and Goss (2011) and Frater et al. (2017). For his contributions to Indian and Chinese radio astronomy see Orchiston and Phakatkar (2019) and Shouguan (2017).

Fig. 2.37 Chris Christiansen (1912–2007) developed two innovative solar grating arrays at the Potts Hill field station and the Chris Cross at Fleurs (courtesy: CRAIA)

Fig. 2.38 The 1.7 m equatorially-mounted antenna was used in the late 1940s and early 1950s for solar monitoring at 3000 MHz, shown here with preparations underway for the November 1948 solar eclipse (courtesy: CRAIA)

This tradition was reinforced further in October 1949 for another solar eclipse (Wendt et al., 2008a). The portable dishes were located at Eaglehawk Neck on the east coast of Tasmania and near Sale in eastern Victoria, and employed in conjunction with the two Potts Hill antennas. In addition, the 1.1 m equatorially-mounted dish (Fig. 2.9) that had been used at the RP Lab for lunar and solar work in 1948–49 was available.

Not content with merely recording solar bursts, Ruby Payne-Scott and Alec Little wanted to record their positions, angular sizes and polarisation, so in early 1949 the RP workshop constructed a new interferometer consisting of three 97 MHz Yagi aerials (Fig. 2.39), aligned E–W, more or less along the northern edge of the eastern reservoir (Little and Payne-Scott, 1951). These were on equatorial mounts, which meant they could track the Sun for four hours each day centred on midday. Crossed dipoles allowed them to receive left-hand and right-hand circular polarisation. The signals were recorded as waves of various shapes on cathode ray tubes, where they were photographed. The Yagis could be used as either swept-lobe or fixed-lobe interferometers, depending on the type of investigation desired. Frank Kerr (1953) described how this interferometer “... was the first one in the world which could locate a source-position on the Sun sufficiently rapidly to be able to operate on the short-lived bursts.” Meanwhile, of an evening this interferometer was used by Bernie Mills to investigate the positions of selected discrete sources.

Fig. 2.39 Joe Pawsey with one of the 97 MHz Yagi antennas used with the three-element position interferometer. The crossed dipoles allowed the polarisation of the solar bursts to be determined (courtesy: *Life* magazine)

According to Pawsey (1954), during the early 1950s solar monitoring continued at Potts Hill using 62, 97 and 200 MHz Yagi antennas (see Fig. 2.34), at 600 and 1210 MHz with the ex-radar antenna, and at 3000 and 9400 MHz using two small parabolas (e.g. see Fig. 2.38). The 62, 97 and 3000 MHz observations were terminated in 1956 when the radio astronomers involved became committed to other more urgent and time-consuming projects. The plan was to continue monitoring at the other frequencies until such observations were no longer required by staff at the Dapto and Fleurs field stations (Future Program for Radio Astronomy, 1958).

In 1949 non-solar research at Potts Hill expanded when Piddington and Minnett began an all-sky survey at 1210 MHz using the 3.05 m dish, and the following year they transferred the project to the much larger ex-radar antenna with a beam of $\sim 1.4^\circ$, and also began observing at 3000 MHz using the 1.7 m dish, which – for this purpose – had been expanded to 2.3 m. At this frequency the dish had a beam width of 1.7° .

Solar astronomy at Potts Hill took a major step forward in 1951 when a 1420 MHz solar grating interferometer was constructed along the southern edge of the eastern water reservoir (Fig. 2.40). This innovative instrument was developed by Chris Christiansen, and consisted of 32 solid metal parabolic dishes each 1.8 m in diameter and spaced at 7 m intervals (Christiansen and Warburton, 1953). Each dish was on a simple equatorial mounting, but there was no drive. Instead, the operator had to manually change the position of each antenna during observations; to quote Christiansen (1976): “... as you run [continuously] from one end to the other you just click them so that you’re following the Sun ... [we] took it in turns. We’d do half an hour at a stretch ... it was fairly strenuous ...”. This novel radio telescope provided a series of 3 arcmin fan beams each separated by 1.7° . Since the Sun’s

Fig. 2.40 Chris Christiansen (above) with the first Potts Hill solar grating array, constructed in 1951. There were 32 solid metal parabolic dishes in the array, all 1.8 m in diameter. Each dish was mounted on a simple polar axis and could be moved manually to follow the Sun. During observations the dish positions were changed approximately every 15 minutes. This involved someone running down the length of the array and adjusting each of the 32 elements by hand. Later, the entire array was donated to a radio astronomy group in India (courtesy: CRAIA)

diameter is 30 arcmin, this meant that the Sun could only be in one beam at any one time. The array was operational from February 1952, and was used daily for about two hours, centred on midday to produce E–W scans of the Sun. Christiansen was assisted throughout by Joe Warburton (1923–2005).

A second solar grating array was erected along the eastern margin of the same reservoir in 1953 (Fig. 2.41). Although this also operated at 1420 MHz, it contained just 16 equatorially-mounted mesh dishes 3.4 m in diameter. From September 1953 to April 1954 this was used to generate a series of N–S scans of the Sun in order to investigate the distribution of radio emission from the ‘quiet Sun’.

In 1954 two Indian visitors to Radiophysics, Govind Swarup (1929–2020; 2006) and R. Parthasarathy, modified the E–W solar array so it could observe at 500 MHz,

Fig. 2.41 The 16-element north–south arm of the solar grating array in July 1953, located on the eastern bank of the Potts Hill reservoir. The E–W arm can be seen in the background on the southern bank (courtesy: CRAIA)

with fan beams of 8.25 arcmin each separated by 4.9° . This instrument was used between July 1954 and March 1955 to investigate emission from the quiet Sun at this new frequency. Soon after this project was completed, the ‘Chris Cross’ was constructed at Fleurs, and the Potts Hill solar program transferred to that field station. Arrangements were made to transfer ownership of the redundant Potts Hill grating array and the 500 MHz receiver to the National Physical Laboratory in India (Orchiston and Phakatkar, 2019). At this time the second solar grating array was also closed down.

One of the most interesting radio telescopes at Potts Hill was a prototype Mills Cross (Fig. 2.42) that was completed in early 1953 to test the cross-type telescope concept (Mills, 1953). Mills recalled that he “... had to convince people it would work, and there were also a number of basic problems I wasn’t quite clear about myself which I wanted to experiment with ...”. Despite his initial skepticism, RP Chief Edward G. (‘Taffy’) Bowen (1911–1991; 1973) was later to applaud Mills’ initiative, describing how he “... had a brainwave ... literally a brainwave, and invented the Mills Cross ...”. The one-tenth scale model built at Potts Hill consisted of N–S and E–W arms, each 37 m in length and containing 24 half-wavelength E–W aligned dipoles backed by a wire mesh reflecting screen. This novel instrument operated at 97 MHz and had an 8° beam, which could be swung in declination by changing the phases of the dipoles in the N–S arm (Mills and Little, 1953). Although some colleagues were skeptical, this prototype worked perfectly well – revealing the Galactic Centre and both Magellanic Clouds – and on this basis a new full-scale Mills Cross was erected at the new Fleurs field station in 1954.

Fig. 2.42 (above) Diagram illustrating the cross-type radio telescope concept. (below) A prototype Mills Cross was constructed quickly and cheaply at Potts Hill in order to test the concept – which it did with considerable success. This innovative new instrument had N–S and E–W arms 37 m long, and operated at a frequency of 97 MHz. The former Georges Heights radar antenna is in the background (courtesy: CRAIA)

With the emerging international interest in hydrogen-line work, a new, more suitable, radio telescope was required to replace the aging ex-Georges Heights radar antenna, and this came in the form of an 11 m dish constructed in 1952–53 (Fig. 2.43). The new dish had a beam width of 1.5° , and as a transit instrument could only be tilted in altitude. It was connected to a four channel receiver, each channel with a bandwidth of 40 kHz (Fig. 2.44). This facility was used extensively by Kerr, Hindman and Robinson for a range of Galactic and extragalactic hydrogen-line projects. In addition, this dish was used by Piddington and Trent for another project. In 1954–55 they carried out a survey of the sky at 600 MHz, using the former Piddington and Minnett 1210 MHz receiver, modified to operate at the lower frequency (the beam width was 3.3° at 600 MHz).

After making important contributions to solar, Galactic and extragalactic radio astronomy, the Potts Hill field station closed in 1963, when the remaining Galactic and extragalactic programs were transferred to Parkes. For detailed histories of the Potts Hill field station see Wendt (2008) and Wendt et al. (2008b, 2008c, 2011a).

Fig. 2.43 An 11 m dish was constructed at Potts Hill in 1952–53 and dedicated to research on the newly-discovered 1420 MHz hydrogen line. This dish replaced the aging ex-Georges Heights antenna (courtesy: CRAIA)

For personal reminiscences of their time at Potts Hill see Davies (2005) and Swarup (2008).

2.7 Penrith

In 1948 the need arose for a site where the spectra of solar bursts could be investigated using a novel type of radio telescope, and the short-lived Penrith field station was founded. This was located on a farm, close to the railway station at Penrith, a township to the west of Sydney at the foot of the Blue Mountains (see Fig. 2.6).

Fig. 2.44 The 4-channel hydrogen-line receiver. Taking readings is Brian Robinson who joined the H-line team in 1953 (courtesy: CRAIA)

Apart from a collection of simple huts which housed the electronic equipment, this field station featured just a single radio telescope, a large rhombic aerial.

This distinctive antenna (Fig. 2.45) consisted of a wooden cross-shaped frame measuring 10.7×7.1 m which supported the wire that detected the radio emission. The cross was anchored at one end, and in order to follow the Sun was first set to the correct position using crude hour angle and declination scales and then moved every 20 minutes or so by making adjustments to a number of different guy ropes. Joe Pawsey was widely regarded as an ‘aerial guru’, and it was he who provided the initial idea of using a rhombic antenna. Unfortunately, he was overseas when it was constructed, and Wild much later recalled that “... he was rather distressed when he came back and saw it. He had ideas of building it out of bamboo – he used to love bamboo (it’s so nice and solid) – and he was horrified to see this rather heavy thing that was dragged around by ropes” (Wild, 1978). Nonetheless, it worked! This one antenna received solar radio emission over the frequency range 70–130 MHz, and displayed it on a cathode ray tube where it was photographed (see Wild and McCready, 1950). Apparently, the idea of attaching the antenna to a swept-frequency receiver came from Taffy Bowen, who was familiar with their use in a radar context during WWII.

The first serious scientific observations at the Penrith field station were full-time solar monitoring in February 1949. Paul Wild (1978) remembers that sometimes a week or more would go by without any solar activity, and that “... this involved an awful lot of work, traveling backwards and forward [from home] and watching, for

Fig. 2.45 (left) The rhombic antenna built by Paul Wild and Lindsay McCready at the Penrith field station. During 1949 this antenna operated with a swept-frequency spectrograph over a frequency range 70–130 MHz to study solar bursts. (right) The simple indicators used to point the antenna at the Sun at the start of each day’s observations (courtesy: CRAIA)

nothing to happen – or so it seemed at the time. And then on other occasions there was huge tremendous activity.” By the end of June the potential of this type of antenna had been proven and the search was on for a more ‘radio-quiet’ site where further antennas could be set up. This led to the founding of the Dapto field station, and in 1951 the short-lived Penrith field station was closed down. It had served its purpose.

Paul Wild (1923–2008) was the driving force behind the founding of the Penrith field station, which initiated his involvement in solar radio astronomy, a field in which he would soon become the world’s leading authority (Biobox 2.5). Receiver development was in the hands of radio engineer John Murray and technician Bill Rowe; Murray would later play a leading role in developing instrumentation for RP’s 21 cm hydrogen line research.

Biobox 2.5: Paul Wild

John Paul Wild (Fig. 2.46) was born in Sheffield, England, on 17 May 1923 and died in Canberra on 10 May 2008. He graduated BA in mathematics and physics from Cambridge University in 1943, and with an MA in 1946. During the latter part of WWII he served as a radio officer on the battleship *HMS King George V* and Sydney was the base for a number of Pacific operations. In 1947 Paul returned to Sydney where he was appointed a Research Officer in the Radiophysics Lab.

Wild specialised in radio studies of the Sun and he led the group studying short-lived phenomena such as violent flares in the solar atmosphere. He was

(continued)

Biobox 2.5 (continued)

Fig. 2.46 During the early 1950s Paul Wild (1923–2008) became the world’s leading authority on solar radio astronomy (courtesy: CRAIA)

largely responsible for the initial design concepts of the Penrith and Dapto radio-spectrographs, the Dapto position interferometer and the Culgoora Radioheliograph (see Chapter 5). He moved quickly through the CSIRO ranks and in 1961 he was appointed a Chief Research Scientist. From 1971 to 1978 he was Chief of the Division of Radiophysics, and from 1978 to 1985 was the Chairman of CSIRO. Over the years Paul published a succession of seminal research papers, plus major review papers in Kuiper’s *The Sun* (1953), *Advances in Electronics and Electron Physics* (1955) and in the 1963 issue of *Annual Review of Astronomy and Astrophysics* (co-authored by RP colleagues Steve Smerd and Alan Weiss).

Paul was widely regarded as one of the world’s foremost solar physicists, and he received numerous awards, including the Jansky Lectureship (US National Radio Astronomy Observatory, 1973), the Herschel Medal (Royal Astronomical Society, 1974), the Lyle Medal (Australian Academy of Science, 1975) and the Royal Medal of the Royal Society of London (1980). In 1970 he was elected a Fellow of the Royal Society. He served as the President of the IAU Radio Astronomy Commission (C40) (1967–70) and as the Foreign Secretary of the Australian Academy of Science (1973–77). In 1978 Paul was appointed Commander of the Order of the British Empire (CBE) and in 1986 was made a Companion of the Order of Australia (AC). For further details see Stewart et al. (2011b), Frater and Ekers (2012) and Frater et al. (2017).

As an interesting aside it should be mentioned that in late 1947, when the Penrith field station was being planned, Ruby Payne-Scott (1947a) prepared a report for the RP ‘hierarchy’ on the “Possibility of Constructing a Spectroheliograph or Spectroheliograph Suitable for Investigating Optical Correlation with Solar Radio Observations”, where she advocated the use of a Lyot-type monochromatic filter.

But in the end it was CSIRO's Division of Physics that ultimately constructed this instrument. Under the guidance of their Chief, Dr Ron Giovanelli (1915–1984), there was close co-operation between this Division's solar optical astronomers and the solar radio astronomers at Radiophysics.

For in-depth accounts of the Penrith field station see Stewart (2009) and Stewart et al. (2010).

2.8 Dapto

This field station was located on a dairy farm just north of the township of Dapto and was set up in 1951 following a systematic search by Paul Wild. A memorandum prepared for Joe Pawsey by Wild on 16 January 1951 lists the criteria used in this search:

The technical requirements of the site are:

- (a) Rectangle of fairly level ground about 80 yds. In N-S direction by 25 yds. E-W. Room for expansion desirable.
- (b) Radio interference in the frequency range 30–250 Mc/s to be as low as possible.
- (c) 240 V mains supply very desirable. Telephone desirable.

The “economic” requirements are:

- (d) The site to be as close to Sydney as possible.
- (e) Readily accessible by road, and public transport if possible.
- (f) Efficient staffing arrangements of site to be possible.
- (g) Reasonably proof against vandalism. (Wild, 1951)

The chief problem was finding a suitable, accessible, radio quiet site (i.e. one that satisfied condition (b) above). In addition to contemplating various sites down the NSW south coast almost to the Victorian border, Wild also looked north of Sydney as far as Wyong, to the southwest of Sydney at Picton, and south of Sydney at Moss Vale, Nowra and Kangaroo Valley. He also considered the existing field stations at Penrith and Hornsby Valley, but found levels of interference at both were unacceptable.

After reviewing various options, Wild successfully recommended Dapto for the new field station. The site was about 95 km south of Sydney (see Fig. 2.6) and readily accessed by road and rail; it was close to the owner's house, a key factor for security purposes; an abundance of flat land was available; the site was fringed by mountains to the north, screening it from Sydney-based radio interference; mains power and telephone were available; and various staff offered to live nearby or commute regularly from Sydney or Wollongong.

With the passage of the years, Dapto would contribute significantly to the international development of solar radio astronomy and, apart from Paul Wild, others who would play a leading role at this field station were John Murray, Jim Roberts (b. 1927), Kevin Sheridan (1918–2010), Steve Smerd (1916–1978) and, in later years, Shigemasa Suzuki (1920–2012).

Initially, the radio telescopes at Dapto consisted of three different crossed-rhombic aerials (Wild, 1951) in a N–S line, which covered the frequency ranges

Fig. 2.47 (above) The Dapto field station showing the three rhombic antennas and the main receiver building. (below) The rhombic antennas were mainly made of wood. Their crossed rhombic configuration allowed polarisation measurements to be made of the solar bursts (courtesy: CRAIA)

40–75, 75–140 and 140–240 MHz (Fig. 2.47). Each aerial was supported by an equatorial mounting, which meant it could be motor-driven to track the Sun. Meanwhile, the crossed-configuration allowed different polarisation measurements

Fig. 2.48 John Murray at Dapto in 1952 with part of the receiving equipment of the radiospectrographs (courtesy: CRAIA)

to be taken. Development of the aerials and the supporting receivers took time, so the three solar radiospectrographs, as they were called, only became operational in August 1952. Inside the receiver hut the signals from the three aerials went to three swept-frequency receivers (Fig. 2.48), and then to cathode ray tubes where they were photographed with cine cameras. This ingenious system allowed a complete spectrum to be obtained every half-second. Kevin Sheridan (1978) recalled that initially it was hard to keep the facility operating successfully: “... it was a very difficult piece of equipment to keep going ... it was really a mechanical monster of sorts ...”.

Paul Wild (1978) recollected that once the radiospectrographs were ready, “... we had a dreadful first three or four months, because we were right in the middle of sunspot minimum. Nothing happened at all.” Between 1958 and 1963 the Sun was more active, and the solar facility was expanded when four new rhombic antennas were added, allowing the lowest frequency received to successively be reduced from 40 to 25 MHz (in 1958), 15 MHz (in 1960) and finally 5 MHz (in 1961). Then in 1963 a 10 m parabolic dish with a log-periodic feed was installed, and this allowed the upper frequency limit to be extended from 210 to 2000 MHz. By this time, the Dapto facility had proved its worth and was no longer unique, for similar radiospectrographs had been installed at Mitaka, Tokyo, in 1952 (see Nakajima et al., 2014) and in 1957 at field stations by radio astronomy groups at Harvard University (Thompson, 2010: 28) and the University of Michigan.

In the same year (1957), three new rhombic aerials were added at Dapto, in order to investigate the positions, sizes and polarisations of different solar burst sources over the frequency range 40–70 MHz, and two further rhombic aerials were added in 1959. Four of these aerials, termed the position interferometer, were used for the position and size studies, and all were located along an E–W line (Wild and Sheridan, 1958). The two most distant antennas were separated by 1 km. Although also made

Fig. 2.49 Paul Wild with one of the simple position interferometer rhombic aerials. Because these aerials remained stationary, they did not require equatorial mounts (courtesy: CRAIA)

with wooden frames, all four rhombics were of simpler design than the radiospectrograph aerials and did not need equatorial mounts as they remained stationary throughout the observations (see Fig. 2.49). The fifth new antenna was designed specifically for the study of polarisation. It comprised a crossed-rhombic aerial of identical dimensions to the position interferometer aerials, but was mounted equatorially so that it could track the Sun during the day. The system was set up so that the operator could manually switch between the position interferometer and the polarimeter, as required. After passing through the receivers the signals were initially displayed on a 30 cm cathode ray tube and photographed with a 35 mm cine camera, but in 1959 this arrangement was altered and the results were combined and preserved as a facsimile record (see Fig. 2.50).

These solar radio telescopes were used to good effect until the development of the Culgoora Radioheliograph, and were a tribute largely to Paul Wild's ingenuity, enthusiasm and leadership (Stewart et al., 2011b). In 1965 the Dapto field station was closed, which also meant the unfortunate loss of a proud institution at Radiophysics: the Dapto parties (see Fig. 2.51). Some of the Dapto aerials were relocated to Culgoora, but most remained at Dapto and were inherited by the University of Wollongong when it took over the site.

For in-depth accounts of the Dapto field station see Stewart (2009) and Stewart et al. (2011a).

Fig. 2.50 Kevin Sheridan inside the receiver building operating the position interferometer facsimile machine. (right) a typical facsimile record showing a Type III solar burst (courtesy: CRAIA)

Fig. 2.51 The Dapto field station was famous for its parties. Leader of the Solar Group, Paul Wild is at front in the dark jersey, with Steve Smerd on guitar and 'Gib' Bogle on clarinet (courtesy: CRAIA)

2.9 Badgery's Creek

This field station was 50 km west–south–west of central Sydney (Fig. 2.6) on a CSIRO cattle research station, and was founded by Bernie Mills (Biobox 2.6) at the end of 1949 so that he could study discrete sources at 101 MHz, free from the electrical interference that had plagued him previously at Potts Hill.

Biobox 2.6: Bernie Mills

Bernard Yarnton Mills (Fig. 2.52) was born in Sydney on 8 August 1920 and died on 25 April 2011. He graduated with BSc, BE (Second Class Honours), ME (First Class Honours) and DScEng degrees from the University of Sydney in 1940, 1942, 1950 and 1959 respectively. In 1942 he joined the Radiophysics Lab and worked on wartime radar developments. After working briefly in other fields, he joined the radio astronomy group in 1948 and quickly showed a flair for developing innovative new aerial systems, such as the Badgery's Creek interferometer and the Mills Cross.

Along with Bruce Slee and Eric Hill, Bernie used the Mills Cross to discover over 600 discrete sources in the southern sky. At the same time the radio astronomy group in Cambridge published a sky survey claiming over 2000 new sources. However, there was very poor agreement between the two surveys, which led to a heated controversy between the Sydney and Cambridge groups as to which survey was in error. Eventually, it was shown that the great majority of the Cambridge sources were fictitious, the result of an instrumental effect known as 'confusion'.

Mills left Radiophysics in 1960 to accept a Readership at the University of Sydney and was later promoted to Professor of Physics (Astrophysics). Bernie was able to secure funding from the US National Science Foundation to construct a much larger version of the Mills Cross near Canberra (see Chapter 5). He received the Lyle Medal from the Australian Academy of Science in 1957, the Britannica Australia Award for Science in 1967 (shared with John Bolton), and the Grote Reber Medal for Radio Astronomy in 2006. He was elected a Fellow of the Australian Academy of Science in 1959 and four years later joined an elite band of Australian radio astronomers when he became a Fellow of the Royal Society. In 1976 Bernie received Australia's highest civil award when he was made a Companion of the Order of Australia (AC). For further details see Frater et al. (2013, 2017), Mills (2006) and Orchiston (2014).

Fig. 2.52 Bernie Mills (1920–2011) invented a new cross-type radio telescope, which inspired several radio astronomy groups in Europe and the United States to build their own versions of the Mills Cross (courtesy: CRAIA)

Fig. 2.53 The Badgery's Creek field station featured three 100 MHz broadside arrays positioned along an E–W line (courtesy: CRAIA)

Initially there were three identical radio telescopes at this site: simple broadside arrays positioned along an E–W line, and mounted so they could be tilted about their E–W horizontal axes (Fig. 2.53). Each antenna contained 24 half-wave dipoles, backed by a reflecting screen. Antenna 2 was located about 60 m to the east of Antenna 1, with Antenna 3 a further 210 m to the east. All cables between the antennas and the receiver hut were buried in order to reduce fluctuations in electrical strength associated with temperature variations. Two different receivers were used with the antennas, so that the outputs of any two aerial spacings could be recorded simultaneously (Fig. 2.54). Between February and December 1950 Mills used this interferometer to conduct a survey of the Galactic distribution of discrete sources.

Mills then wanted to study the positions and angular sizes of four of the Galactic sources, and to do this he set up a two-element variable baseline interferometer. This

Fig. 2.54 Bernie Mills and the receiving equipment at Badgery's Creek (courtesy: CRAIA)

Fig. 2.55 The mobile two-element Yagi array and microwave link formed part of the variable baseline interferometer at Badgery's Creek. This array was used in conjunction with the broadside arrays to study four of the brightest discrete sources at 101 MHz (courtesy: CRAIA)

used one of the three broadside arrays, plus a mobile two-element Yagi array (operating at 101 MHz) and a microwave link (Fig. 2.55). This was the first time such a link had been used in radio astronomy, and to Mills (1976) was simply a matter of logic:

If we wanted to try different spacings and different places, then obviously you couldn't go coiling and uncoiling miles of cables. The radio link was the obvious way of doing it ... and the only real thing I was worried about was getting this compensating delay which I realised was necessary.

During 1952 observations were made of four strong discrete sources at nine different E–W spacings (ranging from 0.3 to 10 km), and three spacings in other directions. At the end of this project Mills transferred to Potts Hill, where he would build the world's first prototype cross telescope. Much later, he explained that

This [Badgery's Creek] survey was actually the basis for the [Mills] Cross because I realised that it was necessary in any survey to have an instrument which would respond to close spacings and large angular size structure. Otherwise, one would simply miss it and miss a lot of the information available in the sky. And it was as a result of this survey that I thought of the Cross as being the sort of thing one must use. One must use pencil beams for surveys. That was the basic idea I had in mind. (Mills, 1976).

Meanwhile, the Badgery's Creek field station was retained by Radiophysics and subsequently used by some of the radio astronomers based at Fleurs, before it was finally closed in 1956.

2.10 Fleurs

Fleurs was situated about 40 km west–south–west of central Sydney (Fig. 2.6), and occupied an expanse of flat land between South Creek and Kemps Creek adjacent to a WWII air strip near Badgery's Creek. Between 1954 and 1963, Fleurs was one of RP's leading field stations as home to three innovative cross-type radio telescopes, the Mills Cross, the Shain Cross and the Chris Cross (Fig. 2.56). Leading radio astronomers associated with this site were Chris Christiansen, Eric Hill (1927–2016), Norman Labrum, Bernie Mills, Dick Mullaly (1924–2001), Alex Shain, Kevin Sheridan and Bruce Slee, assisted by others, including Charlie Higgins and Wayne Orchiston (b. 1943) (see Orchiston and Slee, 2002b).

The first radio telescope at Fleurs was the Mills Cross (Mills et al., 1958), which was constructed during 1953–54 (Figs 2.57 and 2.58) following the success of the small-scale prototype erected at Potts Hill in 1953. In July 1954 Pawsey identified this as RP's number one priority project, and although progress was excellent, "... all available manpower is required to help it along." The cost of constructing the aerial and receiver hut (excluding labour) was the not inconsiderable sum of £14,000 (Mills, 1953). The cross boasted 460 m long N–S and E–W arms, each containing two rows of 250 half-wave dipoles (see Fig. 2.59). The Mills Cross operated at a frequency of 85.5 MHz giving a 49 arcmin beam – which in those days was regarded as remarkable. Signals from the two arms were channeled to the central hut where the receivers and other equipment were located (Figs 2.60 and 2.61).

Although this radio telescope was effectively a transit instrument in that neither arm was fully steerable, by altering the phasing of the dipoles in the N–S arm it was possible to observe different declination strips of sky. Alec Little played a key role

Fig. 2.56 Fleurs site plan showing the locations of the Mills (brown), Shain (yellow) and Chris (blue) Crosses in relation to the two creeks and the airstrip (courtesy: CRAIA)

throughout the design, construction and testing phases (see Fig. 2.62) and Kevin Sheridan assisted with the design and construction of the receiver. Later he reminisced: "I would say we spent about a year just getting it all together, and then two or three months polishing it off. It worked fairly well; it was a fairly good system ..." (Sheridan, 1978). From 1954 to 1957 this "fairly good system" was used by Mills, Sheridan, Slee and Hill to conduct an all-sky survey of discrete sources, and to investigate radio emission from selected sources. Some of the results had important cosmological implications which were to involve Australia in a good deal of international controversy, as we shall see in Chapter 4.

Fig. 2.57 The Mills Cross under construction at Fleurs in 1953–54 (courtesy: CRAIA)

Completion of the Mills Cross sky survey did not spell the end for this radio telescope (see Slee, [2005](#)). In 1958–59 Bruce Goddard, Arthur Watkinson and Bernie Mills used the E–W arm of this antenna, a 91 m section of the S arm of the Cross, and an identical 50-dipole N–S array at nearby Wallacia (Fig. 1.14) to carry out an 85.5 MHz investigation of the sizes of some of the smaller sources in the Mills–Slee–Hill catalogues. In addition, in June 1957 Bruce Slee used the N–S arm of the Cross, at 85.5 MHz, and two helical aerials located about 200 m to the east of the Cross to investigate scattering by solar coronal irregularities. Between June and October 1960, he extended this study using the E–W arm of the Mills Cross in conjunction with the array at Wallacia. From September 1960 to May 1962, Bruce Slee and Charlie Higgins used the N–S arm of the Mills Cross to carry out pioneering observations of radio emission from a number of nearby flare stars. Finally, during

Fig. 2.58 RP photographer Ken Nash uses ‘Flo’ as a vantage point to photograph the new Mills Cross at Fleurs. Ken took many of the photographs reproduced in this book (courtesy: CRAIA)

Fig. 2.59 Aerial view of the completed Mills Cross, looking south, taken in October 1954. The receiver hut is near the junction of the two arms (courtesy: CRAIA)

1961–62, Slee and visiting Cambridge radio astronomer, Peter Scheuer (ca.1930–2001), used the E–W arm of the Mills Cross and barley-sugar arrays erected temporarily at Cumberland Park, Rossmore, Llandilo and Freeman’s Reach

Fig. 2.60 Central area of the Mills Cross showing the receiver hut and the microwave antenna used for communicating with remote sites involved in interferometry (courtesy: CRAIA)

Fig. 2.61 Inside the hut showing the Mills Cross receiving equipment in November 1955, with Bruce Slee examining one of the chart records (courtesy: CRAIA)

(respectively 6 and 10 km south, and 17 and 32 km north of Fleurs – see Fig. 1.14) to research the sizes of selected sources in the Mills–Slee–Hill catalogues.

During 1955 a 19.6 MHz two-element E–W interferometer was constructed at Fleurs. Each aerial consisted of four full-wave dipoles suspended between telegraph poles and separated by 183 m. The aerials were attached to two receivers, one with the aerials connected in phase, and the other out of phase. Observations could be

Fig. 2.62 Alec Little (left) and Bernie Mills taking phase and amplitude readings at different dipoles along the Mills Cross (courtesy: CRAIA)

made for about five hours each day. In addition, in October 1955 two simple radio telescopes operating at 14 and 27 MHz were constructed. Between June 1955 and March 1956, the 19.6 MHz E–W interferometer was used by Alex Shain and Frank Gardner to investigate burst emission from Jupiter (see the next chapter). Parallel observations with the 14 and 27 MHz radio telescopes were also made from November 1955 to March 1956.

In 1956, just two years after the Mills Cross became operational, a much longer low frequency antenna was completed nearby (see Fig. 2.63). This was the Shain Cross (see Shain, 1958), and as early as mid-1954, Pawsey had designated this as RP’s number three priority project (after completion of the Fleurs Mills Cross and the Murraybank 48-channel H-line receiver). Given its distinctive name, there is no surprise that Alex Shain was largely responsible for this radio telescope, but Alec Little did help him with the antenna design and Kevin Sheridan with the receiving equipment. This new radio telescope, operating at a frequency of 19.7 MHz and with a beam width of 1.5° , was built alongside the Mills Cross. Its construction was spurred on by news received from Bernie Mills in mid-1954 that the Department of Terrestrial Magnetism in Washington, DC had just completed a 20 MHz Mills Cross of its own, with arms 634 m long, at its Maryland field station.

Although the Shain Cross had much longer arms than the Mills Cross, its construction was much simpler in that it comprised a series of dipoles strung 4 m above the ground between telegraph poles, with the ground serving as a reflector. The N–S arm was 1151 m in length and contained 151 dipoles, with the main supporting telegraph poles spaced at 46 m intervals; lighter poles at 23 m intervals provided further support and carried the feeder lines. The E–W arm was a little shorter at 1036 m,

Fig. 2.63 (left) Section of the 19.7 MHz Shain Cross at Fleurs, also showing part of the N–S arm of the Mills Cross and the broadside array used for long baseline interferometry. (right) Alex Shain making adjustments to one of the dipole phase switches located along the N–S arm of the Shain Cross. The switches allow the beam to be directed to different E–W positions (courtesy: CRAIA)

contained 132 dipoles, and featured a 30 m gap in the middle. This innovative new radio telescope evolved out of Shain's earlier exploits at the Hornsby Valley field station, and the pilot observations that he and Gardner had made at Fleurs. By exploiting the cross-type principle, Shain was able to use the new Cross to carry out a survey of the Galactic Plane and to monitor decametric burst emission from Jupiter.

After Shain's untimely death in 1960, Bruce Slee and Charlie Higgins continued to use Fleurs for low frequency research. Late in 1961 they used the N–S arm of the Shain Cross to search successfully for radio emission from flare stars. In August 1962 they erected a square array of 19.7 MHz dipoles at Fleurs and an identical array at Freeman's Reach, 32 km to the north in order to investigate the size of the region responsible for the Jovian bursts. In 1963–64 they expanded this project by setting up radio-linked arrays at Dapto and Jamberoo far to the south of Sydney, and at Heaton to the north (see Fig. 2.8).

Fleurs gained its third large radio telescope in 1957 – just in time for the International Geophysical Year – when a major new solar array, the Chris Cross (Christiansen et al., 1961), was completed at a cost of about £21,000 (Costs – Chris Cross, 1957). Named, appropriately, after 'Chris' Christiansen, this innovative instrument comprised 433 m N–S and E–W arms each containing 32 parabolic dishes 5.8 m in diameter (Fig. 2.64). These dishes were constructed of wire mesh suitable for operation at 1420 MHz (21 cm), and were equatorially-mounted to be able to track the Sun. The Chris Cross was constructed adjacent to the Mills and Shain Crosses (Fig. 2.65), and combined the principles of the Mills Cross and the solar grating interferometer. It was the first radio telescope in the world to generate daily two-dimensional high-resolution radio images of the Sun. For more on the Chris Cross see Orchiston (2004b) and Orchiston and Mathewson (2009).

Fig. 2.64 Artist's impression of the Chris Cross and the design details of the individual antennas (courtesy: CRAIA)

Fig. 2.65 View looking south showing sections of all three cross telescopes at Fleurs (from left): antennas in the N–S arm of the Chris Cross, the white woodwork of the Mills Cross and the poles of the Shain Cross (courtesy: Sullivan collection)

A further development occurred at Fleurs in 1959 when an 18 m paraboloid, known as the ‘Kennedy Dish’ after its American manufacturer, was installed at the eastern end of the Chris Cross (Fig. 2.66). As early as 1956 Pawsey and other RP staff had been referring to the acquisition of “... a large aerial (e.g. 60 ft) ...”, intended specifically for H-line work, but in fact this new dish ended up being used for continuum observations. When combined with the dishes of the E–W arm of the

Fig. 2.66 View looking west showing the 18 m Kennedy Dish, installed at Fleurs in 1959, and some of the antennas in the E–W arm of the Chris Cross (courtesy: CRAIA)

Chris Cross, the Kennedy Dish provided the Fleurs radio astronomers with a powerful new compound interferometer, which boasted a 1.5 arcmin fan beam at 1420 MHz (Orchiston and Mathewson, 2009). Of an evening – when the Chris Cross was not operational – this array was used to investigate some of the strongest discrete sources.

A major change took place at Fleurs at the end of 1962 when the Kennedy Dish was transferred to Parkes (Orchiston, 2012) to be used in conjunction with the 64 m Parkes Radio Telescope (see Fig. 1.43). By this time the research programs that justified the construction of the Mills and Shain Crosses had come to an end and Fleurs had served its purpose. No longer required as a field station, on 1 July 1963 the lease was formally transferred to the University of Sydney. The School of Electrical Engineering under the direction of its newly appointed professor, Chris Christiansen, then spent the next decade converting the Chris Cross into the Fleurs Synthesis Telescope – but more on this in Chapter 5.

In summary, during the ten-year interval 1954–63, Fleurs was one of the world’s foremost radio astronomy sites, and it played an important role in furthering solar, Galactic and extragalactic radio astronomy. RP Chief, Taffy Bowen (1984: 97) went so far as to claim that the three Fleurs cross-type radio telescopes “... were among the great successes of the 1950s and were responsible for a large part of the Division’s research output over that period.” They consolidated the international standing of Christiansen and Mills, helped build the emerging reputations of people like Shain, Sheridan and Slee, and served as stepping stones to the Division’s next major advances in instrumentation: the Parkes Radio Telescope and the Culgoora

Fig. 2.67 Interior of the mobile field laboratory ‘Flo’ that was fitted out with a variety of instrumentation (courtesy: CRAIA)

Radioheliograph. Before leaving this account of Fleurs it is only proper that we acknowledge the invaluable contribution of ‘Flo’, the modest little mobile field laboratory (see Figs 2.3, 2.58 and 2.67) that serviced all three cross-type radio telescopes. Flo was a major resource throughout the lifetime of the field station, and for those of us who enjoyed our Fleurs experiences, life without Flo was simply unthinkable.

2.11 Murraybank

The Murraybank field station was located in the Sydney suburb of West Pennant Hills (see Fig. 2.6), on an orchard (‘Rosebank’) owned by the father of RP radio astronomer, John Murray. It was set up in 1956 to carry out H-line observations with a new purpose-built radio telescope and receiver. In a review of the Radio Astronomy Group research programs, Pawsey (1954) specifically mentioned the clear need for first class equipment if the H-line research is to prosper: “The current instrumental deficiency is a receiver giving an instantaneous profile.” In October 1956, he reported that as other work tapered off, it would soon “... be possible to apply our facilities to a new aerial for the H-line work ... [and] develop the new receiver ...” (Pawsey, 1956). Murraybank was the proud recipient of this new equipment, and Dick McGee and John Murray were the two RP radio astronomers who spent most time at this field station.

Fig. 2.68 Installation of the 6.4 m parabolic antenna and adjacent receiver hut at the Murraybank field station. This site in West Pennant Hills was located on an orchard belonging to John Murray's father, and so the name Murraybank (courtesy: CRAIA)

Previous H-line work had taken place at Potts Hill, first with the ex-Georges Heights radar antenna and then with the 11 m transit dish, but what was needed was a new steerable dish dedicated to H-line work at 1420 MHz. At 6.4 m the Murraybank radio telescope (Fig. 2.68) was considerably smaller than its Potts Hill predecessor, but its alt-azimuth mounting meant that interesting areas of the sky could be accessed at will. At 1420 MHz, the beam width was 2.2° .

There was also a marked improvement in the receiving equipment, as the old H-line unit at Potts Hill was replaced by a new 48-channel receiver built mainly by Murray and McGee (Fig. 2.69). This contained 44 separate narrow-band channels, spread at 33 kHz intervals across the frequency 1420 MHz, and four wide-band channels at either end of the range, which were used to obtain reliable zero levels. In mid-1958 the intention was to eventually transfer this new receiver to Fleurs and the Kennedy Dish, but this never happened.

With this new receiver, a complete H-line profile could be obtained in just two minutes, sixty times faster than with the old Potts Hill equipment. Reduction of the large amounts of observational data produced posed a major challenge and relied on the development of early computers (Fig. 1.11). In the main, the Murraybank facility was used by McGee and Murray to investigate neutral hydrogen from the Large and Small Magellanic Clouds and in the Taurus–Orion region, and to conduct an all-sky H-line survey.

Fig. 2.69 Dick McGee (left) and John Murray examine a chart record at Murraybank (courtesy: CRAIA)

For the Radiophysics Lab, Murraybank served an important role as the test-bed for the innovative 48-channel H-line receiver, and this field station only closed down when the receiver was transferred to the newly-opened Parkes Radio Telescope at the end of 1961 (Brooks and Sinclair, 1994).

For detailed accounts of the Murraybank field station see Wendt (2008) and Wendt et al. (2011b).

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