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THE HISTORY OF EARLY LOW FREQUENCY RADIO ASTRONOMY IN AUSTRALIA. 7: PHILIP HAMILTON, RAYMOND HAYNES AND THE UNIVERSITY OF TASMANIA'S PENNA FIELD STATION NEAR HOBART

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Abstract: Following initial experiments near Hobart by Graeme Ellis, Grote Reber and Gordon Newstead from 1955 to 1957, the University of Tasmania established several sites for the study of low frequency radio astronomy, beginning in 1961. This paper describes the antenna array that was constructed at Penna, to the east northeast of Hobart. Between 1962 and 1967 it was used to produce maps of the southern sky at the frequencies of 4.7 and 10.02 MHz and contributed to an overall study of the low frequency emission from the Galaxy. Because of the proximity of the array to the town of Sorell, it was also referred to the 'Sorell Radio Telescope'.

Keywords: Low frequency radio astronomy, Tasmania, Penna, G. Ellis, R. Green, P. Hamilton, R. Haynes

1 INTRODUCTION

By 1960, researchers in the field of low frequency radio astronomy had enjoyed several successes, making it clear that there was great potential for exploring frequencies below 20 MHz. Significant early work was performed in Australia; beginning in 1946, the CSIR (later CSIRO) Division of Radiophysics maintained many field stations, mostly in the Sydney area (see Orchiston and Slee, 2005; Robertson, 1992). Two of these, Hornsby Valley and Fleurs, specialised in low frequency work (see Orchiston et al., 2015a, 2015b).

Because of absorption of radio waves by the Earth's ionosphere, radio astronomy at low frequencies becomes steadily more difficult as the desired frequencies drop below 10 MHz, with the lowest possible frequency being of the order of 1–2 MHz. The ability to detect such frequencies is strongly dependent on the value of the ionospheric critical frequency foF2, which needs to be below the frequency of observation and is dependent on the observer's location. In general, the lowest values of foF2 occur at locations that are sufficiently distant from both the geographic equator and the magnetic poles—and at sunspot minimum during winter nights. Studies of ionospheric conditions in various parts of the world (e.g. see Reber, 1982) showed that two key locations are north eastern North America (in the vicinity of the Great Lakes), and Tasmania (see Figure 1 for foF2 values obtained in Tasmania in 1962).

The year 1954 saw the arrival of Grote Reber in Tasmania, and his work with Graeme Ellis in the following year near Cambridge (see George et al., 2015b) resulted in the first detection of celestial radiation below 2 MHz.

After being absent from Tasmania between December 1956 and October 1960, Ellis returned to Tasmania to take up the appointment of the University of Tasmania's Chair of Physics, and this marked the beginning of the halcyon years of low frequency Tasmanian radio astronomy. His interest in this field inspired several B.Sc. Honours and Ph.D. projects in the 1960s. At this time, the three major observing sites of interest were Richmond (see George et al., 2016), Llanherne (at Hobart Airport, which will

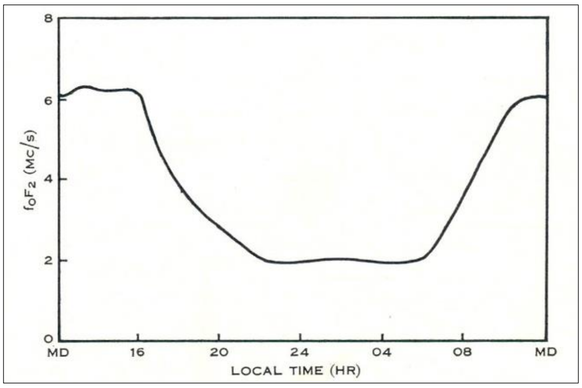

Figure 1: Ionospheric critical frequencies (foF2) for Hobart, measured (most likely at Mount Nelson) in June 1962. At midday, foF2 was ~6 MHz but during the night it dropped to ~2 MHz, easily allowing observations at 4.7 MHz (after Ellis et al., 1963: 548).

be the subject of a future paper in this series) and Penna, the subject of this paper.[1] The University's Penna field station was just north of the township of Midway Point, to the east-north-east of Hobart, between Hobart Airport and the town of Sorell (for Tasmanian localities mentioned in this paper see Figure 2).

2 BIOGRAPHICAL NOTES

2.1 Philip Hamilton

Professor Philip (Pip) Hamilton (Figure 3)[2] completed his B.Sc. at the University of Tasmania in 1961 and commenced a PhD in low frequency radio astronomy there in 1963. Following the establishment of a low frequency array at Penna in 1961–1962 and initial work carried out there by B.Sc. Honours student Robert Green, Hamilton used the array for surveys of the sky at 4.7 MHz and 10.02 MHz right up until it was destroyed by a disastrous bushfire in 1967.

In 1965 Hamilton joined the staff of the Physics Department as a lecturer while still part of the way through his PhD studies, and did not submit his Ph.D. thesis until 1969. He played a role in the design of a major low frequency array at Llanherne (Hobart Airport), and worked with Peter McCulloch to establish a high frequency array, also at Llanherne, which was used mainly for pulsar work.

Hamilton took over as Chair of the Physics Department in the early 1980s and went on to become Pro-Vice Chancellor for Research. He oversaw the transfer to Tasmania of the 26-m antenna from the Orroral Valley Tracking Station near Canberra, and in 1986 this telescope began operation at Mount Pleasant near Hobart.

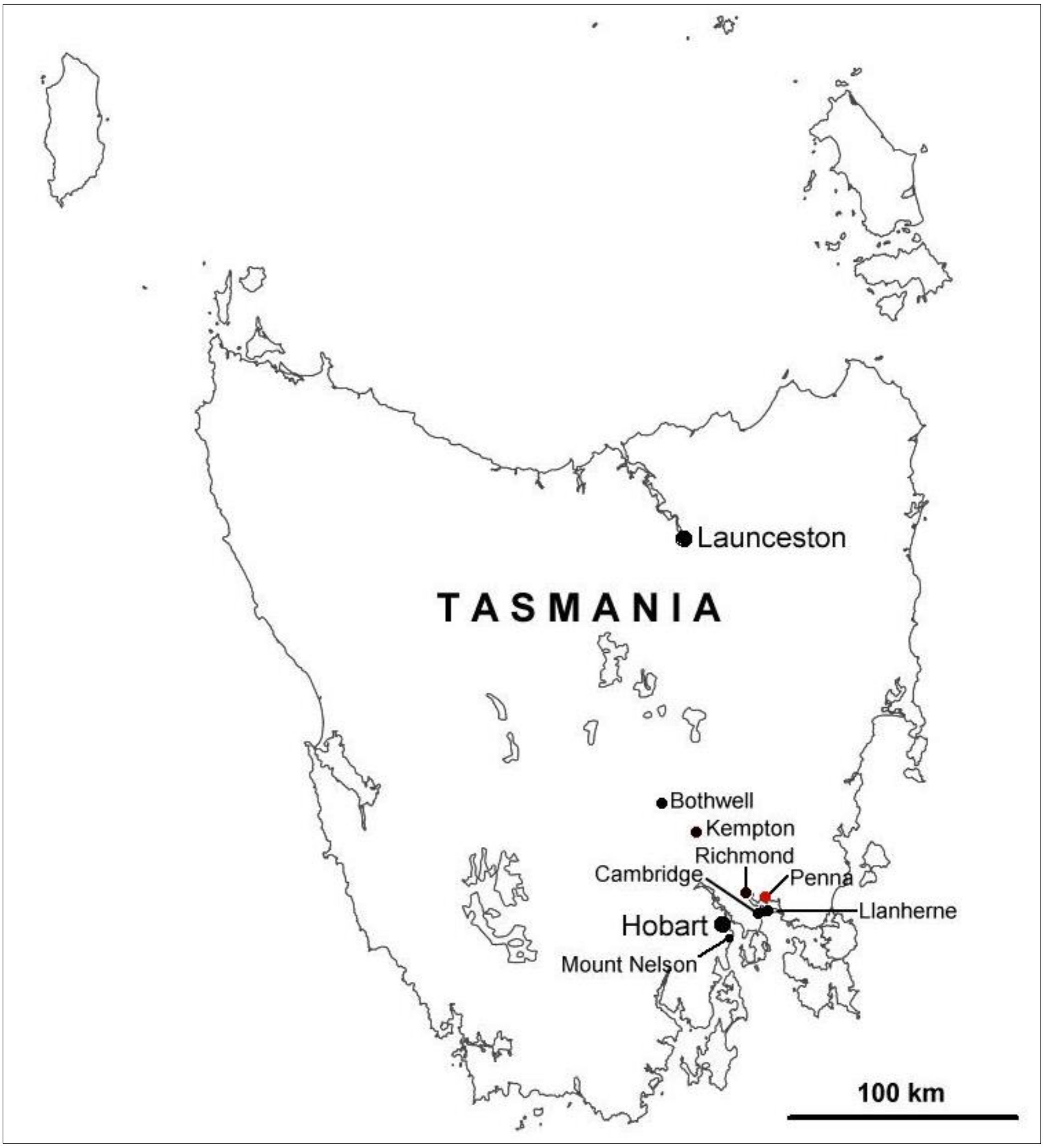

Figure 2: Key radio astronomy sites in Tasmania. This paper discusses the University of Tasmania arrays at Penna, to the east-north-east of Hobart (map: Martin George and Wayne Orchiston).

Hamilton left the University of Tasmania in 1997 to become Pro-Vice Chancellor for Research at Deakin University in Victoria, and later Deputy Vice Chancellor for Research.

In 2006, for his services to science and research, he was awarded an AM in the Queen's Birthday Honours, and in 2007 he received a D.Sc. from Deakin University in recognition of his outstanding scientific achievements, his contribution to the Australian higher education sector and his outstanding contribution to research (Deakin University, 2007). He is now retired.

2.2 Raymond Haynes

Dr Raymond Haynes (Figure 4) completed a B.Sc. at the University of Tasmania in 1964. During his Honours year in 1965 he was supervised by Grote Reber, who was then using an array near Bothwell in southern central Tasmania to make observations at 2.1 MHz.

Haynes began his Ph.D. degree in early 1966, with Graeme Ellis as his supervisor. He used the Penna array during his Ph.D. candidature, working together with Philip Hamilton, and they produced a radio map of the sky at 10.02 MHz.

Following this, Haynes was awarded a Postdoctoral Fellowship by the CSIRO and went to the University of Cambridge. In 1972 he became a CSIRO scientist and performed extensive research work over three decades. His topics included Milky Way molecules, supernova remnants and Galactic magnetic fields.

Haynes was chief author of the authoritative book *Explorers of the Southern Sky: The History of Australian Astronomy*. Although now officially retired, he likes to comment on scientific topics and present lectures on astronomy, and he has a variety of other interests.

3 INSTRUMENTATION

3.1 Location and Planning of the Site

After his 1960 return to Tasmania, Graeme Ellis lost little time in seeking out potential sites for the establishment of low frequency radio astronomy arrays in the Hobart area. One site was selected just north of Richmond (George et al., 2016), where three small non-phased arrays were set up on land owned by a personal friend. However, the desire to establish a more significant array for mapping of the sky led to Ellis seeking out a second large, flat area of land. Having noticed a suitable location at Penna, Ellis approached the landowners of three properties—William and James Reynolds, Rupert Jones and Gerald Barwick—and obtained permission to use the land for the construction of an array, with the agreement that sheep be allowed to continue grazing on the land (see Figure 5). The University paid rent for the Barwick property (K. Barwick, pers. comm., 2016) but not for the Reynolds property (D. Reynolds, pers. comm., 2016); it is not known if there was any financial arrangement made with regard to the Jones property (ibid.).

Figure 3. Philip Hamilton in 2007 (photograph: M. George).

Figure 4: Raymond Haynes in 2017 (courtesy: Raymond Haynes).

Figure 5: The site of the Penna Array outlined in red on a recent aerial image. The rectangle measures 4000 feet × 1000 feet and corresponds to the rectangular area of poles shown in Figure 13. North is towards the top (Map Data Google, DigitalGlobe, 2016).

Graeme Ellis' daughter Elizabeth Ellis (pers. comm., 2008) recalls:

> I remember clearly going out on drives to the property at Penna, pacing it out [i.e. to measure the property]. This was done at weekends and he (Graeme Ellis] would take us along for the drive.

The area of land that was chosen for the array was centred on longitude 147° 31′ 37.8″ E, latitude 42° 46′ 15.5″ S,[3] the position of the hut (see Section 3.3) near the centre of the array having been measured accurately using a February 1966 aerial photograph.

3.2 Site Testing and Early Results

In a radio astronomy equivalent of site testing,[4] which doubtless included an assessment of interference from terrestrial transmissions, Graeme Ellis set up two sets of dipoles near the extreme eastern and western ends of what was to become the Penna Array. Michael Waterworth and Gordon Gowland did the initial surveys:

> Mike Waterworth and I surveyed the scene, with a strange instrument called a theodolite. It was an ancient theodolite—it was a big brass one, an antique. (G. Gowland, pers. comm., 2008.)

Peter McCulloch, who was an undergraduate student at the time, recalls that

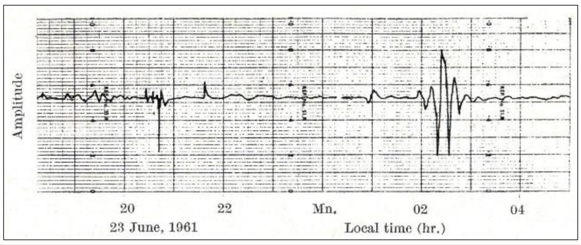

Figure 6. Record of the interferometer observation of Jupiter at 4.8 MHz on 23 June 1961.[6] Jupiter's transit time at Penna was 02h 41m local time (after Ellis, 1962b: 667).

> In 1961 when I was doing third year [i.e. third year of the B.Sc. degree], Ellis built an interferometer at Penna. There were maybe 8 dipoles at each end … [with the two ends being] about 1 km apart. He detected some background emission, and detected Jupiter. At that stage it wasn't an array; it was a test to 'see' things at 4.7 MHz. (P. McCulloch, pers. comm., 2008.)

This initial set up at Penna formed a phase-switching interferometer,[5] with the two sets of dipoles 4,000 ft (~1,219 m) apart. It had a primary beamwidth of 45° (N-S) and 12° (E-W) with the centre of the antenna pattern directed to declination –43°, i.e. to the zenith (Ellis, 1962a, 1962b; University of Tasmania, 1962).

Although there is no record of students being used as part of this very early work at Penna, Kevin Parker and Gordon Gowland—who both commenced work in the Physics Department in 1961—assisted in this initial setup. In particular, Kevin Parker (pers. comm., 2009) recalls that he and Gordon Gowland were involved in the surveying.

Clearly the detection of radio emission from Jupiter (see Figure 6) was unexpected,[7] and was later described as accidental (University of Tasmania, 1963). Even so, Jovian bursts were detected on 29 out of 40 observing nights (Ellis, 1962b), and Ellis assumed that the radiation probably would have been observed on most nights were it not for terrestrial interference.

Two well-known radio galaxies, Centaurus A and Fornax A, also were detected. Ellis (1962a) presented an interferometer record showing Centaurus A and other objects at 4.8 MHz, with a clear maximum amplitude at 20h 29m local time, with an uncertainty of at most a few minutes (see Figure 7). This corresponds precisely to the transit time of Centaurus A, which occurred at 20h 28m local time on that date.

The observations of Fornax A were compared with those of Centaurus A, with the former radio galaxy showing a notably less steep cut off at 4.8 MHz. Ellis (ibid.) interpreted this as indicating a low electron density in the intergalactic medium.

3.3 Construction and Layout of the Main 4.7 MHz array

Construction of the Penna Array began in 1961. It involved physics staff Gordon Gowland, Kevin Parker and Tony Harris. Several Honours students also were involved, with one of the earliest being Michael Waterworth, who recalled working at the site in 1961 as the poles were being inserted into the ground (M. Waterworth, pers. comm., 2011).

The exact period over which the main set of poles were placed into the ground is not specifically recorded, but it would have most likely been over the spring and/or summer of 1961–1962.

Working at Penna was a very early activity in the Physics Department for Kevin Parker:

> The Hydro were in the process of putting the poles in ... they were standard power poles.[8] My first role was to start with Gordon [Gowland], and Tony Harris later on, climbing the poles and erecting the aerials. We made the aerials up, and they were using aluminium conductors, which was a bit radical at that time. They were seven-strand and with a bit of a pulley system to tighten them up. (K. Parker, pers. comm., 2009).

More Honours students assisted in the establishment of the array during early 1962. Peter McCulloch, an honours student at the time, recalled:

> Lectures would go from nine o'clock until morning tea time, and the three Honours students, [together with] Kevin [Parker] and Gordon [Gowland] would work together to string up all the lines. The poles were already put in. (P. McCulloch, pers. comm., 2008.)

These ‘Hydro’ poles to which the dipoles were attached stood 30 ft (9.1 m) above the ground (Green, 1963; K. Bolton, pers. comm., 2007). One of the problems that had to be faced was access to the tops of the poles. Initially, a 30-ft oregon ladder was used (K. Parker, pers. comm., 2009) but it proved to be a difficult task to access the poles this way, especially in the wind (G. Gowland, pers. comm., 2008). Later, the University had the use of an ex-army ‘Blitz’ truck.[9] This was fitted with a tower (Figure 8), and equipped with a short ladder to enable people to work at a height of 30 feet. While not a perfect solution, it was a great improvement. Indeed, In McCulloch’s opinion (pers. comm., 2009), “... the array wouldn’t have been built without it.” However, Gerald Barwick, on whose property a small part of the array was located, forbade the use of the truck on his land, so only the 30-foot ladder was used there.

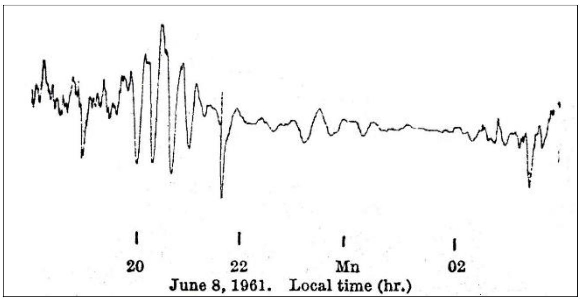

Figure 7: An interferometer record from the night of 8–9 June 1961 at 4.8 MHz that included Centaurus A; this source transited at 20h 28m local time (after Ellis, 1962a: 258).

The Blitz truck was used for several radio astronomy purposes in the 1960s, and is well remembered by everyone involved in the various projects. However, it was in far from perfect condition:

> The Blitz truck was used at Penna. It had been in the possession of the Uni for a long time, possibly by the Cosmic Ray people. One day it got stuck in two gears at once. The mechanic was called from the Uni—Col Matthews—and he got it back to Uni by changing gears with a screwdriver. The gearbox was next to the driver. (P. Hamilton, pers. comm. 2007).

Figure 8: The ex-army ‘Blitz’ truck used by the University of Tasmania for various purposes in the 1960s (after Green, 1963).

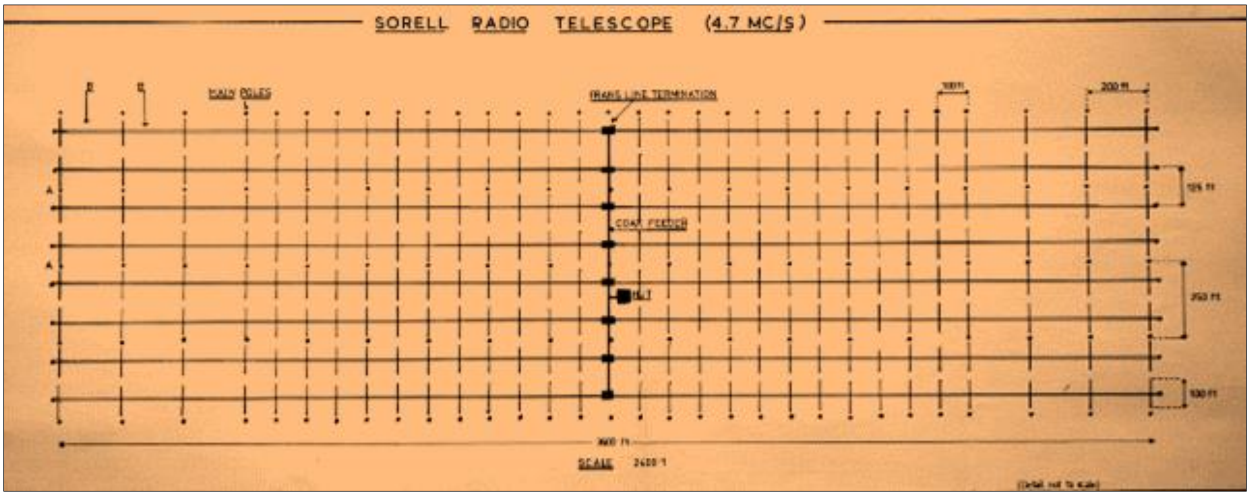

Figure 9: The overall layout of the 4.7 MHz array at Penna (after Green, 1963).

Gordon Gowland (pers. comm., 2008) recalls that the vehicle was used to drive between Penna and Richmond, and

> One very frosty morning, the vehicle was stripped down so that there was a 'naked engine' between the driver and the passenger. It backfired through the carburettor and blew the air filter off. It went up in the air, and Kevin [Parker] quickly pushed it back down onto the carb and we continued our journey.

Another problem encountered in setting up the array was the presence of a creek known as Frogmore Creek at its western end (see Section 4.3).

Green (1963) commented that the completed array consisted of eight E-W rows of dipoles, with 32 dipoles in each row. However, Green's diagram of the layout (Figure 9) shows only 31 north-south lines of dipoles, or 30 if there were no dipoles along the central north-south axis (this is not clear from the diagram). Also, Green's diagram shows the E-W dimension of the array as 3,600 ft, but dimensions are generally quoted as 4,000 × 1,000 ft (e.g. see Green, 1963). This apparent discrepancy is explained in a later diagram (Figure 10), which shows a 200-ft extension at each end in four of

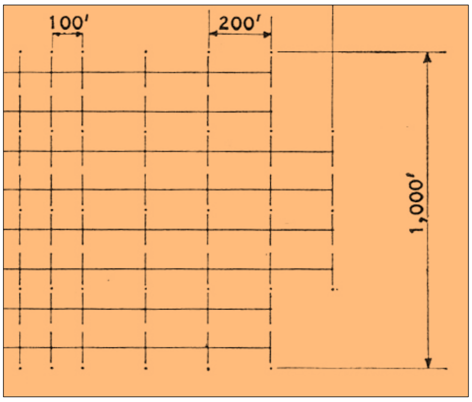

Figure 10: Detail of the layout at the eastern end of the 4.7 MHz array at Penna (after Ellis, Green and Hamilton, 1963).

the rows (Ellis, Green and Hamilton, 1963). That it was mentioned that there were 32 E-W rows of dipoles may therefore be explained if allowance is made for two extra dipoles in the four middle rows but no central dipoles.

Another discrepancy is apparent in that it was later reported that there were 272 half-wave dipoles (Ellis and Hamilton, 1966a; Hamilton, 1969). Even with the extensions to four rows, containing eight dipoles, it seems that number should have been 264 (8 × 32 + 8).

Most of the dipoles were separated by 100 feet (half a wavelength) in an E-W direction but three (or four, in the middle rows—see Figure 9) were separated by twice this amount, in order to reduce the effect of lobes at 90° to the main lobe (Green, 1963). Fewer poles also facilitated construction at the western end of the array, where the aforementioned problems were encountered with Frogmore Creek.

Interestingly, Gowland (pers. comm., 2008) recalled that initially, the array had an area of only 1,000 × 1,000 ft, suggesting that this was at the first stage of construction. Green (1963) commented that at first, only half of the aerials were connected. There may therefore be a connection between these two comments and the possibility of no dipoles down the central axis, effectively 'splitting' the dipoles into eastern and western halves. However, no other evidence has been found to support a two-phase construction process, and indeed, each half would have been 2,000 × 1,000 ft, twice the size recalled by Gowland.[10]

The separation in the centre of each dipole, effected by a spacer, was 4 inches (10 cm) in length. An open-wire transmission line connected each dipole to the main E-W transmission line, which ran underneath the centres of all the dipoles. This open-wire line was aluminium wire and acted as a transformer from the 70-ohm aerial impedance to the 500-ohm characteristic im-

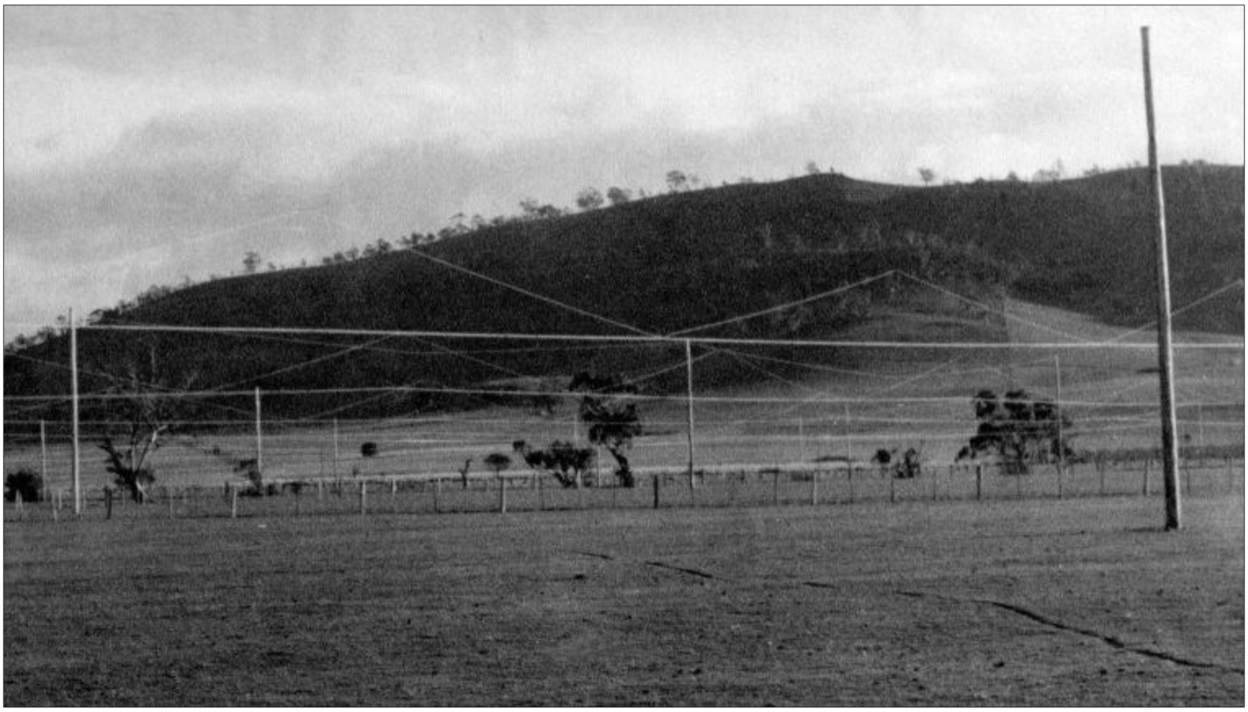

Figure 11: Part of the Penna Array (after Green, 1963).

pedance of the main transmission line (Figures 11 and 12) (Green, 1963). Figure 13 shows the ‘footprint’ of the array on a 1966 aerial photograph, while Figure 14 gives a view of most of the array.

Near the centre of the array was a hut, which contained the receiving equipment (see Figure 15). Kevin Parker (pers. comm., 2008) recalled:

> The hut was almost exactly in the middle of the array. It was a weatherboard structure that was built in the carpenters’ workshop [at the University]. They transported it out there and set it up on concrete blocks. I’d say at a guess it was about 12 foot by 10 foot. It wasn’t very big.

The Hydro-Electric Commission connected a 240 volt power supply, with a main switch in a box that included a meter. The box was in a paddock that contained a bull, which was sometimes a hazard! However, once the array was in

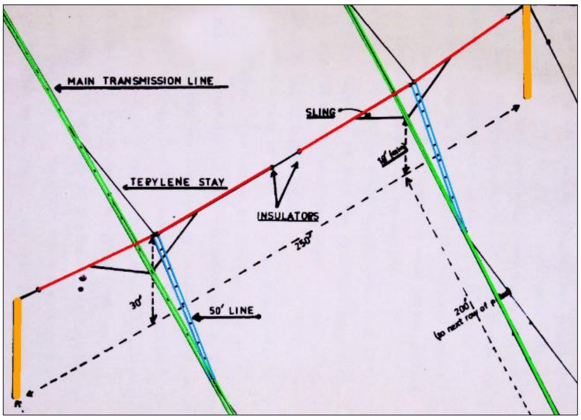

Figure 12: A diagram showing the relationship between the dipoles (red) and main transmission lines (green) (adapted from Green, 1963).

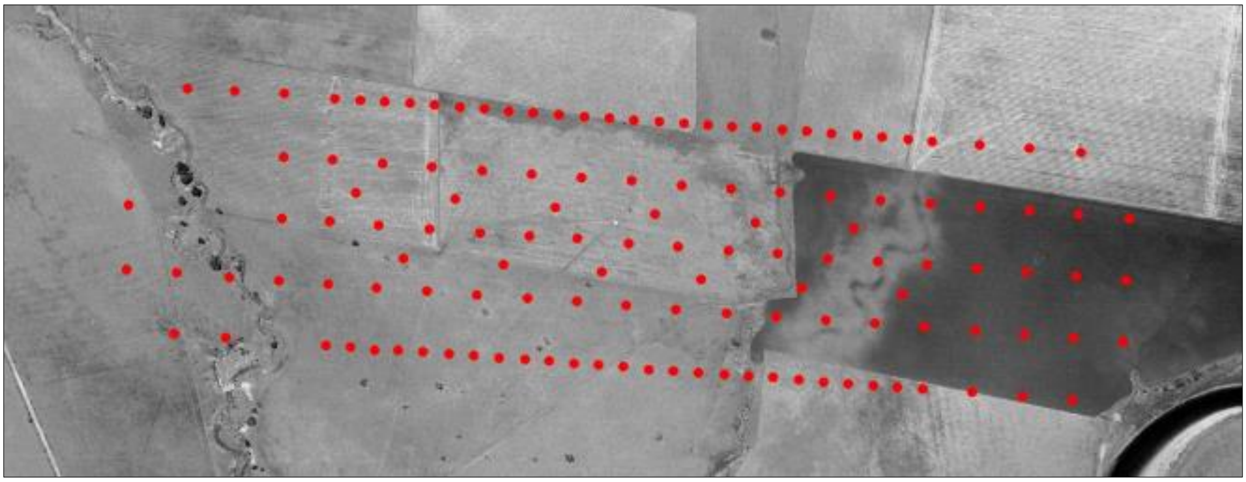

Figure 13: Locations of identifiable poles (red dots) shown on an aerial photograph taken in February 1966, based on the poles’ shadows. The structure of the array can easily be seen (base data from the LIST (www.thelist.tas.gov.au), © State of Tasmania).

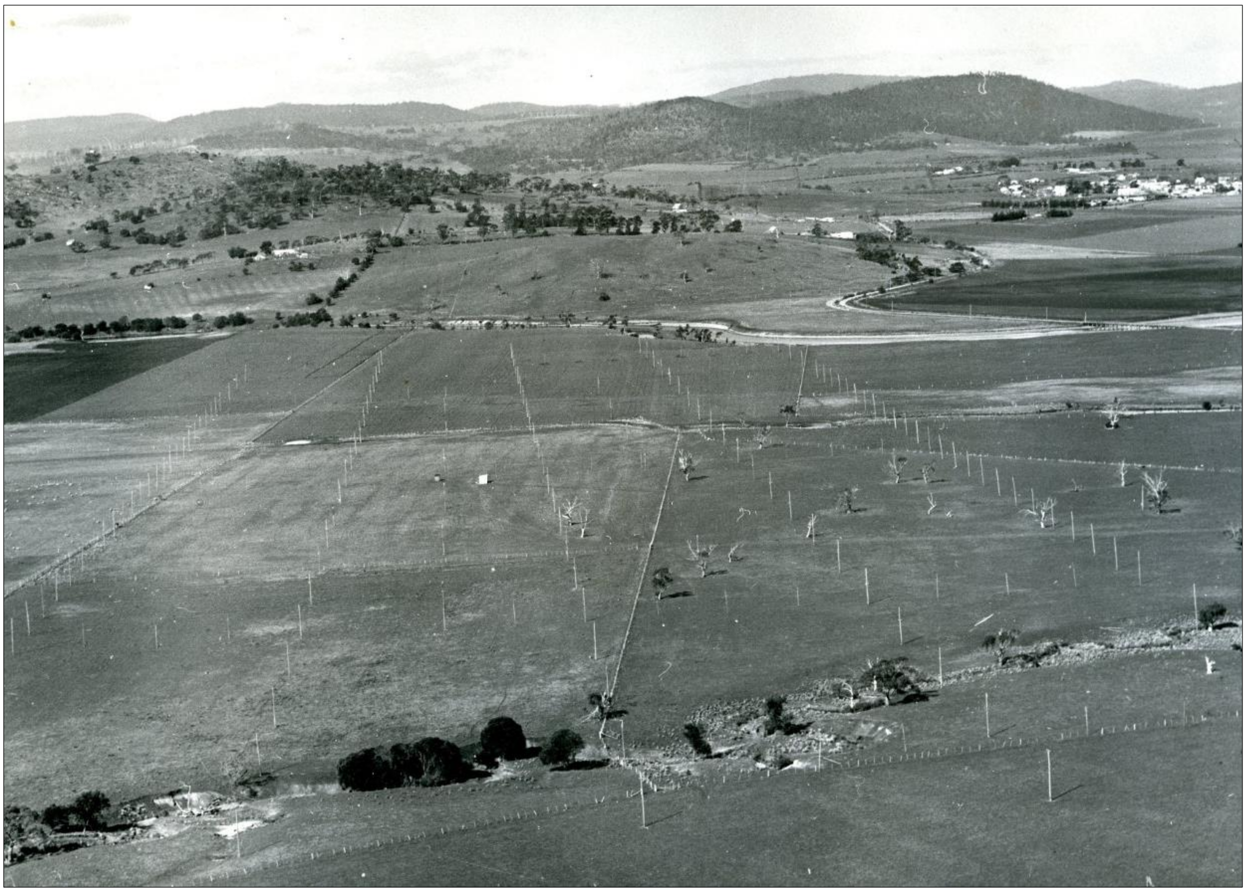

Figure 14: An undated aerial photograph of the Penna Array (courtesy: University of Tasmania).

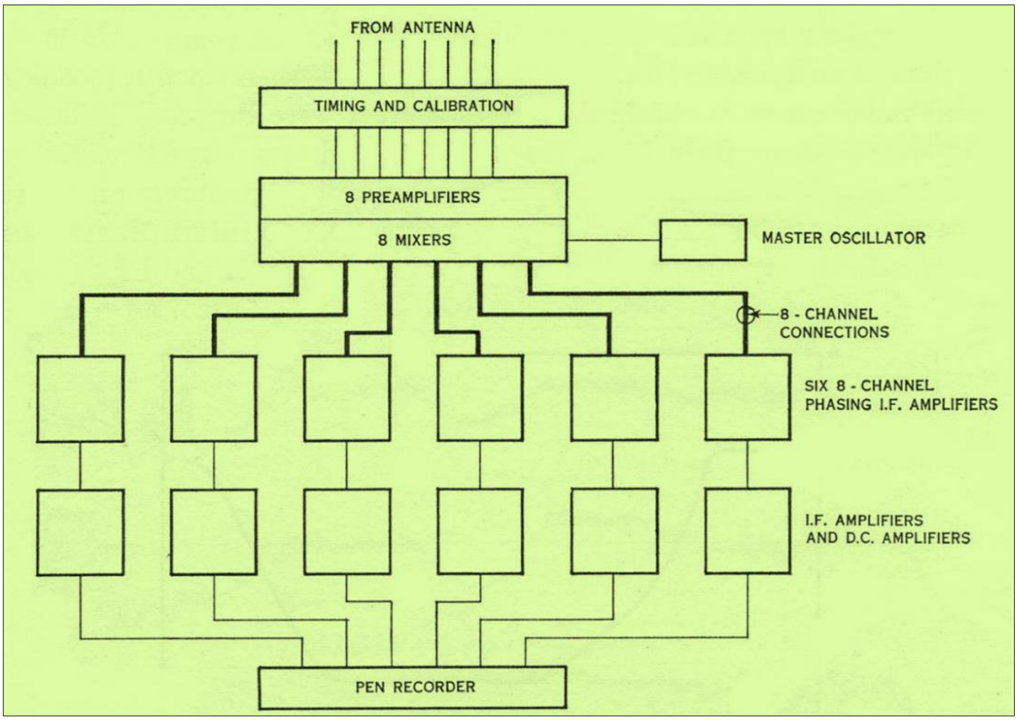

Figure 15: Block diagram of the receiving equipment for the 4.7 MHz observations (Ellis et al., 1963: 547).

operation, there was no need to switch it off (G. Gowland, pers. comm., 2008). The power supply to the hut ran underground and the connection came from Penna Road (K. Parker, pers. comm., 2009).

Contained within the hut was the receiving equipment:

> It was all valve radio equipment. A lot of it was built out of ex-army equipment. There were truckloads of ex-army equipment we got from

somewhere; Prof Ellis had organised it. A lot of it we cannibalised for things like transformers … I remember building a power supply to drive all the heaters on the values and that put out 60 amps, so there was a lot of heat in there (K. Parker, pers. comm., 2008).

Indeed, Keith Bolton, who first was employed by the Physics Department in 1965 and worked on the maintenance of the array, recalled how pleasant it was in winter to be inside the hut, because of this heat (K. Bolton, pers. comm., 2011).

The receiving arrangement allowed simultaneous observation of the sky at six different declinations, by introducing a phase difference in the amplifiers between successive rows, even though significant mismatching of impedances resulted in only a small amount of signal arriving at the receivers (Hamilton, 1969).

It was decided that this electronic method of introducing phase differences method was preferable to using mechanical delays (which are effected by inserting lengths of cable). However, Hamilton (1969) comments that delay cables were indeed used at least partly to effect the phasing, although this may have been only during the second series of observations (see Section 4.1).

The final output was recorded by a 6-channel chart recorder (see Figure 16). Keith Bolton (pers. comm., 2011) commented that all chart recorders used for radio astronomy work were

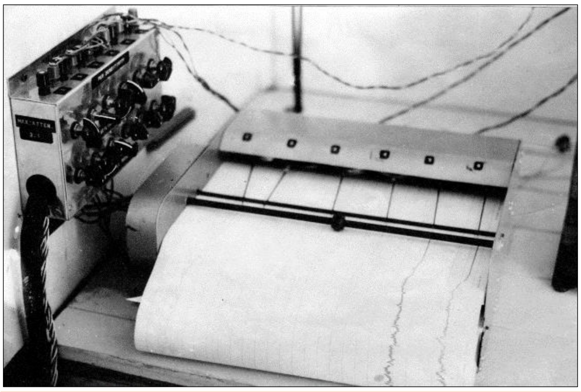

Figure 16: The chart recorder used at Penna, clearly showing the six pens (after Green, 1963).

built at the University.

Later, the array was converted for use at 10.02 MHz and was operated at this frequency in 1965 and 1966. For this purpose, an array of 15 rows each of 25 dipoles was used (Figure 17). The beamwidth was 4° × 5° and based on Hamilton's information and the figure, the array area used for these observations was 932 × 1,250 feet. Phasing was achieved through the use of delay lines (Hamilton 1969; Hamilton and Haynes 1968).

Relatively little information is recorded about the conversion of the array. However, Pip Hamilton (pers. comm., 2007) recalled:

> I did a more detailed survey at 4.7 MHz then restrung it to 10 MHz, then did another survey. The restringing wasn't easy; it took some time.

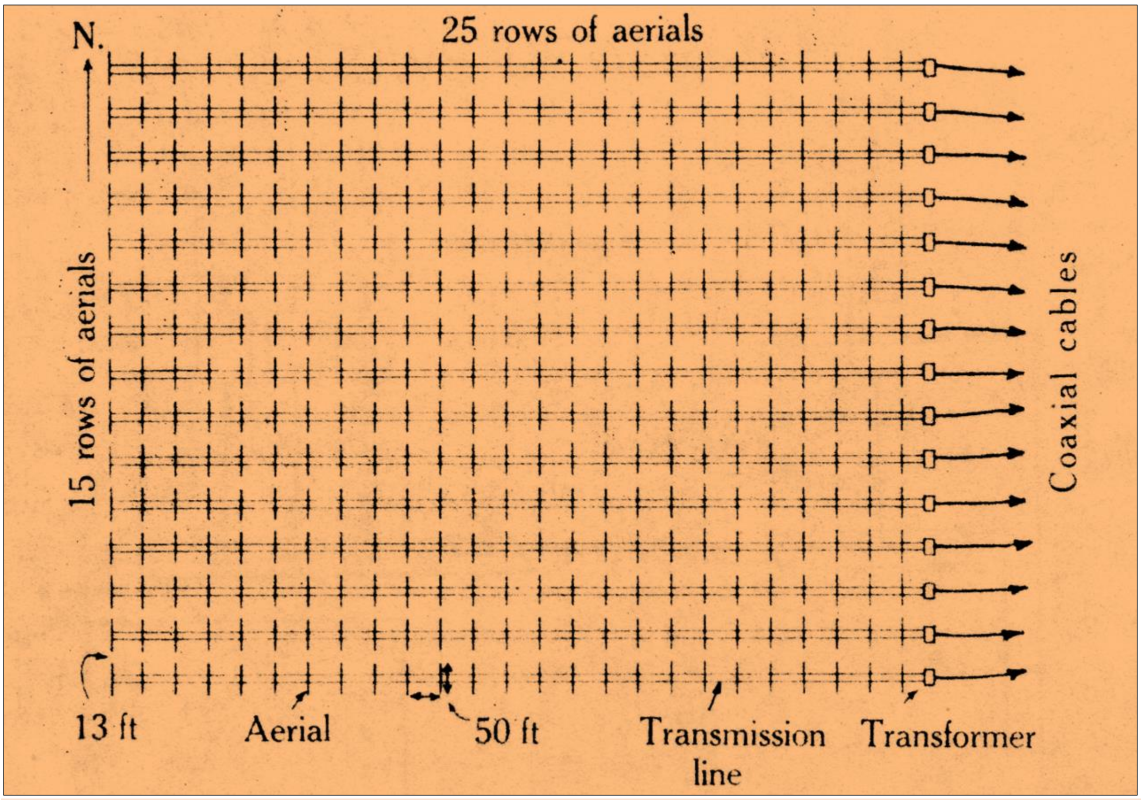

Figure 17: The antenna arrangement used for observations at 10.02 MHz in 1965 and 1966 (after Hamilton and Haynes, 1968: 896).

> Effectively, the whole thing was rebuilt. It was not too expensive. Bill Ellis had organised the staffing appropriately—Gordon Gowland and Kevin Parker were helpful.

4 THE MAIN OBSERVATIONS

Section 3.2 described observations made as a result of the original basic interferometer setup at Penna, where the Jupiter results, especially, were incidental to the site testing. However, the main work at this site was to map the radio sky at 4.7 MHz, and later, at 10.02 MHz. With the solar minimum approaching, it was a good time to be planning these observations: at times of minimum solar activity, the lower degree of ionisation of the ionosphere improves the transmission of the lower radio frequencies. The solar minimum occurred in mid-1964 (see Meeus, 1983).

During the period from March to mid May 1962, the array was used; this would have been largely for testing purposes. However, this took place with only half of the aerials connected. It was found that a 'systematic error' had been introduced in setting up the array (Green, 1963). Green (ibid.) also commented that

> … the array was designed to operate at 4.86 Mc/s but 4.7 Mc/s was finally used. This difference introduced a small phasing error, which was, however, corrected by July 2.

4.1 The 4.7 MHz Observations

The first reliable results from the Penna array, which were at 4.7 MHz, were obtained on 10 June 1962, although on that date the aerials were still being connected to the transmission lines. By 12 June the array was regarded as complete.

Observations at 4.7 MHz were made over two main periods: June 1962 to January 1963, and May to December 1963 (Ellis and Hamilton 1966a; Ellis, Green and Hamilton, 1963). Green (1963) records that the equipment was shut down in January 1963 to enable some modifications to be carried out, and although the specific work was not recorded, this was likely to have been in preparation for the second series of 4.7 MHz observations.

The array formed a transit instrument with 3° (E-W) × 11° (N-S) resolution at 4.7 MHz. The observing method was therefore to use the rotation of the Earth to record different right ascensions. The receiver frequency was swept over a range of 12 kHz each 0.2 second to find frequencies that were not affected by terrestrial transmissions. The pen recorder would chart the signal strength from six different declinations (Figure 18). In some cases, a camera was used to record the display of a cathode ray oscilloscope (Ellis and Hamilton, 1966a).

The most important paper detailing the overall results of the 4.7 MHz survey was that of Ellis and Hamilton (ibid). They comment that reproducible results were obtained on about 60% of nights, the main impediment being transmitting stations. The selected records were the ones least affected by the terrestrial transmissions, or, in the case of records in the region of the Galactic Centre, those that displayed the greatest contrast and were therefore least affected by scattered radiation. The resulting isophote plot of Galactic radiation is shown in Figure 19.

The significant results mentioned in that paper, making use of observations at other frequencies, were that

(1) The emission at the South Galactic Pole (declination −27°) reached a maximum at around 5 MHz, and dropped off rapidly at lower frequencies; this drop off was interpreted as absorption of radiation by ionised hydrogen.
(2) The Milky Way Galaxy had a "… general ionised atmosphere …" with a density of about 0.1 ions/cm^3.
(3) At 4.7 MHz, an absorption 'trough' was observed in the plane of the Galaxy, but the significant trough between about 16^h and 19^h right ascension—straddling the Galactic Centre, which is at 17^h 42^m (epoch 1950)—appeared to have a variable depth which was interpreted as at least partly due to scattered radiation from outside the trough direction; this was attributed to disturbed ionospheric conditions (Hamilton, 1969: 116). This is shown in Figure 20.
(4) Apart from the Jupiter emission mentioned earlier, several discrete sources were recorded. The strongest ones were Centaurus A, Fornax A and Pictor A, in descending order of flux density (Ellis, Green and Hamilton, 1963).

4.2 The 10.02 MHz Observations

The 10.02 MHz observations were made in 1965 and 1966, after the array was modified. Once again, the receiving setup was organised so as to produce simultaneous results at six different declinations, and a radio map was produced of the sky (see Figure 21).

As with the 4.7 MHz observations, there was hindrance from transmitting stations. The receiver's centre frequency was swept over a range of 10 kHz each 0.2 second, with an interesting minimum reading method being chosen. Because a transmitting station would appear as a periodic impulse, the receiving equipment 'learned' to ignore the signal. In this way, even a station appearing where none previously caused a problem would be ignored.

Figure 18: An original chart record from 6 July 1962. On this occasion traces are shown on just five of the six channels (courtesy: University of Tasmania).

At very low radio frequencies, maps of the sky show obvious absorption features along the Galactic Plane. It had already been understood that the absorption was caused by ionisation in the Galactic Plane (see Ellis and Hamilton, 1964; Hoyle and Ellis, 1963).

The researchers noticed a significant difference between the 4.7 MHz and 10.02 MHz surveys: at the higher frequency, the absorption was less obvious, resulting in lower contrast between the Galactic Plane and its surroundings. This was to be expected, as it was already clear (Hoyle and Ellis, 1963) that the intensity of the radiation reached a maximum around 5 MHz, with the decreasing intensity below that frequency needing an ionisation explanation: that is, absorption of radio frequencies because of ionisation became dominant at frequencies below about 5 MHz.

As in the 4.7 MHz survey, several discrete sources were observed. In particular, Centaurus A (NGC 5128) was obvious. Hercules A (the elliptical galaxy 3C 348, just north of the Celestial Equator) and Puppis A (a supernova remnant) also were noted.

A chart recorder was used to record the observations, just as it was with the 4.7 MHz work. Initially the intention was to record images on the cathode ray oscilloscope, but this technique was used only toward the end of the 10.02 MHz observations, and even then it merely supplemented the chart records (Ellis, Green and Hamilton, 1963).

Although two surveys had been carried out, there was still further research to be done (P. Hamilton, pers. comm. 2007). Hamilton and Haynes had a considerable amount of data for the

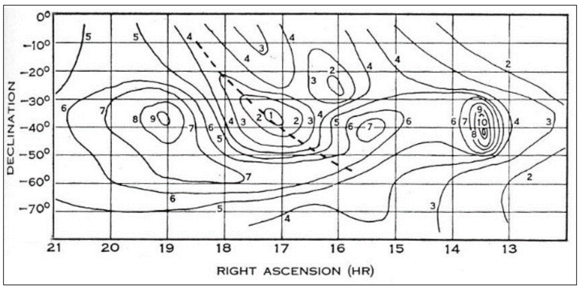

Figure 19: Part of the map of the southern sky at 4.7 MHz. The bright source between 13 and 14 hours right ascension is Centaurus A (adapted from Ellis et al., 1963: 549).

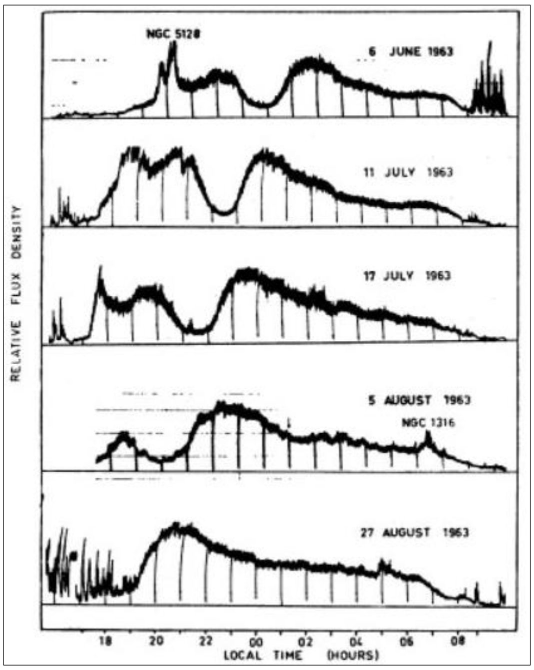

Figure 20: Observations on several different dates in 1963, showing the sidereal effect causing the 'trough' between about 16 and 19 hours right ascension to transit at progressively earlier local times (after Ellis and Hamilton, 1966a: 230).

higher frequency survey (10.02 MHz), but the pair agreed that another set of observations would be highly desirable, as there was still some uncertainty over whether every declination profile was correct. There was therefore a plan to observe over the winter of 1967 and combine these observations with the earlier ones (R. Haynes, pers. comm., 2017). However, because of the untimely destruction of the array in February 1967 (see Section 4.4), these observations were never made.

Hamilton and Haynes therefore needed to make do with what they had in order to produce the 10.02 MHz map. At around this time, the University began operating a new computer—an Elliott 503—and theirs was the first project for which the computer was used. Hamilton and Haynes wrote software in machine code and Algol, respectively, and spent hundreds of hours (often working at night) with paper tape and later with punched cards. Finally, by August 1968 they were able to submit the manuscript of their research paper (Hamilton and Haynes, 1968) to the *Australian Journal of Physics* (R. Haynes, pers. comm., 2017). Figure 21 shows their isophote plot of Galactic radiation at 10.02 MHz.

4.3 Difficulties

Construction of the array was hampered by the presence of Frogmore Creek near the array's western end. The lower altitude of the depression in the land carved out by the creek resulted in the poles being of insufficient height, and short lengths of 4-inch × 4-inch oregon timber were added to the tops of the 'Hydro' poles so that these poles were level with those in the rest of the array (G. Gowland, pers. comm., 2008).

The creek bed also posed a problem for the use of the Blitz truck, which sometimes got bogged (ibid.). On each occasion the radio astronomers were able to retrieve it, but this did slow down their observing programs.

Gordon Gowland (ibid.) also recalls that at one time there was a problem involving an illegal transmitter:

> There was some transmitter that sprung up somewhere and was being a bit of a pain, and we'd never had this before ... On that range of hills towards Cambridge, there was this station that was a monitoring station looking for illegal transmitters ... We must have enlisted their aid, because they tracked it down. I think it was some guy in Richmond who had a scanner, and … he was scanning the police radio, but he was coming up loud and clear on the array. I'm not sure what happened to him.

Several of the physics staff recall that maintenance often was necessary. Gordon Gowland (ibid.) and Raymond Haynes (pers. comm., 2017) especially remember problems with the chart recorder, with the ink "… going everywhere."

Damage caused by weather was also a problem:

> After a storm, you'd find 2 or 3 aerials down. There wasn't a *lot* of maintenance. Most of the problems were valve replacements—they'd wear out. (K. Parker, pers. comm., 2009).

4.4 Destruction of the Array

The Penna Array came to an end on 7 February 1967, at the peak of highly destructive fires which engulfed many parts of southern Tasmania, even encroaching into Hobart suburbs. It was responsible for the loss of 62 lives (Wetten-

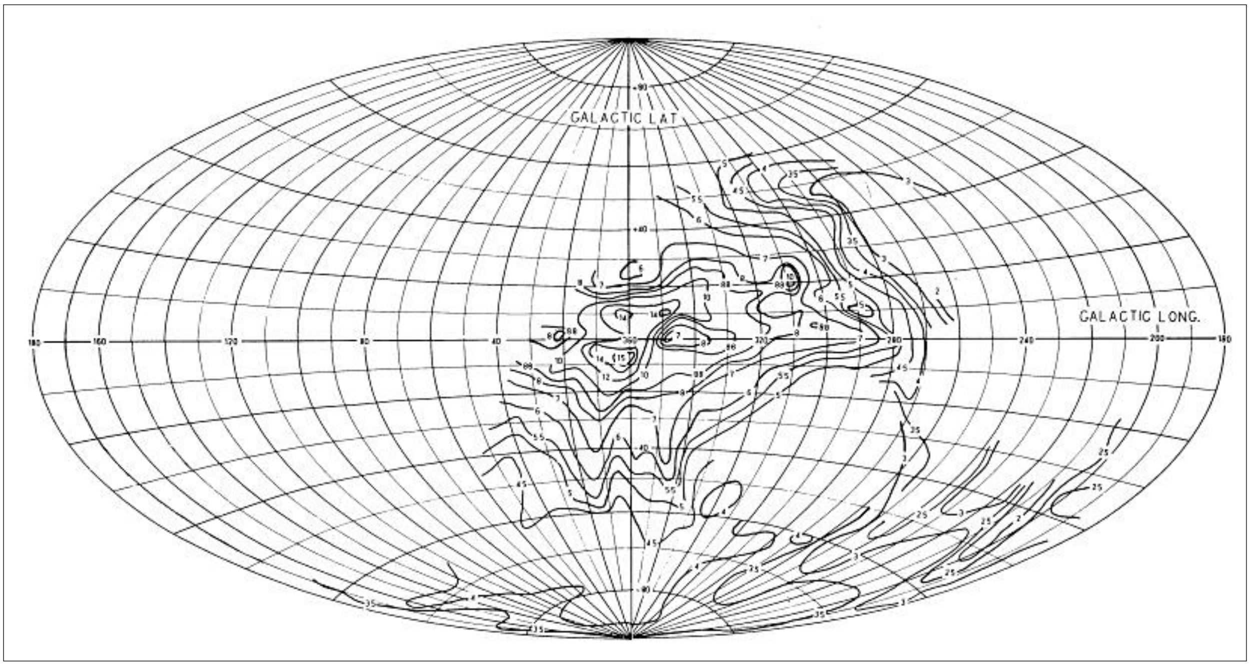

Figure 21: The 10.02 MHz map produced using the modified Penna array, plotted using galactic coordinates (after Hamilton and Haynes, 1968: 898).

Figure 22: The site of the Penna Array after the fire of February 1967. Two poles (one fallen) are seen to have burned bases (photograph by Des McLean, provided courtesy William and Dorothy Reynolds).

hall, 2006). Considerable damage was caused in the Penna area, and there was no attempt made to save the array (D. and W. Reynolds, pers. comm., 2015). Two photographs taken soon after the fire are shown in Figures 22 and 23.

Kevin Parker (pers. comm., 2009) recalled that most of the aluminium had simply disappeared, because it had melted. However, the hut was found to be still standing after the fire:

> The only part of the whole array that was insured was the hut and the equipment—but the grass was so trodden down around the hut that the hut survived (K. Bolton, pers. comm., 2011).

Although Hamilton and Haynes had wished to observe over one more winter (see Section 4.2), Keith Bolton (ibid.) recalled that there were no significant plans for further use and the fire "… saved us pulling it down." The implication is therefore very strong that the array would in any case have fallen into disuse after 1967.

After the fire, there was some urgent clearing work to do. Hamilton and Haynes went out to the array not long after the fire—Haynes is almost certain that it was the next day—to find that some poles had been completely burned and had fallen, with nothing left but a line of ash on the ground. Only a few poles were still standing, and many were still smoking from the fire (R. Haynes, pers. comm., 2017).

The Blitz truck was singed by the fire but still usable:

> We used it [the truck] the whole of that day. We brought some chains and hooks. We dragged the poles so we could move up and down the rows to grab all the wires together. We chopped the wires off. It took us about two days to clean the place up. We assume it was the farmer who cleared the poles. (ibid.).

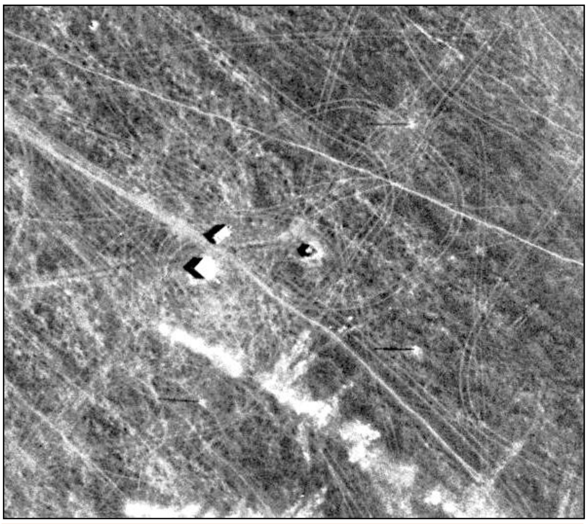

Figure 23: An aerial photograph of the Penna Array site taken in February 1967, shortly after its destruction by fire. The Blitz truck can be seen next to the hut, and clearly visible are its wheel tracks made during the cleaning up of the site (base data from the LIST (www.thelist.tas.gov.au), © State of Tasmania).

Indeed, Keith Barwick (pers. comm., 2016), whose father in late 1966 or early 1967 purchased the property owned by Rupert Jones, recalled that as a young man he assisted in removing some of the poles from that ground.

5 DISCUSSION

The establishment of the Penna Array was the brainchild of Graeme Ellis. The push for low frequency radio astronomy studies in the early 1960s by the University of Tasmania was undoubtedly largely inspired by the initial work done by Ellis and Grote Reber at Cambridge, near Hobart, in 1955 and the follow-up by Ellis and Gordon Newstead (see Ellis and Newstead, 1957; George et al., 2015b; Reber and Ellis, 1956).

It is interesting to contemplate what would have happened in the absence of the mid-to-late-1950s work being performed. Certainly, it would have been known that Tasmania was an excellent place for low frequency radio astronomy, and Ellis had a detailed understanding of the ionosphere (e.g. see Ellis, 1954). However, the search for suitable array sites began very soon after Ellis' 1960 return to Tasmania, indicating his eagerness to proceed quickly with the work and suggesting that he remained mindful of the successes of the earlier Tasmanian efforts.

Interestingly, the construction of the Penna Array coincided very closely with that of one built independently by Grote Reber near the Tasmanian town of Bothwell, which will be described in a future paper in this series. That array, however, was designed to work at 2.085 MHz.

In preparing this paper, attempts were made to locate the researcher who was the first person to officially use the array for research, Robert Green, the 1962 B.Sc. Honours student whose thesis (Green, 1963) was an important reference for this paper. Unfortunately, up to the time of writing, Green had not been located. There is little doubt that he could have provided even more insight into the operation of the array in the very early days.

An interesting question, of course, is the degree to which the fiery end of the array in February 1967 was a setback. Certainly, it was for Hamilton and Haynes, who has hoped to observe over another winter—a 'frustrating' situation (R. Haynes, ibid.). It also cannot be stated with any certainty that no other use would have been found—for example, 'restringing' the array to investigate other wavelengths.

6 CONCLUDING REMARKS

The Penna Array was a major instrument used by the University of Tasmania. Even though plans were in progress for the work to be concentrated at Hobart airport (Llanherne), there was still further work to be done at the time of its destruction in 1967.

During the period when the Penna Array was in use it became increasingly clear that the there was evidence of ionised hydrogen along the plane of our Galaxy (Ellis and Hamilton, 1964, 1966b; Hoyle and Ellis, 1963). The results showed that the ionisation became increasingly apparent at lower frequencies. The Penna Array provided valuable data points for this work, and more generally, contributed to other surveys of the sky that were conducted at low frequencies in the 1960s and 1970s.

Despite being quite sizeable, the existence of the Penna Array was little known by the public, primarily because it was not near a major road. It was the subsequent construction of an array adjacent to Holyman Drive near Hobart Airport that brought considerable public attention to the low frequency radio astronomy research carried out by staff from the University of Tasmania, and this array will be discussed in a future paper in this series.

7 NOTES

1. This is the seventh paper in a series that aims to document pre-1980 low frequency (<30 MHz) radio astronomy in Australia. The first two papers overviewed the research by staff from the CSIRO Division of Radiophysics near Sydney (Orchiston et al., 2015a) and the efforts in Tasmania by Grote Reber and staff from the Physics Department at the University of Tasmania (George et al., 2015a). Subsequent papers looked in depth at individual field stations in Tasmania (see George et al., 2015a, b, c, 2016) and at Hornsby Valley near Sydney (Orchiston et al., 2015b).
2. The following biographical sketch is based on personal communications from Pip Hamilton (2007) and Robert Delbourgo (2017), and Deakin University (2007).
3. This location is five kilometres north of the township of Midway Point. William Reynolds (pers. comm., 2015) commented that the house on the property currently known as Socoma, which was not present in the 1960s, is close to the location of the hut that stood near the centre of the array. Examination of a current aerial image shows that Socoma is approximately 55 metres west of the hut's location.
4. In optical astronomy, major considerations are the quality of the seeing conditions, the presence of artificial light and a study of cloud cover records. The major consideration in radio astronomy is testing for terrestrial radio interference.

5. The phase-switching interferometer was invented by Martin Ryle at Cambridge, and it correlated the signals from two antennas to remove uncorrelated noise.
6. On 23 June 1961 Jupiter's declination was –19°18′, so its maximum altitude as seen from Penna was 66°32′. The planet reached opposition on 25 July, at a declination of –20°15′.
7. The detection of Jovian bursts was described as "unexpected" because it was not anticipated. Although Burke and Franklin reported the detection of Jovian decametric burst emission in 1955, their observations and most other confirmatory observations were made in the 18–20 MHz range. In 1961, when Ellis was setting up the Penna field station, no-one would have anticipated detecting Jovian bursts at 4.8 MHz.
8. The Hydro-Electric Commission, commonly called simply 'The Hydro', was the name given in 1929 to the former Hydro-Electric Department. It was a Government Commission charged with the operation of the State of Tasmania's hydro-electric power stations and the construction of their dams. It is now called Hydro Tasmania. The 30-ft (9.14-m) height of the poles was not ideal for observations at 4.7 MHz for which the ideal height—one quarter of a wavelength—would have been 15.96 metres. However, use was made of them because of their ready availability, and the relative ease of reaching the tops of the poles. Moreover, the pole height was almost ideal for the later observations made at 10.02 MHz.
9. Such trucks were made in large numbers during WWII. The vehicle used by the University appears to be a Ford model (Hervey Bay Museum, 2017).
10. There exists a curious 1963 note about a 3.35 MHz array at Richmond (University of Tasmania, 1963: 52–53). Nowhere are observations with it described in great detail, and nobody interviewed for this paper or the paper about the Richmond arrays (George et al., 2016) recalls such an array at Richmond. A comment from Gordon Gowland (pers. comm., 2008) offers a clue: he made a brief mention of a smaller array at Penna (see Section 3.3). Whether he was referring to the partly-built 4.7 MHz array or to another array is unclear, although a small section of a 3.3 MHz curve was included in a paper published by Ellis and Hamilton (1966b). The history of that particular array requires further investigation.

8 ACKNOWLEDGEMENTS

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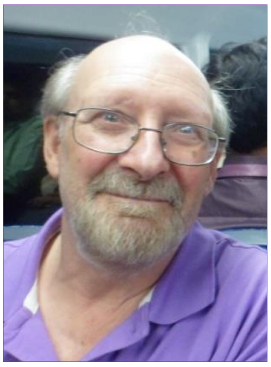
Martin has a special research interest in the history of radio astronomy, and is completing a part-time Ph.D. on the development of low frequency radio astronomy in Tasmania through the University of Southern Queensland, supervised by Professors Wayne Orchiston and Richard Wielebinski (and originally also by the late Professor Bruce Slee). Martin is the Administrator of the Grote Reber Medal for Radio Astronomy, and is a member of the IAU Working Group on Historic Radio Astronomy.

Professor Wayne Orchiston was born in New Zealand in 1943 and works as a Senior Researcher at the National Astronomical Research Institute of Thailand and is an Adjunct Professor of Astronomy at the University of Southern Queensland in Toowoomba, Australia. In the 1960s Wayne worked as a Technical Assistant in the CSIRO's Division of Radiophysics in Sydney, and forty years later joined its successor, the Australia Telescope National Facility, as its Archivist and Historian. He has a special interest in the history of radio astronomy, and in 2003 was founding Chairman of the IAU Working Group on Historic Radio Astronomy. He has supervised six Ph.D. or Masters theses on historic radio astronomy, and has published papers on early radio astronomy in Australia,



England, France, Japan, New Zealand and the USA. He also has published extensively on the history of meteoritics, historic transits of Venus and solar eclipses, historic telescopes and observatories, and the history of cometary and asteroidal astronomy. In 2016 and 2017 Springer published his two latest books, *Exploring the History of New Zealand Astronomy: Trials, Tribulations, Telescopes and Transits* (733 pp.), and *John Tebbutt: Rebuilding and Strengthening the Foundations of Australian Astronomy* (603 pp.). Wayne's next book, co-edited by Tsuko Nakamura, is on *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*, and will be published, also by Springer, in 2017. Currently, Wayne is the Vice-President of IAU Commission C3 (History of Astronomy), and he is a co-founder and the current Editor of the *Journal of Astronomical History and Heritage*. In 2013 the IAU named minor planet 48471 Orchiston after him.

Professor Richard Wielebinski was born in Poland in 1936, and moved with his parents to Hobart, Tasmania, while still a teenager. Richard completed B.E. (Hons.) and M.Eng.Sc. degrees at the University of Tasmania. In his student days he met Grote Reber and was involved in the construction of a low frequency array at Kempton. After working for the Postmaster General's Department in Hobart he joined

Ryle's radio astronomy group at the Cavendish Laboratory, Cambridge, and completed a Ph.D. in 1963 on polarised galactic radio emission. From 1963 to 1969 Richard worked with Professor W.N. (Chris) Christiansen in the Department of Electrical Engineering at the University of Sydney, studying galactic emission with the Fleurs Synthesis Telescope and the 64-m Parkes Radio Telescope. He also was involved in early Australian pulsar research using the Molonglo Cross. In 1970 Richard was appointed Director of the Max-Planck-Institute für Radiostronomie in Bonn, where he was responsible for the instrumentation of the 100-m radio telescope at Effelsberg. In addition,

he built up a research group that became involved in mapping the sky in the radio continuum, studying the magnetic fields of galaxies, and pulsar research. Further developments were the French-German-Spanish institute for mm-wave astronomy (IRAM), and co-operation with the Steward Observatory, University of Arizona, on the Heinrich-Hertz Telescope Project. Richard holds Honorary Professorships in Bonn, Beijing and at the University of Southern Queensland. He is a member of several academies, and has been awarded honorary doctorates by three universities. After retiring in 2004 he became involved in history of radio astronomy research, and is currently the Chair of the IAU Working Group on Historic Radio Astronomy.