

HIGHLIGHTING THE HISTORY OF JAPANESE RADIO ASTRONOMY. 5: THE 1950 OSAKA SOLAR GRATING ARRAY PROPOSAL

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Abstract: In November 1950, a paper was presented at the 5th Annual Assembly of the Physical Society of Japan that outlined the plan for a radio frequency grating array, designed to provide high-resolution observations of solar radio emission at 3.3 GHz. In this short paper we provide details of the invention of this array, which occurred independently of W.N. Christiansen's invention of the solar grating array in Australia at almost the same time.

Keywords: Japan, solar radio astronomy, Osaka City University, solar grating array, Takanori Oshio, Tatsuo Takakura, Shinichi Kaneko, W.N. Christiansen, Minoru Oda

1 INTRODUCTION

The first Japanese radio astronomy observations occurred on 9 May 1948 when Koichi Shimoda observed a partial solar eclipse from Tokyo (Shimoda, 1982; Shimoda et al., 2013). By 1952 there were four different groups of Japanese researchers actively pursuing solar radio astronomy (Ishiguro et al., 2012; Orchiston and Ishiguro, 2017). One of these was based in Osaka, and this short paper deals with that group and specifically with the independent invention of a solar grating array in 1950.¹

2 THE SOLAR GRATING ARRAY

2.1 Introduction

An earlier paper in this series (Orchiston et al., 2016) dealt with the background to the first solar radio astronomy observations at Osaka University during 1949 using a single horn radio telescope operating at 3.3 GHz and mounted on an ex-military searchlight mounting. That paper also described the transfer *en masse* of the Physics staff to the newly formed Faculty of Science and Technology at Osaka City University in early 1950.

On 5 November 1950, a paper (5C7) was presented at the 5th Annual Assembly of the Physical Society of Japan. Thanks to Professor Woody Sullivan we have obtained a copy of the handwritten 8-page paper and an English translation that was prepared by Professor Haruo Tanaka in December 1982.

The paper was titled, "A plan for the localization of noise source on the solar surface by 5-column 5-row electro-magnetic horns". The lead author was Takanori Oshio,² with Tatsuo Takakura and Shinichi Kaneko as co-authors; all were affiliated with Osaka City University and were part of Minoru Oda's group, but only Takakura would go on to make a career in radio astronomy (see Nakajima et al., 2014; Orchiston et al., 2016). The lead author, Takanori Oshio (1920–2002) had been appointed a Lecturer in Physics the previous year, and became a Professor at Osaka City University in 1963. He was interested in the calibration of soft X-ray observations using the X-ray emission from synchrotron radiation as a standard light source for the calibration. Ultimately, Oshio's research led to a collaboration with Professor Minoru Oda who also was interested in research on cosmic ray

physics and later X-ray astronomy (Sasaki, 2003). Apparently Shinichi Kaneko, the third author of the 1950 paper, initially conducted cosmic ray research at Osaka City University, but we have not been able to source biographical material about him that post-dates 1955.

This paper discusses the independent invention of a radio-frequency solar grating array design made almost in parallel with that of W.N. Christiansen at the CSIRO Division of Radio-physics (RP) in Australia. Christiansen presented the first version of his design to RP's Radio Astronomy Committee on 14 March 1950 (see Wendt et al., 2008). This is perhaps another very good example of multiple discoveries, or simultaneous invention, as described by sociologists of science (e.g. see Merton, 1963).

2.2 Influences

In their paper, Oshio et al. (1950) made reference to two prior areas of research. They referred to the Australian observations of

Bolton and Stanley [who] observed the radiating sources of cosmic noise with an accuracy of 0.15 degrees using the interference of direct waves and reflected waves from the sea...

They did not reference a specific publication, but presumably they had read the paper by Bolton and Stanley (1948) that appeared in *Nature*. This reported on the observations at Dover Heights of the Cygnus-A discrete radio source using the technique of sea (or cliff) interferometry. Oshio et al. also noted a paper by Stanier (1950) that also appeared in *Nature* and described the two-element solar interferometry work being carried out at Cambridge. It is surprising that these were the only two papers mentioned from the period that dealt with interferometry.

In a similar manner to Christiansen (1984: 118), Oshio et al. appear to have made the design connection with the optical grating array first proposed by Bernard Lyot (1945). They mention their arrangement of antennas, "...corresponding to a grating or lattice as inferred from optics."

2.3 The Design

The paper by Oshio et al. described how a grating type antenna response could be produced by summing the outputs of a row of identical aerials arranged at integer intervals of their operating wavelength (see Figure 1). They also noted that for observations of the Sun it was important to design the array in such a way that only one response lobe would be located on the Sun at any time and that a drift scan technique could be used to produce a one-dimensional profile of emission across the solar disk by relying on the Earth's rotation. They also considered the effect of a reduction in

resolution as the Sun moved away from the perpendicular to the array axis. This was virtually identical to the design principles described by Christiansen (1953) and Christiansen and Warburton (1953). Figure 2 shows the approximate power response of a single 5-element row of the array proposed by Oshio et al. and based on equation [1] from Christiansen and Warburton (1953: 192).

Although the principles were largely the same, there were a number of key differences between the proposed Japanese array design and Christiansen's earliest grating interferometer. The first of these was that Oshio et al. proposed using equatorially mounted circular horns 50 cm in diameter and 130 cm long rather than dishes (see Figure 3).⁴ Further, the operating frequen-

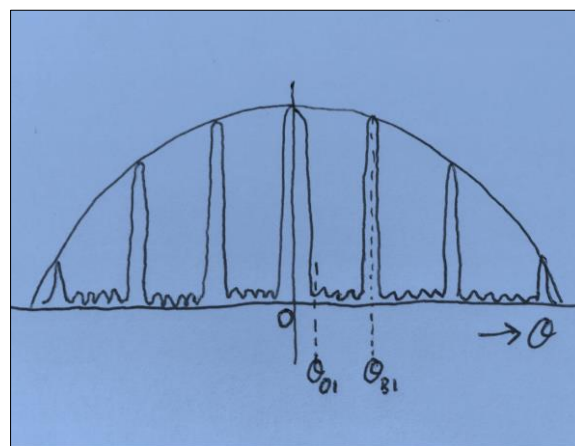


Figure 1: The directivity pattern of the array. Originally Figure 3 of Oshio et al. (1950).³

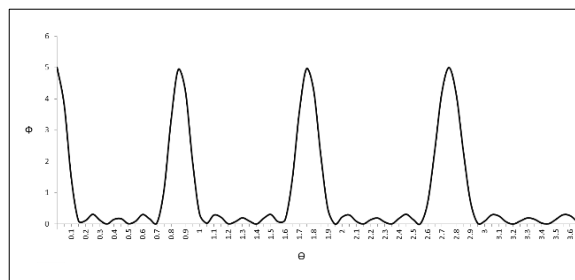


Figure 2: The calculated response of a 5-element grating array operating at a wavelength of 7.5 cm and with an element spacing of 5 m. The y-axis: ϕ = the power received by the array from a point source relative to the power received from a single element of the array. The x-axis: θ = the angle perpendicular to the array baseline and the direction of the source.

cy they chose was 3.3 GHz rather than the 1.42 GHz used by Christiansen, and was selected mainly due to the availability of ex-WWII equipment.

Perhaps the most ambitious aspect of the proposed design was that rather than having a single east-west baseline, they proposed using a 5×5 grid of 25 equatorially mounted horns arranged in a 25×25 m square with spacing of 5 m between aerials (see Figure 4). While an E-W row of aerials would produce the familiar sharp

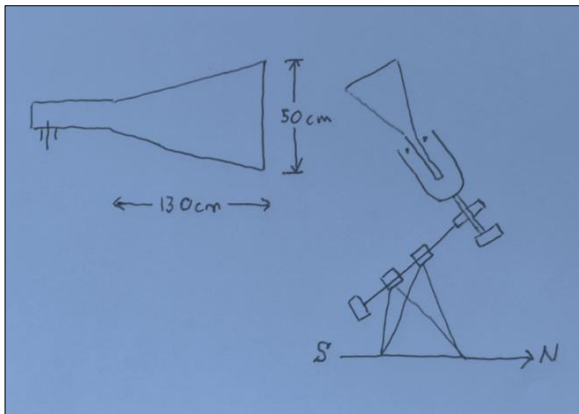


Figure 3: The proposed dimensions of the horn aerial design and its equatorial mounting to allow tracking of the Sun. Originally Figure 9 of Oshio et al. (1950).

fan-beam response, the combination of the 25 elements of the grid would produce a complex two-dimensional grid response, not dissimilar to that produced by the later development of Christiansen’s crossed grating array at Fleurs (Christiansen and Mathewson, 1958; Orchiston and Mathewson, 2009). Oshio et al. describe

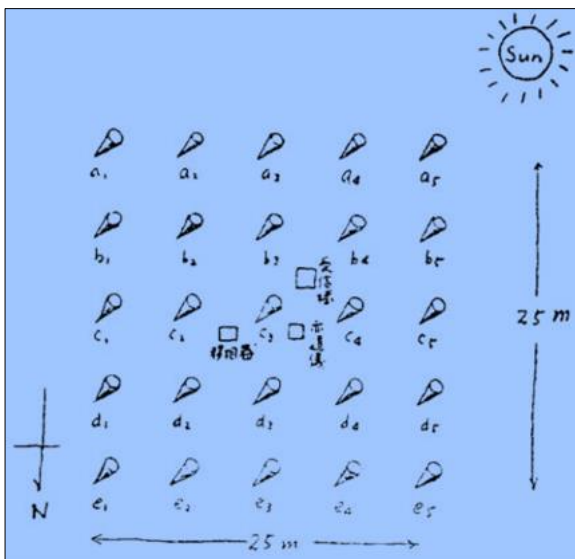


Figure 4: The grid array layout proposed for the array. Originally Figure 7 in Oshio et al. (1950). The three boxes annotated by Japanese characters are the receiver, phase shifter and the master equatorial mount intended to drive the 25 horn aerials for the purpose of tracking the Sun.

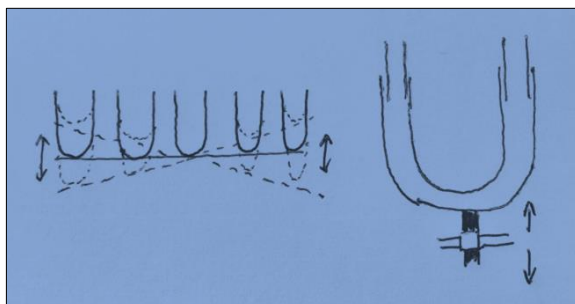


Figure 5: The diagram on the left illustrates the five u-shaped wave guides mounted on a see-saw bench which is rocked to vary the path lengths. The diagram on the right shows the sliding wave guide connected to a flexible coaxial cable. Originally Figure 12 in Oshio et al. (1950).

how

... for a multi-column, multi-row system, the directivity becomes two-dimensional, but the above theory [of a single grating array] can be applied precisely regarding the main axes (in two directions parallel to the antenna arrays).⁵

To further complicate the design, Oshio et al. also proposed dynamically varying the path length of the transmission lines for each row so as to produce a vertical sweeping of the beam response, which they called “... shaking the beam.” They proposed doing this by using a series of five u-shaped wave guides mounted on a rocking see-saw arrangement (see Figure 5). The rocking motion varied the relative path lengths of each array column, and hence the phase, so that the beam pattern was swept in a north-south direction completing a cycle every 17 seconds. The technique of changing the phase of the N-S arm of the Fleurs Crossed Grating Array also was used by Christiansen so that over the course of a day multiple drift scans across the solar disk could be used to create a two-dimensional radio picture of the Sun. However, this was done by a static change to the N-S transmission line path length rather than trying to dynamically sweep the response over the solar disk during an individual drift scan.

Allowing for the slightly larger disk size of the Sun at radio frequencies (presumably on the basis of the reports of others), Oshio et al. assumed a disk of 41.3 minutes of arc, which meant that it would take approximately 2.8 minutes for the Earth’s rotation to move the Sun’s disk horizontally through the maximum beam response, with ten vertical scans completed in the same period. To produce an image, they proposed using an oscilloscope and camera. On the oscilloscope screen a spot, whose brightness was modulated by the signal intensity, would be swept in the vertical axis synchronised to the phase shifter.⁶ The camera’s shutter would then be open for 2.8 minutes to produce a single image. A block diagram of the proposed system design is shown in Figure 6.

3 CONCLUDING REMARKS

It is very likely that this ambitious design, which aimed to produce a single high-resolution image of the radio emission across the solar disk in 2.8 minutes, would have presented a very considerable engineering challenge for any group in the 1950s. Actually achieving accurate transmission pathlengths to maintain phase accuracy through the phase-shifting device would have been extremely difficult.⁷ In many ways, the design was ahead of its time. However, the theory behind the design is sound and could easily have led to the construction of a less ambitious, but more practically achievable one-dimensional grating array similar to that constructed in the

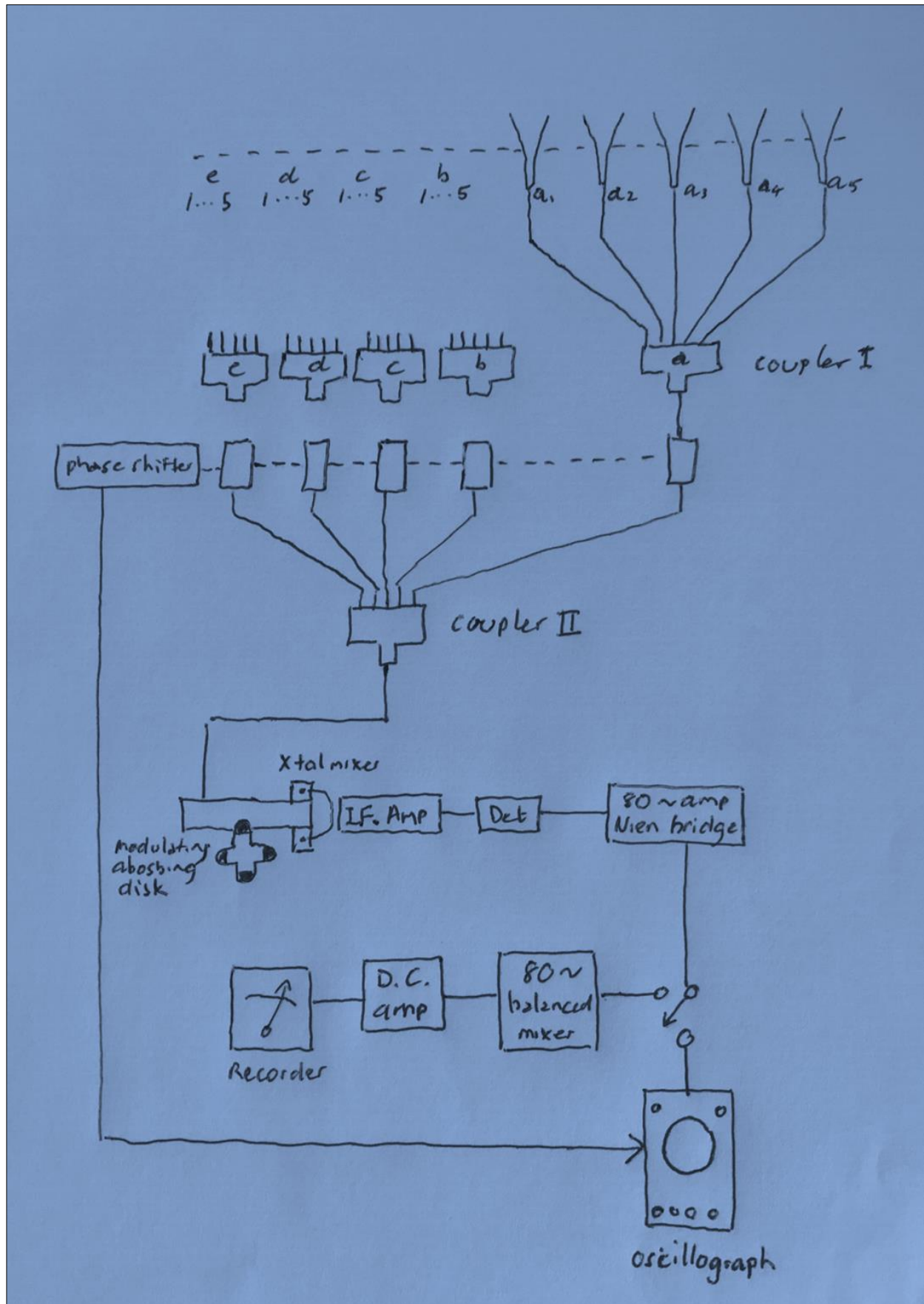


Figure 6: A block diagram of the proposed system. The outputs of each array row are first summed (coupler I) and then passed through the phase shifter before being again summed (coupler II). The output then passes to the receiver where it goes through a modulator (80 Hz) – crystal-balanced mixer – I.F. amplifier – detector – 80 Hz narrowband amplifier and then to the 'Braun tube' (oscilloscope), or is switched to a 80 Hz balanced mixer and the D.C. amplifier and then to a recorder. Originally Figure 8 in Oshio et al. (1950).

period 1951–1952 at Potts Hill in Sydney (Australia) by W.N. Christiansen (1953; cf. Wendt et al., 2008). In fact, Professor Haruo Tanaka of Nagoya University did later construct such an array at Toyokawa, in 1953, and this will be the subject of a later paper in this series that will deal with the radio telescopes designed and constructed by the Toyokawa researchers.

Although Minoru Oda, who headed the group at Osaka City University, did not apply this design in radio astronomy, later he successfully applied similar principles to the invention of a modulation collimator (Oda, 1965) which is now known as an ‘Oda Collimator’ and is used in high energy X-ray observations (Tanaka, 1984: 339).

As discussed by Orchiston et al. (2016), the design outlined by Oshio et al. in their 1950 conference paper was never published and, apart from the construction of a single horn aerial and receiver, the array itself was never constructed.

4 NOTES

1. This is the fifth paper in a series initiated by the IAU Working Group on Historic Radio Astronomy that aims to document, in English, the early development of Japanese radio astronomy. The first paper (Ishiguro et al., 2012) provided a chronological overview, while papers 2–4 dealt respectively with Kōichi Shimoda’s observation of the 9 May 1948 partial solar eclipse (Shimoda et al., 2013); early solar radio astronomy at Tokyo Astronomical Observatory (Nakajima et al., 2014) and early solar research at Osaka University and Osaka City University (Orchiston et al., 2016).
2. In the course of researching this paper we discovered that Takanori Oshio’s name originally was erroneously written as ‘Takabumi Ojio’ in some of the papers listed above in Note 1, and in Tanaka (1984).
3. Note that all figures from the 1950 paper that appear in this paper are tracings of a copy of the original paper which was of too poor a quality to reproduce for publication.
4. Orchiston et al. (2016) note that the horn design which was used with the first single 3.3 GHz receiver was later replaced by a 1-m dish when the horn proved less than ideal.
5. A crossed grating array is a much more economical way of producing this type of beam pattern, but this would have required the conceptual design leap of multiplying the array responses. This innovation would only come later when made by Bernard Mills with the invention of the cross-type array (Mills and Little, 1953) and Christiansen’s subsequent application of it to a grating interferometer

(Christiansen and Mathewson, 1958; cf. Orchiston and Mathewson, 2009).

6. It is interesting to note that Little and Payne-Scott (1951) used a similar recording method for capturing images from their swept-lobe interferometer at 97 MHz which was used for capturing the position, motion and polarisation of short duration solar bursts.
7. Little and Payne-Scott (1951) used a rotating metal arm within a drum to achieve the variable path length change for their swept-lobe interferometer. In their case, they were only using a two-element interferometer and they changed the phase of the local oscillator rather than attempting to change the phase of the actual signal. Fortunately, sensitivity was not a major issue for solar observations as this type of mechanical phase change created significant losses.

5 ACKNOWLEDGEMENTS

We wish to thank Professor Woody Sullivan for kindly supplying a copy of the original Oshio et al. paper *and* an English translation of it that were in the archives that he assembled when researching his comprehensive history of early radio astronomy (see Sullivan, 2009). One of the authors (HW) also would like to thank Professor Bob Frater for his discussions on beam forming in arrays, although any misinterpretation of aspects of electrical engineering is solely that of the author.

6 REFERENCES

- Bolton, J.G., and Stanley, G.J., 1948. Variable source of radio frequency radiation in the constellation of Cygnus. *Nature*, 161, 312–313.
- Christiansen, W.N., 1953. A high-resolution aerial for radio astronomy. *Nature*, 171, 831–833.
- Christiansen, W.N., 1984. The first decade of solar radio astronomy in Australia. In Sullivan, 113–131.
- Christiansen, W.N., and Mathewson, D.S., 1958. Scanning the Sun with a highly directional array. *Proceedings of the Institute of Radio Engineers*, 46, 127–131.
- Christiansen, W.N., and Warburton, J.A., 1953. The distribution of radio brightness over the solar disk at a wavelength of 21 cm. Part I. A new highly directional aerial system. *Australian Journal of Physics*, 6, 190–202.
- Ishiguro, M., Orchiston, W., Akabane, K., Kaifu, N., Hayashi, M., Nakamura, T., Stewart, R., and Yokoo, H., 2012. Highlighting the history of Japanese radio astronomy. 1: An introduction. *Journal of Astronomical History and Heritage*, 15, 213–231.
- Little, A.G., and Payne-Scott, R., 1951. The position and movement on the solar disk of sources of radiation at a frequency of 97 Mc/s. *Australian Journal of Scientific Research*, 4, 489–507.
- Lyot, B., 1945. A monochromatic polarising filter and its applications in solar physics. *Annales d’Astrophysique*, 7, 31–79 (in French).
- Merton, R.K., 1963. Resistance to the systematic study

- of multiple discoveries in science. *European Journal of Sociology*, 4, 237–282.
- Mills, B.Y., and Little, A.G., 1953. A high-resolution aerial system of a new type. *Australian Journal of Physics*, 6, 272–278.
- Nakajima, H., Ishiguro, M., Orchiston, W., Akabane, K., Enome, S., Hayashi, M., Kaifu, N., Nakamura, T., and Tsuchiya, A., 2014. Highlighting the history of Japanese radio astronomy. 3: Early solar radio research at the Tokyo Astronomical Observatory. *Journal of Astronomical History and Heritage*, 17, 2–28.
- Oda, M., 1965. High-resolution X-ray collimator with broad field of view for astronomical use. *Applied Optics*, 4, 143.
- Orchiston, W., and Ishiguro, M., 2017. The early development of radio astronomy in Japan. In Nakamura, T., and Orchiston, W. (eds.). *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. Cham, Springer.
- Orchiston, W., and Mathewson, D.S., 2009. Chris Christiansen and the Chris Cross. *Journal of Astronomical History and Heritage*, 12, 11–32.
- Orchiston, W., Nakamura, T., and Ishiguro, M., 2016. Highlighting the history of Japanese radio astronomy. 4: Early solar research in Osaka. *Journal of Astronomical History and Heritage*, 19, 240–246.
- Oshio, T., Takakura, T., and Kaneko, S., 1950. A plan for the localization of solar sources on the solar surface by 5-column 5-row electromagnetic horns. Paper 5C7 presented at the 5th Annual Assembly of the Physical Society of Japan, November 5. Pp. 8 (in Japanese).
- Sasaki, T., 2003. Obituary: Takanori Oshio (1920–2002). *Journal of JSSRR*, 16, 44–45.
- Shimoda, K., 1982. After Dinner Talk: two reflectors made in 1930. In 13th Okazaki Conference, 1982 Tokyo, Institute for Molecular Science. Pp. 31–35.
- Shimoda, K., Orchiston, W., Akabane, K., and Ishiguro, M., 2013. Highlighting the history of Japanese radio astronomy. 2: Koichi Shimoda and the 1948 solar eclipse. *Journal of Astronomical History and Heritage*, 16, 98–106.
- Stanier, H.M., 1950. Distribution of radiation from the undisturbed Sun at a wave-length of 60 cm. *Nature*, 165, 354.
- Sullivan, W.T. (ed.), 1984. *The Early Years of Radio Astronomy: Reflections Fifty Years after Jansky's Discovery*. Cambridge, Cambridge University Press.
- Sullivan, W.T., 2009. *Cosmic Noise: A History of Early Radio Astronomy*. Cambridge, Cambridge University Press.
- Tanaka, H., 1984. Development of solar radio astronomy in Japan up until 1960. In Sullivan, 335–348.
- Wendt, H.W., Orchiston, W., and Slee, B., 2008. W.N. Christiansen and the development of the solar grating array. *Journal of Astronomical History and Heritage*, 11, 173–184.

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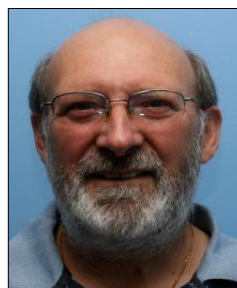
of the CSIRO Division of Radiophysics Potts Hill and Murraybank Field Stations to International Radio



Astronomy.

Astronomy” through James Cook University (Townsville, Australia), supervised by Professor Wayne Orchiston and the late Professor Bruce Slee. Harry has since published a series of papers based upon his thesis research. He is a member of the IAU Working Group on Historic Radio

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telescopes at the Nobeyama Radio Observatory (NRO) where he was in charge of constructing the Nobeyama Millimeter Array. He was the Director of the NRO from 1990 to 1996 and contributed to the open use of the telescopes. While doing research at the NRO, he worked on a plan for a large array at millimeter and submillimeter wavelengths. From 1998, he led the Japanese involvement in the construction of the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile. Masato was a Professor at the NAOJ from 1988 until he retired in 2009. He is now the Japanese representative on the Committee of the IAU Working Group on Historic Radio Astronomy.

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asteroids and in the history of Japanese astronomy, and he has published more than fifty papers in this latter field. His books include *Five Thousand Years of Cosmic Visions* (2011, in Japanese, co-authored by S. Okamura), *Mapping the Oriental Sky*, *Proceedings of the*

ICOA-7 Conference (2011, co-edited by W. Orchiston, M. Sôma and R. Strom) and *Highlighting the History of Astronomy in the Asia-Pacific Region, Proceedings of the ICOA-6 Conference* (2011, co-edited by W. Orchiston and R. Strom). Tsuko is the Chairman of the Executive Committee of the International Conference on Oriental Astronomy.