NRAO ONLINE 42

GRT 1956 Year of Transition, Delays with Freeman, Fox and Partners, Visits of Merle Tuve and Bart Bok

Epigraph :

F.W.G.White opened the "Symposium on Radio Astronomy- A Welcome for Prof Bart Bok to Australia" 4 September 1956:

> … [S]o great had been the achievement of the Radiophysics Laboratory in this field [of radio astronomy, that] the future development of your activities and interests must at all costs be given the greatest of encouragement …

As 1956 began, there was optimism within the Radiophysics Lab; FFP were starting work on the design of the GRT with Barnes Wallis as advisor. The expectation of RP was that by mid-to-late 1956 the design of the GRT would be complete with construction beginning in 1957. In this scenario the completion date would be in 1959. As we will see, the timescale was delayed considerably, almost two years. The major stumbling block was the monumental challenges facing FFP: (1) choice of steel or aluminium, (2) rigid or compensated, (3) equatorial versus alt-azimuth mounts (if the latter the required detailed design of the master equatorial), and (4) the choice of the site in Australia. Before Roderick left for the US, Gilbert Roberts told him that FFP would start with two designs: (1) a 300 foot dish with the Wallis compensating structures and (2) a 150 foot rigid steel aerial.[1]

The vast distance between Sydney and London (17,000 km) was a continuing concern; however the presence of Harry Minnett (RPL)i at FFP starting in late January 1956 was a major benefit.[2] Personality conflict between RPL and FFP in the persons of Bowen, Minnett[3] (RP) and Gilbert Roberts (FFP) also began to play a role in 1956, intensifying in the following two years. Fortunately this conflict had a minor impact on the other participants.

In late April 1956, Bowen[4] was on a short visit to the US. Bowen became peripherally involved with the equatorial alt-azimuth controversy at AUI during the planning for the 140

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[1] NAA C3830, A1/3/11/1, 10 January 1956 from Bethlehem, Pennsylvania, US.
[2] Bowen wrote to Wallis about Minnett: "He has no experience of structural engineering but is skilled in radio astronomy and is an expert on the radio frequency characteristics of aerials." After starting with a study of the "feed support problem", Minnett rapidly became a key figure in understanding and designing the servo system of the GRT. NAA, C3830 A1/3/11/1, 13 January 1956.
[3] And to a lesser degree, Fred White, CEO of CSIRO.
[4] NAA C3830, A1/3/11/3. Letter to Pawsey from Washington D.C. 30 April 1956. Bowen was to return to Sydney within a fortnight, 13 May 1956. On 6 April 1956, Pawsey (as acting Chief of RP) had written Harry Minnett with instructions of how to approach the issue of "compromise between radio [scientific] and engineering factors [with FFP]. We wish to encourage this and you are in London to try to see that it takes place ... [There are] three categories of things to consider: (a) Changes to the

foot telescope (see Lockman, Felix J., Frank D. Ghigo, and Dana S. Balser. "But it was Fun: The First Forty Years of Radio Astronomy at Green Bank." *But it was Fun: The First Forty years of Radio Astronomy at Green Bank* (2007)). AUI was involved in a lengthy discussion whether a pointing accuracy of some tens arc sec could ever be achieved with an alt-azimuth design. Designs by Feld, Husband and Kennedy were available. Bowen wrote: "The first two are frightening and there is a strong body of opinions in favour of the Kennedy design …[5] It is high time that the advocates of the alt-azimuth design did something about this. It looks as if the world will be littered with radio telescopes on alt-azimuth mounts which cannot be driven around." Bowen had clearly been influenced by an exchange which had occurred six weeks earlier between Bowen's US colleagues Merle Tuve of DTM and Dick Emberson[6], the assistant to the President of AUI Lloyd Berkner. Tuve was upset with Emberson after he received the details of Feld's alt-azimuth design of the 140 foot without any details of the servo system. Tuve wrote:

> You should not seek judgement or approval of the Steering Committee [of AUI, which was to meet two weeks later] on the merits of these mounts with such a principle factor not only undetermined but challenged by us [members of the Steering Committee] for nearly a year as impractical and probably impossible in terms of the specifications presented.

Tuve then discussed several photographs of a model 84 foot radio telescope "Carnegie Equatorial Mount", incorporating the Howard Tatel design that was to be used for many 25 metre telescopes after 1958.[7] He suggested that Feld could use these in his design of the 140 foot: "I am frankly not much interested in attending sessions [of the Steering Committee] when they are only about structural calculations for an alt-azimuth mount." Tuve would not attend the meeting unless the problems of the drive and servo limitations of the alt-azimuth mount were on the agenda. As described by Lockman et al (2007), a complex set of negotiations followed after March 1956 between the Steering Committee and the NSF Advisory Panel on Radio Astronomy. Merle Tuve's intervention had forced AUI to consider again an equatorial mount.[8] The uncertainty about an eventual design of a successful alt-azimuth mount was to feed directly into the deliberations in Sydney and London (FFP).

Specification given to FFP, (b) Interpretation of this Specification, and (c) Things not covered in the Specification but of considerable importance."

[5] Bowen reported (the 30 April letter to Pawsey) that "… the MIT servo group ... have said flatly that it cannot go down to the accuracy AUI is calling for."

[6] NAA C3830, A1/3/11/1. 13 March 1956, Tuve to Emberson, copy sent to Bowen.

[7] The designs incorporated tetrahedral structures in order to avoid bending moments on structural elements. The 85 foot/26m telescope constructed by the Blaw-Knox Corp was commonly used as a radio telescope and as a NASA tracking antenna in the following decades.

[8] By January 1957, the decision was made to concentrate on the N.L. Ashton (University of Iowa) equatorially mounted 140 foot design. After a long and complex construction period beginning in August 1958, the 140 foot was opened in October 1965.

On 19 July 1956, Gilbert Roberts[9] wrote Bowen with a long-awaited update on the design study.[10] "In fact, we have not reached many firm decisions, except on certain general principles and a number of lines of investigation have still to be pursued before we could claim to have a complete design." Roberts implied that the complete preliminary report would arrive within the next month. In fact, it would be available in mid-October 1956, a delay of three months; this delay was viewed with frustration by the Australians in 1956. Roberts sent a single drawing, undoubtedly to placate the Australians. This was a very preliminary design for the compensated 300 foot aerial with an alt-azimuth mounting.[11] A major red flag was raised:

> One essential feature that we have not yet adequately developed is the master polar axis mounting [later to be the master equatorial], and its associated drives and servo-controls. This is a highly specialised piece of apparatus … However, we have asked Dr. Wallis [Barnes Wallis] if … he would get some [design] work [by Vickers-Armstrong] … at our expense.

This plan proved to be a pipe dream. The aircraft firm of Vickers-Armstrong was in the thick of defence contracts for the British government and was not interested in "one-off" specialised pieces of equipment. On 14 September 1956, Roberts wrote Bowen with the discouraging news: "it became clear that we [FFP and CSIRO] could 'write-off' all the Vickers organisation, so far as practical assistance is concerned."[12]

In late July 1956, Merle Tuve began a round-the-world trip, originating in the UK with a visit to FFP on 7 August 1956 in London.[13] Tuve's visit was important for the CSIRO radio astronomers due to his close connections with Bowen and Pawsey and his role in acquiring

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[9] Gilbert Roberts, in charge of the 210 foot design.
[10] NAA, C3830 , A1/3/11/1, Part 7.
[11] Already it was clear the equatorial mount was not to be taken seriously. Roberts wrote, "We do not think any useful purpose would be served by attempting a design of a full-scale polar axis mounting, since even if this proved practical, deflections would be extremely difficult to control."
[12] NAA, C3830, A1/3/11/1, Part 7. In addition, another branch of Vickers-Armstrong (Elswick Works) had also turned down the request for design assistance. Other rejections were obtained from Elliot Bros. (who did aircraft control systems) and British Thompson Houston Co. In the end Roberts wrote to Bowen on 17 October 1956 with the good news that Grubb Parsons, "the telescope people", were willing to develop and cost a master equatorial system. The major problem was that the firms were reluctant to design a "one of a kind" instrument. Roberts wrote: "[C]learly the development of a special piece of apparatus, of which there are not likely to be any repeats, and, in fact, not even the certainty of a single order, is a most unattractive proposition for any firm here [in the UK] ..."
[13] NAA C3830, A1/3/11/10 Part 1. On 16 July 1956, Bowen wrote Minnett in London with a description of the importance of Tuve's visit to FFP: "… Merle Tuve played a very big part in the original grant of $250,000 from the Carnegie Corporation and it was this grant which kicked off the whole project. He is also Chairman of AUI's Technical Committee on Radio Astronomy, and if he is impressed with what FFP are doing, this may have an important bearing on future activities at AUI. Perhaps it is worth impressing these two points on Ralph Freeman when you are making arrangements for Merle's visit."

the Carnegie Corporation grant in 1954. At FFP, Tuve met with Freeman, Minnett and Mike Jeffery; Jeffery was to have an important role during the Parkes construction of 1959-1961 as the on-site FFP representative.[14] Due to misunderstandings, the meeting could only occur from 10:30 to 2 pm, including a luncheon. In spite of the short period, a number of issues were discussed.

On 14 and 22 August 1956, Minnett wrote Bowen with details of the discussions at FFP on 7 August 1956[15]. Tuve had been critical: "... [According to Minnett,] [Tuve] criticised certain aspects of the current design with characteristic vigour and bluntness, but approved of others ... It was disappointing to have to show a design which is bound to change … I thought that some of the answers on basic points … were more hesitant that they need have been …There are a [number] of weak points ... which Dr Tuve was able to spot at once."

Minnett pointed out a number of impressions that grew out of this meeting. It appeared that the "biggest uncompensated telescope which could be made to meet the plus or minus 1.2 cm tolerance" would be 180 foot. (The Barnes Wallis compensated 300 foot aluminium dish had a complex electro-mechanical mechanism that could automatically correct the shape of the dish as required due to dead load-- gravity and wind load deflections.) Tuve was in favour of the central support system compared to the two-tower approach (e.g. the Jodrell Bank 250 foot). Tuve preferred steel compared to aluminium alloy (FFP had not decided this issue at the time). FFP told Tuve that the equatorial mounting was still a possibility, even though Roberts and Wallis were dead set against this option. Tuve discovered that the "coordinate converter" (later the "master equatorial", ME) was still an open and unsolved problem.[16] A few days before Tuve arrived, Wallis had reported that his provisional patent on the coordinate-converter was to expire in October 1956. Wallis had asked his patent attorney to "arrange for drawings suitable for a final patent", so there would be no restrictions on "telling Merle Tuve everything he wished to know".

On 27 August 1956, Minnett wrote Bowen again with more details about his impressions of the questions raised by Tuve. He pointed out that the two major questions, compensated versus rigid and equatorial or alt-azimuth, were partly independent. The size of dish for which an equatorial mount would be feasible was not known: "Barnes Wallis in his report speculates that the limiting dish size for an equatorial might be in the range 150-200 feet,

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[14] The Australians were disappointed that Tuve did not meet Wallis or Roberts during the long first of August holiday weekend in the UK. Roberts was visiting Africa (Ghana), where FFP was working on the Volta (now Adomi) Bridge, opened in 1957; Wallis was on holiday in Dorset. The absence of these two was quite unfortunate since Tuve missed seeing two of the important participants; Tuve did not witness any of their contradictory opinions.

[15] NAA C3830 A1/3/11/10 Part 1.

[16] Minnett even feared that the detailed planning for the ME was so delayed that it would be necessary to look hard at the equatorial mounting, even in the face of the opposition of Wallis and Roberts.

but no one ... has worked it out in detail." Minnett was pessimistic: "It is clear that much still remains to be done on the compensating structure problem, particularly when the [ME] is taken into account." He feared that in the end CSIRO would be forced to a 150 foot class telescope, "where rigid dishes and equatorial mounts are feasible."

Bowen regarded Tuve's visit to FFP and then RP as a propitious event since Tuve had acted "as a very useful catalyst" while decisions were to be made.[17] In addition, Tuve brought first hand impressions of FFP to Sydney. Based on this report, Bowen thought that : (1) the two design strategy, one rigid and the other compensation was opportune, (2) the compensated dish was running into difficulties (e.g. how to have a real time compensation of the shape of the dish) while more attention was being given to the rigid design, (3) it was likely that FFP knew something about the cost of the GRT "but we have not yet been informed", (4) the alt-azimuth versus equatorial mounting controversy still was unsettled and (5) the design study would take considerably longer and was not likely to be completed before the end of 1956 (in fact was ten months later, early November 1957).

In a letter of 14 September 1956 from Roberts to Bowen, Roberts reported on his colleagues' reaction to Tuve's visit. Roberts was opposed to a polar mount. Roberts repeated his warning about the polar mount already noted on 19 July 1956[18] (Roberts to Bowen):

> [Tuve] seems to be keen on the Polar Axis type of mounting, but the advantages of this, even if found practical for the size of the dish we have in mind, are doubtful. For instance, deflections due to dead load can readily be compensated in the alt-azimuth mounting, but in the Polar Axis present difficulties. With the Polar Axis mounting, deflections of the structure supporting the axis bearing could not be corrected, whereas with our type of mounting any deflection of the axis of rotation is automatically taken up by the [master equatorial, ME], which alone needs to be accurately levelled. If only we can be satisfied on the [ME] design, and its associated servo mechanism, I feel that our system must be the better solution.

Thus, even without a detailed design study of the [ME], Roberts was firmly convinced of the superior merits of the alt-azimuth mount.

Bowen and Pawsey were influenced by Tuve's assessment of FFP in mid-1956 as they prepared the RP report (sent through Fred White) to R.G. Casey, the Minister of External Affairs and Minister in charge of the CSIRO. Casey was in New York in late October-early November 1956 for the yearly meeting of the General Assembly of the United Nations; he

[17] NAA, C3830, A1/3/11/1, Part 7. 17 September 1956, Bowen to White.

[18] 19 July 1956, Roberts to Bowen: "We do not think any useful purpose would be served by attempting a design of a full-scale polar axis mounting …"

used this opportunity to visit both the Carnegie Corporation and the Rockefeller Foundation. CSIRO gave an official briefing to Casey on 12 October 1956, reporting that Tuve (recently in Sydney) was “satisfied with the progress being made [by FFP]. He warned us that we must not be impatient as … It is essential that the correct design be evolved before we consider letting any construction contract.”[19]

At this point in mid-October 1956, the CSIRO management was becoming increasingly concerned about the escalating delays; the interim report from FFP was already two months behind schedule. Even Fred White was impatient, in a letter to Bowen (11 October 1956):

> While I bear in mind Tuve’s warning that we must not be impatient, nevertheless I am beginning to wonder whether the time is not arriving to place some real pressure on Freeman Fox. There is a danger, I suppose, that Wallis may be somewhat highfalutin in his approach to this problem when one takes into the account the amount of money that we will have to spend. However, the main point seems to me to be where some senior person should not access just where Freeman Fox have got to and if necessary crystalize their thinking in a particular direction. Probably Joe Pawsey should be the person to do it.

In the briefing paper for Casey (see above, 12 October 1956), Bowen also thought that pressure should be placed on FFP: “… time has now arrived for us to put somewhat greater pressure on FFP … to have them consolidate their ideas in a particular direction.”[20]

Then on the next day, the preliminary report from FFP arrived in Sydney. Fortunately, Tuve was still in Sydney, returning to Washington in a few days. He wrote Dick Emberson of AUI on 13 October 1956 that his visit to FFP had an impact:

> Since my vigorous comments to them in London ... they have been studying rigid dish designs ...They find that they can make a dish 325 feet in diameter before the deflections (gravity or a modest wind) will reach 0.3 inch -0.8 cm- from the parabola of best fit. [The numbers given to Minnett a few months earlier were far more pessimistic.] … The report shows sketches of two alt-azimuth mounts, but [Bowen] insists on an equatorial design plus comparison of cost figures. FFP can’t find anybody willing or able to make a suitable drive for alt-azimuth- same trouble as AUI had.[21]

[19] NAA, C3830, A1/3/11/3, Part 4.
[20] NAA, C3830, A1/3/11/1, Part 7.
[21] *Ibid* Also on 19 October 1956, Bowen wrote Ralph Freeman of FFP, the son of the founder, Sir Ralph Freeman, 1880-1950 of FFP. Bowen suggested that FFP might contact AUI with the view of possibly designing two radio telescopes, one for Australia and the other for the US. Nothing concrete arrived from this suggestion.

Summary of the Preliminary Report- October 1956 from FFP[22]

The long awaited "Preliminary Report" dated September 1956 was posted 7 October 1956 in London and arrived in Sydney on 12 October. As had been anticipated, only alt-azimuth mountings were considered. FFP pointed out to Bowen that a detailed design of the master equatorial was still required.

Two main designs were considered: (1) A 300-foot telescope with aluminium support which was to be continuously compensated for dead load and wind load deflections. The Barnes Wallis proposal was clearly the basis for this suggestion. The proposal summary read: "A thin shell of triangular rib members arranged as intersecting spirals, on the assumption that automatic correction of the dish would be required." Aluminium was used due to the difficult access for maintenance and also to reduce weight. The dish was supported on a rigid hub of 54 feet or 16.5 m diameter. (Fig.1 and Fig.2). The "shell was designed on a basis of maximum stress under worst conditions of loading". As Robertson (1992, p 151) has pointed out a new device would have been required to determine the magnitude of the deflections and then be feed-back to a system that would adjust the aluminium support structure. This device was never designed; the development and maintenance costs would have been extreme.[23] The first large radio telescopes[24] constructed with a full compensation structure, "the active surface control", was the Green Bank Robert C. Byrd 100 m unblocked aperture radio telescope, completed in 2000.

The second type of dish (Fig. 3 and Fig. 4) was designed as a rigid dish. The design was optimised for minimum stress in contrast to the compensated aerial. This rigid dish design had a diameter of 225 feet (69 m), "at which the deflections [about 0.25 cm] are all within the specified limits [1 cm]". The main limitation turned out to be pointing accuracy, with predicted errors of about one arc min, the specification from the November 1955 document. Steel tubes were to be used instead of aluminium. The aerial design had geodetic structures supporting the reflector (spiral purlins- the Wallis design) supported in addition by a set of radial trusses (not included in the Wallis design).

[22] NAA, C3830, A1/3/11/1, Part 1 (Surprisingly filed in the rubric for 1 May 1952 to 31 December 1953)

[23] The complex adjustment system was described in some detail. The compensation of the dish surface was carried by means of altering the length of tubular rib members under stress. Variation "of the pressure of the hydraulic fluid contained with the members" was suggested. Some type of photoelectric device for monitoring the instantaneous shape was then required. "Further consideration would have to be given to the above problem before any decision about the feasibility of dish compensation could be made." The required pressures would have been 2 tons per square inch. Certainly, it is not surprising that this proposed design was not considered further; the expenses would have been inordinate with likely long delays.

[24] The 15 m IRAM antennas on Plateau de Bure had an active control for the antennas but this was only used for the initial adjustment of the surface; subsequently routine use was not attempted due to the unreliable nature of the system (David Morris, private communication 2016).

The support tower was to be made of reinforced concrete with space for the operations room, workshops and equipment rooms. The master control polar axis (master equatorial) mounting was located at the intersection of the altitude and azimuth axes of rotation of the dish. The position of the master control was the major variation between scheme A (Fig. 3- note the resemblance to the Wallis design of Fig. 6 NRAO ONLINE 41) and scheme B (Fig.4). The scheme A mount "depends ... on transferring the balancing moment of the counterweights to the moving dish structure by means of a torque tube", a massive structure requiring large and expensive altitude bearings. The elevation drive for this case was to rotate with the dish, clearly a disadvantage. Scheme B (close to the one ultimately adopted) "has the advantage over Scheme A that the axis of rotation in altitude is nearer the paraboloid, and inertia of the moving mass is reduced". The access to the centre of the hub and the weight of the structural parts of the mount were more favourable for scheme B. The only advantage of scheme A was a far simpler connection of the dish to the ME (master equatorial).

For the 300 foot (91m) compensated dish, a metal mast was proposed as the aerial feed structure (Fig. 1); an alternative design was based on a tripod, latticed members supporting a platform 2 feet (61cm) behind the focus of the paraboloid (Fig. 2). For both 225-foot schemes, a tripod was proposed. The maximum wind speed (survival) was to be 100 mph (45 m/s) for the 300 foot and 75 mph (34 m/s) for the 225-foot dishes. The total weight of the 300-foot design was an impressive 525 tons (476 metric tons); for the 225 dish the weights were 790 tons (716 metric tons) for scheme A and 730 tons (662 metric tons) for scheme B. As pointed out above, the deflections of the three designs were impressive, well below specifications.

Finally the effects of increasing the rigid deep rib dish up to 325 feet diameter (almost 100 m) were investigated. At this date, it appeared that the specifications of November 1955 could be met at this diameter. Robertson (1992, p 151) has described Freeman Fox's conclusion:

> … Freeman Fox carried out an investigation of a 150 feet rigid dish with Wallis' geodetic structure and then extended the calculations to determine the maximum size possible without using any form of compensation. Surprisingly, the diameter turned out to be in excess of 300 feet and from there it was a straightforward decision to choose a rigid, uncompensated structure. Steel was selected for the skeleton of the dish because of its superior rigidity compared to aluminium or other light alloys.

The final paragraph of the FFP report was striking:

> Cost estimates are not given in this report since we are not able to put an accurate value to the important non-structural components such as the master control unit, bearings and drive elements. It would seem, however, that a rigid uncompensated

> type of structure, complying with the specified tolerances, can be built up to the largest size for which the available sum [finance] would suffice.

The CSIRO management (Bowen, Pawsey and White) were likely in a state of mixed emotions as the end of 1956 approached. Their optimism was clearly buoyed by the visits of Bart Bok and Merle Tuve in Sept-October 1956. On 18 October 1956, Bowen wrote Bolton at Caltech: "We have just had visits from Bok and Tuve and these have given the radio astronomy programme a big boost. It is quite clear that Bok's arrival in Stromlo [in March, 1957 to Mt. Stromlo] will make a tremendous difference to optical astronomy in Australia and we are all looking forward to it very much."[25] Bok was visiting Australia for four weeks starting in early September 1956, preparing for his move to Canberra as the Stromlo director in early 1957; from 26 September to 4 October 1956 Bok was in Sydney. (see Additional Note 1- Plans for Bart Bok visit to Australia 1956)

A "Symposium on Radio Astronomy" was held in Bok's honour at the RP Lab in Sydney (4-5 September 1956).[26] The opening talks were given by White (Introduction), Pawsey (Radio Astronomy in the Radiophysics Laboratory) and Bok (Radio Astronomy in the US).

On 12 October 1956, White reported to Casey, describing the visit by Bok[27]: "... [T]he present Australian programme [in radio astronomy] was compared [by Bok and White] with that in the US. Professor Bok is very keenly interested indeed in radio as well as optical astronomy. His presence in Australia will insure, first, a close cooperation between Radiophysics and the Australian National University. Secondly, he will be able to assist us to foster even more than in the past a close contact with radio and optical astronomers in the US."

Details of the symposium are presented in Additional Note 2

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[25] From Pawsey correspondence-archive at the CSIRO, CASS, Ron Ekers. Bok was the Director of the Mt Stromlo Observatory of the Australian National University (ANU) from March 1957 to 1966. His name had been suggested to ANU by Pawsey (Frame and Faulker, 2003). Bok had been active in founding radio astronomy at Harvard and played a role in the setting up of AUI (see Chapter 38- Bok wrote Pawsey on 16 June 1961 about the NRAO Directorship).

[26] KE 20/2. CSIRO archive Canberra. The two day symposium had 23 talks with an opening session with talks by White, Pawsey "Radio Astronomy in the RPL", and Bok "Radio Astronomy in the US". Additional sessions were about the solar system, solar radio astronomy, continuum cosmic noise (talks by Reber "Long Wave Radiation of Possible Celestial Origin" and Ellis "Cosmic Radio Emission at Long Wavelengths"), structure of the Milky Way (Bok "Interstellar Gas and Dust" and Twiss "Possibilities of Radio Spectral Lines") and Cosmological Problems (including Mills "Survey of Existing Radio Data" and Twiss "Future Possibilities in Radio Astronomy"). An excursion to the Fleurs field station was held on the following day, 6 September 1956.

[27] NAA C3830 A1/3/11/3, Part V.

A summary of the viewpoint of CSIRO RP, as expressed to FFP on 4 December 1956, consisted of both optimism and concern[28]: (1) Bowen was comfortable with the choice of a rigid as compared to a compensated structure; (2) Bowen was impressed but concerned by the small values of the deflections ("the calculated deflections are notably small …"); he asked FFP to justify these numbers; (3) "The outstanding problem of the equatorial versus alt-azimuth is not discussed. We are most anxious that in view of the large number of unknowns in the drive system of the alt-azimuth and the apparent failure of other groups to reach a satisfactory solution … a very thorough investigation of the feasibility of an equatorial mount be carried out"; (4) The time scales were of great concern. Bowen was sympathetic that "many conflicting factors" had to be sorted out before construction could begin. "We would be concerned … if the study extended beyond twelve months and we would like to urge that every effort be made not to exceed this figure." Bowen used as a lever the facts that the Rockefeller Foundation had a time limit and the Australian Government Department of the Treasury had also applied pressure. CSIRO expected the final design study by early 1957.

In a letter to John Bolton in Pasadena on 18 October 1956, Bowen wrote about the status of the preliminary report from FFP: "We still have no idea of the likely size of the dish we shall get for the money here in hand. My own guess is around 200 feet [close to the final 210 feet for the GRT]."[29]

In a summary of the preliminary design presented to CSIRO head office on 11 December 1956, Bowen mentioned the main points and also the site selection problems. The site should be within 50 miles (80 km) of the CSIRO labs at the University of Sydney campus; at this distance daily commuting from the RPL would be possible. A possible site had been located at Wallacia, just west of the existing site at Fleurs (and 65 km from the centre of Sydney). A major concern in the eyes of Bowen and Pawsey was the uncertain design of the ME. Roberts had written Bowen already on 17 October 1956 with the news that FFP had made contact with Sir Howard Grubb, Parsons and Company Ltd., "the telescope people", who could prepare the "master control unit and associated servo systems".[30]

Probably the major concern for the RP management was the uncertainty of the choice of alt-az or equatorial mounting. Bowen was clearly torn between the advocates for an alt-az (FFP, Wallis) and the formidable opponents (Tuve of the Carnegie Institution of Washington and Bolton and Bruce Rule of Caltech[31]). Even the CEO of CSIRO, White, was concerned (see above, White's letter to Bowen on 11 October 1956).

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[28] NAA C3830, A1/3/11,1, Part 7. Bowen to FFP. A subset of the Technical Advisory Committee had discussed the FFP interim report of September, including Roderick and Wills.

[29] From Bolton correspondence-archive at the CSIRO, CASS, Ron Ekers.

[30] NAA, C3830, A1/3/11/1, Part 7. 11 October 1956.

[31] From the CSIRO CASS archive of Bolton correspondence. John Bolton wrote Bowen on 29 October 1956: "Bruce Rule and I are quite certain that the equatorial is <u>the only solution …</u>. We are not even

As was the case in 1955, Pawsey had organised a meeting on 13 July 1956 to discuss a proposed list of "possible experiments with the GRT".[32] Pawsey and Richard Twiss[33] had prepared the list on 4 July 1956. (Other participants had been Mills, Jim Roberts, Frank Kerr and Lindsay McCready.) Clearly it was desirable to produce such lists during the planning phases of the GRT in order to examine the impact of astronomical desiderata on the form of the future instrument: "This list was compiled with the object of seeing where to place emphasis among the various design features." The report consisted of a list of general attributes of the proposed instrument, such as ease of steering over a large part of the sky, high gain, and high directivity (resolution), enabling the study of compact sources smaller than the beam of the GRT itself. This goal implied the use of interferometer observations for increased angular resolution[34]. A major goal was a survey capacity: "Surveys using the natural directivity of the dish to delineate details. Here a simple diagram is most important."

A list of possible observations followed: detailed imaging of HI in nearby galaxies using the 21 cm line, total HI content in galaxies as a function of Hubble type, detection of the intergalactic medium with redshifted HI, HI in clusters of galaxies, galactic HI absorption, imaging HI emission over key regions of the Milky Way, search for new radio spectral lines (OH,D) , continuum spectra and sizes of extragalactic radio sources, continuum study of HII regions in the Galaxy, galactic background radio emission, and planetary emission, including both thermal and non-thermal. A prescient suggestion was also made that would lead to one of the key GRT results of 1963 (the quasar 3C273 occultations carried by out Hazard, Mackey and Shimmins in 1962- Chapter 32 and NRAO ONLINE 47). In the sundry rubric section the following suggestion was made: "Lunar Occultations, yielding information about lunar atmosphere and details of location and distribution of sources."

A year later (22 July 1957), Pawsey held a similar meeting with the purpose of discussing an update of "Possible Experiments with Implications Regarding Site and Other Requirements".[35] The astronomical experiments were essentially unchanged but did now include an important new topic, **polarisation of line and continuum,** a topic favoured by Pawsey. For each type of observation discussed in 1956, the criterion "freedom from [radio frequency] interference" was categorised as high, moderate or low. More criteria for the location of the possible site of the GRT were listed with emphasis on freedom from

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considering alt- azimuth for dishes of order 500 feet now … After starting off as a one-man minority a year ago last May, I really feel I have made progress."

[32] Christiansen archive given to W.T. Sullivan March 1978.

[33] Richard Q. Twiss (1920-2005). With Hanbury-Brown, one of the inventors of the eponymous intensity stellar interferometer. On staff of RP from 1955 to 1959, when he joined the staff of Hanbury-Brown's group at the University of Sydney.

[34] The report stated that one of the desiderata was: "availability of flat ground at site, use of single or multiple units etc [additional telescopes for interferometry]."

[35] W.T. Sullivan archive.

interference, leading to a possible location farther from Sydney (up to 300 km) and a larger site (order 20 km) to accommodate interferometry.

ADDITIONAL NOTE 1- Plans for Bart Bok visit to Australia 1956[36]

Bok wrote Pawsey on 31 July 1956 from Harvard with plans for his upcoming visit. His wife, the astronomer Priscilla Bok, would not be coming with him to Australia during his one month visit starting in early September. Bok was to meet Merle Tuve in late September after Bok returned to the US. Bok was pleased that Pawsey had organised that Oliphant (to be Bok's boss at ANU) would preside at the symposium on 4 and 5 September; Bok assumed that a number of his future staff from Stromlo would attend the conference. Bok ended the letter with a nice piece of gossip: AUI had chosen the site in Green Bank, West Virginia, as the new NRAO site. In mid-July, the NSF had informally asked Bok "if I could not change my mind about going to Australia and come to West Virginia instead [as Director of NRAO]. My reply was: 'NUTS'". Bok had no intention of changing his mind. In this letter, Bok also mentioned that Tuve and the NSF Panel on Radio Astronomy wanted to invite Pawsey to visit the US "in the not too distant future." They had set aside $8000 for the visit in 1956 or 1957; this suggestion was to be fulfilled in 1957 (See Chapter 28). The committee of US experts expressed a unanimous opinion on behalf of this proposed visit. Only Bok "demurred" since he wanted Pawsey to remain in Australia.

A few months later (23 October 1956), Bok told Pawsey more of this news. Donald Menzel, as head of an AUI committee, approached Bok with an official offer to be the Director of NRAO.

> Apparently I was the unanimous first of the whole committee. This is really crazy, for everyone on the committee knew darn well that I was fully committed to Australia … I might as well take it as a token for an expression of a lot of good will. Anyway, Australia has been so wonderful to me in my first four weeks there that I cannot think of anything nicer than to be there for keeps ... The committee is apparently going to select an American to head [NRAO].

He had heard that Charles Townes, Leo Goldberg, Jesse Greenstein, Albert Whitford and John Hagen were being considered. "[T]here is no restriction with regard to nationality for any of the jobs next to the director." Bok was enthusiastic about his four-week visit: "I find that I have returned home with in every way a really good taste in my mouth. You and Lenore have certainly contributed greatly to having me feel at home in Australia." Many social events had been organised for Bok in Sydney by both Pawsey and Christiansen. At the end of the letter, Bok mentioned to Pawsey that a number of people were interested in Pawsey coming to the US in the next year for a long visit; this suggestion was to be fulfilled in 1957 (see Chapter 28).

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[36] NAA C3830 Z3/1/VII

ADDITIONAL NOTE 2 –Bart Bok's visit to Sydney 1957

In his opening address to the symposium in Sydney, White provided an "insiders" viewpoint of the history of radio astronomy in Australia in the first decade (1945-1956):

> [His new position as Director of Mt Stromlo] will provide Professor Bok with an admirable opportunity of advancing still further the science of astronomy in this country … You all know that he is not only an outstanding astronomer but that he has, with us, a wholehearted interest In the new science of radio astronomy. In fact, he has, I know, played a leading part in the development of this aspect of his science in the US. This is of particular interest to the Division of Radiophysics. I think we can claim with all modesty that this Laboratory has been, and I hope still is, in the forefront of the development of this science … We were all set, therefore, at the end of the war- although perhaps we did not quite realize it ourselves- both from the point of view of interest in the subject, as well as having the radio techniques readily available, to go right ahead. As a consequence we had a period of quite a few years in which we could make many of the initial discoveries in radio astronomy, which was then, of course, a comparatively virgin field. This was a tremendous advantage but I hope that the Radio Astronomy group in Radiophysics will not feel discouraged that this situation cannot continue. In fact they must feel, I hope, exceedingly pleased that radio astronomy is a thriving new science [in a number of other countries] … [It was on the occasion of a recent meeting of the Advisory Council of CSIRO] that we were able to describe to the Council the proposals put forward by Dr Bowen and Dr Pawsey for the building of the [GRT] in Australia … You will appreciate that it is not always easy to obtain the wholehearted agreement of a body of 25 persons having the diverse interests of the members of our Advisory Council. This is particularly difficult when one is called upon to put forward a proposal which, while appealing to the imagination, must be described as of very great scientific interest but with practically no appeal from the point of view of Australian development in industry or agriculture. I can assure you that the view was taken that, so **great had been the achievement of this Laboratory in this field, the future development of your activities and interests must at all costs be given the greatest of encouragement.** (our emphasis) [He then described the US foundations' support, Carnegie and Rockefeller.] ... Dr Bowen obviously deserves very great credit, for I am sure that we would all agree that it is to him that we owe a debt for stimulating interest in the US ... Fortunately for us Professor Bok is also interested in radio astronomy. In this Laboratory, under Dr Bowen and Dr Pawsey, you have also good facilities and will be able to continue to spend a reasonably large sum of money per annum on this activity. When the large telescope [GRT] is built, this, together with the other facilities which you have, will make you, I believe, one of the best equipped laboratories in the world … With these material resources, all that is

> required now is initiative and resource in research to keep the Australian effort in the forefront of this advancing science … We are fortunate that our large telescope will perhaps for some years be the only instrument of this kind in the Southern Hemisphere so that you will have unique opportunities to examine those parts of the sky which cannot be seen by the several telescopes being erected in the Northern Hemisphere. This may provide us with the opportunity of having many visiting radio astronomers.[37] I would certainly like to see a constant flow of astronomers to Australia to take advantage of this situation … In the present situation you will have to exercise greater skill in choosing the problems for investigations if you are keen, as I know you are, to make the sort of original discoveries that are much more easily made in the early days of a science than later on. I suggest that this is the period for critical examination of the Australian programme, to remove from it those lines of work which may not gain outstanding results but to include others that may be more profitable.[38]

After Bok returned to Cambridge, Massachusetts, he wrote Pawsey an effusive letter of thanks[39]:

> In looking back at my little over four weeks in Australia, I find that I have returned home with in every way a really good taste in my mouth. You and Lenore have certainly contributed greatly to having me feel at home in Australia … [T]he evening party [at the Pawsey home] was just a perfect way to get acquainted with lots of people and it helped to make me realize how easy it would be for Priscilla and me to establish good friendships in Australia. The two day symposium was a wonderful experience and I have told all who wished to listen that I could not think of a more powerful scientific meeting in the field of radio astronomy than the one that you and your group put on …

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[37] A suggested "Open Skies" policy.

[38] In this frank historical talk, White also mentioned the achievements of Pawsey: "Fortunately for us these [early] leads [of Jansky and Reber, the latter was in the audience] were not taken up in the US at the end of the war and this gave us an opportunity of making headway without violent competition from that country. I can remember quite distinctly that Dr. Pawsey started thinking about the measurement of radiation from the sun in this Laboratory during the war and, if I recall correctly, actually made some measurements following Southworth." White was also proud of the contributions that Bolton and Bracewell were making: "I very much hope that our contacts with the United States in this field will be maintained and will grow. The very handsome grants that have been made from that country place a responsibility on us and it is ... of interest to note that two officers of [RP] who achieved notable success in this field have now taken up positions in the US. Bolton has gone to Caltech, where ... [he] is developing an active programme. The same thing is happening at Stanford, where Ron Bracewell now has a University appointment. Although we regret losing these two men, nevertheless it is nice to think that a substantial part of the programme over there is in their hands."

[39] NAA C3830, Z3/1/VII. 23 October 1956. He and Priscilla were to arrive by ship in March 1957 from the US.

Fig. 1. Freeman Fox design of 300-foot compensated dish, with a central mast as the aerial feed. Structural members made of aluminium. The compensation would correct for dead loads and wind loading.

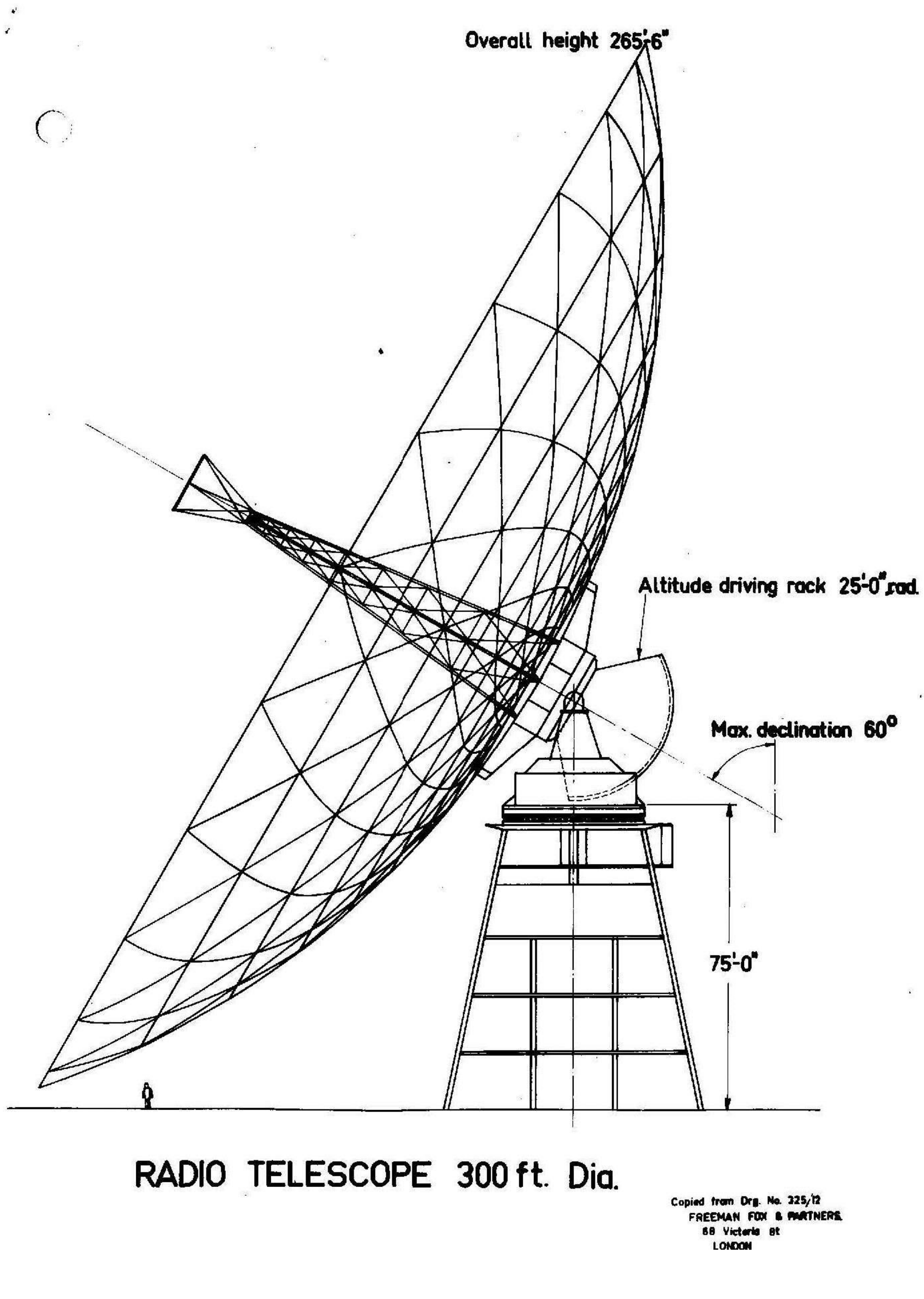

Fig 1956-2. Freeman Fox design of 300 foot dish, compensated. Similar to the design in Fig 2 but with a tripod aerial feed. Design drawing from 18 July 1956

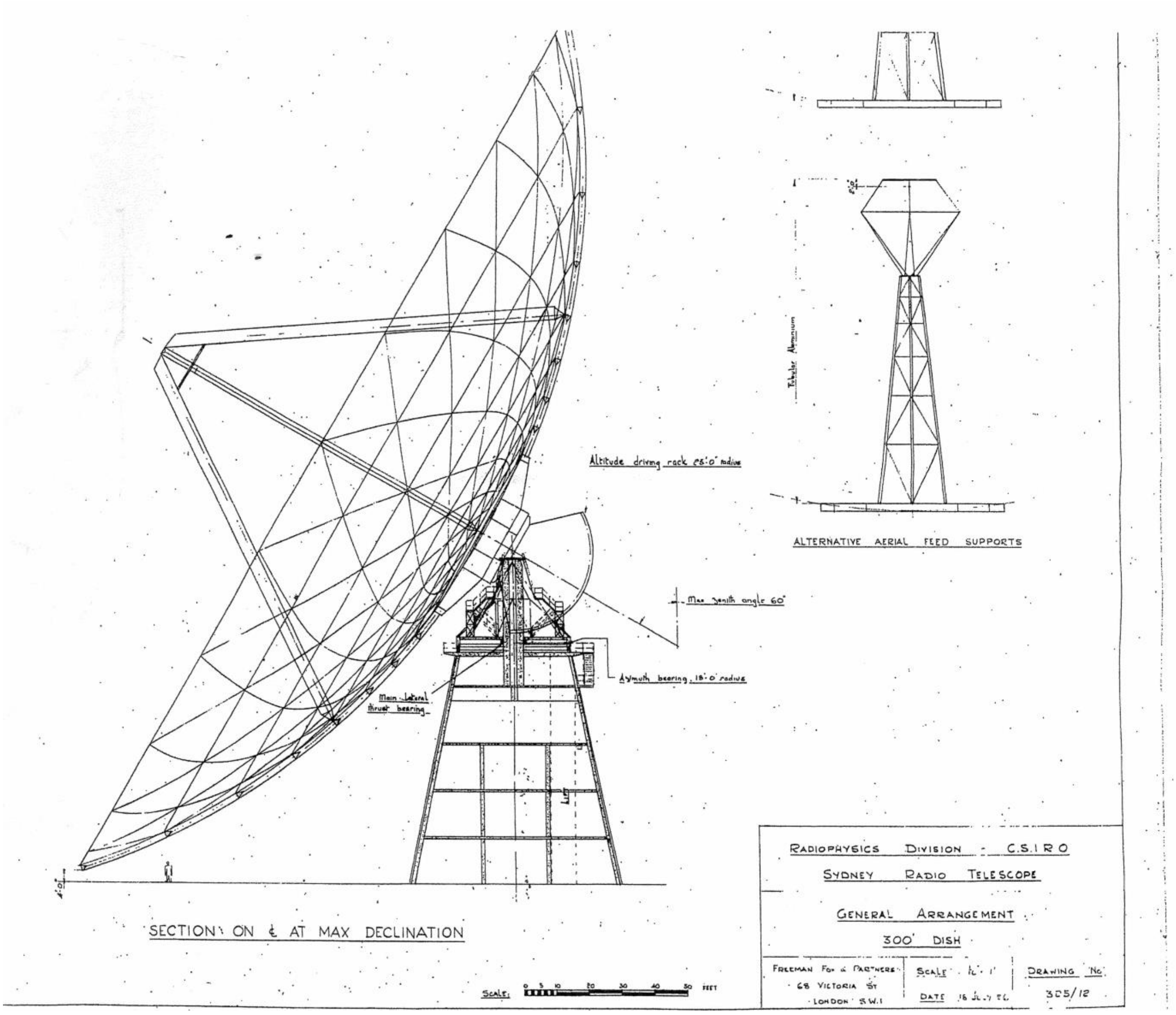

Fig.3. 225-foot dish – non-compensated. Steel structural members. Scheme A . Note the resemblance to the Barnes Wallis design shown in NRAO ONLINE 41 and Chapter 27 Fig 6. Drawing from Freeman Fox 3 September 1956

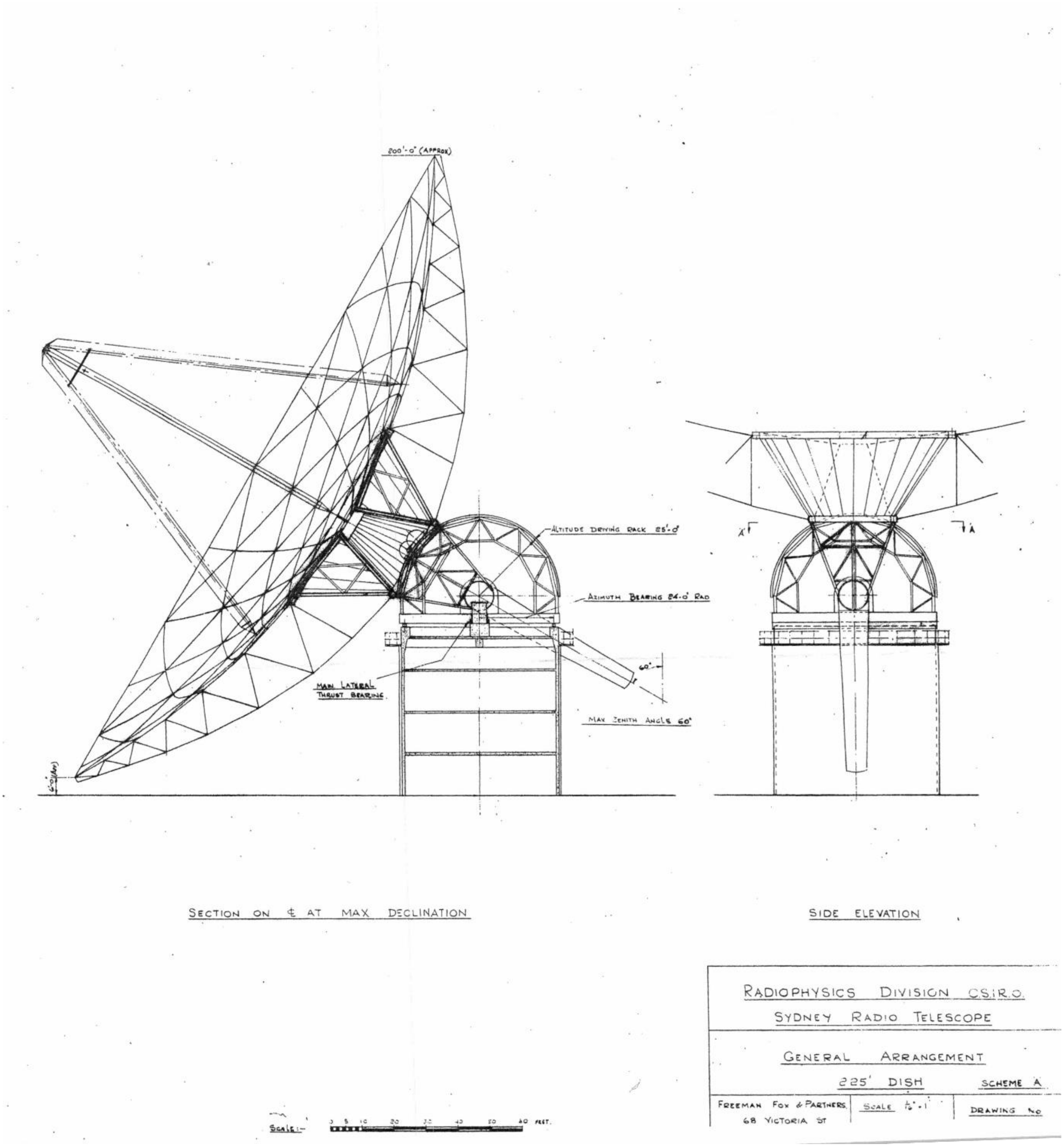

Fig.4 Scheme B (see text), close to the adopted design for the Parkes telescope. 225- foot diameter. Steel structural members. Drawing made by Freeman Fox 11 September 1956