LARGE RADIO TELESCOPES - 1950 TO 1989

by John W. Findlay

1. Introduction

This paper has been written to give some background to the discussions at the Green Bank Workshop on the design for the 100-meter Green Bank Telescope. It is intended to survey the various large (by which I mean effective diameter > 42 meters) instruments which can be described as filled aperture fully steerable telescopes. Thus it will refer only briefly to Arecibo and not at all to Kraus-type instruments such as Nancay. Since I plan to write about some of the NRAO design work which has not led to telescopes being built, I will note here that NRAO, with the co-operation of its chosen contractors, has been eminently successful in building and operating more than thirty telescopes of the 25-meter class (The interferometer, VLA and VLBA telescopes). The lessons learnt from this experience will be valuable in meeting the challenge which lies ahead.

2. The Jodrell Bank 250-foot

Let me start with the Lovell telescope. Lovell told me at the URSI meeting in Geneva in 1950 that he planned to build a very large steerable dish. Thus it is truly the oldest big telescope. The first design was made before the H-line was discovered and so the structure and surface had to be improved while the quest for funding went forward. As early as the 1950's Lovell foresaw the need to shelter from radio interference, and this led him to a focal-plane dish. He also planned to turn the whole dish over, so as to be able to reach the feed point easily from the ground. He used elevation bearings from a battleship gun turret (the Royal Sovereign) and this led him to his wheel-on-track design with the dish supported at the edges. I never learnt his reason for making the reflector surface fron welded steel sheets (but later the Algonquin dish was to get the same). Some of these choices were to be changed when (1971) the telescope became the Mark 1A.

In retrospect, it is clear that Lovell, with his designer Husband, made some very important choices in the original design and construction of the 250-foot. The history of the 250-foot and its later upgrade are in References ([1]) and ([2]). It is interesting to note that Husband was well-known as a bridge builder - he designed and built the bridge on the river Kwai for the film; he also had to design its subsequent successful demolition.

In 1956, before the 250-foot was working, I visited Jodrell with Berkner and Ewen. Berkner was already into the plans for NRAO and facing the questions which Merle Tuve was raising to several of Berkner's proposals. It was clear that Berkner, as he saw the 250-foot rising before him, was not about to be out-done by the British.

3. The CSIRO 210-foot Telescope.

This telescope was being planned when I left the UK in 1956. The driving force was Taffy Bowen; his chosen firm of engineers was Freeman and Fox (of Victoria Street in London) who had built the Sydney harbor bridge.

Bowen was able to persuade Barnes Wallis, (responsible for the R-100 airship, the Wellesley and Wellington bomber geodetic structure and the dam-busters skipping bombs used in WWII) as a consultant. ([3]). Just about everything in the design, construction and use of this telescope was done right. In addition to the Master Equatorial, Wallis made contributions to the design of the structure. CSIRO kept Harry Minnett in the Freeman Fox office as the design progressed. The whole project was later studied carefully by NASA before the DSN 210-foot dishes were built. The center portion of the dish was later re-surfaced for use at mm wavelengths.

4. The USA in early 1957.

In 1967 there was the 60-foot and a smaller dish at Harvard. The NRL 50-foot was good at short cm wavelengths. (Ned Ashton, later to be the 140-foot designer, and also mainly a bridge-builder built this). Blaw Knox had contracted to build three 85-foot antennas, two for JPL and one for Fred Haddock. An NRL group under Trexler was doing moon radar with a "hole in the ground" 220 x 260 feet. This was to lead to the proposal for the Sugar Grove 600-foot. And NRAO was in existence -insofar as it had an NSF contract, plans and a chosen site near Green Bank. Despite RA groups at Ohio State, Cornell, Stanford, NBS and DTM there were still no dishes bigger than 60-feet. CalTech was leading in interferometry with John Bolton.

5. The birth of NRAO.

NRAO was the child of two strong parents, Berkner and Merle Tuve. I knew them both; I had spent six months with Tuve at DTM in 1951 and had known Berkner well since the end of WWII. Their operations are really no part of this story - except that they differed fundamentally on how research should be funded and managed. See ([3]) for an excellent account of the years up to the first five-year contract signed in September 1956. A secondary theme of the present paper is to examine why the USA failed to build a major general purpose filled-aperture antenna. One of the contributing factors can be seen in the way AUI and NRAO began their tasks, but there were many others.

6. The first large NRAO Telescope.

The first funding for NRAO ($85k) arrived in early 1955. The main telescope plan was for the 140-foot. It soon became clear that this might take some time to build, and so it was possible to get Berkner (and Jerry Wiesner - who was close to Berkner) to agree that a Blaw-Know 85-foot should be bought. Meanwhile a steering committee was set up with John Hagen as chairman and Dick Emberson to lead the 140-foot project. It is easy to be wise after 30 years have passed - but if I am critical now it must be remembered that I too accepted what the original feasibility study had produced. The steering committee either made or accepted from the original study the following mistakes:

(a) The choice of 140-feet was neither here nor there. It could easily have been 210-feet (CSIRO) or 250-feet (Jodrell Bank)
(b) The surface and pointing specifications were both hard, but

not impossible, to meet. (Work up to 10 GHz and point to 10 arc seconds).
(c) The choice of an equatorial mount was idiotic.
(d) By the end of the feasibility study, there was no money left and the basic Ashton design had been chosen, but without real knowledge of what was involved.
The real mistakes in the 140-foot were made in the early stages. For example, no one with hindsight will deny (c) above. But the specifications in (b) were rigid, and it was the pointing requirement which caused some of the committee to move to the polar mount. The argument went as follows. Using Alt-Az, a co-ordinate converter was necessary. Both the CSIRO and Dwingeloo (built by Ben Hooghoudt) had used an analog converter. In neither case was it clear that the conversion could keep errors down to a few arc seconds. Why not a computer ? If my memory serves me I heard in the committee "We cannot trust the performance of a major telescope to a computer". Sagely, heads were nodded : optical telescopes were not Alt-Az. And from the choice of a polar mount flowed more problems. The main hydrostatic bearing was chosen because Palomar had a hydrostatic bearing. They were well-understood, and friction-free. But Lovell had already showed that the feared differences between static and rolling friction in a wheel-on-track design were no problem.

To complete the lesson: it turned out that the hydroststic bearing could not be fabricated and machined as designed. A solid casting was needed, restricted in size to existing milling machines and to the need for it to make its way to the site through the railroad tunnels. All finally went well, the telescope got built.

7.The Efflesberg 100-meter, the DSN dishes and the Algonquin Telescope.

I shall leave all these aside in this paper for various reasons. The history and performance of the Efflesberg instrument are very well-known to many at this Workshop. Few problems were met (one in the drive servo) as it came into use. One of its main interests to me is that it was designed (by Krupp) to behave in a homologous manner as the dish elevation changes. This was carried out without much difficulty by a "trial and sucess" method. I have read that the radio performance at short wavelength shows that the computed and measured gain changes with elevation are in good agreement. My recollection is that the welded steel space frames for this telescope, the CSIRO 210-foot and Algonquin were all the fabricated by MAN.

The three telescopes of the Deep Space Network have been extensively described in JPL publications, and their performance is well-known. Their diameter is (has already been ?) increased to 71 meters. For a long time the system noise at some of the frequencies has been the lowest in the world (except for the Bell Labs horn !)
Robert Hall, who was the Blaw Knox designer of the original 85-foot antennas, moved to the Rohr Corporation in Chula Vista and was responsible (with JPL) for the design and construction of all three antennas.

Algonquin was built by the same contractors as the CSIRO 210-foot and there are many similarities between them. As I leave the review of many existing instruments it should be noted that there are papers on all the instruments covered in this paragraph (and several others) in the book edited by Mar and Liebowitz ([4])

The same book covers both the Haystack antenna (which at 36.6 meters falls below my definition of "large") and also the properties of various radomes, including the one through which Haystack observes.

8. A very large filled-aperture telescope.

Let me now turn to a number of design efforts which have been directed to getting a large fully-steerable antenna built in the United States. I shall not bring Arecibo into this story since it does not give full sky cover, and in addition, it did get built and it works.

(a) The Sugar Grove 600-foot telescope.

By 1958 the Sugar Grove telescope had not only got its design work well under way, but already had its first funding; work had started on the site that same year. When Ed. McClain wrote his article ([5]) erection towers were already built. The telescope was to have been a fully-steerable filled-aperture paraboloid; the site at Sugar Grove was combined with Green Bank to be the focal points within the Radio Quiet Zone. (It might well be argued that the formation of the quiet zone was a most valuable outcome from the $45 million which was, I believe, actually spent on the project).

The eventual fate of this telescope may well have been important in turning the US away from large filled-aperture telescopes. The reasons for the abandonment of the project were clearly two-fold. The project managers had started building long before they had a fully tested design. A quote from the Admiral in Bu.Docks in 1964 - "This facility is so important that the Navy decided that instead of designing and testing the various components of design before construction we would design and construct it simultaneously to save roughly three or four years". The second reason was that satellite surveillance was working well by 1964 and thus one of the main tasks for which the instrument was intended could now be done from space.

When I look back to this time, I ask: Why was there no reaction from anyone (AUI, MIT, others) to this cancellation. About $90 million had been committed and in the end about $45 million was spent. Surely the project might have been saved to be shared by the Navy and radioastronomy. As the surveillance task was taken over by satellites the telescope could have been devoted to radio and radar astronomy.

I did make one journey to Sugar Grove after the cancellation to inspect the several acres of beautiful surface panels, built by North American and delivered to the site to be scrapped. And I looked into the enormous underground room (good for four tennis courts) which was screened by walls of a meter thickness of high-conductivity coke.

(b) The CAMROC design and a 300-foot/150-foot for NRL.

Two studies were in process in 1965; both are referred to in (5). The first was by the newly formed CAMROC group, led by Herbert Weiss, for a radome-enclosed dish 440-feet in diameter. In 1969 Weiss was suggesting a price for the antenna and radome of about $20 million.

The design was carried through with the care that one would expect from

MIT. Haystack was in existence and was proving the expertise of the group. Wiesner and Purcell had approved the project. Why did it not get funded? Partly because of the desire of CAMROC to put it in New England - but also I suggest, by the sleeping sickness which by now had spread through the "big-dish" community of radioastronomers. After all seemed to be failing, Fred Whipple tried to "end-run" NSF by getting the Smithsonian to attempt to fund the project. I got into this act by managing a national meeting of radioastronomers and then appearing with Fred and the great S. Dillon Ripley before the Committee of Congress which looks after the Smithsonian. I did also try to persuade Fred to put the telescope either at Green Bank or even on the (not yet decided) VLA site. But this project died.

After the Green Bank 300-foot had started operating, I had started the first efforts to turn the design into a fully-steerable instrument. I could not proceed with this plan, so I turned over the designs, and the engineer (E.R. Faelten) who had worked with me, to Austin Yeomans at NRL who was hoping to build a 300-foot on the Sugar Grove site. The outcome of this work is described by Yeomans in an article in (5) with the title "Design of a 300-foot Research Antenna". This was another antenna which never got built, but Yeomans and J.H. Trexler at NRL finally did build a 150-foot fully steerable instrument at Sugar Grove the design of which Faelten and NRL developed by scaling down the earlier work.

(c) The LFSP study.

By late 1962 the National Academy of Sciences had started the habit of making studies which might be helpful to astronomy and had set up a "Panel on Astronomical Facilities" - led by Al Whitford. Its report [6] recommended (among a lot of other things, one of which was the VLA), that design studies for the largest feasible steerable paraboloid (LFSP) should be started at an early date. It was suggested that $1 million would do such a study. So NRAO took on the task. A group of us started in early 1965 and worked on six different concepts, any one of which might lead to a 200-meter antenna. Some were not completely fully steerable but we wanted the field as open as possible. We looked at Arecibo, but decided that the fact that it was in existence and working allowed it to be a "feasible" solution. The design we liked best was a floating sphere, 217 meters in diameter, carrying inside it the 200 meter dish. This started from the excellent properties of a complete sphere - however when the top of the egg is cut off things get a bit difficult. One good thing which came out of the study was that it encouraged S. von Hoerner to carry through his derivation of homology. In his paper "Homologous Deformations of Tiltable Telescopes" in (5) von Hoerner describes some of the work done in the LFSP study.

8. Other designs and other telescopes.

The NRAO carried through other designs:
(a) A 300-foot fully steerable instrument following S. von H's homology - never built. [7]
(b) A 65-meter telescope for mm-waves - never built. [8]

The design effort involved in planning the 65-meter was very large.

The design effort involved in planning the 65-meter was very large. It was used as a basis for the subsequent proposal for the smaller 25-meter millimeter telescope - also never built. The care taken on the pointing problems, with the proposal for a stabilized platform at or near the intersection of the azimuth and elevation axes may still be of some interest. So also the various methods by which the surface shape could be measured may be relevant to the possible need to consider active control of the surface of a 100-meter telescope at Green Bank.

9. Conclusion.

In this short history I have tried to describe the efforts which have been made over the past years to build a major fully-steerable filled-aperture radio telescope in N. America. Now there is a real and urgent opportunity that the 100-meter will be built at Green Bank. I hope this opportunity will be successfully grasped. In fact, I should like to look ahead to a plan which could lead to the provision of North and South hemispheric cover for ground based radio and radar astronomy, provide communications both to spacecraft and to solar-system planets and also for SETI studies in our galaxy.

Over the next twenty years two clusters of telescopes, one in the Northern and one in the Southern hemispheres should be developed The individual instruments should be 100 meters in diameter. In the South they would cluster around the Parkes dish or the DSN instrument. In the North Green Bank should be chosen. The first plan (perhaps taking 10 to 20 years), would add four dishes to each cluster. As time goes by, more dishes could be added. The clusters would be operable in the co-phased mode or as elements of phased or VLB interferometer systems.

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