Title: ***Radio Telescope Reflectors ~ Historical Development of Design and Construction***
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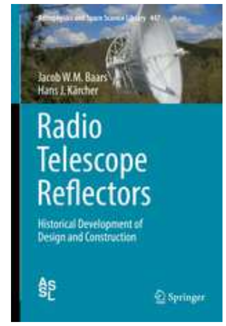

The list price of this book is quite high, even by today’s bloated standards. However, I purchased my copy for 40 USD direct from the publisher’s website, so that should be a buyer’s starting point. But, do not stop there if a heavy discount is not offered. How is such a high list price justified or, more important, is the book worth it? Of course, the answer lies in how badly a reader wishes to read about not only the historical development of radio telescope reflectors but also an introduction to the many fine technical details. One of the authors, Jacob Baars, also has written what is presumably a much more technical (but equally expensive) book titled ***The Paraboloidal Reflector Antenna in Radio Astronomy and Communication: Theory and Practice*** [Baars].

The main focus in the current book is on how the many structural engineering problems associated with massive reflector antennas were identified and solved. The size of the reflectors grew and their operating frequency increased with each new generation. The higher mass and need for higher surface accuracy to enable observations at the higher frequencies (shorter wavelengths) were not easily solvable. Gravitational deformation and pointing and tracking errors became serious issues. Computer hardware and finite element analysis (FEA) software development became essential to solving the structural challenges and problems. For structures, FEA subdivides a large structure such as a reflector, into smaller, simpler parts that are called finite elements. The relatively simple equations that describe these elements are assembled into a larger system of equations that describes the entire structure, and, as a practical matter, these are solvable only by a computer.

In nine chapters, and several pages of acronyms, abbreviations and glossary, the authors describe 27 reflector telescopes varying in diameter from 7.5 m to 500 m. It is clear from this book that reflector designers have their own jargon and the authors forgot to define some terms on first use. Some can be found in the back pages of the book.

Chapter 1, *Introduction*, features a fictitious conversation between an astronomer and an engineer, identified only by their initials that happen to be the same as the two authors. It is during this conversation that the authors describe the layout and numerous reasons for the book. It is revealed that the evolution of radio telescope reflectors owes much to trial and error.

Chapter 2, *Evolution of the Telescope*, compares optical telescopes to radio telescopes including their mounts and geometrical configurations and briefly introduces reflector and pointing precision. Here we learn that a radio telescope reflector consists of two main parts – a backup structure (BUS), on which the reflector surface is mounted, and the surface elements themselves. A certain amount of precision is required in the surface, and this is briefly discussed here, but precision is discussed in much greater detail in later chapters.

Chapter 3, *Birth of Radio Astronomy*, gives a brief description of early radio telescopes including Karl Jansky's "Bruce" antenna (also known as a "merry-go-round" antenna) and Grote Reber's home-built parabolic transit reflector as well as the reflector type antennas salvaged from German radars at the end of World War II. Efforts were then made to purpose-design and -build the first generation of reflector-type radio telescopes at the US Naval Research Laboratory (NRL), in the Netherlands and at Stockert in Germany in the early and mid-1950s.

Over time, other designs evolved as the reflectors became larger and larger to reduce the beamwidth so as to meet increased resolution requirements. Many different structural designs were used and the authors discuss the advantages and disadvantages of each. These designs did not suddenly appear out of the air and it is quite obvious that much engineering work went into them. One interesting design was the NRAO 300 ft transit telescope, a "cheap and quick deal" to allow observations while the long-delayed 140 ft radio telescope was being built at Green Bank in Virginia. The 300 ft scope collapsed from metal fatigue after 26 years of service so taxpayers presumably got their money's worth before it fell apart.

Chapter 4, *Structural Design of Reflector Antennas: Homology*, is over 40 pages. It discusses an approach using the *principle of homologous deformation*. The idea is to design a structure that, when it deforms due to gravity as the reflector tilts while tracking a celestial object, deformation is the same (or nearly the same) everywhere. The goal is to not reduce reflector performance more than some specified limit. Three limits are discussed: Gravitational, which is unavoidable; Thermal, based on the thermal expansion and contraction with temperature, not only ambient temperature but transient solar heating as clouds move in and out; and Stress – at the stress limit, the antenna collapses under its own weight.

Sebastian Von Hoerner published a couple papers ({VonHoerner67a} and {VonHoerner67b}) while at NRAO Green Bank that describe homology concepts as applied to radio telescopes. In terms of surface deformation, the authors use as reference a shortest operational wavelength that is 16 times the rms (root mean square) reflector deformation or, stated another way, an rms deformation that is 1/16th the shortest wavelength. The thermal limit is based on the same condition. The authors give a reflector diameter of 600 m as the stress limit with steel construction, but they do not discuss how this was derived. This chapter shows gravitational deformation patterns for several large radio telescope reflectors with considerable discussion of the 100 m Effelsberg reflector in Germany.

Chapter 5, *Emergence of Millimeter-Wavelength Telescopes* goes into detail about the need for more precision all around as observing wavelengths became shorter. In these cases, the deviation limits of the reflector surface from its specified geometric form become increasingly difficult to achieve. As noted in chapter 4, the authors discuss these deviations as no more than 5 – 6% (a factor of 1/16th) of the shortest operational wavelength. Thus, if the shortest wavelength is 1 mm (300 GHz), the rms surface deviation should be smaller than 60 µm. The authors discuss thermal effects and their control and even tidal effects if the reflector is near the ocean. Surface deformation certainly is important but there also is the question of pointing precision and stability. The authors say these should be smaller than 1/10th of the half-power beamwidth (HPBW). For a 25 m telescope operating at 1 mm wavelength, the HPBW is around 10 arcsec; therefore, the pointing precision should be better than 1 arcsec (0.00027778°).

Chapter 6, *Submillimeter-Wavelength Telescopes*. Submillimeter wavelength radio telescopes operate from about 300 GHz to 1 THz. There are a few editing errors in this chapter, such as the authors talking about 1 GHz when they meant 1 THz. Several submillimeter-wavelength telescopes around the world are mentioned, but the CARMA (*Combined Array for Research in Millimeter-wave Astronomy*) array in California operated by the Owens Valley Radio Observatory (OVRO) is only very briefly. The 2014 SARA Western Conference was held at OVRO and participants toured the CARMA facility (see picture below).

A few of the radio telescopes used in CARMA, which was located on Cedar Flat in the Inyo Mountains east of the Owens Valley Radio Observatory in California. The reflectors have a mirror-like finish. The facility was decommissioned about a year after the March 2014 SARA Western Conference when this picture was taken. Image © 2014 W. Reeve

The last part of chapter 6 includes a detailed structural comparison of two radio telescope designs at the ALMA (*Atacama Large Millimeter/submillimeter Array*) facility in Chile. Although the specifications and end-product of the two types is the same, their designs are quite different, reflecting the preferences of the funding agencies. Compared are weights, deformation behavior, astigmatism, bearing and drive systems and dynamic behavior.

Chapter 7, *Alternative Reflector Geometries* includes the Green Bank Telescope (GBT), FAST (Five-hundred-meter Aperture Spherical radio Telescope), Arecibo Observatory, John Kraus's "Big Ear" and a similar radio telescope at Nancay in France. Other reflectors discussed in this chapter include large horn antennas ("Little Big Horn" at Green Bank), the Allen Telescope Array, and the MeerKAT and Square Kilometre Array (SKA). The discussion of these telescopes is not as detailed as the other, more conventional reflector radio telescopes discussed in the previous chapters.

Chapter 8, *Electromagnetic Aspects of the Reflector Antenna*. Here, the authors briefly describe the differences between reflector antennas used for radio astronomy and those used for communications, particularly satellite and spacecraft communications. A table is given that summarizes the major parameters of an antenna including beamwidth, aperture efficiency (antenna efficiency), gain, antenna solid angle, main beam solid angle, beam efficiency, scatter efficiency, blocking efficiency, and lateral and axial defocus. Each of these parameters is defined by an equation and then the text discusses how they can affect radio telescope performance. Another table is given that summarizes the tolerance requirements for several of the parameters in terms of 10% gain reduction.

Chapter 9, *Concluding Review and a Dialogue on Management Aspects*. The astronomer and engineer introduced in chapter 1 continue their discussion, but this chapter also includes a tabular summary of all 27 reflector radio telescope antennas discussed in the book. This summary appears to be misplaced; it should have been in the introduction. The authors also briefly discuss other aspects of large reflector antennas including project management, industrial and systems engineering, contracting and manufacturing. Engineers who have worked with theoreticians know how these things can go.

This book makes clear that there is no single best design or material type. As with everything else technical, there are tradeoffs between costs, materials and methods.

Overall, I found the book well-written and easy to read. On the other hand, I was disappointed that it does not mention deformation measurement procedures or methods. Also, the book includes many colored deformation contour plots but these have no scale. Many give a sigma (or rms) value but no contour interval so it is difficult to do any real interpretation of the plots.

I suspect that at least some readers of this review are like me and simply enjoy learning about different antenna types and how they are built. I have no plans to build any large antenna structures but I might be able to apply to much smaller structures the things I learned about the larger structures. Maybe some readers are contemplating building or refurbishing a large radio telescope and this book may be useful to them. Radio astronomy has moved to huge arrays of small antennas or to making observations from spacecraft but very large reflectors still have their place and purpose.

Citations:

[Baars] Baar, J., The Paraboloidal Reflector Antenna in Radio Astronomy and Communication: Theory and Practice, Springer, 2017

{VonHoerner67a} Von Hoerner, S., The Design of Large Steerable Antennas, available at https://library.nrao.edu/public/memos/65/65U/65U_002.pdf

{VonHoerner67b} Von Hoerner, S., Homologous Deformations of Tiltable Telescopes, available at https://library.nrao.edu/public/memos/65/65U/65U_005.pdf

Reviewer - Whitham Reeve is a contributing editor for the SARA journal, Radio Astronomy. He obtained B.S. and M.S. degrees in Electrical Engineering at University of Alaska Fairbanks, USA. He worked as a professional engineer and engineering firm owner/operator in the airline and telecommunications industries for more than 40 years and now manufactures electronic equipment used in radio astronomy. He has lived in Anchorage, Alaska his entire life. Email contact: whitreeve@gmail.com