Title: ***Radio Astronomy: An Introduction***
Author: S. Joardar and J. Claycomb
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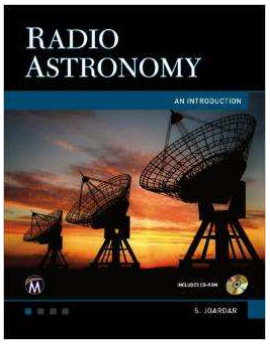


This review is the first of three covering contemporary radio astronomy books. Many professional introductory books about radio astronomy have been written since World War II; for example, see [Pawsey], [Hulst], [Jennison], [Kraus] and [Burke], but ***Radio Astronomy: An Introduction*** is one of a handful of books on the subject published in 2015 and 2016. Two other current books I plan to review are ***Essential Radio Astronomy*** [Condon] and ***Fundamentals of Radio Astronomy: Observational Methods*** [Marr], both with 2016 copyright dates. Interestingly, the 2016 copyright date printed in the front papers of my edition of ***Radio Astronomy: An Introduction*** is wrong; it actually was published in 2015 and the *Preface* was written in 2014. There apparently is a 2012 edition but I am not familiar with it.

Radio Astronomy: An Introduction is a moderately priced book compared to many modern radio astronomy books. The book reviewed here appeared to be a good one on a quick flip-through the day it arrived. I saw many illustrations and equations, and it left a good first impression. I later read it cover-to-cover over a period of a month. This book is primarily about radio astronomy that involves large parabolic dish reflector antennas and arrays and is more of a reference book or handbook than a textbook. It turns out my good first impression was diminished somewhat, as I describe below.

The target audience as stated in the *Preface* includes professional radio astronomers, students, engineers and academics. My review is from the standpoint of a long-time radio engineer who also is a radio astronomy student. The book's presentation is based on calculus at about the level of a 2nd year college calculus course, so it is suitable for advanced undergraduate and graduate students and anyone with an engineering or physics degree. However, serious readers will need at least one undergraduate course on antenna theory to follow the concepts in the chapters that cover the various types of radio telescope antennas, which primarily are parabolic dish reflector antennas and interferometer arrays made from them.

Radio Astronomy: An Introduction has ten chapters covering fundamentals, radio wave polarization and propagation, radio telescope design including arrays, interferometers and receiving systems, downstream techniques such as mapping and image processing, and a "special" chapter on the Giant Metrewave Radio Telescope (GMRT) near Pune in India, reflecting that one of the authors, Joardar, is with the Tata Institute of Fundamental Research in India and involved with the GMRT. Five appendices include coordinate systems, antenna terminology, radiation potentials, radio spectral lines and a list of radio observatories and their characteristics. The bibliography at the back of the book has 127 entries. I found the 10 page index, also in the back, to be missing many entries.

Each chapter and each appendix incudes review questions at the end, appearing to support the authors' claim that the book is suitable as a text in a radio astronomy course. However, there are no worked problems or

examples within the text, but several review problems in each chapter do have "hints". I inquired about a *solutions manual* from the publisher and was told none is available. This imposes obvious limits on the use of this book in most university classrooms; it is even more limiting for readers who are not formal students. What good is a reader's attempted solution to a review problem that may be wholly incorrect? Another potential limitation in an academic setting is that almost all important equations are given as they would be in a handbook rather than derived as they should be in a textbook.

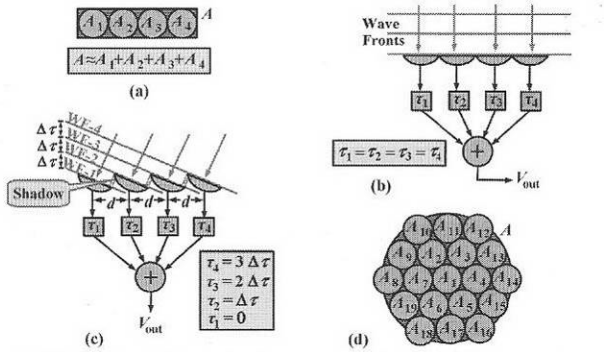
The first chapter, *Foundations of Radio Astronomy*, sets the tone for the rest of ***Radio Astronomy: An Introduction***. It very briefly describes celestial emission mechanisms and the principles of receivers, antenna temperature, polarization and signal processing. All of these subjects are described in more detail in later chapters, but their treatment in chapter 1 is quite uneven. Many new terms unique to radio astronomy are used without any definition. This chapter only very briefly describes why we need to study celestial radio emissions in the first place and what we hope to learn from them and how. Missing is discussion of the current effort being put into low frequency radio astronomy using large arrays of crossed-dipole antennas. These arrays are used for the study of highly red-shifted celestial hydrogen line emissions starting with the so-called Dark Ages to the end of Reionization in the early universe. The antenna array techniques discussed later in ***Radio Astronomy: An Introduction*** are applicable to those low frequency efforts but the book makes no connection to them.

Chapter 2, *Fundamentals of Radio Astronomy*, wastes no time describing in general mathematical terms the relationship between the power radiated from a location in the sky and the power received at a radio telescope. Sky brightness, brightness spectrum and total radio brightness are very briefly described. The absence of a few simple examples significantly reduces the utility of this chapter to readers who are not already familiar with the fundamentals, thus they are going into later chapters with a handicap. On the other hand, the authors are careful to include units of measure when discussing equations, helping immeasurably to reduce errors when the equations are actually used. However, I noted that the units are not always formatted correctly (for example, no space between a number and its unit, which oftentimes makes the values hard to read by a speed reader). This book obviously was written by physicists because the Greek letter *ν* is used for frequency and not the English letter *f* used by engineers (my main complaint: It is very difficult to distinguish the Greek letter *ν* from the English letter *v* that often is used to denote velocity, and both often appear in engineering and physics equations). Chapter 2 would be much better if Appendix B, *Antenna Terminology for Radio Telescopes* had been included in the antenna sections.

From my perspective, a few things are missing from chapter 2. One is a table of relatively powerful celestial radio sources, their location in the sky, types of emission and spectral content and radio flux levels. These may have been left out because they already have been discovered and studied and are of no interest to the authors, but students of radio astronomy have to start somewhere and can learn a lot from studying this type of information. If nothing else, they learn that the emissions received on Earth are very weak from even powerful celestial radio sources. Also missing are maps of the radio sky at various frequencies, which are helpful to visualize the extent of these radio sources.

Readers finding the explanations in chapter 2 too brief will be disappointed by the rest of the book because all topics are treated in much the same way – a brief one or two sentence description followed by an equation or two (or five) with no further explanation. This chapter has numerous illustrations, as do the other chapters, and these are important to the text; however, many have such small annotations and are often so overcrowded they

are very difficult to read (see an example right, figure 4.29 shown actual size). Perhaps a motivated reader would take the trouble to view the full-size illustrations on the supplementary CD while studying the book, but the cost of this is low reading and learning efficiency and, to me, a major annoyance.



Polarization Analysis is covered in chapter 3, but the introductory portions are too brief for anyone not already familiar with radio wave polarization. The authors briefly discuss the polarization ellipse, Poincaré sphere and Stokes parameters. The discussion of unpolarized (randomly polarized) and partially polarized radio waves, which represent emissions from many types of celestial radio sources, are described in terms of the Stokes parameters.

I think that much of the value in ***Radio Astronomy: An Introduction*** is in chapter 4, *Designing Single Dishes and Phased Arrays*, chapter 5, *Interferometry and Radio Arrays*, and Chapter 7, *Interferometer Aperture Synthesis and Radio Mapping*. Each of these chapters builds on the chapter before it. Chapter 7 also uses chapter 6, *Receiving Systems*. The antenna and interferometer chapters are densely packed with equations. Readers specifically interested in radio astronomy applications of dish antenna arrays will find useful information and mathematical treatments in these chapters. Unfortunately, there are limited and uneven descriptions of various dish feed systems using horns, log periodic dipole arrays and other wideband antennas. The authors only provide a nod toward the many low frequency arrays such as the Low Frequency Array (LOFAR) and Long Wavelength Array (LWA) that use crossed-dipole antenna arrays.

Chapter 6, *Receiving Systems*, is only about 25 pages long, too brief for an introduction to receivers, but it is useful nonetheless. The authors mathematically describe several receiver types and their sensitivities in terms of the radiometer equation:

$$\Delta T_{\min} = K_s \cdot \frac{T_{Sys}}{\sqrt{\tau \cdot \Delta \nu}}$$

This is only one of a few radio astronomy books in which I remember seeing a list of *sensitivity factors* K_S that are used in the radiometer equation for various receiver types (Kraus calls them *sensitivity constants* [Kraus]). Covered in chapter 6 are: 1) Total power receiver; 2) Dicke receiver using square wave modulation and broadband video amplifier followed by square wave multiplication; 3) Dicke receiver using square wave modulation and narrowband video amplifier followed by sine wave multiplication; 4) Dicke receiver using sine wave modulation and narrowband video amplifier followed by sine wave multiplication; 5) Graham receiver; 6) Correlation receiver with small antenna noise compared to receiver noise; 6) Additive interferometer with identical antennas; 7) Multiplicative interferometer with identical antennas; and 8) Phase-switched interferometer with identical antennas, square wave switching and square wave multiplication. Most of these are designed to compensate for the inherent gain instabilities in radio electronics that can compromise calibrated received power measurements. Unfortunately, the authors provide neither rigorous derivations nor their references for the various sensitivity factors, and there may be discrepancies in them. Even Dicke's own analysis was later found to have an error; see {Wait}. Chapter 6 also includes very brief descriptions of receiver

calibration and pulsar receivers with the mathematics involved in coherent and incoherent dedispersion of received pulsar emissions.

Chapter 9, *Propagation Effects in Radio Astronomy*, seems in the wrong place to me. It follows chapter 8, *Interferometer Data Calibration and Image Processing* but would be better placed earlier in the book. The authors discuss Faraday rotation and ionospheric effects on celestial radio observations, including scattering and scintillation. However, like most in this book, the discussions are theoretical and no practical applications or examples are given. Radio frequency interference is not even mentioned, but I suppose one might argue that RFI is not a "propagation effect" except in the high frequency band.

The GMRT is used in chapter 10 as an example radio telescope array. It is a Y-shaped array consisting of 30 individual dish antennas that went into service in 1995. This chapter has many block diagrams that illustrate the various subsystems. I feel the authors missed a good opportunity to show how the individual chapters in this book were applied or could be applied to the design of the GMRT. Unfortunately, however, there are no specific details that indicate why particular design decisions were made, thus leaving the reader to wonder about them rather than being helped by them. Not obvious from this chapter is that the future for constructing new large radio telescopes arrays is quite limited. Fewer and fewer organizations are actually building anything. Radio astronomy has moved to nationalized terrestrial installations and spacecraft that produce huge amounts of open-access data. Users post-process that data using software for their specific project and most have very little idea about the hardware involved or how the data originally was obtained.

Appendices usually are considered supplemental to a book, adding information that is not essential for the book's main purpose but still related to it. However, in ***Radio Astronomy: An Introduction*** two of the appendices include basic and important introductory material that should be in the main body of the book: Appendix A, *Coordinate Systems Used In Radio Astronomy*, and already mentioned Appendix B, *Antenna Terminology for Radio Telescopes*. Appendix C, *Radiation Potential Formulation*, and Appendix D, *Radio Spectral Lines*, are not essential to the book's main purpose but apply to advanced study. Appendix D will be of interest to readers wishing to review the mathematics behind neutral hydrogen (H1) emissions at 1420 MHz and their Doppler line broadening.

Given the current interest in solar radio astronomy and space weather, this book completely misses the boat on those subjects. There are many problems yet to be solved in these fields, but very little is devoted to them in this book. Solar radio emissions as well as Jupiter radio emissions are much stronger than galactic and extra-galactic emissions, and perhaps the authors do not consider these sub-fields important because of that. Another deficiency is very little attention is given anywhere to radio frequency interference. RFI is a major problem worldwide and the reason that professional radio telescopes are sited in remote areas far from civilization, thus greatly increasing their construction and operation costs. The problems of RFI even at nationalized radio telescopes located on special "quiet sites" cannot be overstated, so the authors' lack of attention to it is somewhat surprising.

While reading the book I noticed a few errors in some of the illustrations, some obvious and some not. I also noticed some relatively minor editing oversights such as a reference in a chapter to the wrong equation numbers in another chapter.

The equations describing particular concepts, such as dish antenna design, are presented more like a handbook or equation atlas than a textbook. The lack of worked examples significantly hinders the usefulness of this book as an introduction to radio astronomy. Learning from it cannot be done without other introductory reference material, so it is not a go-to book. To get the most from this book, readers will need access to online information about the many subjects covered too briefly. Alternately, readers can forego this book altogether and spend their hard-earned money on better introductory books.

I originally ordered the Kindle version of this book but found the equations very difficult or impossible to read. Part of the problem is size but resolution is so poor that zooming just makes them blurrier. The same is true of the illustrations – they simply are not readable in the Kindle version. The printed book includes a supplementary CD but the Kindle edition does not. All in all, the Kindle version is a waste of money, but the overall quality of the printed version is much higher. The supplemental CD includes all illustrations embedded in PowerPoint files, so a reader has access to illustrations that are at least readable. The PowerPoint files can be viewed with a free viewer from Microsoft, or the illustrations may be extracted with a full version of PowerPoint.

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Reviewer - Whitham Reeve is a contributing editor for the SARA journal, *Radio Astronomy*. He worked as an engineer and engineering firm owner/operator in the airline and telecommunications industries for more than 40 years and has lived in Anchorage, Alaska his entire life.