

Microwave Instrumentation for Radio Astronomy

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Invited Paper

Abstract—Radio astronomy is a branch of science that allows observation of natural radio signals from cosmic sources. Microwave techniques are employed in large radio telescope systems in diverse ways. Starting with early vacuum tube receivers at meter wavelengths, low-noise receivers have pushed the leading edge of technology, culminating in present-day receivers employing HFET amplifiers, superconducting tunnel junctions, and other advanced receiving elements. We discuss the principles of such devices, modern receivers, and modern radio telescope systems both operational and under development.

Index Terms—Amplifiers, radio astronomy, radio receivers, superconductor-insulator-superconductor mixers.

I. INTRODUCTION

RADIO astronomy as a branch of science was born in 1932 with the discovery by Jansky of “electrical disturbances apparently of extra terrestrial origin” [1]. As a branch of science it encompasses many topics: astronomy, physics, chemistry, and many fields of engineering. Kraus, in the preface to his book [2], which was the first comprehensive treatment of the field, wrote “radio astronomy embraces a wide range of topics from physical phenomena to receiver and antenna design.” This paper, therefore, can give only a glimpse of this broad and fascinating field; it is intended to explore the connection of radio astronomy to the field of interest of the IEEE Microwave Theory and Techniques Society (IEEE MTT-S).

New developments in microwave technology have made possible the creation of more complex and sensitive instruments, which, over the last 50 years, have brought about fascinating discoveries about our solar system, other solar systems, the interstellar medium, galaxies, and the evolution of the Universe. Jansky’s discovery of “a steady hiss type static of unknown origin” was discovered at a wavelength of 14.6 m, hardly what one would classify as microwaves today. Soon the experiments shifted to much higher frequencies with early attempts by Reber in 1937 to observe at 10- and 33-cm wavelengths and his successful observations of the galactic plane at 187-cm wavelength [3]. Progress in microwave technology during and after World War II allowed for great advances in radio astronomy antenna and receiver technologies. These advances brought about a steady stream of important discoveries. These include the discovery of radiation from the Sun and Moon (1946),

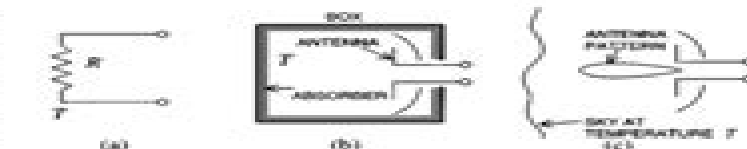


Fig. 1. (a) Resistor at temperature T . (b) Antenna in an absorbing box at temperature T . (c) Antenna observing sky at temperature T (after [2]).

the discovery of radiation from galactic hydrogen (1951), radio observations of the OH lines in the interstellar medium (1963) followed by discovery of many other lines of interstellar species, the discovery of quasars (1963), the discovery of the cosmic microwave background radiation (CMBR) (1965), and the discovery of pulsars (1967). One could add at the end of this very incomplete list the relatively recent discoveries of radio evidence for the existence of black holes, gravitational wave radiation, details of the birth of stars and other solar systems, and the discovery of the anisotropy of the CMBR, which directly measures the structure of the early Universe. An excellent summary of pre-1988 research and development is contained in [4].

This paper is intended to introduce the reader to the basic concepts used in radio astronomy and provide a short review of microwave instrumentation used in this field. In Section II, the basic radiometric and interferometric concepts are introduced. Section III provides a review of low-noise devices used in radio astronomy receivers, while Section IV gives examples of radio astronomy receivers. A glimpse of existing radio astronomy observatories, and a short review of current and future projects are given in Sections V and VI.

II. FUNDAMENTAL PRINCIPLES

A. Radiometers

Consider the situation shown schematically in Fig. 1 (after [2]). The available noise power in a unit bandwidth p of a resistor [see Fig. 1(a)] at a certain temperature T is given by the Nyquist relation, which under the Rayleigh-Jeans approximation to the Planck law is

$$p = kT \quad (1)$$

where $k = 1.38 \times 10^{-23} \text{ J K}^{-1}$ (Boltzmann constant) and T is the absolute temperature. The resistance of that resistor can

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Instrumentation And Techniques For Radio Astronomy

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Instrumentation And Techniques For Radio Astronomy:

Instrumentation and Techniques for Radio Astronomy Paul F. Goldsmith, 1988 **Literature 1989, Part 1**
Astronomisches Rechen-Institut, 2013-11-11 From the reviews Astronomy and Astrophysics Abstracts has appeared in semi annual volumes since 1969 and it has already become one of the fundamental publications in the fields of astronomy astrophysics and neighbouring sciences It is the most important English language abstracting journal in the mentioned branches The abstracts are classified under more than a hundred subject categories thus permitting a quick survey of the whole extended material The AAA is a valuable and important publication for all students and scientists working in the fields of astronomy and related sciences As such it represents a necessary ingredient of any astronomical library all over the world Space Science Review Dividing the whole field plus related subjects into 108 categories each work is numbered and most are accompanied by brief abstracts Fairly comprehensive cross referencing links relevant papers to more than one category and exhaustive author and subject indices are to be found at the back making the catalogues easy to use The series appears to be so complete in its coverage and always less than a year out of date that I shall certainly have to make a little more space on those shelves for future volumes The Observatory Magazine **Wspc Handbook Of Astronomical Instrumentation, The (In 5 Volumes)** , 2021-05-07 Our goal is to produce a comprehensive handbook of the current state of the art of astronomical instrumentation with a forward view encompassing the next decade The target audience is graduate students with an interest in astronomical instrumentation as well as practitioners interested in learning about the state of the art in another wavelength band or field closely related to the one in which they currently work We assume a working knowledge of the fundamental theory optics semiconductor physics etc The purpose of this handbook is to bring together some of the leading experts in the world to discuss the frontier of astronomical instrumentation across the electromagnetic spectrum and extending into multimessenger astronomy *Manual of Remote Sensing: Theory, instruments, and techniques* Robert Grier Reeves, American Society of Photogrammetry, 1975 *Research and Technology Program Digest Flash Index* , 1967
Interferometry and Synthesis in Radio Astronomy A. Richard Thompson, James M. Moran, George W. Swenson, Jr., 2001-04-25 Comprehensive authoritative coverage of interferometric techniques for radio astronomy In this Second Edition of *Interferometry and Synthesis in Radio Astronomy* three leading figures in the development of large imaging arrays including very long baseline interferometry VLBI describe and explain the technology that provides images of the universe with an angular resolution as fine as 1/20 000 of an arcsecond This comprehensive volume begins with a historical review followed by detailed coverage of the theory of interferometry and synthesis imaging analysis of interferometer response geometrical relationships polarimetry antennas and arrays Discussion of the receiving system continues with analysis of the response to signals and noise analog design requirements and digital signal processing The authors detail special requirements of VLBI including atomic frequency standards broadband recording systems and antennas in orbit Further

major topics include Calibration of data and synthesis of images Image enhancement using nonlinear algorithms Techniques for astrometry and geodesy Propagation in the neutral atmosphere and ionized media Radio interference Related techniques intensity interferometry moon occultations antenna holography and optical interferometry Interferometry and Synthesis in Radio Astronomy Second Edition is comprehensive in that it provides an excellent overview of most radio astronomical instrumentation and techniques **NASA Technical Memorandum** ,1991 Technology and Management Assistance Programs of the Small Business Administration United States. Congress. Senate. Select Committee on Small Business,1976

Research and Technology Program Digest United States. National Aeronautics and Space Administration, Oversight of the National Science Foundation United States. Congress. House. Committee on Science, Space, and Technology,1989 **Scientific and Technical Aerospace Reports** ,1991 Lists citations with abstracts for aerospace related reports obtained from world wide sources and announces documents that have recently been entered into the NASA Scientific and Technical Information Database **1989 National Science Foundation Authorization** United States. Congress. House. Committee on Science, Space, and Technology. Subcommittee on Science, Research, and Technology,1988

The Future of Small Telescopes in the New Millennium Terry D. Oswalt,2012-12-06 The motivation for these volumes is to provide a vision for the future of small telescopes While this is an admirable task ultimately I believe that as happens all the time in science the prognostications will be overtaken by a rapidly changing scientific reality As Virginia Trimble points out in chapter 1 the kinds of big questions that face us as astronomers today are rather different than the ones that drove the construction of astronomical facilities through much of the twentieth century Right now it appears that small telescopes will not have a lot of influence in answering those questions though they will of course contribute enormously to the many issues discussed throughout the three volumes We are on the verge of opening a whole new parameter space that may revolutionize the way we think of small telescopes and their role in astronomy the domain of the rapidly variable sky While the LSST is the most prominent example it is a long way in the future Nemiroff Rafert chapter 2 consider the value of monitoring large parts of the sky on a continuous basis using technology similar to a webcam They have installed their CONCAM2 at four locations including Kitt Peak A related project built and operated by the Harvard graduate student Gaspar Bakos HAT-1 Hungarian Automated Telescope also is in operation at Kitt Peak

Government-wide Index to Federal Research & Development Reports ,1966 Research and Technology Objectives and Plans Summary , A compilation of the summary portions of each of the RTOPs used for management review and control of research currently in progress throughout NASA P i **The Rise of Astrophysics in Modern Spain** Francisco Sánchez,2021-02-23 With foreword by astrophysicist and Queen guitarist Brian May This book describes the unlikely development of astrophysics in Spain set against the final decade of Franco's rule and the country's transition to democracy The author Founding Director of Spain's Instituto de Astrofísica de Canarias gives a firsthand account of his own and others' odyssey in establishing the field in Franco's Spain showing how in a mere half

century Spain was able to transform from a scientific backwater to a world player in astronomy and astrophysics The book is a behind the scenes warts and all depiction of how Big Science gets done showing the motivations sometimes as entertaining as they are infuriating that drive scientific institutions and the scientists who work for them Many astronomers both professional and amateur and historians know of the great scientific work being done in Spain but there is very little published information available about the complex story underlying it This English edition now makes that story accessible for the lay reader With its casual yet captivating narrative the book is a rare and inspiring contribution to the history of astrophysics science policy education and outreach U.S. Government Research Reports ,1964 **A Directory of**

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