

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),

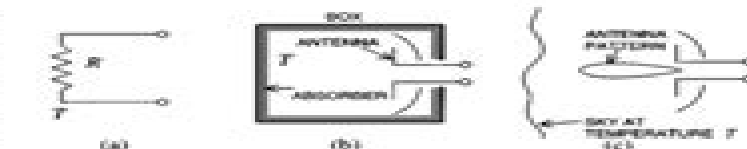


Fig. 1. (a) Resistor at temperature T . (b) Antenna in an absorbing box at temperature T . (c) Antenna observing sky at temperature T (after [2]).

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

Paul F. Goldsmith



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

Instrumentation for Large Telescopes Jose M. Rodriguez Espinosa, A. HERRERO (Ed), Francisco Sánchez, 1997-10-09 A new generation of large ground based telescopes are just coming into operation They will take astronomical research well into the next century These extremely powerful telescopes demand specially designed instruments and observing techniques The VII Canary Islands Winter School of Astrophysics gathered together leading experts from around the world to review this technology Based on the meeting this timely volume presents eight specially written chapters covering all aspects of telescope instrumentation This book provides an essential reference for all astronomers who will be the users of these large telescopes It reviews both the challenges involved in designing successful instrumentation and the questions in astronomy they must address We are taken from the fundamentals of astronomical imaging low and high resolution spectroscopy and polarimetry up to the state of the art technology in adaptive optics and laser guide stars interferometry image pattern recognition and optical near and mid infrared arrays This timely volume provides an excellent introduction for graduate students and an invaluable reference for researchers using the latest generation of large astronomical telescopes

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 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 Instrumental in War Steven Walton,2005-05-01 Scientific research and instrumentation are crucial for military action today but they have not always been so This collection investigates 500 years of the relationship between warfare research and instruments both physical and intellectual to understand this interaction With U S English and French examples contributors provide examples from army and naval history to show how governments and individuals made warfare scientific developing instruments stations and organizations that furthered the cause Some developments directly aided war efforts others were parts of normal science in peacetime and others were relatively ineffective in directly bringing about military change These developmental histories shed light on the origins of modern scientific warfare Contributors Steven A Walton William A Lynch Jamel Ostwald Seymour H Mauskopf James R Fleming Gerard P Scharfenberger William M McBride David Alan Grier Sebastien Soubiran Kenton Kroker Deborah J Warner Peter Galison *Literature 1985, Part 1* S. Böhme,U. Esser,Prof. Dr. W. Fricke,H. Hefele,Inge Heinrich,W. Hofmann,R. Krahn,V. R. Matas,Dr. Lutz D. Schmadel,G. Zech,2013-12-11 Astronomy and Astrophysics Abstracts aims to present a comprehensive documentation of the literature concerning all aspects of astronomy astrophysics and their border fields It is devoted to the recording summarizing and indexing of the relevant publications throughout the world Astronomy and Astrophysics Abstracts is prepared by a special department of the Astronomisches Rechen Institut under the auspices of the International Astronomical Union Volume 39 records literature published in 1985 and received before August 15 1985 Some older documents which we received late and which are not surveyed in earlier volumes are included too We

acknowledge with thanks contributions of our colleagues all over the world We also express our gratitude to all organizations observatories and publishers which provide us with complimentary copies of their publications On account of the introduction of an object index the scope of index information will be considerably enlarged beginning with this volume In connection with the subject index an additional source to satisfy the needs of retrieval is opened up Starting with Volume 33 all the recording correction and data processing work was done by means of computers The recording was done by our technical staff members Ms Helga Ballmann Ms Mona El Choura Ms Monika Kohl Ms Sylvia Matyssek Ms Karin Burkhardt Ms Susanne Schlotelburg and Mr Stefan Wagner supported our task by careful proofreading It is a pleasure to thank them all for their encouragement Heidelberg September 1985 The Editors Contents Introduction NASA Technical Memorandum, 1991 **Oversight of the National Science Foundation** United States. Congress. House. Committee on Science, Space, and Technology, 1989 **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 Flash Index, 1967 1989 National Science Foundation Authorization United States. Congress. House. Committee on Science, Space, and Technology. Subcommittee on Science, Research, and Technology, 1988 *Research and Technology Program Digest* United States. National Aeronautics and Space Administration, *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 I Hungarian Automated Telescope also is in operation at Kitt Peak 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 *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 *U.S. Government Research Reports* ,1964 A Directory of Information Resources in the United States: Physical Sciences, Engineering National Referral Center (U.S.),1971

The book delves into Instrumentation And Techniques For Radio Astronomy. Instrumentation And Techniques For Radio Astronomy is an essential topic that must be grasped by everyone, ranging from students and scholars to the general public. This book will furnish comprehensive and in-depth insights into Instrumentation And Techniques For Radio Astronomy, encompassing both the fundamentals and more intricate discussions.

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 - Chapter 5: Conclusion
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