

# USER DOCUMENTATION

## THE WESTERBORK SYNTHESIS RADIO TELESCOPE USER DOCUMENTATION

EDITED BY  
OLAF M. KOLKMAN

JULY 16, 1993

VERSION  
1.0.0

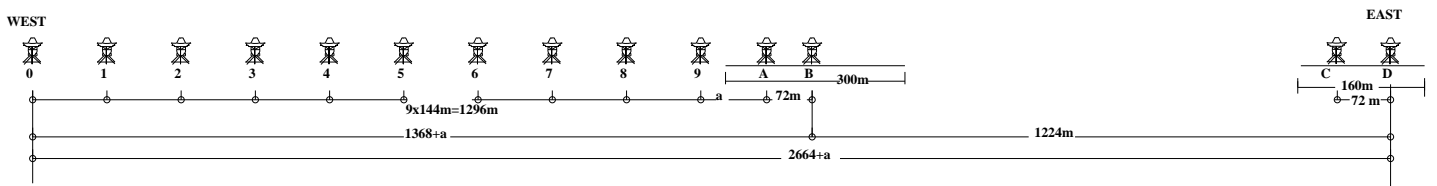


**Netherlands Foundation for Research in Astronomy**  
**Stichting Astronomisch Onderzoek in Nederland**

Postbus 2, 7990 AA Dwingeloo, the Netherlands

Oude Hoogeveensedijk 4, Dwingeloo

tel: 05219-7244, telefax:05219-7332



# WSRT

USER DOCUMENTATION

## PREFACE

# INTRODUCTION TO THE WSRT USER DOCUMENTATION

## INTRODUCTION

This is the user documentation for the Westerbork Synthesis Radio Telescope. It replaces the old manual and the WSRT information packet.

The old manual was released in 1980. It contained several useful articles but it had not been updated since its release and much of the information presented was out of date. In 1987 a WSRT information packet was released for users of the WSRT. This information packet contained a brief description of the instrument and all the information needed to write a proposal.

The user documentation replaces the documents mentioned above. It contains new material and updated parts from the old manual and the information packet.

## THE STRUCTURE AND CONTENTS OF THE DOCUMENTATION

The user documentation consists of six parts which can be used and distributed separately. Each part is relevant for a separate stage of using the WSRT. The advantage of this modular approach is that the sizes of the individual parts do not become too large and that the individual parts are easy to maintain. To provide easy access to the information each individual part has its own table of contents in addition to a table of contents and subject index for the complete user documentation.

Below a general description of the contents of the user documentation is given.

The documentation begins with a short description of the user documentation documentation (which is what you are reading now), a table of contents, a subject index, and a list of references.

Part 1: Proposing for WSRT observing time.

This part contains all the information necessary to write a proposal. Here we present a summary of the capabilities of the WSRT, explain how time is awarded, supply the necessary addresses and present a list of persons whom to contact with specific questions.

This part can be used individually and will be sent to people who are interested in observing with the WSRT. There is some redundancy with information in other parts of the documentation.

### Part 2: Introduction to the theory of aperture synthesis

This part contains an introduction to the theory of aperture synthesis with some emphasis on the WSRT. It is probably not needed by experienced radio astronomers but may be of use to those who are new to the field. This part contains some chapters with introductory theory with references to the standard literature. In the last chapter we included a bibliography and a 'dictionary' for quick reference to standard literature.

### Part 3: Specific aspects of the WSRT

In this part we describe the different modes of operation of the WSRT, provide some technical information and explain how a setup must be specified when proposing for an observation. There is some redundancy with the first part of the documentation. While writing a proposal the less experienced WSRT user may find it useful to consult this part for more details about the differences between the several instrumental setups.

### Part 4: Calibration and reduction of WSRT data

In this part we describe the corrections and calibrations that are and/or need to be performed on WSRT data. We present some tips and hints for further data reduction and present pictures with errors that may be encountered in WSRT maps.

### Part 5: Various

In this part we present equations, graphs and tables that may be useful for the specification of a proposal or during the reduction phase. We also included a brief guide to ARCQUERY, the archive query software.

### Part 6: NewStar

The second version of the user documentation will contain the NewStar program descriptions and recipes. We expect that this part will become available before the end of 1993. NewStar is the special software for  $u, v$ -data processing, developed at the NFRA.

## THE FORMAT OF THE MANUAL

The documentation was produced using the  $\LaTeX$  type setting program. The output format of the manual is PostScript. The advantages of this are that the User Document can be distributed electronically and can be reproduced locally by the user without loss of quality of pictures and text. (WISIWYG, what I see is what You get.)

Another format we considered for the reproduction of the documentation was  $\TeX$ -Info.  $\TeX$ -Info is a system with which information can be reproduced on paper and online on a computer terminal. We did not choose for this system because it is not able to display information like mathematical formulae and figures. We also think that the information in the documentation will be read elsewhere than behind a computer terminal.

## THE PRODUCTION, DISTRIBUTION AND MAINTENANCE OF THE MANUAL

The user documentation was produced in a 16 month period. The work was done on a computer account in Groningen. All texts were typeset in  $\LaTeX$  and all figures were redrawn using SM, Xfig and IslandDraw. All the files were shipped to an account (referred to as the documentation account) at NFRA Dwingeloo and will be maintained at NFRA. Observers who showed interest in the use of the WSRT are always supplied with the most recent version of part 1 of the documentation. A complete copy of the user documentation can be obtained in two ways.

1. A copy of the user documentation can be requested at NFRA. This can be done by sending an e-mail request to the documentation account or by contacting the NFRA secretary by surface mail or telephone.

2. An alternative way to obtain a copy of the documentation is to make use of anonymous ftp to obtain the necessary PostScript files.

The user documentation is maintained on the documentation account at NFRA. Whenever parameters of the instrument change, new information becomes available, or errors in the documentation are corrected a new version of the user documentation will be released. The structure of the user documentation is such that changes in the text do not need to affect more than a few pages. So to update the user documentation to a new version only a few pages need to be replaced or added in a recent version. Users of the documentation can register themselves so that they are informed about the change to a new version so they can update their private copy. Updates can be obtained in a similar way as a complete version of the documentation i.e. PostScript format on the anonymous ftp-node and paper copies by surface mail. Information about recent updates can be found in the NFRA-Newsletter and on the anonymous ftp-node.

## OBTAINING OR UPDATING A PRIVATE COPY OF THE USER DOCUMENTATION

### OBTAINING THE USER DOCUMENTATION

The documentation is stored in postscript format on an anonymous ftp node. It can be printed out on every regular postscript device. To obtain a copy of the documentation use the following procedure.

- Find a suitable computer and type `ftp rzmws10.nfra.nl` or if the route cannot be found `ftp 192.87.1.160`
- At the prompt username type: `anonymous`. Type your e-mail address as password.
- type `get README` to get the README file and read it
- Change directory to `wsrt.userdoc/total.copy/`
- type `binary` to set the file transport to binary
- type `mget part*.ps.Z` and `y` at the prompt
- type `get registration.form`
- Leave ftp by typing `quit`
- Uncompress the files and print files on a postscript printer e.g.  
`zcat part*.ps.Z |lpr -s -P{ printername }`

should work in a 'standard' UNIX environment.

- Fill in the `registration.form` and send it to `wsrt@nfra.nl`. You will then be informed when new versions of the documentation appear.

In the case you are not able to get, uncompress or print out the User Documentation, you are requested contact NFRA at the user documentation account.

Remember that obtaining a complete version of the user documentation is a somewhat time consuming job. First you have to transfer a few mega bytes of data at a rate typically of the order of 5kb per second. Then you have to print the documentation, which takes in the order of 1 to 2 hours.

It is in most cases more practical to Xerox a library copy and ftp the updates or to obtain a paper copy from NFRA.

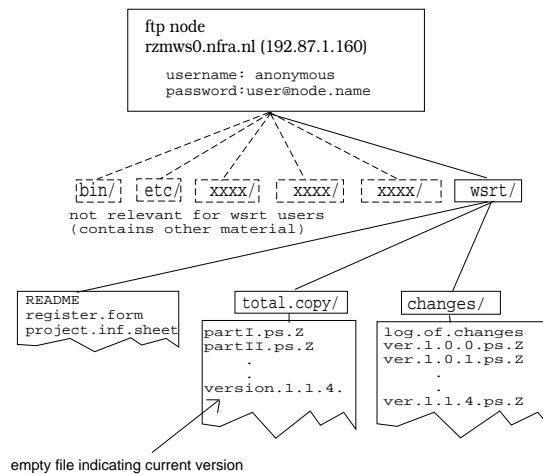


Figure 1.1: Directory structure of the anonymous ftp node on which a user can find the complete WSRT User Documentation

## UPDATING THE USER DOCUMENTATION

Whenever information is added to the documentation or information has been changed in the documentation a new version appears. The User Document as obtained from the `wsrt.userdoc/total.copy/` directory on the anonymous ftp node is always the most recent one.

Once you have sent in the registration form you will be informed by e-mail when the documentation is changed. You may then obtain a new version of the User Documentation. However, because ftp-ing and printing completely new parts is not only cumbersome but also bad for the environment (paper, toner, energy) the most recent changes are placed in files on a separate directory on the anonymous ftp-node. In this directory (`wsrt.userdoc/changes/`) there is a file called `log.of.changes` which contains information about the changes since appearance of the manual referring to the corresponding version numbers. By comparing the version number on the front cover of your manual you will be able to see which files you have to ftp to obtain a updated version of the manual. The reader is strongly advised to read this `log.of.changes`-file before ftp-ing new files. Of course you may always decide to obtain a new full copy of the Documentation in which all cross referencing and page numbering is correct.

**NB:** To get notification about new versions you should be registered. To register send the registration form from the anonymous ftp-node to the documentation account. If you do not have e-mail available please send a message by surface mail to the NFRA secretary.

## ADDRESSES

The person responsible for the maintenance of the user documentation and its distribution can be contacted by: sending an e-mail message to the documentation account or via the NFRA secretary. Complaints about, suggestions on, requests for, and contributions to the user documentation should also be sent tot he documentation account or the NFRA secretary.

documentation account : WSRT@NFRA.NL

NFRA Secretary : NFRA  
P.O. Box 2  
NL-7990 AA Dwingeloo  
The Netherlands  
tel:+31-(0)5219-7244  
fax:+31-(0)5219-7332

## CONCLUDING REMARKS

The WSRT user documentation will provide all scientists interested in using the WSRT with useful and up-to-date information. Regular maintenance will ensure that one is always provided with information about the latest developments in the hardware of the WSRT or in the software used to reduce its data. If you are interested in a copy please obtain one at the anonymous ftp-node (rzmws10.nfra.nl (192.87.1.160)), send a request for a paper copy to the documentation account (wsrt@nfra.nl), or contact the NFRA secretary (Postbus 2, NL-7990 AA Dwingeloo, The Netherlands). This is also the address to send your registration form to. A copy of the registration form can be found below or on the anonymous ftp-node.

If you have any comments or suggestions about improving this documentation please contact us at the documentation account (wsrt@nfra.nl), or contact the NFRA secretary (Postbus 2, NL-7990 AA Dwingeloo, The Netherlands). We specially welcome

- Additions of anything you feel is missing from this documentation.
- Any remarks and/or suggestions which may improve the intelligibility of parts of the user documentation.
- Detections of typos, etc.

## COPYRIGHT

The 'WSRT User Documentation' is copyright © 1993 by the Netherlands Foundation for Research in Astronomy (NFRA). The 'WSRT User Documentation' or parts of it may be freely copied and distributed for non-commercial purposes.

Care has been taken to present all information in the 'WSRT User Documentation' correct and up to date. However, NFRA cannot accept any responsibility for any losses resulting from its use.

## ACKNOWLEDGMENTS

The editing and production of this documentation was done as a civil service project financially supported by NFRA.

The Netherlands Foundation for Research in Astronomy is financially supported by the Netherlands Organization for Scientific Research.

---

--- Registration Form ----- WSRT User Documentation ---

- (..) I obtained a copy of (a part of) the WSRT User Documentation and I want to be informed by e-mail when updates appear.
- (..) I would like to receive a paper copy of the WSRT proposal packet (Part 1 of the User Documentation).
- (..) I would like to receive a paper copy of part ... of the WSRT User Documentation.
- (..) I would like to receive a copy of the complete WSRT User Documentation.

My name is: .....

address: .....

.....  
 .....  
 .....  
 .....

country: .....

telephone: (...)..... E-mail: .....

Please send this form to:

NFRA  
 Postbus 2  
 NL-7990 AA Dwingeloo  
 The Netherlands

or a similar message by e-mail to WSRT@NFRA.NL

-----

# WSRT

USER DOCUMENTATION

## CONTENTS

**Preface**

**Table of Contents**

**Index**

**Glossary**

**References**

### **Part I Proposing for WSRT Observing Time**

<b>1</b>	<b>Introduction</b>	<b>I-1-1</b>
1.1	The Westerbork Synthesis Radio Telescope (WSRT) . . . . .	I-1-1
<b>2</b>	<b>Summary of technical capabilities of the WSRT</b>	<b>I-2-1</b>
2.1	Geometry . . . . .	I-2-1
2.2	Observing modes . . . . .	I-2-2
2.3	Receivers and backends . . . . .	I-2-2
2.3.1	The spectral line backend (DXB) . . . . .	I-2-4
2.3.2	The continuum backend (DCB) . . . . .	I-2-4
2.3.3	Very Long Baseline Interferometry (VLBI) . . . . .	I-2-5
2.4	Future developments . . . . .	I-2-5
2.4.1	Pulsar Filterbank . . . . .	I-2-5
2.4.2	The DZB backend . . . . .	I-2-5
2.4.3	The multifrequency front ends . . . . .	I-2-5
2.5	The WSRT vis-a-vis the VLA . . . . .	I-2-6
2.6	References . . . . .	I-2-6
<b>3</b>	<b>WSRT Proposals</b>	<b>I-3-1</b>
3.1	The proposal procedure . . . . .	I-3-1
3.1.1	Introduction . . . . .	I-3-1
3.1.2	The program committee . . . . .	I-3-1
3.1.3	WSRT scheduling . . . . .	I-3-1
3.2	Acknowledgment . . . . .	I-3-2
3.3	Guidelines for submission of proposals . . . . .	I-3-2
3.3.1	Contents of the proposal . . . . .	I-3-2
3.3.2	Submission and evaluation . . . . .	I-3-3
3.3.3	The project information sheet . . . . .	I-3-3



<b>4</b>	<b>The archive of WSRT observations</b>	<b>I-4-1</b>
4.1	Introduction . . . . .	I-4-1
4.2	Archive research possibilities . . . . .	I-4-1
4.3	Availability of the archived data . . . . .	I-4-2
4.4	Sky coverage and sensitivity . . . . .	I-4-2
4.5	Exploring the archive . . . . .	I-4-3
4.6	Requesting data . . . . .	I-4-3
<b>5</b>	<b>Addresses and contact persons</b>	<b>I-5-1</b>
5.1	Addresses . . . . .	I-5-1
5.2	Contact persons . . . . .	I-5-2
<b>6</b>	<b>Useful tables</b>	<b>I-6-1</b>

## Part II Introduction to the Theory of Aperture Synthesis

<b>1</b>	<b>Introduction</b>	<b>II-1-1</b>
<b>2</b>	<b>The measurement of visibilities</b>	<b>II-2-1</b>
2.1	The basic equation of aperture synthesis . . . . .	II-2-1
2.2	A simple correlating interferometer . . . . .	II-2-1
2.2.1	Response to a monochromatic point source . . . . .	II-2-2
2.2.2	Response to a monochromatic extended source . . . . .	II-2-2
2.3	Delay tracking . . . . .	II-2-4
2.3.1	The effect of bandwidth . . . . .	II-2-4
2.3.2	Delay tracking . . . . .	II-2-5
2.3.3	Bandwidth smearing . . . . .	II-2-6
2.4	Summary . . . . .	II-2-6
2.5	References . . . . .	II-2-7
<b>3</b>	<b>Recovering the brightness distribution</b>	<b>II-3-1</b>
3.1	Image formation and field of view . . . . .	II-3-1
<b>4</b>	<b>The Fourier transformation</b>	<b>II-4-1</b>
4.1	Introduction . . . . .	II-4-1
4.2	The Fourier transform . . . . .	II-4-1
4.3	The image and spectral domain . . . . .	II-4-2
4.4	Some important Fourier relations . . . . .	II-4-2
4.5	References . . . . .	II-4-6
<b>5</b>	<b>Fast Fourier transform effects</b>	<b>II-5-1</b>
5.1	FFT effects and functional relationships . . . . .	II-5-1
5.2	Synthesized beam and grading . . . . .	II-5-5
5.3	Grating Responses . . . . .	II-5-7
5.4	Errors, Sidelobes and Confusion . . . . .	II-5-7
5.5	References . . . . .	II-5-9
<b>6</b>	<b>The coordinate system</b>	<b>II-6-1</b>
6.1	$u, v$ and $l, m$ coordinates . . . . .	II-6-1
6.2	The difference between 3d and E-W coordinates . . . . .	II-6-3
6.3	References . . . . .	II-6-3

<b>7</b>	<b>Temperature, brightness and sensitivity</b>	<b>II-7-1</b>
7.1	Antenna temperature . . . . .	II-7-1
7.2	Brightness Temperature . . . . .	II-7-2
7.3	Relations between Flux density, Brightness and Temperatures . . . . .	II-7-3
7.3.1	Estimates of $\Omega_A$ . . . . .	II-7-3
7.3.2	Conversion factor $T_b(\text{K})-S(\text{mJy})$ . . . . .	II-7-4
7.4	Sensitivity . . . . .	II-7-4
<b>8</b>	<b>Effects in Fourier transformed spectra</b>	<b>II-8-1</b>
8.1	Introduction . . . . .	II-8-1
8.2	Phase effects . . . . .	II-8-6
8.3	Tapering . . . . .	II-8-9
8.4	Delay effects . . . . .	II-8-10
8.5	Fast Fourier Transform effects . . . . .	II-8-10
8.6	Noise Distribution in Tapered Spectra . . . . .	II-8-11
8.7	Other tapers . . . . .	II-8-13
8.8	References . . . . .	II-8-13
<b>9</b>	<b>Bibliography and References</b>	<b>II-9-1</b>
9.1	Book reviews . . . . .	II-9-1
9.2	Dictionary . . . . .	II-9-5

## Part III Specific Aspects of the WSRT

<b>1</b>	<b>Technical Specifications of the WSRT</b>	<b>III-1-1</b>
1.1	Geometry of the Array . . . . .	III-1-1
1.2	Observing Modes . . . . .	III-1-1
1.3	Receivers and backends . . . . .	III-1-2
1.3.1	The spectral line backend (DXB) . . . . .	III-1-2
1.3.2	The continuum backend (DCB) . . . . .	III-1-4
1.3.3	Very Long Baseline Interferometry (VLBI) . . . . .	III-1-4
1.4	Future developments . . . . .	III-1-5
1.4.1	Pulsar Filterbank . . . . .	III-1-5
1.4.2	The DZB backend . . . . .	III-1-5
1.4.3	The multifrequency front ends . . . . .	III-1-5
<b>2</b>	<b>The calculation of the sensitivity</b>	<b>III-2-1</b>
2.1	Sensitivity Calculations . . . . .	III-2-1
2.1.1	Calculating the sensitivity for a standard setup . . . . .	III-2-1
2.1.2	Calculating the sensitivity for a non-standard setup . . . . .	III-2-2
<b>3</b>	<b>Specifying the backend setup</b>	<b>III-3-1</b>
3.1	Choosing the instrumental setup . . . . .	III-3-1
3.2	The setup for line observations . . . . .	III-3-1
3.2.1	Examples . . . . .	III-3-4
3.3	The setup for continuum observations . . . . .	III-3-5
3.4	The setup for other modes of operation . . . . .	III-3-6
3.4.1	Autocorrelation . . . . .	III-3-6
3.4.2	Pulsar observations with the DCB. . . . .	III-3-7
3.5	References . . . . .	III-3-7

---

<b>4</b>	<b>Polarization measurements with the WSRT</b>	<b>III-4-1</b>
4.1	Description . . . . .	III-4-1
4.2	Definitions . . . . .	III-4-2
4.3	Examples . . . . .	III-4-4
4.4	Errors . . . . .	III-4-7
4.5	References . . . . .	III-4-7
<b>5</b>	<b>On the use of redundant baselines</b>	<b>III-5-1</b>
5.1	A sketch of the technique . . . . .	III-5-1
5.2	Redundancy and the WSRT . . . . .	III-5-2
5.3	References . . . . .	III-5-3
<b>6</b>	<b>Mosaicing</b>	<b>III-6-1</b>
6.1	Introduction . . . . .	III-6-1
6.2	Theoretical Background . . . . .	III-6-1
6.3	Mosaic Implementations . . . . .	III-6-2
6.4	Spatial frequency coverage optimization . . . . .	III-6-2
6.5	Information for users interested in the use of mosaicing observations . . . . .	III-6-4
6.6	References . . . . .	III-6-4
<b>7</b>	<b>The WSRT Correlators</b>	<b>III-7-1</b>
7.1	Digital Correlators - a synopsis of theory . . . . .	III-7-1
7.2	The DLB/DXB . . . . .	III-7-2
7.2.1	The WSRT receiver system . . . . .	III-7-4
7.2.2	The Frontends . . . . .	III-7-4
7.2.3	The IF to video conversion . . . . .	III-7-4
7.2.4	The A/D conversion . . . . .	III-7-5
7.2.5	The Digital Delay . . . . .	III-7-5
7.2.6	Correlator Modes . . . . .	III-7-6
7.3	The DCB . . . . .	III-7-6
7.4	References . . . . .	III-7-6
<b>8</b>	<b>WSRT Beams</b>	<b>III-8-1</b>
8.1	WSRT primary beam properties . . . . .	III-8-1
8.1.1	Introduction . . . . .	III-8-1
8.1.2	Some theory . . . . .	III-8-1
8.1.3	Beam properties . . . . .	III-8-3
8.1.4	Pointing effects . . . . .	III-8-4
8.1.5	Beam determination . . . . .	III-8-4
8.1.6	Main beam total power and polarization patterns . . . . .	III-8-5
8.1.7	Sidelobe patterns . . . . .	III-8-7
8.1.8	Suggestions for further work . . . . .	III-8-8
8.1.9	References . . . . .	III-8-8
8.2	WSRT Baselines . . . . .	III-8-9
8.3	Synthesized Beam cross-cuts and integrals . . . . .	III-8-9
8.3.1	Calculation of synthesized beams . . . . .	III-8-11
<b>9</b>	<b>Shadowing</b>	<b>III-9-1</b>
9.1	Introduction . . . . .	III-9-1
9.2	Geometrical Shadowing calculation . . . . .	III-9-1
9.3	Antenna Shadowing and Observing Limits . . . . .	III-9-4
9.4	Remarks . . . . .	III-9-5
9.5	References . . . . .	III-9-5

---

<b>10</b>	<b>Baselines, delays and fringes</b>	<b>III-10-1</b>
10.1	Delay Path lengths . . . . .	III-10-1
10.2	Fringe frequency . . . . .	III-10-2
10.3	Position angle of the projected baseline on the sky . . . . .	III-10-3

## Part IV Calibration and Reduction of WSRT Data

<b>1</b>	<b>Calibration of WSRT data</b>	<b>IV-1-1</b>
1.1	On-line corrections . . . . .	IV-1-1
1.1.1	The on-line corrections . . . . .	IV-1-1
1.1.2	The determination of correction parameters. . . . .	IV-1-3
1.1.3	Check of the on-line corrections . . . . .	IV-1-4
1.2	Post observational corrections of WSRT data at NFRA . . . . .	IV-1-5
1.3	References . . . . .	IV-1-8
<b>2</b>	<b>Tips, Hints, FAQ</b>	<b>IV-2-1</b>
2.1	Reducing 21 cm Line data . . . . .	IV-2-1
2.1.1	Introduction . . . . .	IV-2-1
2.1.2	Reduction of Line data . . . . .	IV-2-1
2.2	Frequently Asked Questions . . . . .	IV-2-3
<b>3</b>	<b>Errors in maps</b>	<b>IV-3-1</b>
3.1	General Remark . . . . .	IV-3-1
3.2	Symmetries . . . . .	IV-3-1
3.3	Representation of errors . . . . .	IV-3-2
3.4	Single-interferometer errors . . . . .	IV-3-2
3.5	Constant gain errors . . . . .	IV-3-2
3.6	Varying phase errors . . . . .	IV-3-2
3.7	Constant phase and varying gain errors . . . . .	IV-3-3
3.8	Errors in a fixed telescope . . . . .	IV-3-3
3.9	Errors in a movable telescope . . . . .	IV-3-3
3.10	SRT baseline pole . . . . .	IV-3-3
3.11	Missing hour angle . . . . .	IV-3-3
3.12	$N \times 12$ hour synthesis . . . . .	IV-3-3
3.13	Atmosphere . . . . .	IV-3-4
3.14	Cross-talk . . . . .	IV-3-4
3.15	DCB-offsets . . . . .	IV-3-4
3.16	DLB-offsets . . . . .	IV-3-4
3.17	Traveling ionospheric disturbances (TID) at 92 cm . . . . .	IV-3-4
3.18	Closure errors . . . . .	IV-3-4
3.19	References . . . . .	IV-3-5

## Part V Various

<b>1</b>	<b>Miscellaneous tables and graphs</b>	<b>V-1-1</b>
1.1	Useful Equations and graphs . . . . .	V-1-1
1.1.1	Plane Trigonometry . . . . .	V-1-1
1.1.2	Spherical Trigonometry . . . . .	V-1-3
1.2	Coordinate Transformations . . . . .	V-1-4
1.2.1	Altitude ,azimuth – $\alpha, \delta$ transformation . . . . .	V-1-4
1.2.2	$l, b - \alpha, \delta$ transformation . . . . .	V-1-6
1.2.3	Precession (approximate — From Kraus (86) . . . . .	V-1-6

---

1.3	Molecular and Recombination Line frequencies . . . . .	V-1-6
1.4	References . . . . .	V-1-6
<b>2</b>	<b>Some mathematical expressions of visibility functions</b>	<b>V-2-1</b>
2.1	Visibility function for a circular source . . . . .	V-2-1
2.2	Visibility function for a double point source . . . . .	V-2-2
<b>3</b>	<b>The Archive of WSRT Observations: a brief guide</b>	<b>V-3-1</b>
3.1	Contents and composition . . . . .	V-3-1
3.1.1	Contents . . . . .	V-3-1
3.1.2	Composition . . . . .	V-3-1
3.1.3	The software . . . . .	V-3-1
3.2	Starting an archive query . . . . .	V-3-1
3.3	Selecting and retrieving observations . . . . .	V-3-2
3.4	People to contact for information . . . . .	V-3-4
3.5	Summary of ARCQUERY commands . . . . .	V-3-5

---

# WSRT

USER DOCUMENTATION

## INDEX

The Roman numbers in the page numbers indicate in which part the item can be found. The titles of the parts are summarized below. In the preface we give a short description of the contents of the parts.

- I** Proposing for WSRT Observing Time
- II** Introduction to the Theory of Aperture Synthesis
- III** Specific Aspects of the WSRT
- IV** Calibration and Reduction of WSRT Data
- V** Various
- VI** The NewStar Software

- A/D conversion, III-7-5
- aberration correction, IV-1-2
- accuracy
  - pointing, I-2-1, III-1-1
  - surface, I-2-1, III-1-1
- acknowledgment, I-3-2
- addition theorem, *see*  $\Lambda$  Fourier transform, relations
- addresses, I-5-1
- aliasing, II-8-2, II-9-5
- allocation priority, I-3-3
- amplitude
  - ripples
    - suppression of, II-8-9
    - ripples, II-8-8
  - amplitude correction, III-7-2
  - amplitude corrections, IV-1-2
  - Amplitude decorrelation
    - delay tracking, III-7-6
  - amplitude decorrelation
    - phase tracking, III-7-5
  - amplitude information, III-7-1
- antenna
  - geometrical area, II-7-1
  - accuracy
    - pointing, I-2-1, III-1-1
    - surface, I-2-1, III-1-1
  - beam, *see*  $\Lambda$  beam
  - efficiency factor, II-7-1, II-7-5
  - geometrical area, II-7-5
  - normalized reception pattern, II-2-3
  - pattern, II-3-1, II-9-5
  - power pattern, II-2-2
  - reception pattern, II-2-2
  - temperature, II-7-1
- aperture
  - effective, II-7-1, II-7-5
- aperture synthesis, II-5-1
  - basic relation, II-2-1
- archive, V-3-1
- ARCQUERY
  - short guide, V-3-1
- ARQUERY
  - short guide, V-3-5
- array
  - geometry, I-2-1, III-1-1
- atmosphere
  - errors, IV-3-4
  - phase fluctuations, II-5-7
- atmospheric corrections, IV-1-5
- auto-correlation, III-6-1
- autocorrelation, III-3-6
- availability of WSRT, I-3-1
- Azimuth-Elevation diagram, V-1-5
- backend
  - characteristics, I-2-4–I-2-5, III-1-2–III-1-5
  - continuum, *see*  $\Lambda$  DCB
  - DCB, *see*  $\Lambda$  DCB
  - DXB, *see*  $\Lambda$  DXB
  - line, *see*  $\Lambda$  DXB
- backends, I-2-2–I-2-5, III-1-2–III-1-5

- pulsar filterbank, I-2-5, III-1-5
- bandpass
  - edge, II-8-7
- bandshape function, II-2-4
- bandwidth, II-2-4, II-7-1, II-8-1
  - choosing the, III-3-1
  - limited, II-4-5
  - noise equivalent, II-7-6
  - smearing, II-2-6, II-9-5
- baseline
  - projected on the sky, III-10-3
- baseline corrections, IV-1-5
- baseline pole, III-10-1
  - error, IV-1-2
  - error in, IV-3-3
- baseline separation
  - choosing the, III-3-3, III-3-5
- baseline vector,, II-2-2
- baseline-pole, II-9-5
- baselines, III-8-9
  - non-standard, I-2-4, III-1-4
  - redundant, *see*  $\Lambda$  redundancy
  - redundant, table, III-5-2
  - spacings, III-8-9
  - standard, I-2-4, III-1-4
- beam
  - Gaussian, II-7-3
  - integrated, II-7-3–II-7-4
  - power and polarization, III-8-4
  - restoring, II-7-3
  - synthesized, II-5-5, III-8-9–III-8-12
    - integral over, II-5-8
    - RA for 2.8 km baseline, I-2-3, III-1-3
  - theoretical synthesized, II-7-3
- beam properties, III-8-3
- bibliography, II-9-1–II-9-4
- bit modes, III-2-3
- Boltzmann’s constant, II-7-1
- books, II-9-1
- brightness, II-7-3, II-7-4
- brightness distribution, II-3-1, II-4-2, II-7-2
- brightness temperature, *see*  $\Lambda$  temperature, brightness
- calculation of visibility, V-2-1
- calibration, IV-1-1–IV-1-8
  - of mosaic data, IV-1-5
  - redundancy, *see*  $\Lambda$  redundancy
- channel separation, I-2-3, I-2-4, I-6-4, III-1-3, III-1-4
- channel usable, III-3-2
- choosing your setup, III-3-1
- chromatic aberration, II-2-6
- circular polarization, III-4-2
- CLEAN, II-5-8, II-7-3, II-9-5
- clock error, IV-1-2
- closure error, IV-3-4
- coherence
  - function, II-2-7, II-9-5
  - matrix, III-8-1
  - spatial, II-2-3, II-2-6
- complex channels
  - number of, I-2-3, III-1-3
- complex numbers
  - notation, II-2-1
- confusion, II-5-9
- constant gain error, IV-3-2
- constant phase error, IV-3-3
- contact persons, I-5-2
- continuum
  - backend, *see*  $\Lambda$  DCB
  - default settings (table), I-3-5
- conversion factor
  - flux–brightness temperature, II-7-4
- convolution, II-4-4–II-4-5
- convolution theorem, *see*  $\Lambda$  Fourier transform, relations
- coordinate system
  - $l, m$ , *see*  $\Lambda l, m$  coordinates
  - $u, v$ , *see*  $\Lambda u, v$  coordinates
  - astrometric, II-6-2
  - equatorial, II-6-1
  - relation between, II-6-2
  - unit vectors, II-6-1, II-6-2
- coordinate systems, II-6-1–II-6-3
  - for linear polarization, III-4-1
  - transformation, V-1-4
  - $l, b - \alpha, \delta$ , V-1-6
  - Altitude ,azimuth  $- \alpha, \delta$ , V-1-4
- corrections, IV-1-1–IV-1-8
  - amplitude, IV-1-2
  - atmosphere, IV-1-5
  - baseline, IV-1-5
  - DC offsets, IV-1-3
  - delay, IV-1-2
  - determination of parameters, IV-1-3
  - dipole, IV-1-5
  - extinction, IV-1-2
  - frequency, IV-1-3
  - gain/phase, IV-1-7
  - interference(EMI), IV-1-8
  - on-line, IV-1-1–IV-1-5
  - phase, IV-1-2
  - pointing, IV-1-1
  - precession, nutation, and aberration, IV-1-2
  - quantization, IV-1-2

- shadowing, IV-1-7
- standard, IV-1-5
- temperature, IV-1-2
- Van Vleck, IV-1-2
- correlation, *see*  $\Lambda$  Fourier transform, relations
- correlation degradation factor, *see*  $\Lambda$  degradation factor
- correlator modes, III-2-3
- cross-talk, IV-3-4
- crossed dipole
  - seepolarization,crossed dipole, III-4-4
- data manipulation, II-5-1
- DC offsets correction, IV-1-3
- DCB, I-2-3, I-2-4, III-1-3, III-1-4, III-7-6
  - offsets, IV-3-4
  - pulsar observations, III-3-7
  - specifying the setup, III-3-5
- deadline for proposals, I-3-3
- degradation factor, II-7-6, II-9-5
  - digital vs. analogue correlation, III-2-3
- degradation fctor, III-2-3
- delay, III-7-5
  - geometrical, III-10-1
  - stability, III-7-6
  - tracking accuracy, III-7-6
- delay correction, IV-1-2
- delay effects, II-8-10
- delay tracking, II-2-4–II-2-5
- dictionary, II-9-5–II-9-7
- Digital correlators
  - theory, III-7-1
- digital delay, II-8-10, III-7-5
- digitization, III-7-1
- dipole
  - ellipticity
    - difference, III-4-2
    - sum, III-4-2
  - nominal position angle, III-4-2
  - orientation, I-2-1, III-1-1
  - setting error
    - difference, III-4-2
    - sum, III-4-2
- dipole corrections, IV-1-5
- direction vector,, II-2-2
- dirty beam, II-9-5
- dirty map, II-9-5
- DLB, III-7-2
  - offsets, IV-3-4
- DLB/DXB, III-7-2
- DLB/DXB *also see* DXB, I-2-4, III-1-2
- DXB, I-2-4, III-1-2, III-7-2
  - autocorrelation, III-3-6
  - redundant configurations, III-5-4
  - setup
    - table of completeness descriptions, III-5-6
    - specifying the setup, III-3-1–III-3-5
- dynamic range, II-5-7, II-5-9, IV-1-5
- dynamic range, obtaining a high, III-5-1
- DZB, I-2-5, III-1-5
- effective frequency resolution, II-8-5
- EMI, IV-1-8
- equations
  - useful, V-1-1–V-1-6
- equatorial coordinate, V-1-6
- error
  - gain, IV-3-1
  - in fixed telescope, IV-3-3
  - in matched flux density, II-7-5
  - in measured flux density, II-7-5
  - in movable telescope, IV-3-3
  - in total flux density, II-7-6
  - phase, IV-3-2
  - pointing, IV-1-1
- errors
  - pointing effects, III-8-4
  - delay, IV-1-2
  - illustrations of, IV-3-5
  - in maps, IV-3-1–IV-3-5
  - on-line correction of, *see*  $\Lambda$  corrections,on-line
  - phase, IV-1-2
  - uncorrectable, IV-1-3
- expansion
  - power series of common functions, V-1-2
- extended source, III-6-1
- extinction
  - tropospheric, IV-1-7
- extinction correction, IV-1-2
- fast Fourier transform, *see*  $\Lambda$  Fourier transform, fast
- FFT, *see*  $\Lambda$  Fourier transform, fast
- field of view, I-2-3, III-1-3, III-6-1
- field repetition function, II-5-2
- filler, I-3-3
- filters, III-7-4
- fixed telescope
  - error, IV-3-3
- flux density, II-7-2, II-7-3
  - of extended sources, II-5-9
  - matched, II-7-2, II-7-3, II-7-5
    - error in, II-7-5
  - measured
    - error in, II-7-5
  - observed, II-7-4



- total, II-7-6
  - error, II-7-6
- Fourier spectrum, II-4-2
- Fourier transform, II-4-1–II-4-6, II-8-1
  - definition, II-4-1
  - fast, II-5-1–II-5-5
    - effects, II-8-10
  - functions and their, II-4-3
  - inverse, II-3-1
    - definition, II-4-1
  - of even and odd functions, II-4-2
  - properties, II-3-1
  - relations, II-4-2–II-4-6
  - two dimensional, II-4-1
  - visibility, II-5-1
- frequencies
  - table of molecular and line, V-1-9
  - lines, V-1-6
- frequency
  - channels, I-6-4, II-8-12
    - usable, III-3-2
  - effective resolution, I-6-4, II-8-12
  - fringe, III-10-2
  - video, *see*  $\Lambda$  video frequency
- frequency bands (DCB)
  - choosing, III-3-5
- frequency channels
  - choosing the number of, III-3-2
- frequency conversion, IV-1-2
- frequency correction, IV-1-3
- frequency domain, II-4-2, II-8-2
  - spectral, II-8-1
- frequency range, I-2-3, III-1-3
- fringe, II-9-5
  - demodulation, III-7-5
  - frequency, III-10-2
- fringe frequency
  - figure, III-10-4
- fringe function, II-2-2
- fringe stopping, II-8-10, II-9-5, III-7-6
- frontend
  - mounting of, I-2-1, III-1-1
  - multi frequency, I-2-5, III-1-5
- function
  - convolving, II-5-1
  - sampling, II-4-7
  - visibility, *see*  $\Lambda$  visibility
- functions
  - and their Fourier transform, II-4-3
  - boxcar, II-5-5
  - delta, II-5-2, II-8-7
  - even and odd, II-4-2, II-8-1
  - grading, II-5-5, II-9-5
  - impulse, *see*  $\Lambda$  functions, delta
  - involved in map making, II-5-2
  - rectangle, II-4-3
  - shah, II-4-3, II-8-2, II-9-6
  - sinc, II-4-3, II-5-5, II-8-4
  - time cross-correlation, II-8-1
- gain corrections, IV-1-7
- gain error, *see*  $\Lambda$  error, gain
- gain factor, III-4-2
- galactic coordinates, V-1-6
- Gaussian source, visibility of, V-2-1
- geometrical delay, III-10-1
- geometry
  - of the array, I-2-1, III-1-1
- GIPSY, IV-2-1
- grading, II-5-2, II-5-5–II-5-7
  - efficiency factor, II-7-6
  - function, *see*  $\Lambda$  functions, grading
  - Gaussian, II-7-3
  - truncated Gaussian, II-5-7
- grating ellipse, *see*  $\Lambda$  grating ring
- grating function, II-5-2
- grating ring, II-5-5, II-5-7, II-5-8, II-9-6
  - distance to, I-2-3, III-1-3
- grid, II-5-1
- Hamming taper, *see*  $\Lambda$  taper, Hamming
- Hanning taper, *see*  $\Lambda$  taper, Hanning
- HI
  - data reduction, IV-2-1
- hour angle
  - missing, IV-3-3
- IF system, III-7-4
- IF to video conversion, III-7-4
- illumination function, *see*  $\Lambda$  functions, grading
- image domain, II-4-2, II-9-6
- image plane, *see*  $\Lambda$  image plane
- incoherence
  - spatial, II-2-6
- information sheet, I-3-1
- instrumental term
  - $\epsilon$ , III-4-2
  - $\eta$ , III-4-2
- interference, III-10-3
- interference corrections, IV-1-8
- interferometer
  - coordinates, II-6-2
  - east-west, II-6-2
  - error, IV-3-2
  - ideal, II-2-1–II-2-7
    - assumptions, II-2-6
  - response

- extended source, II-2-2
- point source, II-2-2
- simple correlating, II-2-1, II-2-2
- inverse Fourier transform, *see*  $\Lambda$  Fourier transform, inverse
- ionosphere, IV-1-4, IV-1-5
  - effect in map, IV-3-4
- large scale structure, II-5-8
- leakage, II-8-5
- line
  - backend, *see*  $\Lambda$  DXB
- line data
  - reduction, IV-2-1
- line frequencies, V-1-9
- line observation
  - calibration of, II-8-6
  - default setting(table), I-3-7
- linear polarization component, III-4-2
- linear polarized position angle, III-4-2
- linear spacing between telescopes (graph), III-9-2
- linearity theorem, *see*  $\Lambda$  Fourier transform, relations
- linearly polarized intensity, III-4-2
- $l, m$ 
  - coordinates, II-3-1, II-6-1
  - definition, II-6-2
- local mode of operation, I-2-2, III-1-1
- map
  - integral over synthesized, II-5-8
- MARK2, *see*  $\Lambda$  MK2
- MARK3, *see*  $\Lambda$  MK3
- matched flux density, *see*  $\Lambda$  flux density, matched
- maximum bandwidth, I-2-3, III-1-3
- missing hour angle, IV-3-3
- missing spacings, II-5-8
- mixer, III-7-4
- MK2, I-2-3, I-2-5, III-1-3, III-1-4
  - bandwidth, I-2-3, III-1-3
- MK3, I-2-3, I-2-5, III-1-3, III-1-4
  - bandwidth, I-2-3, III-1-3
- mode
  - autocorrelation, III-3-6
  - local - of operation, I-2-2, III-1-1
  - mosaic, I-2-2, III-1-2
  - observing, I-2-2, III-1-1
  - pulsar observations, III-3-7
- modes
  - correlator, III-7-6
- molecular line frequencies, V-1-6
- mosaic
  - $u, v$ -coverage, III-6-3
  - implementation, III-6-2
- mosaic mode, *see*  $\Lambda$  mode, mosaic*see*  $\Lambda$  mode, mosaic
- mosaicing, II-9-6, III-6-1–III-6-4
  - theory, III-6-1
- movable telescope
  - error, IV-3-3
- NCP projection, *see*  $\Lambda$  North Celestial Pole projection
- noise
  - calculation of, III-2-2
  - confusion, II-5-9
  - estimation of, III-2-1
  - in map, II-5-5
  - in tapered spectra, II-8-11
  - in total HI map, IV-2-3
  - receiver, III-2-1
  - table for for 21 cm, III-2-3
  - thermal, II-7-1, III-2-1
- noise equivalent bandwidth, II-8-5
  - table, III-2-4
- noise power, II-7-1, II-7-5
- non standard baselines, I-2-4, III-1-4
- non-standard baselines, *see*  $\Lambda$  baselines, non-standard
- North Celestial Pole projection, II-6-3
- nutation correction, IV-1-2
- Nyquist relation, II-7-1
- observational setup, *see*  $\Lambda$  setup, specifying
- observing
  - limits
    - shadowing, *see*  $\Lambda$  shadowing, observing limits
- observing limits
  - shadowing, *see*  $\Lambda$  shadowing, observing limits
- observing mode
  - mosaicing, III-6-1
  - polarization, III-4-1
- observing modes, I-2-2, III-1-1
- offset, pointing, III-8-4
- on-line corrections, IV-1-1–IV-1-5
- output format, IV-1-8
- parallactic angle, V-1-4
- parallel dipoles, *see*  $\Lambda$  polarization, parallel dipoles
- Pascal's triangle, V-1-2
- persons, contact, I-5-2
- phase
  - effects, II-8-6–II-8-9
  - ripples, II-8-8
  - suppression of, II-8-9
- phase center, *see*  $\Lambda$  phase reference point
- phase corrections, IV-1-2, IV-1-7

- 
- phase error, *see*  $\Lambda$  error, phase
  - phase reference point, II-2-1, II-9-6
  - phase shift, II-4-4
  - phase tracking
    - accuracy, III-7-5
  - Planck law, II-7-2
  - point sources, visibility of two, V-2-2
  - pointing accuracy, I-2-1, III-1-1
  - pointing correction, IV-1-1
  - pointing effects, III-8-4
  - pointing model, IV-1-1
  - polar axis, IV-1-2
  - polarization, III-4-1–III-4-7
    - accuracy, III-4-7
    - angle, II-9-6
    - circular, III-4-2
    - crossed dipole, III-4-4
    - errors, III-4-7
    - fractional, III-4-1
    - parallel dipoles, III-4-5
    - position angle, III-4-1
    - primary beam, *see*  $\Lambda$  primary beam
    - Stokes parameters  $I$ ,  $Q$ ,  $U$ ,  $V$ , III-4-1, III-8-1
    - vector, III-4-1
  - polarization pattern
    - primary beam, III-8-5
  - power, II-7-1
    - noise, II-7-1, II-7-5
    - spectral, II-7-1
  - power pattern
    - primary beam, III-8-5
    - synthesized beam, III-8-11
  - precession
    - formulae, V-1-6
  - precession correction, IV-1-2
  - primary beam, II-9-6, III-8-1–III-8-8
    - power and polarization, III-8-4
  - program committee, *see*  $\Lambda$  proposing, program committee
  - projected baseline, III-10-3
  - proposing, I-3-1–I-3-6
    - dead line, I-3-3
    - evaluation, I-3-3
    - guidelines, I-3-2
    - information sheet, I-3-1
    - interim proposals, I-3-1
    - program committee, I-3-1
    - submission, I-3-3
  - publication
    - acknowledgment, I-3-2
  - pulsar observations, I-2-5, III-1-5, III-3-7
  - quantization correction, IV-1-2
  - radial sampling function, II-5-2
  - radiation
    - monochromatic, II-2-2
  - radio sources
    - diagram, V-1-8
  - Rayleigh-Jeans law, II-7-2
  - receiver
    - rotation of the feeds, III-4-2
  - receiver system
    - description of, III-7-4
  - receivers, I-2-2–I-2-5, III-1-2–III-1-5
  - recombination line frequencies, V-1-6
  - rectangle function, *see*  $\Lambda$  functions, rectangle
  - rectangular sampling function, II-5-2
  - reduction of line data, IV-2-1
  - redundancy, III-5-1–III-5-3
    - configurations for DXB, III-5-4
    - table of baselines, III-5-2
    - WSRT, III-5-2
  - reflection, II-5-5
  - refraction, IV-1-2
    - tropospheric, IV-1-7
  - resolution
    - spatial, III-10-5
  - response
    - matrix, III-8-2
  - rotation
    - of frontend feeds, III-4-2
  - sampling, II-3-1, II-4-5, II-8-2, III-7-1
    - discrete, II-8-7
    - interval, II-8-4
  - sampling rate, II-8-2, III-7-5
  - sampling theorem, *see*  $\Lambda$  Fourier transform, relations
  - scheduling, I-3-1
  - self-calibration, IV-1-5
  - sensitivity, II-7-4–II-7-6, II-9-6, III-2-1–III-2-3
    - 21 cm observations(table), I-6-3, III-2-5
    - after smoothing, III-2-1
    - calculation, III-2-1
    - calculation of, III-2-2
    - estimation of, III-2-1
    - for a non standard setup, III-2-2
    - for a standard setup, III-2-1
    - theoretical for 12h measurement, I-2-3, III-1-3
  - service
    - observing, I-3-1
  - setup
    - specifying, III-3-1–III-3-7
    - autocorrelation, III-3-6
    - bandwidth, III-3-1
-

- baseline separation, III-3-3, III-3-5
- DCB, III-3-5
- DXB, III-3-1
- examples, III-3-4
- frequency bands (DCB), III-3-5
- frequency channels, III-3-2
- pulsar observations, III-3-7
- spatial resolution, III-3-3
- taper, III-3-2
- shadowing, III-9-1
  - calculation, III-9-1
  - observing limits, III-9-4
    - graph, III-9-3
  - tables, III-9-6
- shadowing corrections, IV-1-7
- shah function, *see*  $\Lambda$  functions, shah
- shift theorem, *see*  $\Lambda$  Fourier transform, relations
- short spacing, III-8-11
- side-lobes, II-8-5
- sidelobe, III-5-1
- sidelobe patterns, III-8-7
- sidelobes, II-5-1, II-5-7
- similarity theorem, *see*  $\Lambda$  Fourier transform, relations
- sinc function, *see*  $\Lambda$  functions, sinc
- single sideband, III-7-4
- smoothing, II-4-4
- snapshot, I-2-6
- spacing
  - missing, II-5-8
  - short, III-8-11
- spacings
  - synthesized beam for different, III-8-11
  - table, III-8-10
- spatial domain, II-4-2
- spatial frequency, II-4-2
  - coverage optimization (mosaicing), III-6-2
- spatial frequency brightness distribution, *see*  $\Lambda$  visibility function
- spatial frequency filter, II-5-5
- spatial frequency sensitivity function, II-5-2
- spatial resolution
  - choosing the, III-3-3
- spectra, II-8-1–II-8-13
- spectral domain, II-4-2
- spectral power, II-7-1
- spectrum
  - of continuum point source, II-8-6
- spherical trigonometry, V-1-3
- standard baselines, *see*  $\Lambda$  baselines, standard
- standard corrections, IV-1-5
- (non-)standard baselines, *see*  $\Lambda$  baselines, non-standard
- Stokes parameters, II-9-6, *see*  $\Lambda$  polarization, Stokes parameters
- structure
  - extended, III-6-1
  - large scale, II-5-8
  - low level, II-5-8
- surface accuracy, I-2-1, III-1-1
- synthesis measurement
  - error in, IV-3-3
- synthesized beam, III-8-9–III-8-12
- system temperature
  - measurement of, III-7-2
- taper, II-5-2, II-8-4, II-8-7, II-9-7
  - choosing the, III-3-2
  - effective frequency resolution, I-6-4, II-8-12
  - Hamming, II-8-13, II-9-6
  - Hanning, II-8-10, II-9-6
    - effective frequency resolution, II-8-10
    - properties, I-6-4, II-8-12
  - noise tapered spectra, II-8-11
  - properties, I-6-4, II-8-12
  - uniform, II-8-4, II-8-9
    - effective frequency resolution, II-8-5
    - noise equivalent bandwidth, II-8-5
    - properties, I-6-4, II-8-12
- taper function, II-5-2
- tapering, II-8-9–II-8-10
- tapes, IV-1-8
- telescope
  - error, IV-3-3
- temperature
  - system
    - measurement of, III-7-2
    - antenna, II-7-1, II-7-3, II-9-7
    - brightness, II-7-2, II-7-3, II-9-7
    - noise, III-7-2
    - objects, II-7-1
    - resistor, II-7-1
    - source, II-7-3
    - system, I-2-3, II-7-5, II-7-6, II-9-7, III-1-3
      - table, I-6-1, III-2-3
  - temperature corrections, IV-1-2
  - temperature(s), II-7-1–II-7-4
- tied array, II-9-7
- time domain, II-8-2
- total intensity, III-4-2
- Traveling ionospheric disturbances (TID)
  - effect in map, IV-3-4
- trigonometry, V-1-1
- troposphere, IV-1-7
- uncorrectable errors, IV-1-3
- uniform taper, *see*  $\Lambda$  taper, uniform

*u, v*

- coordinates, II-6-1
- definition, II-6-2
- domain, II-4-2
- plane, II-3-1, II-5-1
  - (position of) structures in, II-4-2
  - ellipses, II-3-2, II-5-2

UV FITS, IV-1-8

Van Vleck correction, IV-1-2

varying gain error, IV-3-3

varying phase error, IV-3-2

video bandpass, II-8-1

video frequencies, III-7-4

video frequency, II-8-1

visibility, II-2-1–II-2-4, II-2-6, II-3-1, II-9-7

- amplitude, II-2-4, II-2-5
- calculations, V-2-1–V-2-2
- complex, II-2-3
- cosine, II-2-3
- definition, II-2-3
- fourier transforming the, II-5-1
- Gaussian source, V-2-1
- phase, II-2-4, II-2-5
- point sources, V-2-2
- sine, II-2-3

VLA, I-2-6

VLBI, I-2-3, I-2-5, II-9-7, III-1-3, III-1-4

Westerbork unit, II-9-7

window, *see*  $\Lambda$  taper

zero frequency, *see*  $\Lambda$  video frequency 0

---

# WSRT

USER DOCUMENTATION

## GLOSSARY

$A$	: azimuth
$a$	: altitude
$A(\sigma), A(l, m)$	: antenna reception pattern
$A_e$	: effective aperture of antenna
$A_T$	: geometrical cross-sectional area of antenna aperture
$A_N(\sigma), A_N(l, m)$	: normalized antenna reception pattern ( $= A(\sigma)/\mathbf{A}(\mathbf{0})$ or $A(\sigma)/\mathbf{A}_{\max}$ )
$B$	: total bandwidth
$B(\sigma)$	: brightness distribution in direction $\sigma$
$B'(\sigma)$	: modified brightness distribution in direction $\sigma$
$b$	: channel separation $b = B/N_F$
$b$	: new galactic latitude
$D$	: degradation factor, increase in noise when using a digital instead of an analogue correlator
$\mathbf{D}$	: baseline vector
$\mathbf{D}_\lambda$	: baseline vector in units of wavelength
$D_\lambda$	: length of baseline vector in units of wavelength
$D_{\lambda, \max}$	: maximum baseline length in units of wavelength
$D_{\lambda, \min}$	: minimum baseline length in units of wavelength
$D_{\lambda, \text{inc}}$	: baseline length increment in units of wavelength
$\mathbf{E}$	: complex electric field column vector
$E_x$	: x component of complex electric field column vector
$E_y$	: y component complex electric field column vector
$D_{\text{proj}}$	: projected baseline length
$D_x, D_y, D_z$	: components of baseline vector in equatorial coordinates
$\hat{\mathbf{e}}_{\mathbf{u}}$	: unit vector of the astrometric coordinate system, points to $\delta = 0^\circ, h = 0^h$
$\hat{\mathbf{e}}_{\mathbf{v}}$	: unit vector of the astrometric coordinate system, points to $\delta = 0^\circ, h = 6^h$
$\hat{\mathbf{e}}_{\mathbf{w}}$	: unit vector of the astrometric coordinate system, points to $\delta = 90^\circ$
$\hat{\mathbf{e}}_{\mathbf{x}}$	: unit vector of the equatorial coordinate system, points to $\delta = 0^\circ, h = 0^h$
$\hat{\mathbf{e}}_{\mathbf{y}}$	: unit vector of the equatorial coordinate system, points to $\delta = 0^\circ, h = 6^h$
$\hat{\mathbf{e}}_{\mathbf{z}}$	: unit vector of the equatorial coordinate system, points to $\delta = 90^\circ$
$\mathbf{F}$	: response matrix
$F(\mathbf{D}_\lambda, \mathbf{s}_0)$	: fringe function
$F(\mathbf{s}_0)$	: fringe function
$F(\mathbf{s})$	: fringe function
$G$	: grading function
$G$	: (complex) gain factor
$g(u, v)$	: grading function

---

$G(l, m)$	: Synthesized beam (Fourier transform of the grading)
$H(\nu)$	: bandpass shape function
$H_i$	: signal in Hanning tapered frequency channel
$H_{AV}$	: average signal signal in added Hanning tapered channels
$H(\beta)$	: normalized voltage main beam response
$h$	: hour angle
$h_0$	: hour angle of pointing center
$h(t)$	: time cross correlation function
$I$	: Stokes parameter, total intensity (complex)
$I_b(R)$	: integral of synthesized beam of circular area with radius $R$
$J_0$	: zero order Bessel function
$j$	: imaginary unit ( $j = \sqrt{-1}$ )
$K_\lambda$	: Constant involved in noise calculation
$K(\beta)$	: normalized voltage crosstalk term
$k$	: Boltzmann's constant
$L$	: left hand circular = $I - V$
$L_s$	: linear shadowing
$l$	: new galactic longitude
$M$	: factor depending on type of receiver and dipole combination
$N_B$	: Bitmode (equals 1 or 2)
$N_{BL}$	: number of spacings
$N_F$	: number of frequency channels
$N_I$	: number of interferometers
$N_P$	: Number of polarizations
$n$	: an integer vallue
$M$	: scaling factor depending on type of receiver and dipole combination used
$m$	: fraction of polarization
$P$	: percentage polarization
$P_s$	: polarization summation factor
$P_A$	: polarization position angle
$P(R)$	: normalized synthesized beam intensity at radius $R$
$p$	: position angle of the baseline
$Q$	: Stokes parameter, linear polarization component (complex)
$q$	: parallactic angle
$R$	: right hand circular = $I + V$
$\mathbf{R}(\rho)$	: Rotation matrix
$R_{EW}$	: complex response of a polarization interferometer
$RT$	: shorthand for radio telescope
$R_{tel}$	: Telescope response
$r(\mathbf{D}_\lambda, \mathbf{s}_0)$	: response of a correlating array as a function of baseline seperation and pointing direction
$\mathbf{S}$	: coherence matrix
$S_{xx}, S_{xy}, \dots$	: components of the coherence matrix
$S$	: observed flux
$S_0$	: source flux density
$S_m$	: matched flux density
$\mathbf{s}$	: direction vector pointing to arbitrary center
$\mathbf{s}_0$	: direction vector pointing to field center
$s_x, s_y, s_z$	: components of pointingvector in equatorial coordinates
$T_A$	: antenna temperature

---

---

$T_F$	: system temperature of fixed telescope
$T_M$	: system temperature of movable telescope
$T_b$	: brightness temperature
$T_n$	: noise temperature
$T_r$	: temperature of a resistor
$T_s$	: system temperature
$t$	: integration time
$U_i$	: signal in frequency channel $i$
$U$	: Stokes parameter, linear polarization component (complex)
$\mathbf{V}$	: output voltage column vector
$V_x$	: x component of output voltage column vector
$V_y$	: y component output voltage column vector
$V$	: Stokes parameter, circular polarization component (complex)
$W$	: power
$W_A$	: power measured by radio antenna
$W_r$	: power at resistor terminal (Nyquist)
$w$	: spectral power (power per unith bandwidth)
$w_A$	: spectral power (power per unith bandwidth) measured by antenna
XX	: (complex signal in) correlation channel made from dipole X and dipole X in telescope 'p' and 'q' respectively
XY	: (complex signal in) correlation channel made from dipole X and dipole Y in telescope 'p' and 'q' respectively
YY	: (complex signal in) correlation channel made from dipole Y and dipole Y in telescope 'p' and 'q' respectively
YX	: (complex signal in) correlation channel made from dipole Y and dipole X in telescope 'p' and 'q' respectively
$\alpha$	: right accension
$\beta$	: boresight angle
$\beta_f$	: full width at half maximum of the power beam
$\beta_m$	: distance from the center to the point at which the voltage polarization has its maximum
$\beta_0$	: the distance in degrees of the beam center to the first null of the voltage pattern
$\Gamma(u, v, t)$	: coherence function
$\Delta\Phi$	: phase shift
$\delta\nu$	: noise equivalent bandwidth
$\delta$	: declination
$\delta_0$	: declination of pointing center
$\sigma_{av}$	: r.m.s. noise in added frequency channels after (Hanning) tapering
$\delta\nu$	: frequency separation, bandwidth
$\Delta^-$	: (scalar) dipole setting error difference ( $=\Delta_{RTWEST} - \Delta_{RTEAST}$ )
$\Delta^+$	: (scalar) dipole setting error sum ( $=\Delta_{RTWEST} + \Delta_{RTEAST}$ )
$\Delta S$	: error associated with total flux density $S$
$\Delta S_{rms}$	: thermal noise fluctuations in total flux density
$\epsilon$	: (complex small instrumental term ( $=\Delta^- - j\Theta^+$ ))
$\eta_a$	: aperture efficiency
$\eta_g$	: grading efficiency factor
$\eta$	: (complex small instrumental term ( $=\Delta^+ - j\Theta^-$ ))
$\Theta^-$	: (scalar) dipole ellipticity difference ( $=\Theta_{RTWEST} - \Theta_{RTEAST}$ )
$\Theta^+$	: (scalar) dipole ellipticity sum ( $=\Theta_{RTWEST} + \Theta_{RTEAST}$ )
$\nu$	: frequency

---



---

$\Omega_A$	: beam area (integral over the beam)
$\rho$	: rotation angle
$\sigma$	: vector in image plain ( $\sigma = \mathbf{s} - \mathbf{s}_0$ )
$\sigma$	: error associated with matched flux density $S_m$
$\sigma_{XX}, \sigma_{XY}$ , etc:	error associated with matched flux density for different polarizations
$\tau_g$	: geometrical delay
$\tau_i$	: inserted delay
$\Phi$	: latitude
$\Phi_z$	: phase of complex number $z$
$\Phi_{\mathcal{V}}$	: visibility phase
$\chi$	: nominal position angle of dipole
$\chi^+$	: sum of nominal position angle of dipoles = $\chi_W + \chi_E$
$\chi^-$	: nominal position angle of dipole = $\chi_W - \chi_E$
$\mathcal{V}$	: complex visibility
$ \mathcal{V} $	: visibility amplitude
$\mathbf{III}$	: Shah function
$\Re(z)$	: real part of complex number $z$
$\Im(z)$	: imaginary part of complex number $z$
++	: paralel dipoles
+x	: crossed dipoles

---

# WSRT

USER DOCUMENTATION REFERENCES

In the User Documentation we refer to several articles and books. For convenience we included a list of all those references.

- Abramowitz, M. and Stegun, I.A., (1965): "*Handbook of Mathematical functions*" Dover Publications Inc., New York. ISBN 0-486-61272-4.
- Baars, J.W.M., Brugge, J.F. van der, Casse, J.L., Hamaker, J.P., Sondaar, L.H., Visser, J.J. and Wellington, K.J. (1973): *Proc IEEE* **61**, p. 158.
- Baars, J.W.M. and Hooghoudt, B.G. (1974): *Astron. & Astrophys.* **31**, p. 323.
- Blackman, R.B and Tukey, J.W., (1959): "*The measurement of power spectra : from the point of view of communications engineering*". Dover publications, New York. ISBN 0-486-60507-8 first appeared in: Bell system technical journal **37** (1958).
- de Blok and Woudt, (1992): 'WSRT polarization at 21 cm' students radio practicum report.
- Bos, A. (1985): 'On instrumental effects in spectral line observations' Ph.D. Thesis, University of Leiden
- Bos, A. (1993): *NFRA internal tech. report*, **200** (available at NFRA).
- Bos, A., Raimond, E., and Someren Greve, H.W. van (1981): *Astron. & Astrophys.* **98**, p. 251.
- Bracewell, R.N. (1978): "*The Fourier Transform and Its Applications (2nd edition)*" McGraw-Hill International Book Company. ISBN 0-07-007013-X.
- Braun, R. and Walterbos, R.A.M. (1985): *Astron. & Astrophys.* , **143**, p. 307.
- Bregman, J.D. *et al.*(1982): '6 cm bundel van een 25 m SRT spiegel', *NFRA NOTE, Draft* (available at NFRA).
- Bregman, J.D. (1983): 'WSRT antenna pattern reference data', *NFRA NOTE*, **417** (available at NFRA).
- Brouw, W.N. (1971): Ph.D. Thesis, University of Leiden.
- Brouw, W.N. (1974): *NFRA internal tech. report*, **78** (available at NFRA).
- Brouw, W.N. and van Someren Gréve, H.W.(1973): *NFRA internal tech. report*, **112** (available at NFRA).
- Brigham, E.O. (1974): "*The Fast Fourier Transform*" Prentice-Hall.
- Burns, W.R (1972): *Astron. & Astrophys.* , **19**, pp. 41.
- Casse, J.L., Woestenburg, E.E.M. and Visser, J.J. (1981): *I.E.E.E. Trans. Micr. Theory and Techn.*, **30**, 2, pp. 201-209
- Christiansen, W.N. and Högbom, J.A. (1985): "*Radio Telescopes*". Cambridge University Press 1969, 1985(2<sup>nd</sup> ed.). ISBN 0-521-26209-7 (2<sup>nd</sup> ed.) / 0-521-07054-6 (1<sup>st</sup> ed.)(see also review in part II Chapter 9.1, book 4).
- Ekers, R.D. and Rots, A.H. (1979): "Short spacing synthesis from a primary beam scanned interferometer" in Proc. IAU Coll. 49 "*Image Formation from Coherence Functions in Astronomy*", Ed. C. van Schooneveld. D. Reidel (Dordrecht, Holland), pp. 61-66
- Gonzales, C. and Wintz, P. (1987): "*Digital Image Processing*" Addison-Wesley Publishing Company 1987 ISBN 0-201-11026-1.
- Hamaker, J.P. (1979): in '*Image Formation from Coherence Functions in Astronomy*' Ed. Schooneveld, C. D Reidel Publishing Company
- Harris, F. (1978): 'On the use of windows for Harmonic analysis with the discrete Fourier Transform' *Proc IEEE*, **66** no.1, pp. 51-83.

- Henneken and Robijn, (1989): 'WSRT polarization at 327 MHz' students radio practicum report.
- Högbom, J.A. (1974): *Astron. & Astrophys. Suppl.* , **15**, p. 417.
- Högbom, J.A. and Brouw, W.N. (1974): *Astron. & Astrophys.* , **33**, p. 289.
- Kraus, J.D. (1986): "*Radio Astronomy*" (2nd edition) Cygnus-Quasar Books, Ohio. ISBN:- (see also review in part II Chapter 9.1, book 6).
- Lilley and Palmer (1967): *Astrophys. J. Suppl.* **16**, p. 143.
- Lovas, Snyder and Johnson (1979): *Astrophys. J. Suppl.* **41**, p. 451.
- Morris et al (1964): *Astrophys. J.* **139**, p. 551.
- Napier, P.J., Thompson, A.R. and Ekers, R.D. (1983): 'The Very Large Array; Design and Performance of a Modern Synthesis Radio Telescope', *Proc IEEE*, **71**, pp. 1295-1320.
- Noordam, J.E. and de Bruyn, A.G. (1982): *Nature*, **299**, pp. 597-600.
- Perley T.J. and Readhead, A.C.S. (1984): *ARA&A*, **22**, pp. 97.
- Perley, R.A., Schwab, F. and Bridle, A.H. (Editors) (1989): "*Synthesis Imaging in Radio Astronomy*". Astronomical Society of the Pacific.. ISBN:0-937707-23-6. (see also review in part II Chapter 9.1, Book 2).
- Q.M.C. (1978): 'Quality Monitoring Committee report on 6 cm beam properties'.
- Resch, G.M. (1984): 'Water vapour radiometry in geodetic applications', in "*Geodetic refraction, effects of electromagnetic wave propagation through the atmosphere*", ed. F.K. Brunner, Springer Verlag, Berlin, pp.53.
- Rohlfs, K. (1986): "*Tools of Radio Astronomy*". Springer Verlag, Berlin.. ISBN:3-540-16188-0/0-387-16188-0. (see also review in part II Chapter 9.1, book 1).
- Rots, A.H. (1975): Ph.D. Thesis, University of Groningen.
- Someren Greve, H.W. van (1974): *Astron. & Astrophys. Suppl.* , **15**, p. 343.
- Spoelstra, T.A.Th. (1983): *Astron. & Astrophys.* , **120**, pp. 313-321.
- Spoelstra, T.A.Th. (1984): *Radio Science*, **19-no3.**, pp. 779-788.
- Spoelstra, T.A.Th. (1992): 'Ionosphere and Troposphere seen through a Radio Interferometer' in "*Remote Sensing of the Propagation Environment*", AGARD Conference Proceedings 502, Advisory Group for Aerospace Research & Development, Neuilly sur Seine, France.
- Tan, G.H. (1990): *NFRA NOTE*, **555** (available at NFRA).
- Thompson, A.R., Clark, B.G. and Napier, P.J (1980): *Astrophys. J. Suppl.* , **44**, pp. 151-167.
- Thompson, A.R., Moran, J.M. and Swenson Jr., G.W. (1986): "*Interferometry and Synthesis in Radio Astronomy*". John Wiley & Sons, New York.. ISBN 0-471-80614-5. (see also review in part II Chapter 9.1, book 3).
- Verschuur, G.L. and Kellerman, K.I. (Editors) (1988): "*Galactic and Extragalactic Radio Astronomy (2nd edition)*" Springer Verlag, Berlin.. ISBN 0-387-96575-0 / 3-540-96575-0 (see also review in part II Chapter 9.1, book 5).
- Weiler, K.W. (1973): *Astron. & Astrophys.* **403**, p. 403.
- Weiler, K.W., v. Someren Gréve, H.W. and Piersma (1973): '21 cm primary beam properties of the WSRT' *NFRA internal tech. report*, **117** (available at NFRA).
- Weiler, K.W. and Wilson, A.S.(1977): *Astron. & Astrophys.* **58**, pp. 17-26.
- Weiler, K.W. and Raimond E. (1977): *Astron. & Astrophys.* **54**, pp. 965-975.
- Weiler, K.W. and de Pater, I (1980): *Astron. & Astrophys.* **91** p. 41.
- Wieringa, M.H. (1992): *Experimental Astronomy*, **2**, pp.203-225.