The Consultative Committee for Space Data Systems

Recommendation for Space Data System Practices

DELTA-DOR QUASAR CATALOG UPDATE PROCEDURE

RECOMMENDED PRACTICE

CCSDS 506.3-M-1

MAGENTA BOOK
February 2018

The Consultative Committee for Space Data Systems

Recommendation for Space Data System Practices

DELTA-DOR QUASAR CATALOG UPDATE PROCEDURE

RECOMMENDED PRACTICE

CCSDS 506.3-M-1

MAGENTA BOOK

February 2018

AUTHORITY

Issue:	Recommended Practice, Issue 1
Date:	February 2018
Location:	Washington, DC, USA

This document has been approved for publication by the Management Council of the Consultative Committee for Space Data Systems (CCSDS) and represents the consensus technical agreement of the participating CCSDS Member Agencies. The procedure for review and authorization of CCSDS documents is detailed in *Organization and Processes for the Consultative Committee for Space Data Systems* (CCSDS A02.1-Y-4), and the record of Agency participation in the authorization of this document can be obtained from the CCSDS Secretariat at the e-mail address below.

This document is published and maintained by:

CCSDS Secretariat
National Aeronautics and Space Administration
Washington, DC, USA
E-mail: secretariat@mailman.ccsds.org

STATEMENT OF INTENT

The Consultative Committee for Space Data Systems (CCSDS) is an organization officially established by the management of its members. The Committee meets periodically to address data systems problems that are common to all participants, and to formulate sound technical solutions to these problems. Inasmuch as participation in the CCSDS is completely voluntary, the results of Committee actions are termed **Recommendations** and are not in themselves considered binding on any Agency.

CCSDS Recommendations take two forms: **Recommended Standards** that are prescriptive and are the formal vehicles by which CCSDS Agencies create the standards that specify how elements of their space mission support infrastructure shall operate and interoperate with others; and **Recommended Practices** that are more descriptive in nature and are intended to provide general guidance about how to approach a particular problem associated with space mission support. This **Recommended Practice** is issued by, and represents the consensus of, the CCSDS members. Endorsement of this **Recommended Practice** is entirely voluntary and does not imply a commitment by any Agency or organization to implement its recommendations in a prescriptive sense.

No later than five years from its date of issuance, this **Recommended Practice** will be reviewed by the CCSDS to determine whether it should: (1) remain in effect without change; (2) be changed to reflect the impact of new technologies, new requirements, or new directions; or (3) be retired or canceled.

In those instances when a new version of a **Recommended Practice** is issued, existing CCSDS-related member Practices and implementations are not negated or deemed to be non-CCSDS compatible. It is the responsibility of each member to determine when such Practices or implementations are to be modified. Each member is, however, strongly encouraged to direct planning for its new Practices and implementations towards the later version of the Recommended Practice.

FOREWORD

Through the process of normal evolution, it is expected that expansion, deletion, or modification of this document may occur. This Recommended Practice is therefore subject to CCSDS document management and change control procedures, which are defined in the *Organization and Processes for the Consultative Committee for Space Data Systems* (CCSDS A02.1-Y-4). Current versions of CCSDS documents are maintained at the CCSDS Web site:

http://www.ccsds.org/

Questions relating to the contents or status of this document should be sent to the CCSDS Secretariat at the e-mail address indicated on page i.

At time of publication, the active Member and Observer Agencies of the CCSDS were:

Member Agencies

- Agenzia Spaziale Italiana (ASI)/Italy.
- Canadian Space Agency (CSA)/Canada.
- Centre National d'Etudes Spatiales (CNES)/France.
- China National Space Administration (CNSA)/People's Republic of China.
- Deutsches Zentrum für Luft- und Raumfahrt (DLR)/Germany.
- European Space Agency (ESA)/Europe.
- Federal Space Agency (FSA)/Russian Federation.
- Instituto Nacional de Pesquisas Espaciais (INPE)/Brazil.
- Japan Aerospace Exploration Agency (JAXA)/Japan.
- National Aeronautics and Space Administration (NASA)/USA.
- UK Space Agency/United Kingdom.

Observer Agencies

- Austrian Space Agency (ASA)/Austria.
- Belgian Federal Science Policy Office (BFSPO)/Belgium.
- Central Research Institute of Machine Building (TsNIIMash)/Russian Federation.
- China Satellite Launch and Tracking Control General, Beijing Institute of Tracking and Telecommunications Technology (CLTC/BITTT)/China.
- Chinese Academy of Sciences (CAS)/China.
- Chinese Academy of Space Technology (CAST)/China.
- Commonwealth Scientific and Industrial Research Organization (CSIRO)/Australia.
- Danish National Space Center (DNSC)/Denmark.
- Departamento de Ciência e Tecnologia Aeroespacial (DCTA)/Brazil.
- Electronics and Telecommunications Research Institute (ETRI)/Korea.
- European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)/Europe.
- European Telecommunications Satellite Organization (EUTELSAT)/Europe.
- Geo-Informatics and Space Technology Development Agency (GISTDA)/Thailand.
- Hellenic National Space Committee (HNSC)/Greece.
- Indian Space Research Organization (ISRO)/India.
- Institute of Space Research (IKI)/Russian Federation.
- Korea Aerospace Research Institute (KARI)/Korea.
- Ministry of Communications (MOC)/Israel.
- Mohammed Bin Rashid Space Centre (MBRSC)/United Arab Emirates.
- National Institute of Information and Communications Technology (NICT)/Japan.
- National Oceanic and Atmospheric Administration (NOAA)/USA.
- National Space Agency of the Republic of Kazakhstan (NSARK)/Kazakhstan.
- National Space Organization (NSPO)/Chinese Taipei.
- Naval Center for Space Technology (NCST)/USA.
- Research Institute for Particle & Nuclear Physics (KFKI)/Hungary.
- Scientific and Technological Research Council of Turkey (TUBITAK)/Turkey.
- South African National Space Agency (SANSA)/Republic of South Africa.
- Space and Upper Atmosphere Research Commission (SUPARCO)/Pakistan.
- Swedish Space Corporation (SSC)/Sweden.
- Swiss Space Office (SSO)/Switzerland.
- United States Geological Survey (USGS)/USA.

DOCUMENT CONTROL

Document	Title	Date	Status
CCSDS 506.3-M-1	Delta-DOR Quasar Catalog Update Procedure, Recommended Practice, Issue 1	February 2018	Original issue

CONTENTS

Section Page

1 INTRODUCTION 1-1

1.1 PURPOSE 1-1
1.2 APPLICABILITY 1-2
1.3 STRUCTURE OF THIS DOCUMENT 1-2
1.4 NOMENCLATURE 1-2
1.5 DEFINITIONS 1-3
1.6 REFERENCES 1-3

2 OVERVIEW OF THE DELTA-DOR TECHNIQUE 2-1

2.1 SPACECRAFT AND QUASAR OBSERVATIONS 2-1
2.2 RATIONALE 2-2

3 RADIO SOURCE CATALOG SPECIFICATION 3-1

4 CRITERIA FOR ACCEPTING CATALOG UPDATE 4-1

5 STRUCTURE OF THE REGISTRY (PARAMETERS DESCRIPTION/ LEGAL VALUES) 5-1

5.1 OVERVIEW 5-1
5.2 NAME 5-1
5.3 ANGULAR POSITIONS 5-1
5.4 RIGHT ASCENSION ERROR 5-2
5.5 DECLINATION ERROR 5-2
5.6 CORRELATED FLUX DENSITY 5-2
5.7 STRUCTURE INDEX 5-2

ANNEX A PROCEDURE TO UPDATE SANA REGISTRY (NORMATIVE) A-1
ANNEX B SECURITY, SANA, AND PATENT CONSIDERATIONS (INFORMATIVE) B-1
ANNEX C PROCEDURE TO DEVELOP A CATALOG (INFORMATIVE) C-1
ANNEX D EXTRACT AND SAMPLE CATALOG (INFORMATIVE) D-1
ANNEX E ABBREVIATIONS AND ACRONYMS (INFORMATIVE) E-1
ANNEX F INFORMATIVE REFERENCES (INFORMATIVE) F-1

Figure

2-1 Delta-DOR Observation Geometry 2-1
D-1 Sample Page of Radio-Source Catalog D-1

1 INTRODUCTION

1.1 PURPOSE

Delta Differential One-Way Ranging (Delta-DOR) is a Very Long Baseline Interferometry (VLBI) technique that can be used in conjunction with Doppler and ranging data to improve spacecraft navigation by more efficiently determining spacecraft angular position in the plane of sky. It involves the simultaneous use of multiple ground stations, possibly belonging to different agencies, for acquisition of both spacecraft and quasar signals.

The quasar sources required for Delta-DOR measurements have to be known a priori. The quality of a Delta-DOR measurement depends on the availability of compact and strong quasars, together with the knowledge of their precise positions.

Delta-DOR operations require a quasar catalog, geared to Delta-DOR measurements.

Historically, quasar catalogs are populated by astronomers, via VLBI campaigns. This is highly valuable information for Delta-DOR measurements, and established reference catalogs exist today.

The X-band catalog adopted as a starting point for this book is based on the one reported in reference [1]. This catalog has been adopted because it has been developed and used, over the years, to perform Delta-DOR measurements.

This catalog is now available as a SANA registry (reference [3]):

http://sanaregistry.org/r/radio_sources

An update to an X/Ka-band quasar catalog is under preparation.

All space agencies should support the extension of the existing catalog as follows:

a) increasing the number of observed, validated, and cataloged X-band sources;
b) further developing an X/Ka-band catalog;
c) providing separate correlated source flux estimates for each quasar, each frequency band, each baseline;
d) providing information on flux variation versus time on each baseline of interest.

The purpose of this Recommended Practice is to provide:

– specifications for a quasar catalog to be used in Delta-DOR measurements;
– procedures and qualitative criteria to evaluate whether the updates of such catalogs are acceptable;
– description of the registries to be included in a quasar catalog;
– procedures to update SANA entries;
– informative description of building a catalog update.

1.2 APPLICABILITY

This CCSDS Quasar Catalog Update Procedure applies to agencies doing Delta-DOR operations and to all requests to create and manage the quasar catalog registered in the SANA. It shall be binding on the Delta-DOR WG and on all CCSDS member, affiliate, and service provider organizations that supply and manage information for these quasar registries.

1.3 STRUCTURE OF THIS DOCUMENT

In addition to this section, this document contains the following sections and annexes:

– Section 2 provides a general overview of the Delta-DOR technique.

– Section 3 addresses the specifications for a radio source catalog.

– Section 4 describes the criteria for accepting a catalog update to be submitted to SANA.

– Section 5 provides the description of the registry structure.

– Annex A is the procedure to update the SANA registry.

– Annex B addresses security, SANA, and patent considerations.

– Annex C illustrates the procedure to build a quasar catalog.

– Annex D provides an extract of the current catalog.

– Annex E is a list of abbreviations and acronyms applicable to Delta-DOR.

– Annex F is a list of informative references.

1.4 NOMENCLATURE

1.4.1 NORMATIVE TEXT

The following conventions apply for the normative specifications in this Recommended Practice:

a) the words ‘shall’ and ‘must’ imply a binding and verifiable specification;

b) the word ‘should’ implies an optional, but desirable, specification;

c) the word ‘may’ implies an optional specification;

d) the words ‘is’, ‘are’, and ‘will’ imply statements of fact.

NOTE – These conventions do not imply constraints on diction in text that is clearly informative in nature.

1.4.2 INFORMATIVE TEXT

In the normative sections of this document, informative text is set off from the normative specifications either in notes or under one of the following subsection headings:

– Overview;

– Background;

– Rationale;

– Discussion.

1.5 DEFINITIONS

For the purposes of this document, the following definitions apply.

Name: Source name in common usage in astronomical community.

very long baseline interferometry, VLBI: Technique that allows determination of angular position for distant radio sources by measuring the geometric time delay between received radio signals at two geographically separated antennas.

1.6 REFERENCES

The following publications contain provisions which, through reference in this text, constitute provisions of this document. At the time of publication, the editions indicated were valid. All publications are subject to revision, and users of this document are encouraged to investigate the possibility of applying the most recent editions of the publications indicated below. The CCSDS Secretariat maintains a register of currently valid CCSDS publications.

[1] *X-Band Radio Source Catalog*. Module 107, Rev. D, October 22, 2015 in *DSN Telecommunications Link Design Handbook*. DSN No. 810-005.

[2] Alan L. Fey, David Gordon, and Christopher S. Jacobs, eds. *The Second Realization of the International Celestial Reference Frame by Very Long Baseline Interferometry*. IERS Technical Note No. 35. Frankfurt am Main, Germany: IERS, 2009.

[3] "DDOR X-Band Radio Sources." Space Assigned Numbers Authority. http://sanaregistry.org/r/radio_sources

[4] *CCSDS SANA Registry Management Policy*. Issue 1. CCSDS Record (Yellow Book), CCSDS 313.1-Y-1. Washington, D.C.: CCSDS, May 2016.

[5] *Space Assigned Numbers Authority (SANA)—Role, Responsibilities, Policies, and Procedures*. Issue 2. CCSDS Record (Yellow Book), CCSDS 313.0-Y-2. Washington, D.C.: CCSDS, May 2016.

2 OVERVIEW OF THE DELTA-DOR TECHNIQUE

2.1 SPACECRAFT AND QUASAR OBSERVATIONS

Very long baseline interferometry is a technique that allows determination of angular position for distant radio sources by measuring the geometric time delay between received radio signals at two geographically separated stations. The observed time delay is a function of the known baseline vector joining the two radio antennas and the direction to the radio source.

An application of VLBI is spacecraft navigation in space missions where delay measurements of a spacecraft radio signal are compared against similar delay measurements of angularly nearby quasar radio signals. In the case where the spacecraft measurements are obtained from the phases of tones emitted from the spacecraft, first detected separately at each station, and then differenced, this application of VLBI is known as Delta Differential One-Way Ranging. The observation geometry is illustrated in figure 2-1. Even though data acquisition and processing are not identical for the spacecraft and quasar, both types of measurements can be interpreted as delay measurements, and they have similar information content and similar sensitivity to sources of error. The data produced in such a measurement session are complementary to Doppler and ranging data.

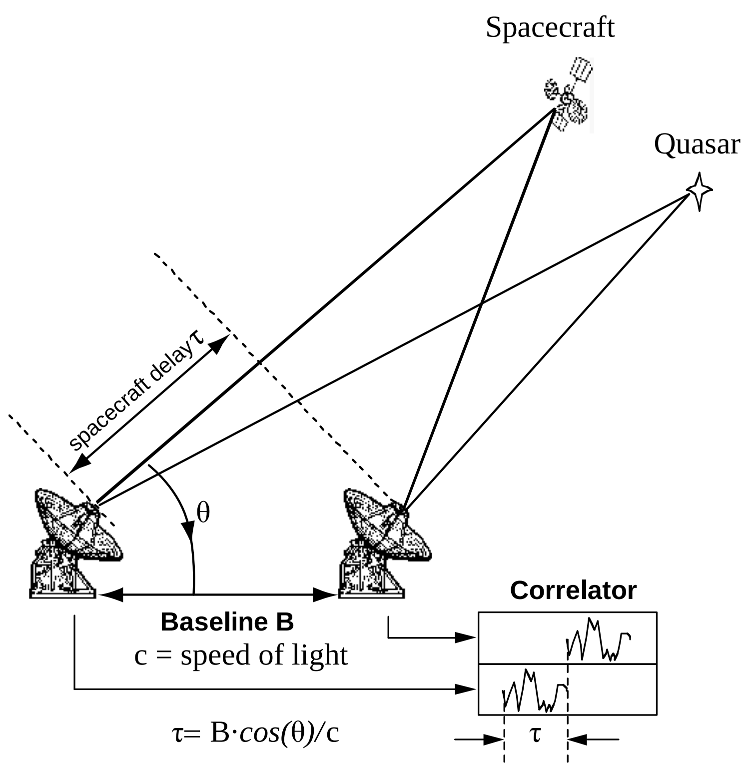

Figure 2-1: Delta-DOR Observation Geometry

2.2 RATIONALE

Quasar sources needed for Delta-DOR measurements have to be known a priori:

– Quasars define a celestial reference frame which is used in the Orbit Determination (OD) process, which makes use of the Delta-DOR measurements.

– In Delta-DOR, the instrument consisting of two or more stations used as an interferometer to measure spacecraft position must be calibrated by observing quasars.

– Up to a few quasars can be used as calibrators of the single spacecraft (S/C) DOR measurement.

The quality of a Delta-DOR measurement depends on the availability of:

– Compact sources: This kind of source (e.g., point-like) allows a better identification of a defined source position in the plane-of-sky, thus enabling better determination of the calibrator position to be used in the measurement.

– Knowledge of quasar source precise positions and related uncertainty: This knowledge is needed since the quasar delay is used to calibrate the Delta-DOR measurement. Ideally, a perfectly known quasar position would lead to better determination of spacecraft position in the celestial reference frame.

– Strong quasars (correlated flux density): A strong correlated flux is a desirable property, since it allows better jitter performance in the quasar delay computation with a limited integration time. Unfortunately, correlated flux can be highly variable over time, and therefore there is little control on this parameter. Often a trade-off is necessary between different quasars near the tracked S/C to identify the best source(s) to be used as calibrators.

– Sources angularly close to the target S/C: Such property is important to ensure spatial coherency between the S/C and the quasar delay measurement, thus enabling better calibration performance.

These properties are required in a quasar catalog that is geared to Delta-DOR measurements. The catalog must specifically address the four properties cited above and cover the frequencies that are normally used in deep space operations: X-band (8.4 – 8.5 GHz) and Ka-band (31.8 – 32.3 GHz).

Quasar measurements made for Delta-DOR use tend to be limited in sensitivity as compared to measurements made for astrometric and geodetic purposes. Also, since most of the deep space missions are flown in the solar system ecliptic plane, there is a particular interest in having a higher number of sources near the ecliptic plane.

For the actual planning of a Delta-DOR measurement, the catalog is searched to find candidate sources that are angularly close to the spacecraft position at the measurement time, compact, and of sufficient flux.

Specific sources are selected for observation based on the criteria of minimizing measurement error. This process is further described in *Delta-DOR—Technical Characteristics and Performance* (reference [F2]).

3 RADIO SOURCE CATALOG SPECIFICATION

3.1 A common radio source catalog shall be used by all space agencies to facilitate consistency in radio source selection, pointing, and correlating.

3.2 The catalog shall provide, as a minimum:

a) a unique name for each radio source (see section 5);

b) coordinates and coordinate uncertainties for each radio source;

c) an estimate of flux and structure (i.e., apparent coordinate variability) for at least the radio sources that are likely to be used for Delta-DOR observations.

3.3 The catalog may contain a full or partial correlation matrix for source coordinate uncertainty.

3.4 The SANA radio source catalog (reference [3]) should be used as the standard Delta-DOR catalog.

NOTE – The SANA registry is based on the JPL catalog (reference [1]). It meets the minimum requirements, as defined in 3.2, and is updated as new survey work is completed. It should be noted that up-to-date flux estimates and structure estimates are not available for all radio sources.

4 CRITERIA FOR ACCEPTING CATALOG UPDATE

4.1 The proposed new quasar catalog, to be submitted to SANA, shall contain at least the information as specified in 3.2.

NOTE – A catalog update is always presented as a complete new catalog (see A2.1).

4.2 The proposed new catalog shall be presented with documentation, as described in 4.3, that can be used to judge the suitability of such catalog for Delta-DOR applications.

4.3 The accompanying documentation should include, as a minimum:

a) description/reference to models used for

 1) tropospheric/ionospheric calibrations,

 2) terrestrial reference frame,

 3) Earth orientation parameters,

 4) uncertainty of the coordinates noise floor;

b) number of observations and related information on timespan over which such observations have been taken;

c) number and distribution of sources;

d) comparison of the proposed catalog with the ICRF2 reference frame (reference [2]).

4.4 All new sources shall have a unique name. No existing name shall be changed.

4.5 The proposed updated catalog shall be reviewed by a group that is qualified to perform this task, e.g., by the Delta-DOR Working Group (while it exists) or other external expert group called the Radio Catalog Expert Group.

4.6 The Radio Catalog Expert Group is formed by volunteers from related fields with expertise in VLBI and spacecraft tracking and navigation. Initial membership shall be the members of the D-DOR WG and other experts, by invitation.

4.7 The Radio Catalog Expert Group is only required to meet electronically, using the CCSDS mailing list D-DOR-RCEG@mailman.ccsds.org. The group shall review any proposed catalog updates by an email poll, or by teleconference if more discussion is required.

5 STRUCTURE OF THE REGISTRY (PARAMETERS DESCRIPTION/ LEGAL VALUES)

5.1 OVERVIEW

Structure of the registry and parameter description are given hereafter (an example of the catalog is in annex D):

5.2 NAME

The Name field contains the name most commonly used in the literature for the source.

5.3 ANGULAR POSITIONS

5.3.1 OVERVIEW

5.3.1.1 The Angular positions shall be specified by a pair of angular coordinates: RA and DEC. It should be noted that while right ascension used to be defined as the angular distance along the celestial equator from the intersection of the equator and the ecliptic, but this is no longer true once one becomes concerned with accuracy levels < 100 milliarcseconds (500 nrad).

5.3.1.2 Since 1 January 1998, right ascension, and most importantly the origin of RA, have been defined by conventional agreement as to the value of the RA of extragalactic radio sources. In practice this means that the axes implicitly defined by a set of source positions must agree with the ICRF2 (reference [2]) to within the formal uncertainty of the ICRF2 axes, or approximately 10 µas (1 standard deviation). Thus the orientation of the celestial frame axes may vary in future realizations by roughly that amount.

5.3.1.3 RA and DEC are given in the J2000 reference frame (reference [2]).

5.3.2 RIGHT ASCENSION

Right Ascension shall be presented in the form '*HH MM SS.ssssssss*', where the first subfield gives hours of RA followed by (time) minutes of RA and (time) seconds of RA to eight decimal places.

5.3.3 DECLINATION

Declination shall be presented in the form '*Sign DD MM SS.sssssss*', where

– the first subfield, *Sign*, gives the sign of declination (a blank is allowed and is interpreted as a positive declination);

– the remaining subfields give angular declination in degrees, minutes, and seconds to seven decimal places.

NOTE – A minus sign applies to the whole declination (*DD MM SS.sssssss*). For example, a declination of –00 00 00.*sssssss* is read as minus 0.*sssssss* arcseconds of declination. This means that users desiring decimal representations of declination must first convert from degrees, minutes, seconds format to decimal format before applying the relevant sign.

5.4 RIGHT ASCENSION ERROR

Right Ascension Error (RA Error) shall provide the formal one standard deviation right ascension uncertainty in units of seconds of time.

5.5 DECLINATION ERROR

Declination Error (DEC Error) shall provide the formal one standard deviation declination uncertainty in units of arcseconds of angle.

5.6 CORRELATED FLUX DENSITY

5.6.1 The Correlated Flux Density is an estimate of the average correlated flux density for observations along particular baselines. Average correlated flux density values should be reported for each baseline when available. This value, in Janskys (Jy), is computed from the measured signal-to-noise ratio (SNR), based on a normalized sampling rate, using the formula:

$$S(Jy) \approx SNR/150$$

5.6.2 The SNR is determined during the cross-correlation and fringe-fitting of actual radio source observations. If no recent observations of a radio source are available, no value shall provided for correlated flux. Independent values for the correlated flux density on different baselines shall be reported in the catalog.

NOTE – Correlated flux densities are only given for the Goldstone-Madrid and Goldstone-Canberra baselines. A new catalog may contain more flux information from other baselines.

5.7 STRUCTURE INDEX

5.7.1 The Structure Index shall be determined through the following relationship between the radio source structure index and the median value of the VLBI structure delay corrections (reference [2]):

$$SI = 1 + 2 \log(\tau_{median})$$

NOTE – Here SI is the structure index, and τ_{median} is the median value of the structure delay corrections (ps). A value for τ_{median} in the range of 0–40 ps is typical for a source that is point-like. A value in the range of 40–60 ps is typical for a source that has significant structure. The source structure itself can contribute an error of this magnitude to the delay error budget. Values of the delay scatter greater than 60 ps are typical for sources with large, extended, and possibly variable structure.

5.7.2 The values shall be inserted only when reliable information on such quantity are available; otherwise the field shall be left blank.

ANNEX A

PROCEDURE TO UPDATE SANA REGISTRY

(NORMATIVE)

A1 OVERVIEW

The procedure to update the SANA quasar catalog is defined here.

A2 PROCEDURE

A2.1 The catalog update shall be of the complete catalog (i.e., it shall include both sources that are already present within the published catalog, as well as new proposed sources); ‘deltas’ with respect to an existing catalog will not be accepted.

A2.2 The catalog update shall be reviewed by the Radio Catalog Expert Group.

A2.3 The Radio Catalog Expert Group shall apply the following criteria to determine whether to authorize the new catalog:

a) completeness of the proposed catalog in terms of information given within the catalog description, as defined in section 3;

b) applicability of the catalog to Delta-DOR operations (e.g., relevance of the frequency band of the proposed catalog);

c) applicability of the minimum acceptance criteria illustrated in section 4.

NOTE – The Radio Catalog Expert Group is in charge of assessing any new candidate catalog and deciding when and if the SANA registry will be updated.

A2.4 Once accepted by the Radio Catalog Expert Group, the catalog will be submitted by the group to SANA for Registry update.

A2.5 The format in which the catalog is submitted is an Excel spreadsheet with column titles as specified in section 5.

ANNEX B

SECURITY, SANA, AND PATENT CONSIDERATIONS

(INFORMATIVE)

B1 SECURITY CONSIDERATIONS

B1.1 OVERVIEW

This annex presents the results of an analysis of security considerations applied to the technologies specified in this Recommended Practice.

B1.2 CONSEQUENCES OF NOT APPLYING SECURITY TO THE TECHNOLOGY

The consequences of not applying security to the systems and networks on which this Recommended Practice is implemented could include potential loss, corruption, and theft of data.

B1.3 POTENTIAL THREATS AND ATTACK SCENARIOS

Potential threats or attack scenarios include, but are not limited to, (a) unauthorized access to the programs/processes that generate and interpret the messages, and (b) unauthorized access to the messages during transmission between exchange partners. Protection from unauthorized access during transmission is especially important if the mission utilizes open ground networks such as the Internet to provide ground-station connectivity for the exchange of data. It is strongly recommended that potential threats or attack scenarios applicable to the systems and networks on which this Recommended Practice is implemented be addressed by the management of those systems and networks, and that adequate authentication, suitable protocols, and secured interfaces for the exchange of this information be utilized.

B1.4 SECURITY CONCERNS RELATED TO THIS RECOMMENDED PRACTICE

B1.4.1 Data Privacy

Privacy of data formatted in compliance with the specifications of this Recommended Practice should be assured by the systems and networks on which this Recommended Practice is implemented.

B1.4.2 Data integrity

Integrity of data formatted in compliance with the specifications of this Recommended Practice should be assured by the systems and networks on which this Recommended Practice is implemented.

B1.4.3 Authentication of Communicating Entities

Authentication of communicating entities involved in the transport of data which complies with the specifications of this Recommended Practice should be provided by the systems and networks on which this Recommended Practice is implemented.

B1.4.4 Data Transfer Between Communicating Entities

The transfer of data formatted in compliance with this Recommended Practice between communicating entities should be accomplished via secure mechanisms approved by the IT Security functionaries of exchange participants.

B1.4.5 Control of Access to Resources

This Recommended Practice assumes that control of access to resources will be managed by the systems upon which provider formatting and recipient processing are performed.

B1.4.6 Auditing of Resource Usage

Auditing of resource usage should be handled by the management of systems and networks on which this Recommended Practice is implemented.

B1.5 UNAUTHORIZED ACCESS

Unauthorized access to the programs/processes that generate and interpret the messages should be prohibited in order to minimize potential threats and attack scenarios.

B1.6 DATA SECURITY IMPLEMENTATION SPECIFICS

Specific information-security interoperability provisions that may apply between agencies involved in an exchange of data formatted in compliance with this Recommended Practice should be specified in an ICD.

B2 SANA CONSIDERATIONS

B2.1 GENERAL

The recommendations of this document rely on the SANA registries described below. New assignments in these registries, in conformance with the policies identified, will be available at the SANA registry Web site: http://sanaregistry.org. Therefore the reader needs to look at the SANA Web site for all the assignments contained in these registries.

B2.2 REGISTRY FOR RADIO SOURCE

The DDOR X-Band Radio Sources Registry contains the fields defined in section 5 of this Magenta Book. The registry is located at

http://sanaregistry.org/r/radio_sources

The procedure to update this Registry is defined in annex A of this Magenta Book.

The policy that governs updates to this Registry is as follows:

a) The SANA implements a Quasar Catalog Registry.

b) The Review Authority for the Quasar Catalog Registry is the Radio Catalog Expert Group.

c) The Registration Rule for the Terminology Registry is b) Change requires an engineering review by a designated expert or group (cf. reference [5]).

d) Each Quasar Catalog Registry entry includes: unique identifier, right ascension, declination, right ascension error, declination error, source flux in the band of interest (X and Ka), structure index.

e) The request for quasar catalog entry assigns and provides a unique ISO OID for the quasar.

f) The update policy of the quasar catalog is for the entire quasar catalog. No single entries of the catalog can be updated.

B3 PATENT CONSIDERATIONS

No patent rights are known to adhere to any of the specifications of the Recommended Practice.

ANNEX C

PROCEDURE TO DEVELOP A CATALOG

(INFORMATIVE)

C1 INTRODUCTION

The following is an informative description of the process used to do observations and process data in order to develop a catalog. General references on VLBI and source position estimation are provided in annex F.

C2 ORGANIZING A CAMPAIGN

The radio catalog engineer organizes an observing campaign.

a) Goals: First the goals of the campaign are set. These goals may include improving the overall accuracy of the radio frame, updating the fluxes to account for variable sources, and making the catalog more dense in a region of interest such as the area near a planetary encounter with compact and strong sources.

b) Source selection: Based on the goals defined in the previous step, candidate sources are selected from assorted radio surveys. These candidates are intended to be added to the existing list of proven sources.

c) General considerations of observation configuration: Next, a specific set of observations is planned. This includes applying for observing time on various sets of antennas, designing the placement of channels, and finally designing the sequence of observations: source, RA, Dec, start time, and source integration time.

d) Input data description (example): Inputs to the scheduling of the sequence include the list of sources, a catalog of RA, Dec in J2000, a catalog of station positions, scanning mode(s), slew rates, Azimuth/Elevation limits.

C3 PERFORMING A CAMPAIGN TO ACQUIRE DATA

General description (VLBI data): At this stage a set of antenna pointing predicts are first generated and then delivered to the stations, and a set of channel frequencies and other configuration information are provided for the VLBI backend and data recorder. This will also include the start/stop times for each observations of a source. This information is used to acquire data from multiple stations that are then transferred to a central location for correlation purposes.

NOTE – Delta-DOR Raw Data Exchange Format (RDEF) (reference [F3]) can be used for the purpose of exchanging raw data, but is not mandatory.

C4 PROCESSING DATA

C4.1 Correlation processing: Correlation processing is done for each baseline connecting two antennas that provided observations. A day's worth of radio catalog observations can produce several TBytes of data recorded at rates from 128 to 4096 Mb/s. As a result, it is necessary to run an initial stage of signal processing which cross-correlates (multiplies with a set of lags) the data samples from each pair of stations and averages the cross correlation sums to a moderate rate, typically about one normal point per second.

C4.2 Fringe fitting: The correlation output for a set of time and frequency points is then sent to the fringe fitting stage (reference [F6]), where it is Fourier transformed in order to produce a-priori estimates of delay and phase rate, which are used to correct cycle slips, and then to bootstrap least squares final estimate of group delay and phase rate.

C4.3 Preliminary observable modeling and parameter adjustment: The group delays and phase rates are then sent to a sophisticated model that accounts for geometry, relativity, geophysical effects, atmospheric effects, instrumental drifts, etc. After modeling the residual group delays and phase rates, a least-squares parameter adjustment is entered to refine parameters of interest, such as source RA, Dec, station locations, as well as 'nuisance parameters' to account for the instrumentation, and troposphere (reference [F5]).

C4.4 Data editing: Once the preliminary modeling and parameter adjustment is done, the resulting residuals are examined for outliers. Outliers are then either removed or, if resources allow, the fringe fitting stage is revisited to look for the cause of the outlier from antennas being late on source, dead channels, RFI, etc. If a cause is found then the data processing can be iterated to produce a corrected data set.

C4.5 Run global solution: The corrected data set from a day's observing is then merged into the cumulative database of all radio catalog observations. Then the modeling and parameter estimation stages are run on the merged data set to produce the RA, Dec, and other parameters. The set of RA and Dec parameters and the related error estimations are the raw catalog (see reference [F5]).

C5 VALIDATING RESULTS

In order to validate the global solution, two types of verification are done: internal and external.

a) Internal verification: This task examines the RMS scatter of delay residuals, station locations, nutation parameters, clocks, and tropospheres and compares them against expected values and/or known standard models.

b) External verification: This task compares the candidate catalog against the International Astronomical Union's (IAU) International Celestial Reference Frame (e.g., ICRF2) and other high-quality radio catalogs. At this stage, the analyst verifies that the candidate catalog is rotationally aligned with the ICRF, that zonal trends are within required limits, and RA/Dec scatter versus other catalogs is at the expected levels. Once these checks are done the catalog is ready to be provided to the Radio Catalog Expert Group for consideration to be submitted to SANA as an updated catalog.

ANNEX D

EXTRACT AND SAMPLE CATALOG

(INFORMATIVE)

Figure D-1 is a page, provided for reference, from the current quasar catalog (reference [1]).

	Right Ascension				Declination			RA error	DEC error	Source Flux (Jy)		SI
Name	HH	MM	SS.sssss	Sign	DD	MM	SS.ssssss	(s)	(asec)	GDS-MAD	GDS-CAN	
2357-326	0	0	20.39996	-	32	21	1.2341485	3.61E-05	0.001007			
2358+406	0	0	53.08159		40	54	1.7931619	0.000154	0.002037			
2358-161	0	1	5.328731	-	15	51	7.0756294	3.48E-05	0.000984			
2358+605	0	1	7.099627		60	51	22.8028338	0.000305	0.003409			
2358+189	0	1	8.62157		19	14	33.8016881	4.03E-06	7.45E-05			
2359-221	0	2	11.98152	-	21	53	9.8647879	0.000136	0.003339			
0000-199	0	3	15.94945	-	19	41	50.4043557	0.00018	0.007192			
0000-197	0	3	18.67501	-	19	27	22.3553356	3.46E-05	0.000954			
0000+212	0	3	19.35002		21	29	44.5078137	3.32E-05	0.000955			
0001+478	0	3	46.03099		48	7	4.2008098	0.021676	0.132364			
0001-120	0	4	4.915003	-	11	48	58.3857125	1.2E-05	0.000403			
0001+459	0	4	16.12766		46	15	17.9701176	2.78E-05	0.000585			
0002-478	0	4	35.65549	-	47	36	19.6040785	1.15E-05	0.000201			
0002+200	0	4	35.7583		20	19	42.3173063	1.46E-05	0.000275			
0002+541	0	5	4.363398		54	28	24.9248304	4E-05	0.00038	0.22		
0002-170	0	5	17.93378	-	16	48	4.6787946	2.82E-05	0.000904			
0002+051	0	5	20.21555		5	24	10.8005007	0.000132	0.002139			
GC 0003+	0	5	57.17539		38	20	15.1490655	5.25E-06	7.55E-05	0.3	0.4	3.4
0003-302	0	6	1.123205	-	29	55	50.096628	0.000202	0.005681			
0003+340	0	6	7.382583		34	22	20.4058169	1.85E-05	0.000474			
0003-066	0	6	13.89289		-6	23	35.3354137	3.4E-06	5.37E-05	1.07	1.01	3.1
0003+123	0	6	23.05612		12	35	53.0973123	5.77E-05	0.001051			
0004+240	0	6	48.7894		24	22	36.3929012	7.46E-05	0.001362			
0005+568	0	7	48.46856		57	6	10.4391862	0.000305	0.003235			
0005-239	0	8	0.369657	-	23	39	18.1508447	2.57E-05	0.000746			
0005+114	0	8	0.838337		11	44	0.7746711	5.79E-05	0.00107			
0005-262	0	8	26.25253	-	25	59	11.5391634	3.83E-05	0.001258			
0005+683	0	8	33.4727		68	37	22.048025	0.000391	0.001454			
0006-363	0	8	33.66109	-	36	1	25.0414158	0.000122	0.005695			
0006+061	0	9	3.931849		6	28	21.2400688	9.5E-06	0.000263	0.12	0.12	
0006+397	0	9	4.17358		40	1	46.7048409	3.07E-05	0.000643			
0007-325	0	9	35.55782	-	32	16	36.9309139	4.66E-05	0.001102			
0007+439	0	10	30.04645		44	12	42.5044093	2.93E-05	0.000869			
III ZW 2	0	10	31.00591		10	58	29.504194	3.82E-06	6.23E-05			0.9
GC 0007+	0	10	33.99061		17	24	18.7612505	5.34E-06	9.46E-05	0.17	0.11	3.7
0008-311	0	10	34.90968	-	30	54	15.3008586	4.8E-05	0.001719			
0008-307	0	10	35.74238	-	30	27	47.4164553	0.000145	0.004305			
0008-300	0	10	45.17732	-	29	45	13.1769533	5.09E-05	0.002702			
P 0008-42	0	10	52.51757	-	41	53	10.7751151	0.000248	0.008466			

Figure D-1: Sample Page of Radio-Source Catalog

ANNEX E

ABBREVIATIONS AND ACRONYMS

(INFORMATIVE)

Abbreviations used in this document are defined with the first textual use of the term. All abbreviations used in this document are listed below.

Term	Meaning
CCSDS	Consultative Committee for Space Data Systems
DDOR	Delta-DOR
Dec	declination
Delta-DOR	delta differential one-way range
DOR	differential one-way range
DSN	Deep Space Network
ESA	European Space Agency
G/T	antenna gain to system noise temperature ratio
Hz	Hertz
IAU	International Astronomical Union
ICRF	International Celestial Reference Frame
ID	identifier
IF	interface
J2000	J2000 reference frame (as per ICRF, reference [2])
JAXA	Japan Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory
Jy	Jansky

NASA	National Aeronautics and Space Administration
nrad	nanoradian(s)
OD	orbit determination
OID	object identifier
ps	picosecond(s)
RA	right ascension
RDEF	[Delta-DOR] Raw Data Exchange Format
RF	radio frequency
RFI	radio frequency interference
SANA	Space Assigned Number Authority
S/C	spacecraft
SNR	signal-to-noise ratio
VLBI	very long baseline interferometry

ANNEX F

INFORMATIVE REFERENCES

(INFORMATIVE)

[F1] *Delta-Differential One Way Ranging (Delta-DOR) Operations*. Issue 2. Recommendation for Space Data System Practices (Magenta Book), CCSDS 506.0-M-2. Washington, D.C.: CCSDS, February 2018.

[F2] *Delta-DOR—Technical Characteristics and Performance*. Issue 1. Report Concerning Space Data System Standards (Green Book), CCSDS 500.1-G-1. Washington, D.C.: CCSDS, May 2013.

[F3] *Delta-DOR Raw Data Exchange Format*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 506.1-B-1. Washington, D.C.: CCSDS, June 2013.

[F4] M. J. L. Kesteven and A. H. Bridle. "Index of Extragalactic Radio-Source Catalogs." *Journal of the Royal Astronomical Society of Canada* 71, no. 1 (February 1977): 21–39.

[F5] Ojars J. Sovers, John L. Fanselow, and Christopher S. Jacobs. "Astrometry and Geodesy with Radio Interferometry: Experiments, Models, Results." *Reviews of Modern Physics* 70, no. 4 (October 1998): 1393.

[F6] J.B. Thomas. *Interferometry Theory for the Block II Processor*. JPL Publication 87-29. Pasadena, California: JPL, October 15, 1987.