ESCS (ENHANCED SINGLE-DISH CONTROL SYSTEM)

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The advent of new-generation microwave receivers, with multi-beam configurations, instantaneous bandwidth up to 2 GHz wide and a few tens of simultaneous channels, forces the complete re-design of the observation management system for the Medicina 32-m dish. Our goal is to enable the antenna to perform high-sensitivity deep surveys in single-dish mode - in continuum, spectrometry and polarimetry.

This requires innovation in the control management and execution of the observations. The upgrade - which involves different aspects such as noise calibration for gain stability, on-the-fly mapping procedures, data output format and archiving - is expected to improve the continuum sensitivity by about two orders of magnitude. The new system is called ESCS (Enhanced Single-dish Control System).

In addition, following RadioNet recommendations, we are working on a new User Support System including telescope manuals, Exposure Time Calculators and an electronic proposal submission tool based on the Northstar software developed by Synergy (a working group on RadioNet facility integration) and ASTRON (the Netherlands Foundation for Research in Astronomy).

The overall upgrade will make the Medicina antenna one of the prime instruments for high-frequency continuum observations, as it combines both the necessary sensitivity and resolution for an efficient survey of large regions of the sky. The scientific goals of this work are manifold and range from Galactic studies to searches for specific extragalactic sources (e.g. young radio galaxies) up to cosmological applications. The system will also be an important instrument for any kind of high-frequency follow-up.

Design and development instruments and system requirements have been identified for the ESCS system, at present under construction.

This document provides brief descriptions of these preliminary stages.

ESCS DESIGN AND DEVELOPMENT INSTRUMENTS

The main software/hardware instruments to develop the ESCS system have been identified in:

- Unix-Linux platform
- ACS (Antenna Control System) framework
- PCs - other machines
- TCP/IP and CORBA communication protocols
- C++ as programming language, Python for scripting
- QT libraries and JAVA for GUI
- Doxygen as automatic documentation tool
- UML (Unified Modelling Language) to schematise the system architecture

A draft version of the system diagram will be produced following a list of the main contents. This diagram will suggest priorities, task distributions and deadlines.

ESCS SYSTEM REQUIREMENTS

1. OBSERVING MODES

- 1.1. Modes list
  - 1.1.1. Tracking
    - 1.1.1.1. Position switching
    - 1.1.1.2. Raster scan
    - 1.1.1.3. Beam switching
  - 1.1.2. On The Fly scan
    - 1.1.2.1. Cross scan
    - 1.1.2.2. Beam switching OTF
    - 1.1.2.3. Spiral scan
  - 1.1.3. Wobbling
  - 1.1.4. Frequency switching
- 1.2. Antenna pointing
  - 1.2.1. Coordinate systems
- 1.3. Subreflector
- 1.4. Derotator
- 1.5. Safety rules: antenna auto-parking
- 1.6. Dynamical antenna time allocation

2. CALIBRATIONS

- 2.1. Pointing
  - 2.1.1. Use of metrological facilities
- 2.2. Antenna Gain
- 2.3. Focus
- 2.4. Atmospheric attenuation
- 2.5. Flux
- 2.6. Polarisation
- 2.7. Multi-beam geometry
- 2.8. RFI monitoring

3. DATA ACQUISITION

- 3.1. Common Graphic User Interface (GUI)
  - 3.1.1. Textual shells for expert users
- 3.2. Scheduling
- 3.3. Receiver switching and setup
- 3.4. Backend switching and setup
- 3.5. Data rate and synchronisation
- 3.6. Housekeeping data collection and management
- 3.7. Multiple backend usage
- 3.8. Guest backends/software

1 OBSERVING MODES

1.1 Modes list

1.1.1 Tracking: proper tools must allow to perform sidereal tracking, along with more complex modes – by means of constant and variable rates applied to the coordinates; an internal ephemeris calculator could be implemented to track Solar System objects starting from their orbital parameters;

1.1.1.1 Position switching: alternate on-source and off-source acquisitions;

1.1.1.2 Raster scan: sequence of discrete tracking acquisitions to map a given area of the sky;

1.1.1.3 Beam switching: two beams are employed, one is kept on-source, the other off-source. Periodical inversion of the beams, achieved with a different pointing, is allowed to take into account the different gains.

1.1.2 On-The-Fly scan: the antenna performs a scan using a constant rate on a well defined sky target - identified by means of user defined parameters, such as start and end position. Usually the scan is along the great circle connecting the two points, unless differently specified (e.g. pure R.A. scan at a constant Dec.). Sequences of scans can be appropriately set to map a defined area of the sky (usually by scripts generating a schedule of the scan sequence once provided centre coordinates, area size and grid step). Users can select the beams to be employed: using two or three aligned beams only, the source is scanned and a proper ON-OFF operation is performed off-line to remove the atmospheric contribution. The single acquisition is very fast – e.g. the rate should allow to scan a beam in down to 0.1 seconds. According to the receiver gain calibration procedure (see § 3.5) the acquisition rate should be as fast as 100 Hz. The user should be able to set scan coordinates in the Celestial, Galactic and Horizontal systems, at least;

1.1.2.1 Cross-scan: two orthogonal scans centred on the source;

1.1.2.2 Beam switching OTF: two non-aligned beams respectively scan the source and an adjacent sky area. Periodical inversion of the beams is allowed to take into account the different gains.

1.1.2.3 Spiral scan: starting from a central point, the scan takes place moving the antenna along an outward spiral.

1.1.3 Wobbling: on-source and off-source acquisitions are achieved tilting the subreflector. The possible movements vary accordingly to the receiver position and the beam width. Mechanical constraints allow a maximum wobbling frequency of about 1Hz;

1.1.4 Frequency switching**:** the spectral observations are performed always tracking on-source and varying the local oscillator frequency, in order to alternate the line position in different portions of the sampled band.

Tracking and OTF-scan modes have been identified as those to be implemented with highest priority.

1.2 **Antenna pointing**

The privileged operating mode is the "time-tagged program track". It minimises the load for the station computer and offers the best tracking quality. It is widely independent of the latency fluctuations in the computers and in the communication line.
The pointing model rms is required to reach the value of 0.1*HPBW.

1.2.1 Coordinate systems

For any given observing mode, users must be allowed to insert the source coordinates in the system they prefer (Equatorial, Horizontal, Galactic, etc…). The system is in charge of converting them to the altazimuth commands needed to point the antenna.

1.3 Subreflector

The system must take care of the secondary mirror movements. On the backup structure 3 mechanical actuators are installed and allow the mirror to tilt around the x and y axes. Besides the whole system can translate along the x and y axis. These adjustments are aimed at conveying the incoming radio waves to the selected secondary focus feed, and can be exploited to perform wobbling observations and focus tuning.
The mirror must be completely retracted along the y axis when the primary focus is used (this fulfils the frequency agility requirements).

1.4 Derotator

To use the derotator, which is to be installed for the 22 GHz multi-beam, it is necessary to develop a specific software tool. It is to be noticed that several kinds of observations do not require the field to be derotated, so the derotator activation must be optional.

Derotator specifications:

	Medicina	***SRT***
Rotation range (°)	±130	±120
Rotation speed (°/sec)	4.37	4.37
Positioning Accuracy (arcsec, on sky)	0.055	0.036
Positioning Resolution (arcsec, on sky)	0.020	0.013

1.5 Safety rules: antenna auto-parking

To minimise damage risks an automatic antenna-parking system must activate in extreme weather conditions.

1.6 Dynamical antenna time allocation

The constant updates on the antenna status and on the site conditions allow a dynamical allocation of the antenna time. It is possible to run high-priority observations – e.g. requiring low atmospheric opacity – only if weather conditions are sufficiently good, otherwise starting the “normal” observations. This kind of management requires the definition of parameter thresholds and the presence of operators who take care of the observation switch in real-time.

2 CALIBRATIONS

To achieve better performance, it is useful to include a “calibration start-up” at the beginning of every observing run.

Measurements useful to calibrate the observations and track the antenna performance should be obtained periodically (at least daily, depending on weather conditions and observing frequency). Non-invasive procedures – such as the measurement of meteorological parameters – can be frequently performed during the observation and stored in the station log and/or within the output files. All the setup and calibration procedures are meant to be stored in local files and are available to the local staff to obtain statistics and useful data for the antenna monitoring.

2.1 Pointing

The procedure consists of performing cross-scans on point-source calibrators to obtain updated information on pointing accuracy. A similar procedure already exists in the Field System (FIVEPT command), and could inspire the development of such a tool. The present FS pointing model seems to be accurate enough up to 22 GHz (see par. 1.2) and could be used in the ESCS system.

2.1.1 Use of metrological facilities

To obtain a higher precision pointing, several devices could be activated and monitored on-line – e.g. inclinometers (already available) or temperature sensors (already available on the alidade, to be installed on the quadrupod). The metrology group of the Sardinia RadioTelescope (SRT) is already working on this task.

However, it is not clear, yet, how to relate the measured parameters with the pointing error. There are delays between the inclinometer measurement – monitoring the alidade deformations – and the pointing error, and their correlation is not perfect. In addition, the quadrupod deformations cannot be quantified. Further data must be collected on this topic, and the metrology group could exploit external personnel to complete this task.

2.2 Antenna Gain

Periodic calibration campaigns produce a model of the antenna gravitational deformations. Further elements must be taken into account, introducing calibration procedures to be carried out during the observation sessions, since:

- different beams are expected to show different gains (requiring flat-field acquisitions);
- multi-beam gravitational deformations must be taken into account;

2.3 Focus

Moving the antenna during daytime, the different exposure to solar heat produces temperature variations and, as a consequence, focus migration: focus calibration is needed. The way to achieve it for a multi-beam receiver is being studied. The focus position could be determined performing a cross-scan on a strong source and finding the subreflector placement which maximises the received power. Various radiotelescopes (such as the GBT and Effelsberg antennas) provide the user with an auto-focus tool, which could be usefully implemented in our system as well. However, it is to be ascertained whether extremely accurate and frequent calibrations are necessary for the 32-m dish – it is possible that a lower-accuracy procedure, involving temperature sensors only, is enough.

Is a Z-axis migration possible? The cross-scan can only calibrate X&Y migrations. Repeated cross-scans at different Z to find the one maximising the gain must to be considered at the first test campaign, at least, so to check how relevant the effect is.

2.4 Atmospheric attenuation

Since no independent radiometer is available, the opacity measures ("sky dips", i.e. measures of the T_{sys} at different elevations to achieve an estimation of the τ value) are to be carried out with the 32-m dish during the observation sessions.

2.5 Flux

A proper standard flux calibration procedure should be set and made available to users (observers/operators). It is intended to find the Count-to-Jy calibration factors for all channels (up to 14: two polarizations and 7 receivers). It could be one scan (or sequence of) on a sky flux calibrator. A list of possible calibrators well spread throughout R.A. must be made available.

Besides the standard procedure, users may exploit their own calibration procedures.

2.6 Polarisation

A proper standard polarisation calibration procedure shall be set and made available to users (observers/operators). It is intended to find the Count-to-Jy calibration factors for both Q and U, polarisation angle and polarisation leakages (instrumental polarisation fraction), both in combination with the total flux calibration and polarisation only calibration (e.g. background diffuse emission cannot use total flux data, because of the missing large scale flux). Polarisation case is more complex than total flux and cannot be defined yet, the procedure (even the concept) depending on the backend actually in use (e.g. analog or digital continuum backends). It is to be discussed after the final selection of the backend to be used.

2.7 Multi-beam geometry

The position of the beams w.r.t. the pointing reference point must be measured and included in the output data, in order to correctly recover the sky pointing of each beam.

2.8 RFI monitoring

In order to provide the observers with all the useful information, it is important to monitor the RFI presence in the various radio bands.

It is impossible to daily monitor the RFI, since this procedure would subtract antenna time, but meaningful statistics can be extracted mixing several inputs:

- archived information about stable and known RFI;
- "listening campaigns" carried out by the on-site RFI Group;
- dedicated observations performed with the 32-m dish, especially within the bands which cannot be covered by the RFI Group instruments;
- detections reported in user feedbacks.

A spectral quick-look of the data under acquisition allows the user to preview the status. The incoming data could be displayed both in a "refresh mode" and a "cascade mode", to follow their evolution with time.

It is the user to choose the observation setup taking into account the presence of RFIs and considering the receivers IF can be subdivided into N sub-bands (N=4, 8 or 16 - TBD - or hundreds/thousands in case of digital correlation back-ends). The actual removal of RFI-affected data is then performed off-line. The Westerbork and Effelsberg antennas are provided with a RFI mitigation system which should to be investigated.

3 DATA ACQUISITION

3.1 Common Graphic User Interface (GUI)

The ESCS system, even if composed of several units, is planned to be accessible from a unique Graphic User Interface: starting from a single panel, the users will be able to configure their observations completing all the phases of the antenna setup.

The programs should be differentiated because every kind of observation requires specific setups and commands, however the interface should be common (with different windows dedicated to the various backends). Visualization and input of sky position(s) and observing parameters (e.g. scan rate) will be common to all of the backend windows. Once the user has selected the wanted backend, a dedicated application manages it, while the overall system takes care of the antenna pointing and other tasks.

Simplifications and grouping can be imagined, e.g. continuum observations can be thought as spectral acquisitions taking place with a single, or very few, channel and a very large bandwidth. Every specific window of the interface, hiding a program dedicated to the selected backend, should contain the default setup relative to standard observations. The various parameters can then be set by the user and saved in a configuration file. The parameters can also be set by schedule files which can be loaded through the GUI.
Also antenna monitors, calibration and quick-look panels will be accessed in this framework.

3.1.1 Textual shells for expert users

Every section should have textual and graphic interfaces (“expert” and “novice” modes respectively), so that expert users can exploit the textual shells to perform a more sophisticated setup and use custom pipelines.

3.2 Scheduling

The system must produce human readable and editable schedules. This can be obtained applying some macros to initial input parameters: in case the antenna is to produce a map, for instance, the user could indicate the map centre coordinates and the map extension – or the start and end point coordinates – so that the system produces a list of scan schedules. The map will be realized by performing the whole scan sequence.
Of course, users can write their own schedules, according to a standard form, or edit the existing ones. If system failures cause the observations to stop, then the acquisition is to be automatically restored starting from the schedule line which was in execution before the interruption.
In the future, a software tool able to consider a given source list and produce an optimised schedule could be developed – for example to observe a sequence of targets in time intervals around their transit.

3.3 Receiver switching and setup

The receiver switching and setup procedures must be completely commanded by means of straightforward selections in proper panels of the GUI, hiding the involved subreflector positioning.

3.4 Backend switching and setup

The backend switching and setup procedures must be completely commanded by means of straightforward selections in proper panels of the GUI.

3.5 Data rate and synchronisation

The 22 GHz multi-beam receiver will have 14 output lines, each having a 2 GHz bandwidth. Every output line will see the calibration noise mark oscillating at 42 Hz. This implies the acquisition of a value every 12 milliseconds.
The sky measurement (p_i) and its calibration (by means of the noise mark $p_i(m)$):

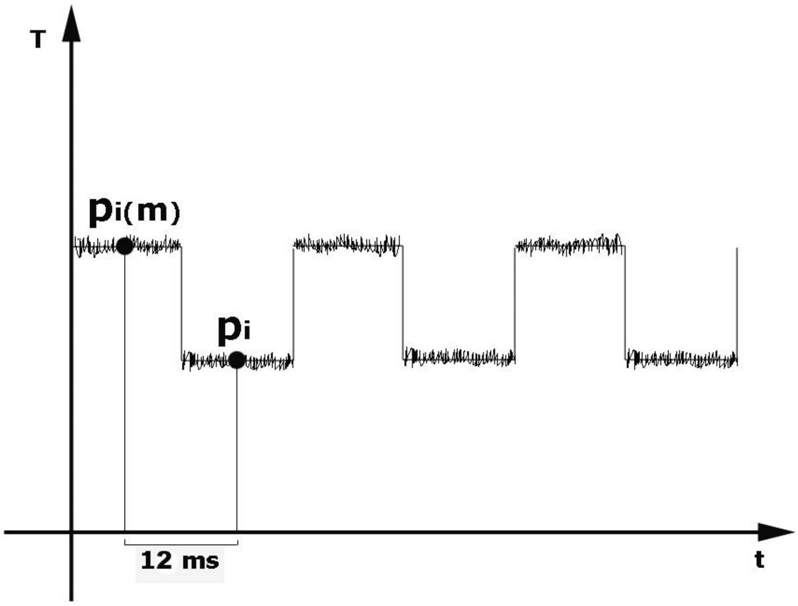
$\left(p_i \; ; \frac{p_i}{p_i(m) - p_i} T_{cal} \right)$ every 24ms

If the observed band is split into 4 sub-band boards, the acquired data – taking into account also the polarisation parameters – will be:

14 x 4 x 2   every 12 ms

→ 9334 sample/s

The needed dynamics is 20 bit, which is translated inside the computer in 32 bit.



As a consequence, the recorded data, including all the system data such as the time mark, will reach an amount of about 37 KByte/s.

This corresponds to the production of 3 GByte every 24 hours, which is compatible with the available hardware, both in terms of network transmission rate and hard-disks storing capacity.

The synchronisation of the different computers will be performed via software: this allows synchronisations down to 1-ms, which seems to be sufficient, unless specific constraints require hardware solutions, that should be investigated together with the backend developers. It must be evaluated whether and when real-time is needed (it seems it isn't, considering the observing frequencies and the mechanics we are dealing with).
A different solution could be to couple the time labels to the acquired data by means of the oscillating noise mark within the backend.
The backends will probably be installed next to the frontends, thus reducing the needed cables; however many problems could rise.

3.6 Housekeeping data collection and management

A lot of monitors coming from different antenna instruments and tools will be recorded more slowly than the scientific data. In the following a non-comprehensive list:

- Antenna data: inclinometers, temperature sensors,…
- Receiver data: vacuum value, cryo temperature, power supplies status, LNA currents, indoor temperature, other device temperatures,...
- Meteo data: outdoor temperature, atmospheric pressure, humidity, wind speed

3.7 Multiple backend usage

The possibility to use different backends simultaneously (e.g. to acquire continuum and spectrometric data together) should be included; the MBFITS format allows the data storage in a single file, however even the production of more distinct MBFITS files is adequate. It must be noticed that the contemporary "dual acquisition" doubles the data rate.

3.8 Guest backends/software

Some political choices should be made by the Institute: the aim is having "open sky" antennas coordinated by common rules. The system we want to implement must prove to be effective, in order to induce the users to migrate to it: a specific, complete and tested system is more productive and invites new users to exploit efficient and already existing services. However a "back door" should be left open in order to welcome external users who need to use different operating systems because of technical constraints.
In this "transition phase" our goal is to gather as many backends and users as we can, providing solutions to those who are already developing custom devices. In the future the Institute should give strong recommendations to produce compatible hardware and software.
The success of this complex "revolution" in the antenna management and development, with common rules and strict policies, will strongly depend on the possibility to have dedicated stable station personnel.

4 DATA OUTPUT

4.1 MBFITS

Following the present trend, the ESCS group chose the MBFITS format as a standard for every observation performed with the 32-m Medicina dish. This hierarchical format allows the use of multi-beam receivers and is being developed by several groups around the world (§ APEX MBFITS manual). Also for archive purposes and other users' use (after the restricted-use time), any observation should be stored in MBFITS format. If guest backends do not have a native MBFITS output, a converter to an at least minimal MBFITS format should be provided.

4.2 Guest users

Guest users could initially archive their own data in a custom format - while our system records some basic parameters in a proper file - later the data files are to be converted at least in FITS format for our archives. In the future, MBFITS should be considered as a standard output, required to anybody accessing the Institute antennas. It is recommended that the Medicina station develops a FITS-to-MBFITS converter.

5 OBSERVATION TOOLS

5.1 Field System

The so-called “Field System” is a system conceived for VLBI observations, and represents a standard for all the antennas involved in these interferometric activities. As a consequence, it must still be available in the future. It is planned to be run on a separate computer: the Field System will work as a client of our ESCS.

5.2 Quick look

A constant update of the data quick-look must take place during the observations. The user must be able not only to monitor the antenna status, but to evaluate the results of the calibration operations and have a preview of the acquired data. Various panels must be displayed to accomplish to these requests, providing also the possibility to interact with this quick-look facilities and execute basic commands and pipelines.

5.3 Data reduction tools

The Medicina station should be provided with a series of data reduction tools, in order to perform an accurate off-line analysis for any given kind of single-dish observation. It must be determined which software is available off-the-shelf – preferably choosing among the most widespread programs in use – or if custom solutions are needed, to perform data reduction for:

- Total power
- Polarimetry
- Spectroscopy
- Multiple backends
- Exotic (space probes tracking, space debris monitoring, ...)

5.4 Beam map

It is desirable to produce maps of the beams up to the secondary lobes – or even further – to be employed in the “clean” phase of the post-processing. Since the 32-m dish is a quite small antenna, its relatively low sensitivity could make it difficult to reveal the secondary lobes, which are 18-20dB under the main lobe. Even operating a cross-scan on a strong source, they might not be mapped. However, it is important to try to obtain the beam maps because they would be extremely helpful, especially in deep surveys.

5.5 Catalogues

Catalogues of specific sets of sources are functional to various phases of the observation. In particular, updated lists of calibrators must be available to the observer.

5.5.1 Calibrators

To perform an accurate system calibration, and to calibrate the acquired data, the system must include catalogues of:

- pointing calibrators
- antenna gain calibrators
- polarimetry calibrators
- raw calibrators (Sun, Moon, planets)

The information relative to the listed sources – e.g. coordinates, flux, etc… – is to be frequently revised. It is possible to retrieve updates from observatories, such as the VLA, which monitor these calibrators and periodically dispatch accurate measures.

The calibrator flux is often expressed as a function of frequency, in the form of a polynomial curve. In analogy to a present FS tool, the expected flux of the needed calibrator should be computed on-line considering the running observation setup and depending on the relative dimension with respect to the antenna beam.

5.5.2 Source catalogues

Source catalogues are widely available on the Internet querying on-line databases (such as SIMBAD). However the most important ones could be included in the local system, for the observers to consult.

It would be possible to keep track of all the observed sources, automatically building a database of all the entries received by the antenna pointing system, but this approach is not believed to be effective. In fact, this database would end up containing also mistaken inputs; moreover, the observers might not want to share details about the targets they are studying.

5.6 “Static antenna” mode

The system should include the possibility to check the antenna setup without commanding the source pointing. This way, the user performs the complete antenna setup and checks the correct functioning of the selected receiver and backend, but does not lose time with dish slewing. It is equivalent to a normal observation, but the source tracking and antenna motion are disabled. This can be obtained simply including a check-box in the main setup panel to enable/disable the actual pointing commands.

5.7 Absentee observations

In perspective, all the antennas ruled by the Institute of Radioastronomy are planned to mainly provide absentee data. This means the Institute staff carries out the observations – using the various antennas – on behalf of the commissioning astronomers and in cooperation with the local station operators. This policy is aimed at optimising the antenna usage (e.g. exploiting the best weather conditions for high frequency projects).

Particularly expert and frequent users could then be authorised to have direct remote access. Anyway a “standard visitor mode” will be available to the astronomers wishing to attend their observations.

5.7.1 Rules

Specific rules must be fixed to:

- decide if the project can be operated in absentee mode;
- qualify the user to the Institute if remote access is asked for.

5.7.2 NOC (Network Operation Control)

In the future, all the IRA radiotelescopes could be operated from any of the Institute locations. The NOC group should then coordinate and control these network activities.

6 DATA ARCHIVE

6.1 Archived data

A first solution could be to list the MBFITS files – including: observations, tests, calibrations, etc… - with some basic parameters like target, backend, date/time, gain, focus, etc…, so that queries could be performed. It is important to define the most important keywords to be included in the files.

The initial idea is to develop this database in MSQL but, since ACS provides an archive structure, this architecture could be exploited, however keeping in mind that the archive is planned to be common to all the IRA telescopes.

A comprehensive archive of the acquired data and the related information must include all the following items:

- Meteorological data
- Opacity data
- Antenna gain data
- Focus position data
- Pointing error data
- RFI data
- Housekeeping data
- Observations data

6.1.1 User’s feedback

Several parameters will be acquired automatically to monitor the antenna performance. But a feedback from the observers is equally useful, to obtain – in brief – details on how the session was carried out, on the faced difficulties, on the data quality and also subjective impressions on the overall service.

6.2 Grants

General users could access observation/calibration files only, while local staff could be granted access to files flagged as “private”.

6.3 Queries

The database must be queried by several parameters. Ideally, by any of the parameters included in the file headers, in order to perform specific queries for a number of scientific, statistic and maintenance purposes.

6.4 Antenna performance monitoring

Examining in due course the various items given above (§ 6.1) the antenna performance can be monitored and evaluated. Also the weather conditions and RFI situation at the site can be traced, producing meaningful statistics.

7 UPDATING ELECTRONIC DOCUMENTATION

7.1 Antenna performance database

The collection of the archived data allows for a database, organized in some way. This can be the basis to produce the update of electronic documentation.

7.2 Quasi-real time update of electronic documentation

Quasi-real time means that the documentation coming from the database must not be “blindly” processed but well organized after careful checks performed by station people. This is to avoid the propagation of bad and wrong information. After that, a pre-defined electronic form could be conveniently automatically filled by an appropriate software.