ALMA Memo 370

A comparison of availability of major radio interferometers

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1 Introduction

This memo gives an overview of historically achieved availability performance at major radio observatories around the world. The instruments analysed have similar attributes as the proposed ALMA radio telescope:

- an open user facility available to scientists
- interferometer radio telescope
- relatively large number of elements (N > 10)

Instruments like the Very Large Array (VLA) [1], Very Long Baseline Array (VLBA) [2] and the Westerbork Synthesis Radio Telescope (WSRT) [3] satisfy these conditions.

The purpose of this analysis is to obtain a proper overview on instrument availability and use this as a basis for determining a suitable objective for ALMA.

Due to the intrinsic nature of radio interferometers, these systems show a graceful degradation in performance, which makes it difficult to assess their availability. For this reason a separate section in this memo is dedicated to define a practical method, based on experience at the VLA and VLBA, to calculate availability for a radio interferometer.

Just for illustration, availability data for a single dish radio telescope, the Swedish-ESO Sub-millimeter Telescope (SEST) [4] operated by ESO, has been included.

2 Defining availability for a radio interferometer

In this paragraph, before going into more detail on the specific definition of availability for radio interferometers, an introduction is given to the general definition of availability as often used in internationally accepted standards and literature. The second part of this section addresses then the particular problem of availability of a radio interferometer and presents a practical analysis model that will be used in assessing the performance of the different instruments.

2.1 Definition of availability

A general definition of availability as among others found in an ESA glossary document is:

> *Availability*
> The ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided.

Note that often discrimination is made between two sub-types of availability, the *inherent availability* of a product and the *operational availability*. Instead of the term *operational availability* also *operational readiness* is used in the literature.
Definitions are as follows:

> *Inherent availability*
> Inherent availability reflects the percentage of time a product would be available if no delays due to maintenance, supply, etc. (i.e. not design related) were encountered:

$$A_i = \frac{MTBF}{MTBF + MTTR} * 100\% \qquad \text{(I)}$$

> *MTBF* – Mean Time Between Failure, *MTTR* – Mean Time To Repair

> *Operational availability*
> Operational availability is similar to inherent availability but includes the effects of maintenance delays and other non-design factors. The equation for operational availability is:

$$A_o = \frac{MTBM}{MTBM + MDT} * 100\% \qquad \text{(II)}$$

> *MTBM* – Mean Time Between Maintenance, *MDT* – Mean Down Time

Note, that MTBM addresses all maintenance, both corrective, in other words failures and their repair, and preventive, whereas MTBF only accounts for failures. MDT includes MTTR and all other time involved with downtime, such as delays.
Thus, A_o reflects the totality of the inherent design of the product, the availability of maintenance personnel and spares, maintenance policy and concepts, and other non-design factors, whereas A_i reflects only the inherent design.

So, operational availability addresses the system's readiness to perform its intended function at a particular point in time. A common practical problem is to define the exact criteria to determine if a system is ready to perform its intended function and this depends very much on the use of the system.
A simple example can illustrate this problem. Consider a car, which has a specified maximum speed of not less then 200 km/hr. But for some reason the actual maximum speed is only 180

km/hr. If the car is to be used for normal transport in a residential area, this discrepancy in maximum speed will not be noticed and the user will state that it can perform for the function that he had in mind.
However if the car is to be used for racing then this discrepancy in maximum speed will surely be noticed by the driver. As a consequence he will state that the car is not ready for the use he intended.
This problem also exists for radio telescopes, one can think of the receiver system temperature that is higher then normal. Does this directly lead to a situation where the radio telescope is down or is it still useable for doing measurements that will satisfy the observing astronomer?
It is obvious that the definition of a radio telescope being "up" or "down" involves a subjective measure. On the basis of the similarity of the analysed radio telescopes, especially the way they are operated, it is assumed that the definition of "up" or "down" used at each instrument is also similar. This means that at least a fair comparison between the instruments can be made.

Another issue that needs caution when addressing availability of a system is the exact definition of what the system consists of and that the matching values for MTBF, MTBM, MTTR and MDT are used.
A specific example with regard to this statement for the radio interferometers analysed is the following:
The mean down time of the instrument, which includes the time to repair a failure on the instrument, does not necessarily reflect the actual time to repair the faulty sub-system. Often a faulty sub-system is only replaced by a properly working unit, putting the whole instrument back to operational order in little time. The repair time of the faulty sub-system is done off line and will often take longer then the repair time to rectify the fault caused by this sub-system in the whole instrument.
For this reason the availability data in this memo should not be used for predicting resource needs for maintenance staff.

2.2 VLA/VLBA availability model of a radio interferometer

In the previous section it was indicated that often there is a practical problem in the exact definition if a system is ready to perform its intended function or not and that radio telescopes are no exception to this rule.

For radio telescopes based on the interferometer principle this problem is even more complicated then for a single dish telescope. The fact that multiple antennas are used in an interferometer causes the instrument to have a graceful roll off in performance. Often, despite the even complete failure of one antenna element, this doesn't prevent the interferometer of providing the capability of making useful measurements. This is especially true for interferometers that have a large number of elements.
On the other hand when a failure occurs at e.g. the central correlator, the downtime of this part is most likely to result in non-availability of the whole instrument.

A useful elucidation on the calculation of availability for radio interferometers, is given by the down time calculation methodology in use at NRAO for both VLA and VLBA.
This methodology is based on the concept of *total possible antenna observing time* $t_{tot\_ant\_obs}$, which is the product of the *total possible project observing time* t_{tot_obs} and the total number of antenna elements N of the radio telescope:

$$t_{tot\_ant\_obs} = t_{tot\_obs} * N \tag{III}$$

Antenna downtime t_{ant_down} due to a single interferometer element, e.g. caused by a front-end failure or maintenance, is directly equal to the actual downtime t_{down}:

$$t_{ant\_down} = t_{down} \tag{IV}$$

If a common sub-system in the interferometer fails, e.g. the complete correlator, then the resulting antenna downtime is equal to the product of the actual sub-system downtime multiplied by the total number of antenna elements:

$$t_{ant\_down} = t_{down} * N \qquad \text{(V)}$$

Operational availability A_o as defined by expression (II) is now rewritten for this specific methodology:

$$A_0 = \frac{t_{tot\_ant\_obs} - \sum t_{ant\_down}}{t_{tot\_ant\_obs}} * 100\% \qquad \text{(VI)}$$

The following calculation example will clarify this methodology:

> Assume that we want to calculate the operational availability of a radio interferometer with 10 antenna elements in March 2000. The instrument should normally operate 24 hours a day the whole year around, the total possible observing time for the month March 2000 expressed in minutes is:
>
> $t_{tot\_ant\_obs}$ = 31*24*60*10 = 446.400 minutes
>
> During this month downtime is encountered due to various causes:
> -Maintenance on a single antenna element:
> t_{ant_down} = 250 minutes
>
> -Central power failure of correlator:
> t_{ant_down} = 20*10 = 200 minutes
>
> -Downtime due bad weather at antenna site:
> t_{ant_down} = 600*10 = 6000 minutes
>
> Total downtime in this month is:
>
> Σ t_{ant_down} = 6450 minutes
>
> Instrument operational availability in March 2000 is now equal to:
>
> $$A_o = \frac{446400 - 6450}{446400} * 100\% = 98{,}6\%$$

Although this methodology is not perfect, it is a very practical way to make availability calculations for a radio interferometer more objective. It reduces the subjective discussion if an instrument is available to perform its intended function or not.

3 *Radio telescope availability data*

Though it was not an explicitly stated objective, in the information received from all analysed radio telescopes it turned out that they all focus on the operational availability. So the downtime includes besides failures also the time due to, among others, retrofits, operator errors, external interference, weather and the limited amount of resources for maintenance.

3.1 VLA availability

Historical downtime data for most of the month over the period 1996 to 2000 was received for the Very Large Array. The calculation of operational availability follows the methodology outlined in section 2.2.
Table 1 gives a summary of the monthly operational availability of this instrument. More details are given in appendix A.

Year-month	Total possible antenna observing time [min]	Total antenna downtime per month [min]	Operational Availability
1996-January	1205280	no information available	
1996-February	1088640	no information available	
1996-March	1205280	no information available	
1996-April	1166400	no information available	
1996-May	1205280	no information available	
1996-June	1166400	29976	0,97
1996-July	1205280	55925	0,95
1996-August	1205280	51586	0,96
1996-September	1166400	36158	0,97
1996-October	1205280	68460	0,94
1996-November	1166400	105742	0,91
1996-December	1205280	107551	0,91
	Average operational availability		0,95
1997-January	1205280	no information available	
1997-February	1088640	24168	0,98
1997-March	1205280	no information available	
1997-April	1166400	no information available	
1997-May	1205280	no information available	
1997-June	1166400	49922	0,96
1997-July	1205280	54358	0,95
1997-August	1205280	42305	0,96
1997-September	1166400	69867	0,94
1997-October	1205280	76656	0,94
1997-November	1166400	69661	0,94
1997-December	1205280	99592	0,92
	Average operational availability		0,95
1998-January	1205280	48918	0,96
1998-February	1088640	77076	0,93
1998-March	1205280	43872	0,96
1998-April	1166400	35925	0,97
1998-May	1205280	44113	0,96
1998-June	1166400	46306	0,96
1998-July	1205280	74125	0,94
1998-August	1205280	53394	0,96
1998-September	1166400	27994	0,98
1998-October	1205280	58215	0,95
1998-November	1166400	86687	0,93
1998-December	1205280	79523	0,93
	Average operational availability		0,95
1999-January	1205280	58352	0,95
1999-February	1088640	42130	0,96
1999-March	1205280	30735	0,97
1999-April	1166400	109758	0,91
1999-May	1205280	100159	0,92
1999-June	1166400	69634	0,94
1999-July	1205280	47850	0,96
1999-August	1205280	60626	0,95
1999-September	1166400	29743	0,97
1999-October	1205280	36520	0,97
1999-November	1166400	77216	0,93
1999-December	1205280	216436	0,82
	Average operational availability		0,94
2000-January	1205280	44318	0,96
2000-February	1127520	49047	0,96
2000-March	1205280	no information available	
2000-April	1166400	no information available	
2000-May	1205280	no information available	
2000-June	1166400	no information available	
2000-July	1205280	no information available	
2000-August	1205280	no information available	
2000-September	1166400	no information available	
2000-October	1205280	no information available	
2000-November	1166400	no information available	
2000-December	1205280	no information available	
	Average operational availability		0,96

Table 1, VLA operational availability 1996 - 2000

For a limited number of months additional information was available for the VLA which shows how many telescopes were available at a given time. This data is presented in table 2.

	Percentage of time that x VLA telescopes are available									
Year-month	27	26	25	24	23	22	21	20 - 1	0	Total
1999-August	32,8	31,6	23,5	7,0	2,8	0,2	0,0	0,8	1,3	100,0
1999-September	43,0	34,7	12,7	4,2	2,1	1,3	0,9	0,9	0,2	100,0
1999-October	47,1	27,1	17,6	2,6	3,6	0,5	0,6	0,1	0,8	100,0
1999-November	64,6	27,2	4,4	0,4	0,0	0,0	0,7	0,4	2,3	100,0
1999-December	26,6	45,4	6,9	2,3	2,6	1,5	0,8	0,5	13,4	100,0
2000-January	55,3	35,9	6,9	0,7	0,8	0,0	0,0	0,0	0,4	100,0
2000-February	43,1	35,0	10,6	2,6	3,7	1,6	1,5	0,0	1,9	100,0
2000-March	22,4	38,2	21,4	7,7	1,3	1,4	1,2	0,9	5,5	100,0
2000-April	63,9	26,0	4,1	2,6	0,0	0,0	0,0	0,0	3,4	100,0

Table 2, number of available VLA telescopes at a given time

Over the given period, on avarage 90 percent of the time, less then then 4 telescopes were unavailable for use.

3.2 VLBA availability

For the Very Long Baseline Array, a set of complete historical downtime data per month over the period 1997 to 2000 was received. Similar to the VLA, also here the calculation of operational availability follows the methodology outlined in section 2.2.
Table 3 gives a summary of the monthly operational availability of this instrument. More VLBA downtime details are given in appendix B.

Year-month	Total possible antenna observing time [min]	Total antenna downtime per month [min]	Operational Availability
1997-January	446400	50236	0,89
1997-February	403200	48253	0,88
1997-March	446400	59282	0,87
1997-April	432000	46879	0,89
1997-May	446400	47568	0,89
1997-June	432000	54178	0,87
1997-July	446400	57035	0,87
1997-August	446400	72183	0,84
1997-September	432000	51332	0,88
1997-October	446400	45889	0,90
1997-November	432000	46813	0,89
1997-December	446400	45451	0,90
			0,88
1998-January	446400	56993	0,87
1998-February	403200	47624	0,88
1998-March	446400	49049	0,89
1998-April	432000	47805	0,89
1998-May	446400	51718	0,88
1998-June	432000	57483	0,87
1998-July	446400	58979	0,87
1998-August	446400	58345	0,87
1998-September	432000	50707	0,88
1998-October	446400	45784	0,90
1998-November	432000	47734	0,89
1998-December	446400	53489	0,88
			0,88

Year-month	Total possible antenna observing time [min]	Total antenna downtime per month [min]	Operational Availability
1999-January	446400	56094	0,87
1999-February	403200	48832	0,88
1999-March	446400	47057	0,89
1999-April	432000	54683	0,87
1999-May	446400	54162	0,88
1999-June	432000	56209	0,87
1999-July	446400	62146	0,86
1999-August	446400	56791	0,87
1999-September	432000	49340	0,89
1999-October	446400	60613	0,86
1999-November	432000	61455	0,86
1999-December	446400	61461	0,86
			0,87
2000-January	446400	51330	0,89
2000-February	417600	46423	0,89
2000-March	446400	53326	0,88
2000-April	432000	50363	0,88
2000-May	446400	63249	0,86
2000-June	432000	60161	0,86
2000-July	446400	62662	0,86
2000-August	446400	62044	0,86
2000-September	432000	54849	0,87
2000-October	446400	61194	0,86
2000-November	432000	48367	0,89
2000-December	446400	59815	0,87
			0,87

Table 3, VLBA operational availability 1997 - 2000

3.3 WSRT availability

No recent, long term, periodic data on instrument downtime was available for the WSRT. The reason for this was that the WSRT has undergone several major upgrades of its sub-systems, among others replacement of front ends, correlator, control software and general overhaul of the telescope structures, for more then the last 6 years. It goes without saying that these efforts had a large impact on the readiness of the instrument to carry out astronomical observations.
Despite this situation, intermittent downtime data of all sub-systems was available. Based on this data it is estimated that the WSRT operational availability is on the order of 85 %. It is expected that this figure will improve over time when the old, worn out, DCB and DXB back ends will be replaced by the new DZB back end. A partial DZB, consisting of 1/8 of the final back end, has been running for almost 2 years without any failures. Currently the integration of the full DZB takes place at the WSRT.
The inefficiency in the use of the instrument due to the non-perfect scheduling of 12 hours observations has not been taken into account in this figure. This since the instrument is in principle ready to perform its intended function.

Interesting data was available on the repair time of sub-systems for the WSRT, figures are presented in table 4.

Item	Mean Time To Repair
Mechanical sub-systems	4 hours
Cryogenics	120 hours
Front ends	8 hours (of which is 60 % is idle time)
Telescope drive electronics	1 hour
Old back end (DCB, DXB)	8 hours

Table 4, WSRT sub-system repair times

Despite the repair times as given in table 4, the repair time due to failure of such a sub-system in the WSRT itself is much lower. This is caused by the fact that failing sub-systems are not directly repaired but are only replaced by a properly functioning unit. The time to repair a failure in the WSRT instrument is normally less then a day and often on the order of an hour.
This practical example supports the advantage of having sub-systems designed as Line Replaceable Units (LRU) in a system.

3.4 SEST availability

For the SEST no detailed periodic data on downtime was available. However sufficient averaged data was provided to assess the long-term availability of this instrument. Due to restructuring of the operation of this telescope in March 2000, two different values for operational availability have been determined. Table 5 shows the data, all normalised to a year, and resulting operational availability.

Before March 2000	
Total observing time:	8760 hours/year
Total downtime:	2672 hours/year
Operational availability	69,50%

After March 2000	
Total observing time:	8760 hours/year
Total downtime:	3928 hours/year
Operational availability	55,20%

Table 5, SEST operational availability

The reduced availability of SEST from March 2000 on doesn't have a technical background. It is caused by a reduction in maintenance staff. This resulted in longer maintenance down time of the instrument and as follows from the definition also this non-technical downtime is reflected in the operational availability.

3.5 A comparison of instrument availability

A summary of all averaged operational availability data per telescope is presented in table 6.

Instrument	Av. Operational availability
VLA (1996 – 2000)	95 %
VLBA (1997 – 2000)	88 %
WSRT	85 %
SEST (before March 2000)	69 %
SEST (after March 2000)	55 %

Table 6, summary of averaged operational availability data

It is shown that the operational availability figures for the three major interferometry based radio telescopes are close to each other.
In comparison, from the operational availability figures of SEST before March 2000 and the interferometry based radio telescopes the graceful degradation behaviour of the latter seems plausible.

4 Implications for ALMA

Based on the data of existing radio interferometers at first sight an objective of obtaining an operational availability of more then 85 % seems not unrealistic. But this will mean that the technologies applied in the instrument should be sufficiently well mature and design and engineering is to high standards. This assumption is probably true for most radio telescopes operating in the centimeter region, but can not be directly translated to an instrument like ALMA operating in the sub-millimeter range.
Especially the SIS devices used in the front ends and the sub-millimeter local oscillator multipliers are examples of emerging technology unavoidable in the ALMA system that will go through a period of infancy diseases when they become operational in ALMA. This transition to mature technology will definitely have an impact on the operational availability of the ALMA instrument. A more precise figure for this impact on availability is at this moment hard to give. Detailed study on the reliability of those components is proposed to obtain more insight and concrete figures.

Another topic that is likely to play a role in the availability of a sub-millimeter telescope are the weather conditions. Two, weather related, aspects that have an impact on ALMA downtime can be distinguished, high wind speed and bad atmospheric conditions.
High wind speed will affect the pointing accuracy of the telescopes. The current ALMA prototype antenna specifications [5] state that the full performance must be met during day times when average wind speed is below 6 m/sec and during night time when the average wind speed is below 9 m/sec. Antennas will be operational with reduced performance with wind speeds up to 20 m/sec. Measurement data obtained by NRAO and ESO at Chajnantor show that respectively approximately 48 %, 68 % and 98 % of the time the wind speed is below 6 m/sec, 9 m/sec and 20 m/sec.
Although the ALMA antennas will be located at Lano de Chajnantor, probably the best site in the world for sub-millimeter observations, still part of the time the atmosphere is such that no practical observations can be made at the shortest wavelengths.
Though the effect of bad weather/atmosphere can have a dramatic impact at the higher operating frequencies of ALMA, it is not considered here in this operational availability figure. It is foreseen that the ALMA instrument has an adaptive scheduling scheme whereby the instrument changes to lower frequency observing programmes when the atmosphere prevents reasonable observations at the shorter wavelengths. Mildly adverse weather conditions should therefore normally not lead to the instrument being unavailable for doing astronomical measurements.
A more detailed analysis of the site characterisation data should provide a concrete prediction for the down time due to bad atmospheric conditions.

5 Concluding remarks

The outcome of this analysis shows that there is good concurrence on the operational availability of the three major interferometry based radio telescopes.

This result will act as an objective for defining an operational availability figure for ALMA. It will be used in the reliability calculation of the overall instrument, system design as well as the allocation of reliability figures for sub-systems and components.
Care has to be taken about the impact on reliability and availability of sub-systems where new, non-mature technology is applied.
The impact of weather on the ALMA instrument is another issue that has to be incoporated in the availability analysis.

6 Acknowledgement

The preparation of this memo wouldn't have been possible without the kind contribution of the following people:

- Mark Bentum / ASTRON Westerbork, who wrote a very useful document about the availability and reliability of the WSRT
- Philip Hicks / NRAO Socorro, who provided the data on the VLA
- Lars-Åke Nyman / ESO La Silla, who provided data on the SEST
- Peggy Perley / NRAO Socorro, who provided the data on the VLBA

I'm indebted to these people for their help in providing me with the necessary data and discussions about the issue of availability.

7 Appendix A, VLA downtime and operational availability data

Year-month	Possible project observing time [min]	Number of antennas	Total possible antenna observing time [min]	Antenna down time due to holiday [min]	Percentage of antenna down time according to downtime report	Total antenna downtime per month [min]	Operational Availability
1996-January	44640	27	1205280	25920		no information available	
1996-February	40320	27	1088640	0		no information available	
1996-March	44640	27	1205280	0		no information available	
1996-April	43200	27	1166400	0		no information available	
1996-May	44640	27	1205280	0		no information available	
1996-June	43200	27	1166400	0	2,57	29976	0,97
1996-July	44640	27	1205280	0	4,64	55925	0,95
1996-August	44640	27	1205280	0	4,28	51586	0,96
1996-September	43200	27	1166400	0	3,10	36158	0,97
1996-October	44640	27	1205280	0	5,68	68460	0,94
1996-November	43200	27	1166400	38880	5,93	105742	0,91
1996-December	44640	27	1205280	51840	4,83	107551	0,91
			Average operational availability in 1996				0,95
1997-January	44640	27	1205280	25920		no information available	
1997-February	40320	27	1088640	0	2,22	24168	0,98
1997-March	44640	27	1205280	0		no information available	
1997-April	43200	27	1166400	0		no information available	
1997-May	44640	27	1205280	0		no information available	
1997-June	43200	27	1166400	0	4,28	49922	0,96
1997-July	44640	27	1205280	0	4,51	54358	0,95
1997-August	44640	27	1205280	0	3,51	42305	0,96
1997-September	43200	27	1166400	0	5,99	69867	0,94
1997-October	44640	27	1205280	0	6,36	76656	0,94
1997-November	43200	27	1166400	38880	2,73	69661	0,94
1997-December	44640	27	1205280	51840	4,14	99592	0,92
			Average operational availability in 1997				0,95
1998-January	44640	27	1205280	25920	1,95	48918	0,96
1998-February	40320	27	1088640	0	7,08	77076	0,93
1998-March	44640	27	1205280	0	3,64	43872	0,96
1998-April	43200	27	1166400	0	3,08	35925	0,97
1998-May	44640	27	1205280	0	3,66	44113	0,96
1998-June	43200	27	1166400	0	3,97	46306	0,96
1998-July	44640	27	1205280	0	6,15	74125	0,94
1998-August	44640	27	1205280	0	4,43	53394	0,96
1998-September	43200	27	1166400	0	2,40	27994	0,98
1998-October	44640	27	1205280	0	4,83	58215	0,95
1998-November	43200	27	1166400	38880	4,24	86687	0,93
1998-December	44640	27	1205280	51840	2,40	79523	0,93
			Average operational availability in 1998				0,95
1999-January	44640	27	1205280	25920	2,75	58352	0,95
1999-February	40320	27	1088640	0	3,87	42130	0,96
1999-March	44640	27	1205280	0	2,55	30735	0,97
1999-April	43200	27	1166400	0	9,41	109758	0,91
1999-May	44640	27	1205280	0	8,31	100159	0,92
1999-June	43200	27	1166400	0	5,97	69634	0,94
1999-July	44640	27	1205280	0	3,97	47850	0,96
1999-August	44640	27	1205280	0	5,03	60626	0,95
1999-September	43200	27	1166400	0	2,55	29743	0,97
1999-October	44640	27	1205280	0	3,03	36520	0,97
1999-November	43200	27	1166400	38880	3,40	77216	0,93
1999-December	44640	27	1205280	51840	14,27	216436	0,82
			Average operational availability in 1999				0,94
2000-January	44640	27	1205280	25920	1,56	44318	0,96
2000-February	41760	27	1127520	0	4,35	49047	0,96
2000-March	44640	27	1205280	0		no information available	
2000-April	43200	27	1166400	0		no information available	
2000-May	44640	27	1205280	0		no information available	
2000-June	43200	27	1166400	0		no information available	
2000-July	44640	27	1205280	0		no information available	
2000-August	44640	27	1205280	0		no information available	
2000-September	43200	27	1166400	0		no information available	
2000-October	44640	27	1205280	0		no information available	
2000-November	43200	27	1166400	38880		no information available	
2000-December	44640	27	1205280	51840		no information available	

8 Appendix B, VLBA downtime and operational availability data

Year-month	Possible project observing time [min]	Number of antennas	Total possible antenna observing time [min]	Unscheduled antenna downtime based on monthly downtime report [min]	Antenna downtime due to monthly scheduled maintenance [min]	Antenna downtime due to yearly station maintenance [min]	Total antenna downtime per month [min]	Operational Availability
1997-January	44640	10	446400	8236	42000	0	50236	0,89
1997-February	40320	10	403200	6253	42000	0	48253	0,88
1997-March	44640	10	446400	17282	42000	0	59282	0,87
1997-April	43200	10	432000	4879	42000	0	46879	0,89
1997-May	44640	10	446400	5568	42000	0	47568	0,89
1997-June	43200	10	432000	2098	42000	10080	54178	0,87
1997-July	44640	10	446400	4955	42000	10080	57035	0,87
1997-August	44640	10	446400	20103	42000	10080	72183	0,84
1997-September	43200	10	432000	9332	42000	0	51332	0,88
1997-October	44640	10	446400	3889	42000	0	45889	0,90
1997-November	43200	10	432000	4813	42000	0	46813	0,89
1997-December	44640	10	446400	3451	42000	0	45451	0,90
					Average operational availability in 1997			0,88
1998-January	44640	10	446400	14993	42000	0	56993	0,87
1998-February	40320	10	403200	5624	42000	0	47624	0,88
1998-March	44640	10	446400	7049	42000	0	49049	0,89
1998-April	43200	10	432000	5805	42000	0	47805	0,89
1998-May	44640	10	446400	9718	42000	0	51718	0,88
1998-June	43200	10	432000	5403	42000	10080	57483	0,87
1998-July	44640	10	446400	6899	42000	10080	58979	0,87
1998-August	44640	10	446400	6265	42000	10080	58345	0,87
1998-September	43200	10	432000	8707	42000	0	50707	0,88
1998-October	44640	10	446400	3784	42000	0	45784	0,90
1998-November	43200	10	432000	5734	42000	0	47734	0,89
1998-December	44640	10	446400	11489	42000	0	53489	0,88
					Average operational availability in 1998			0,88
1999-January	44640	10	446400	14094	42000	0	56094	0,87
1999-February	40320	10	403200	6832	42000	0	48832	0,88
1999-March	44640	10	446400	5057	42000	0	47057	0,89
1999-April	43200	10	432000	12683	42000	0	54683	0,87
1999-May	44640	10	446400	12162	42000	0	54162	0,88
1999-June	43200	10	432000	4129	42000	10080	56209	0,87
1999-July	44640	10	446400	10066	42000	10080	62146	0,86
1999-August	44640	10	446400	4711	42000	10080	56791	0,87
1999-September	43200	10	432000	7340	42000	0	49340	0,89
1999-October	44640	10	446400	18613	42000	0	60613	0,86
1999-November	43200	10	432000	19455	42000	0	61455	0,86
1999-December	44640	10	446400	19461	42000	0	61461	0,86
					Average operational availability in 1999			0,87
2000-January	44640	10	446400	9330	42000	0	51330	0,89
2000-February	41760	10	417600	4423	42000	0	46423	0,89
2000-March	44640	10	446400	11326	42000	0	53326	0,88
2000-April	43200	10	432000	8363	42000	0	50363	0,88
2000-May	44640	10	446400	21249	42000	0	63249	0,86
2000-June	43200	10	432000	8081	42000	10080	60161	0,86
2000-July	44640	10	446400	10582	42000	10080	62662	0,86
2000-August	44640	10	446400	9964	42000	10080	62044	0,86
2000-September	43200	10	432000	12849	42000	0	54849	0,87
2000-October	44640	10	446400	19194	42000	0	61194	0,86
2000-November	43200	10	432000	6367	42000	0	48367	0,89
2000-December	44640	10	446400	17815	42000	0	59815	0,87
					Average operational availability in 2000			0,87

9 References

[1] See: http://www.aoc.nrao.edu/vla/html/VLAhome.shtml

[2] See: http://www.aoc.nrao.edu/vlba/html/VLBA.html

[3] See: http://www.astron.nl/wsrt/index.htm

[4] See: http://www.ls.eso.org/lasilla/Telescopes/SEST/SEST.html

[5] *Project Description ALMA Prototype Antenna*, Call for Tenders, European Southern Observatory, Garching / Germany, 30 July 1999