Report on the experiences with the ESA-Dresden radio telescope

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Overview and Summary:

From January to March 2007, the ESA-Dresden radio telescope, working in the 10-12 GHz range, was thoroughly tested in operations at the International Space University (ISU). This report describes the principal experiences obtained during the commissioning period of the instrument and the work by three Masters students for their Personal Assignments which covered that period of time. These comprehensive tests and observations show that the ESA-Dresden telescope is a useful instrument which allows students to obtain meaningful data which can be quantitatively interpreted and also provides a magnificent opportunity for an interested person to explore the radio sky following his/her own ideas. The instrument performs well, although there are some limitations in the stability of the positioning system. The features provided can profitably be used to execute semi-automatic survey observations. The apparatus is too complex and also too sophisticated to be used merely as a demonstration tool. These two aspects, along with the cost, make one also hesitate to foresee its wide use in secondary schools, despite its relatively easy operation. Furthermore, the telescope demands a high level of enthusiasm and engagement of the teacher. But put in the hands of such a resourceful person, it will be very useful.

The report is organized as follows: Section 1 gives an overview of the events and the use of the telescope during this time. Experiences and impressions about the hardware and its installation at our site are presented in Section 2, together with our recommendations. In Section 3 we relate our experiences with the positioning system and our suggestions for improvements. The various types of observations performed, our procedures and methods of interpretation, and the principal results are covered in some detail in Section 4. An overall assessment of the performance, the capabilities, and possible applications of the radio telescope in given in Section 5, along with recommendations.

In Appendix A we describe a variety of observational projects, most of which we had been able to try out, with our experiences, interpretation instructions or ideas, and suggestions for further development.

In Appendix B we give constructional suggestions for a more simplified Ku-band radio telescope than the ESA-Dresden instrument, but capable of performing all the basic observational projects useful at secondary school level and beyond, and at a substantially lower cost.

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1 Sequence of Events

Oct. 06: Temporary installation on the roof of the Boeing lecture theatre by ESA colleagues. Shortly afterwards, the antenna was twice blown over by gusts of wind. At first sight, only slight damage of the dish was evident by a minor indention of its rim.

Dec. 06/Jan. 07: Final installation of the mounting on the roof of the middle tower, with six additional buckets of concrete as weights on the base-plate; laying of the coax and control cables from the roof into the observatory room. This required an extension of the 25 m long cables by about 5 m.

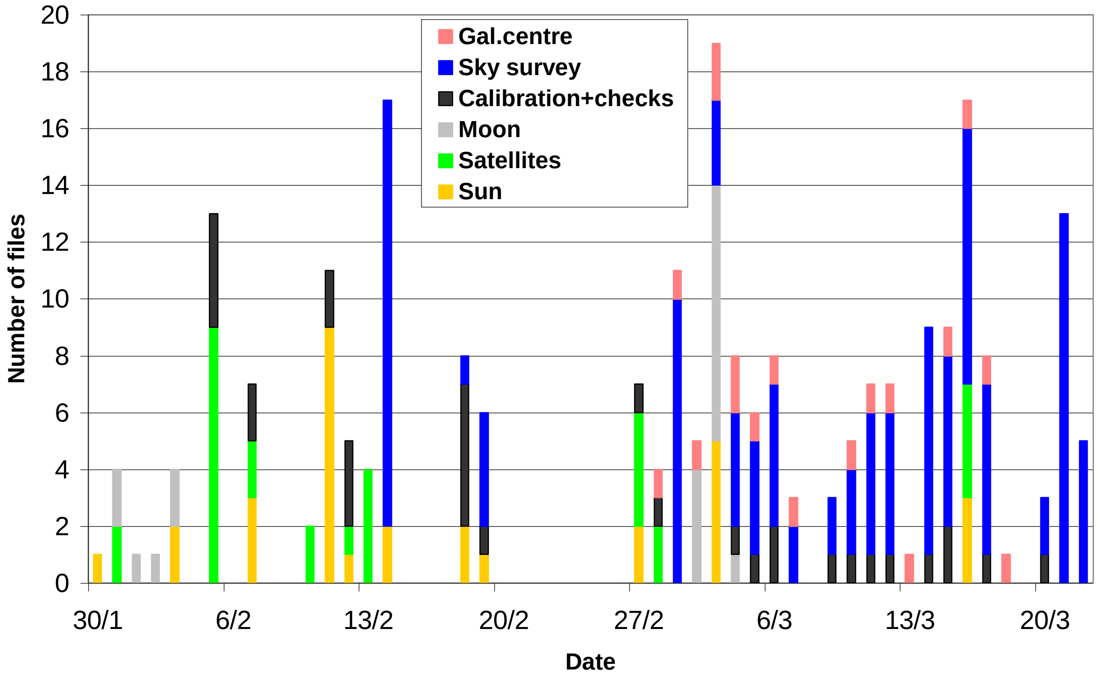
Jan. 07: Start of the personal assignment work of Marc Cornwall, Laure-Hélène Milhome, and Aravind Saini S.: Final assembly of the dish on the roof, connecting the cable to the indoor units, and first observations. Since then, continuous observations and tests were conducted.

Feb. 07: The low intensity of the solar signal and the broad antenna pattern lead to the confirmation that the dish was out of focus. Close inspection and comparison with the pictures of the prototype revealed that the arm carrying the LNB (Low Noise Block) had been bent upwards by about 10°, evidently a result of the falling over on its provisional location. The straightening the arm resulted in an antenna beam as narrow and to solar signals as strong as expected from the prototype measurements.

Jan. 07 – March 07: Execution of various tests on the system performance, observations of various objects (Sun, Satellites, Moon, Galactic Centre, Sky background) using various techniques (simple positioning, stepped scans, manual scans, slow motion scans).

Late April 07: Remounting of the antenna dish in an upside-down configuration in order to permit again flux calibrations by observing the ground. Test observations of the Sun and the Moon.

The histograms below give an impression of the number and the volume of observational data files taken each day during the personal assignments, until late March. One notes that in February we concentrated on the basic observations of the Sun, the satellites, and a variety of tests. Once the solar drift scans had been mastered, more ambitious programs were started, such as a survey of the sky, and an attempt to detect emission from the Galactic centre by observations lasting more than 8 hours and giving more than 500 kB of data. At the times of the Full Moon, lunar observations were performed, the second ones giving a positive detection, owing to the repair of the telescope.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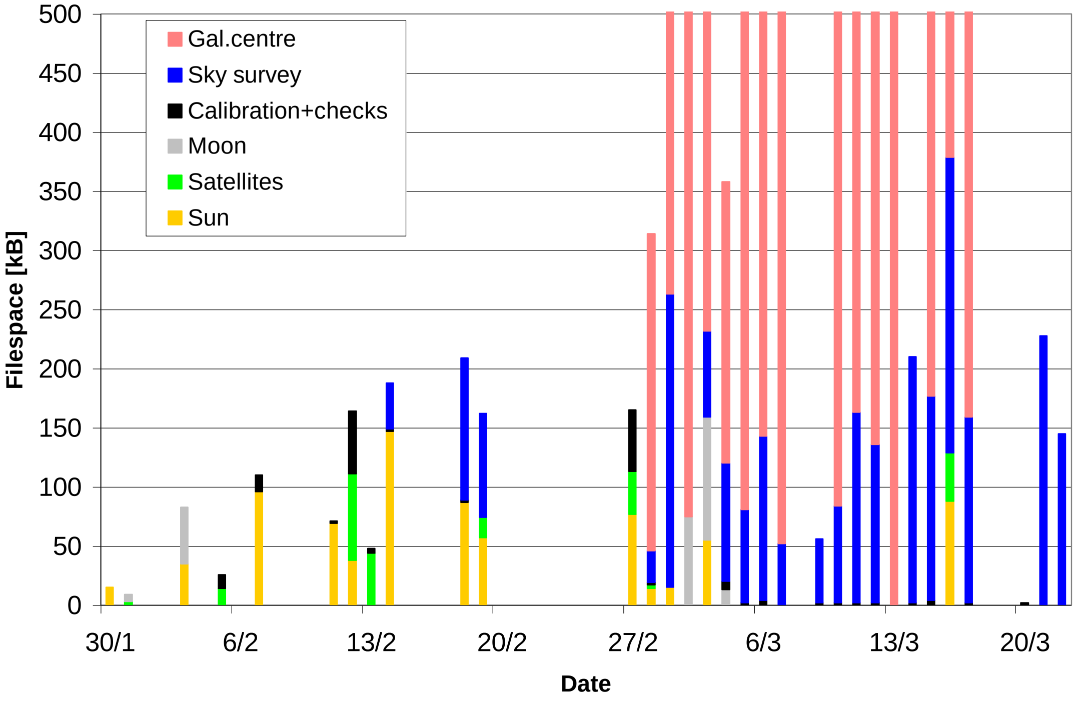
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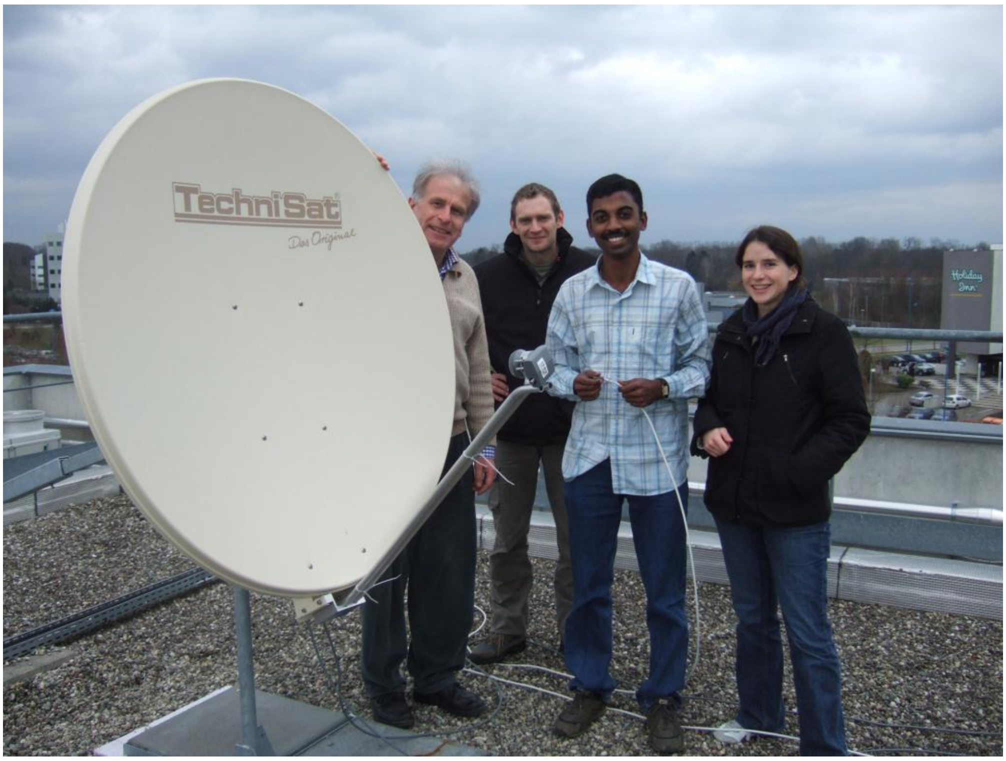
2 Our Installation at ISU

2.1 Cables

The antenna is placed on the antenna platform on the roof of the middle tower of the ISU building. Thus, an entirely unobstructed view in all direction is possible.
From this height, there are practically no buildings or trees that are significantly above the horizon – with the exception of other satellite antennas in the western corner.
Below is the antenna dish during final assembly. The additional concrete buckets have not yet been placed on the base-plate. Near the right rim of the image, the Holiday Inn hotel building can be seen, which serves as our flux calibrator. Note that it does not project above horizon.



The antenna and control cables are brought down as straight as the building permitted, but in the end all cables had to be extended by about 5 m to reach the indoor unit in the ISU “Radio Observatory” room, seen here during the third of a sequence of solar drift scans:

The installation of the cables proved somewhat of a challenge, as it turned out that there was unfortunately no direct cable conduit from the antenna platform to the room with the computer server and other electronics. Thus, a more complicated route had to be found, and additional holes had to be drilled. All this took up an appreciable amount of thoughts, time, and effort by the technical team of ISU!

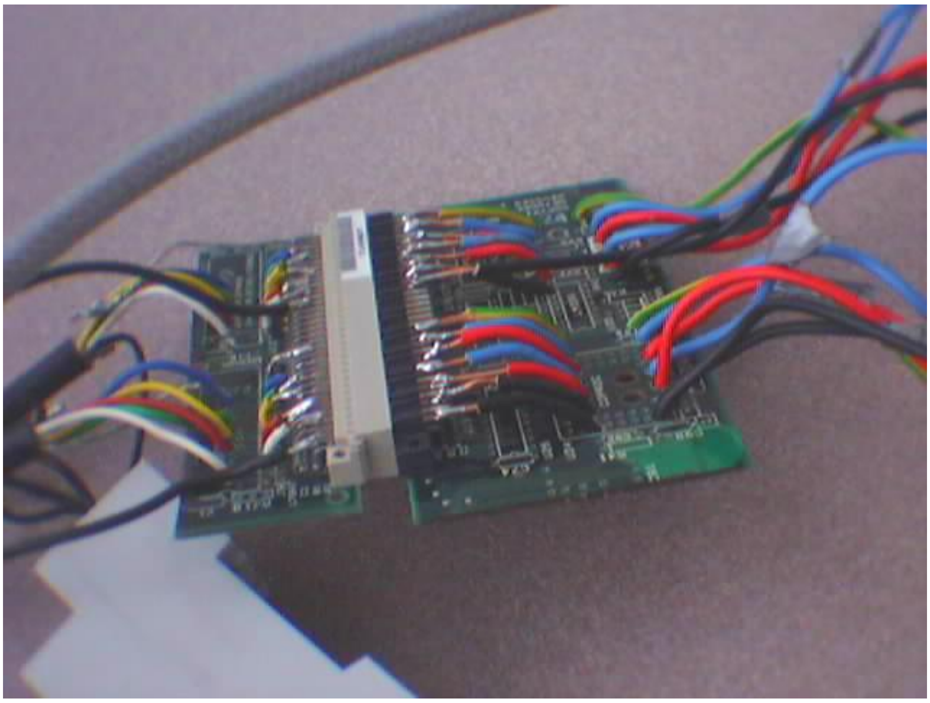
Thus, the coaxial cable has a total length of slightly more than 30 m, which results in a cable attenuation of about 10 dB. However, this is absolutely no problem, because the output signal from the LNB is about 50 dBµV for the noise background, and the AMA receiver had a noise floor of less than 30 dBµV, which leaves a comfortable margin of about 20 dB for cable losses. We have also tested adding a broadband amplifier immediately following the LNB – by inserting a SatFinder which gives about 15 dB gain. Although this – predictably – did not improve the signal to noise ratio, it confirmed that cable loss was not a problem in our installation, but also proved the utility of such a device if we had needed it.

Recommendations: The assembly manual states that the cable length should not exceed about 30 m. Since it may not be possible to adhere to this constraint, we suggest that the user could be informed about the above estimate, which shows that with the low noise background of the receiver, cable lengths of even 60 m – resulting in a cable loss of 20 dB – would still be acceptable. Furthermore, it may be pointed out that in case of too high a cable attenuation, it would be easy to compensate for it by inserting a standard broadband amplifier just after the LNB. These give a gain of about 20 dB and are available even from large supermarkets for about € 20.

2.2 Surge protection

The antenna is grounded to the main earth system of the roof, it is surrounded by grounded railings and has a couple of other antennas and the main lightning rod in its close vicinity, thus giving adequate lightning protection.

Instead of using the elaborate system for surge protection, as suggested by the designers, we decided because of costs constraints on the rather basic routine of physically disconnecting the coax and control cables from the interior units whenever the telescope is not in use. This would protect the sensitive indoor electronics from any spikes picked up by the outdoor part. This procedure is considered adequate for the winter season. During late spring and summer, we shall remove the antenna from its exterior position, as our students will not be in Strasbourg campus, and thus no observational activities are foreseen. The connections for the control cables were done using connectors salvaged from computer equipment. Both azimuth and elevation cables are together, and thus, there can be no confusion. The connections can easily be made or undone.



2.3 Estimates of the wind load

Application of the basic formula for the force on a circular dish gives:

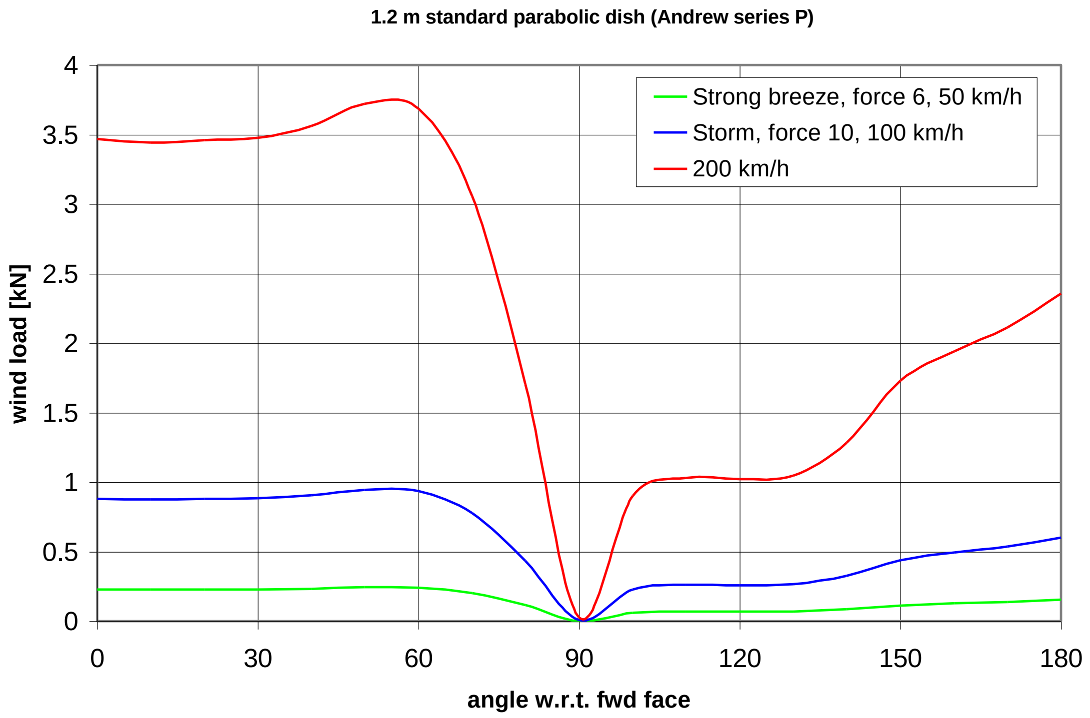
$$\begin{aligned} \text{Force} &= \text{area} * \text{air density} * (\text{wind speed})^2 \\ &= (3.14 * 0.6^2) * 1.2\ \text{kg/m}^3 * u^2 \\ &= u^2 * 1.36\ \ \text{m/s} \\ &= u^2 * 0.105 \quad \text{with } u \text{ in km/h} \end{aligned}$$

However, this force has to be corrected for a leverage factor, since the antenna dish is mounted on a tube to the base-plate, so that its centre is about 1 m above ground; the base-plate has a side-length of 50 cm. If we suppose that a uniform distribution of the weights is equivalent to letting the weight act at the centre of the base-plate, the length of the short arm is 25 cm. Thus the weight necessary to hold down the base-plate is 4 times the force acting on the dish:

The following table gives an overview of the forces acting on the antenna and the base-plate, as a function of the strength of the wind:

	Beaufort number	Wind speed [km/h]	Force [kN]	4* Force [kN]
Calm	**0**	0	0	0
light air	**1**	1…6	0.000 … 0.004	0.000 … 0.015
light breeze	**2**	7…11	0.005 …0.013	0.021 … 0.051
Gentle breeze	**3**	12…19	0.015 … 0.038	0.060 … 0.151
moderate breeze	**4**	20…29	0.042 … 0.088	0.168 … 0.352
fresh breeze	**5**	30…39	0.094 … 0.159	0.377 … 0.637
strong breeze	**6**	40…50	0.168 … 0.262	0.670 … 1.047
near gale	**7**	51…62	0.272 … 0.403	1.089 … 1.610
Gale	**8**	63…75	0.416 … 0.589	1.662 … 2.356
strong gale	**9**	76…87	0.605 … 0.793	2.419 … 3.170
Storm	**10**	88…102	0.811 … 1.089	3.244 … 4.358
violent storm	**11**	103…117	1.111 … 1.433	4.444 … 5.734
Hurricane	**12**	117…	1.433 …	5.734 …
		150	2.356	9.425
		200	4.189	16.755

One should add that the wind load on a parabolic dish antenna remains quite constant with the angle of incidence. The following diagram was compiled from the wind load calculator from an antenna manufacturer (Andrew Corp.). Although these data were obtained for a centred parabolic dish, one may expect that they also give a good indication for our off-centred antenna.



From the values of our table we may estimate what would happen to our antenna, if it was held down by various counterweights:

- Original design: 4 concrete slabs (from the assembly manual):
  Volume : 50 by 50 by 5 cm = 12500 cm³
  Density : 2.4 g/cm³
  Mass : 30 kg each
  The four slabs have a total mass of 120 kg.
  Weight : 1.1 kN
  Maximum wind force: Beaufort 6.

- Our initial configuration: our 2 concrete slabs
  Volume : 50 by 50 by 3 … 4 cm = 7500 … 10000 cm³
  Density : 2.4 g/cm³
  Mass : 18 kg … 24 kg each
  The two slabs have a total mass of 36 … 48 kg.
  Weight of about 0.36 … 0.48 kN
  Maximum wind force: Beaufort 4 … 5.
  No wonder that it was blown over so easily!

- Our present configuration: 2 concrete slabs and 6 buckets of concrete
  Mass of each bucket: 17 kg
  Total weight: 1.3 … 1.5 kN
  Maximum wind force: Beaufort 7

We have adopted the routine to remove the dish reflector in case of storm warnings and also during longer periods of inactivity (vacations time).

In his report M.Cornwall (2007) arrives at more optimistic constraints. The reason for the difference in our calculations is under investigation.

Recommendations: As this issue is of rather crucial importance for a permanent installation, but is dealt with in the assembly manual only in a rather brief way, we strongly suggest that the documentation should be updated to either give detailed instructions to the (non-expert) user how to deal with this point or at least urge him to acquire proper technical consultation.

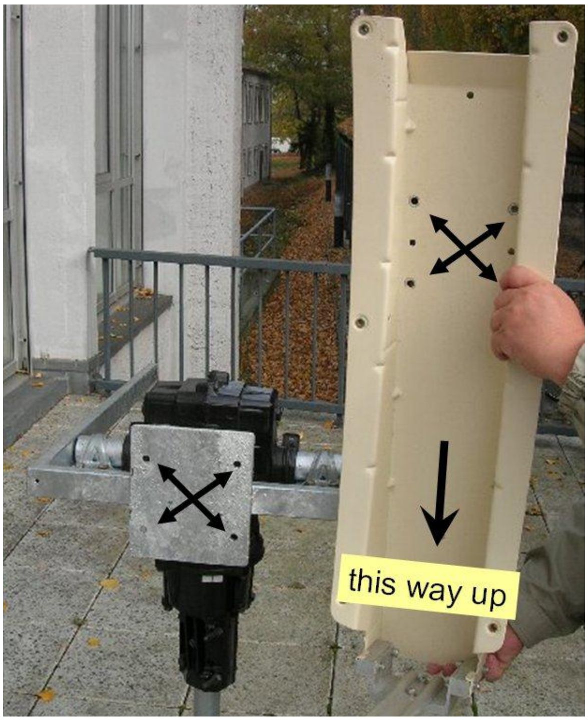
2.4 Assembly

The final assembly of the antenna was done by the students. This was rather easy, because it involved but the re-assembly of the partly disassembled exterior unit. We noticed:

- The antenna on its mounting gives a rather flexible impression: it is easy to let it swing by what appear to be one or two degrees. It has a rather appreciable play in the elevation; albeit it seems that the weight of the dish keeps it in the lower position.
- With only two concrete slabs as a base weight, it is fairly easy to topple it by simply pushing the centre of the dish with your hand sideways. This is a simple and nice experiment for the students, which gives a direct impression of the wind force necessary to upset the dish. It also demonstrates that the mounting is more stable against force parallel to the long side of the base-plate than against the force acting in the other direction.
- With all 6 buckets of concrete placed on the base-plate, the students could convince themselves that a much larger force is necessary!

Recommendations:

- We did not make much use of the step-by-step instructions and details of the assembly manual. It was felt among the students that the presence of several clear pictures and diagrams would have been quite sufficient, even if they had had to start by unpacking the boxes.
- We strongly suggest that the antenna dish should not be mounted in conventional orientation, but with the LNB arm on the top. This gives the great advantage that the offset dish can be directed towards the ground to pick up its thermal emission and thus permit an absolute flux calibration of the overall system. This is easily done by mounting the dish support by its four screws simply upside-down, as indicated in this picture taken from the Assembly Manual.



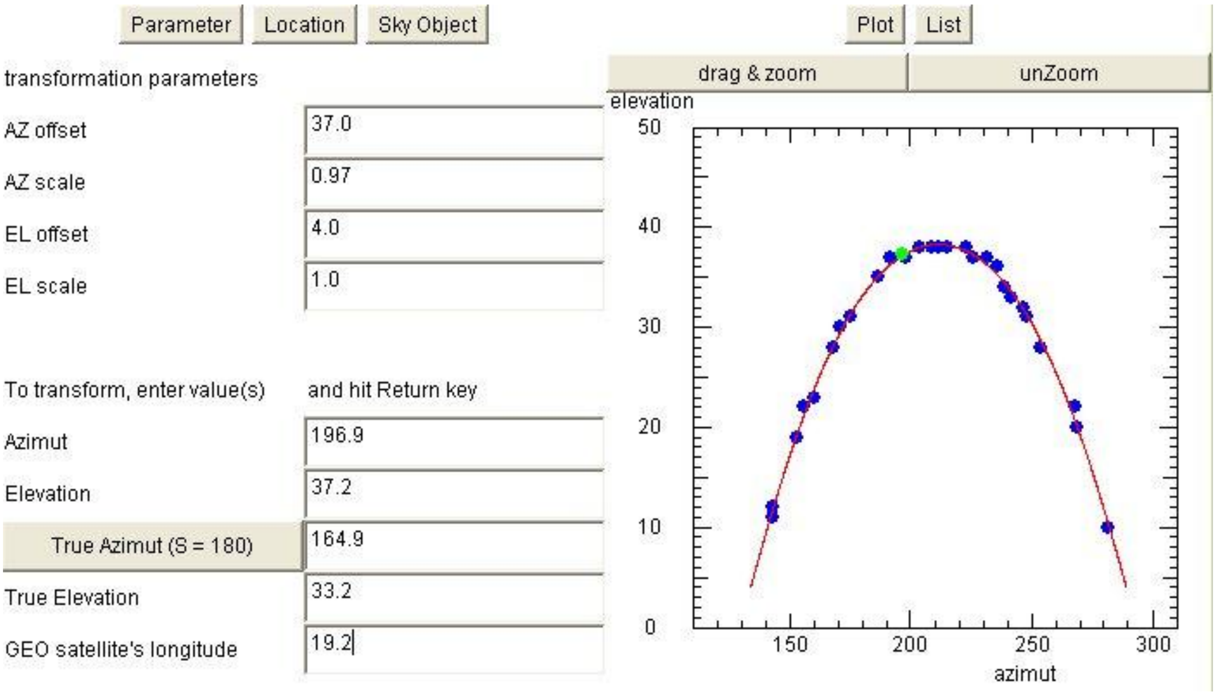
3 Positioning System

One of the first things noticed by the students was that the parameters determined in a calibration of the positioning system were not stored permanently on the computer. Neither was there a button, like “Save configuration” nor it was evident from the source code that these parameters were stored in a setup file on hard disk when one exited the program.

To avoid the rather tedious recalibration routine, we took an entirely different approach, by using a Java applet (or any other small program) to transform between true coordinates (azimuth and elevation) and the values displayed and used by the software. Since it had been verified during the placement of the antenna mounting that it was almost exactly vertical, we may assume that the transformations in the two angles are independent of each other. Since the rotator and controller units apparently were quite properly aligned by the manufacturer, the essential feature was to apply offset angles, but we also allowed a scaling factor. Hence, the transformation formulae are:

azimuth = scale_AZ * True_azimuth + offset_AZ
elevation = scale_EL * True_elevation + offset_EL

We determined the four parameters by searching as many geostationary TV satellites as possible, and measure their positions in “our” coordinate system. The knowledge that all these satellites must have positions on the “Clarke belt” which can be calculated for our location, allows to derive the parameters by manually finding a best match between the satellite positions (blue dots) and the Clarke belt (red curve) in the screen shot below:



transformation parameters

AZ offset	37.0
AZ scale	0.97
EL offset	4.0
EL scale	1.0

To transform, enter value(s) and hit Return key

Azimut	196.9
Elevation	37.2
True Azimut (S = 180)	164.9
True Elevation	33.2
GEO satellite's longitude	19.2

As can be seen, the scale factors are indeed very close to unity. Our approach permits to change the transformation easily, if this becomes necessary. It also is based on the measurements of as many satellites as the user wishes and thus ensures a good overall accuracy.

The applet also permits to compute the position of a geostationary satellite from its longitude – as shown here by the green dot for the Astra 1-H satellite.

Recommendations

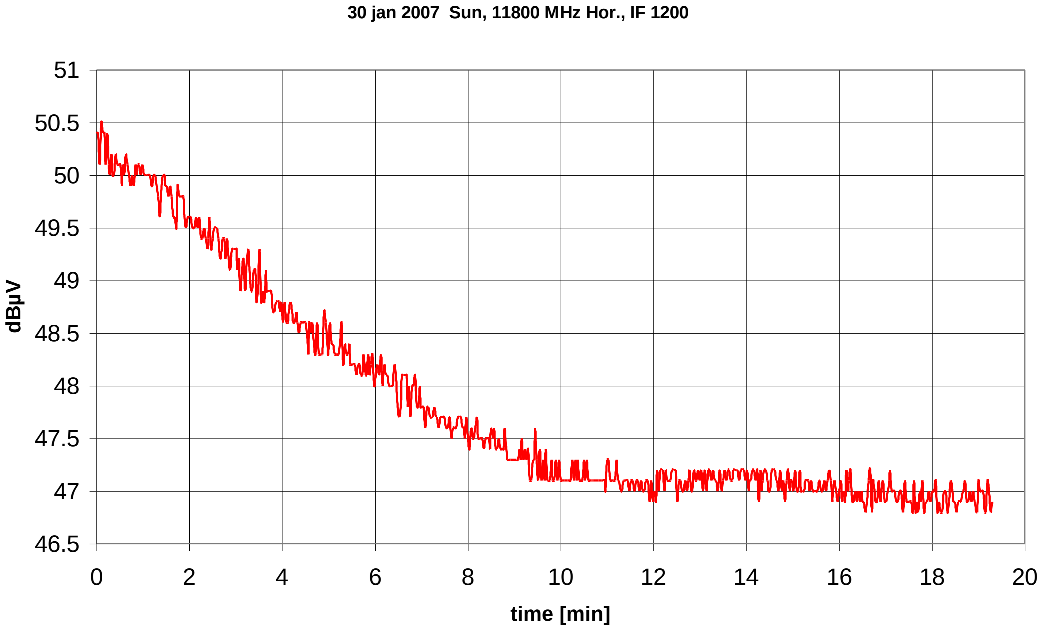
- Automatic or optional storage of calibration parameters in a configuration file on hard disk
- Manual entry of the calibration parameters to allow determination by external means, as well as to permit a soft-ware implemented calibration of the telescope's coordinates, irrespective of the actual orientation of the telescope.
- We recommend our positional calibration method, based on as many satellites as possible, rather than the routine suggested in the manual. The transformation coefficients found by such an adjustment could be directly entered to the software.
- Show the current position with one decimal place after the point: while this certainly exceeds the accuracy and stability of the system, it removes the present uncertainty whether 23 means 23.4 or rather 22.7. It had been noticed frequently that the numbers changed during observations without any effected change of position. Likewise, the positions at the start-up of the system could differ by 1° from the position where the telescope had been left after the previous observation run. Obviously, this is due to thermal drift of the voltages which measure the positions. While such a high demand for stability would push the hardware beyond its design limits, a more precise indication would remove the uncertainty of the user. Perhaps, it could be of educational value to investigate this instability, trace its origins, and learn about the limits of a system …!
- The accuracy and stability of the system is really at the limit for the narrow beam of the 1.2 m dish: It has frequently been noticed that the Sun was missed by what must have been less than a degree in attempts of full drift scans. Since the measured solar temperature depends on getting the real maximum as well as the antenna pattern, it might be rather frustrating for a student to miss the Sun despite his diligence of predicting the transit position and then arrive at a much lower value for the temperature.
- In such an event, a short actuation of the elevation control lead to an increase of the signal by 1 dB, while the elevation angle remained the same on the display.
- Furthermore, the user, unwary of the unavoidable backlash of such a system, may click the buttons in any direction.
- In the pulsed operation, the positioning apparently moves by 1 degree at every pulse … but why does it sometimes takes 2 deg? Or does it mean that it moves not by precisely 1.0 deg? This needs clarification and if possible, improvement. The very useful feature of being able to cover a region in the sky in a systematic fashion is severely handicapped by the present uncertainty about the true positions
- It would be better if one could control the size of the steps taken in azimuth and elevation. This would be very useful when making systematic scans across the sky and measuring the antenna pattern by stepping in elevation across a satellite
- The label "speed reductions" is misleading. It makes one expect that the speed of the rotators is slowed down … It would make much more sense to specify the time interval between two successive pulses … or perhaps the number of data points taken at each location!
- It would also be useful to have the option to record the current position for each measurement taken.

- If one wanted to track a celestial body for a long time, the inclusion of the rather simple transformation from equatorial to horizontal coordinates must be part of the system. The technique proposed by the designers of using linear interpolation in both angles would be adequate for shorter intervals, and would teach the student about celestial motions, but it would certainly not be applicable if one wanted to execute a daytime tracking of the Sun, in the hope to catch a solar radio burst (as they do not occur within the one or two hours of the activity) …
- … however, since the step size of the "time controlled rotation" is finite and does not seem to be constant, it might not be worth implementing such a tracking feature. The designer's example of tracking the Sun (Fig.24 in the Operating Manual) shows clearly the effects of the finite size steps. It remains to be seen whether this would push the telescope beyond its capabilities.
- Tracking a celestial object would be asked for if one would want to integrate over the signal of a weak source. However, such a long-term integration would also necessitate frequent excursions to an off-source position to integrate over the background, and then coming back to the exact position of the source. Since such a requirement would clearly be beyond of what seems to be the limits of the stability of the positioning system, we have the impression that an accurate tracking of celestial objects is not an urgent necessity for the instrument.
- It would be better if the minimum and maximum limits for the input values for elevation and azimuth could be altered by the user in some setup menu – or a setup file, rather than forcing him to apply these changes to the source code. These values should be modifiable to the individual location. While playing with the source code would appeal to people interested in programming, it might make things more difficult for a teacher who likes to concentrate on the physics issues. In our case, we it was essential to reach below the horizon for flux calibration … we defeated the software by entering 5° elevation and then used the 'down' button of the Yaesu controller to reach 0°, the lowest elevation.
- The students made use of the Operating Manual, and rather quickly got familiar with the controls and the observation routine. Once, the description of the "Calibration of tracking speed with known satellite positions" (section 3.2.1) was executed in detail to judge the clarity of the manual. It was found that following precisely the instructions one does not pick up the second satellite, because the two satellites are at different elevations (Astra 1-H at 31.7°, Telecom 2D at 33.3°), even with the wider antenna beam before the repair of the LNB arm.

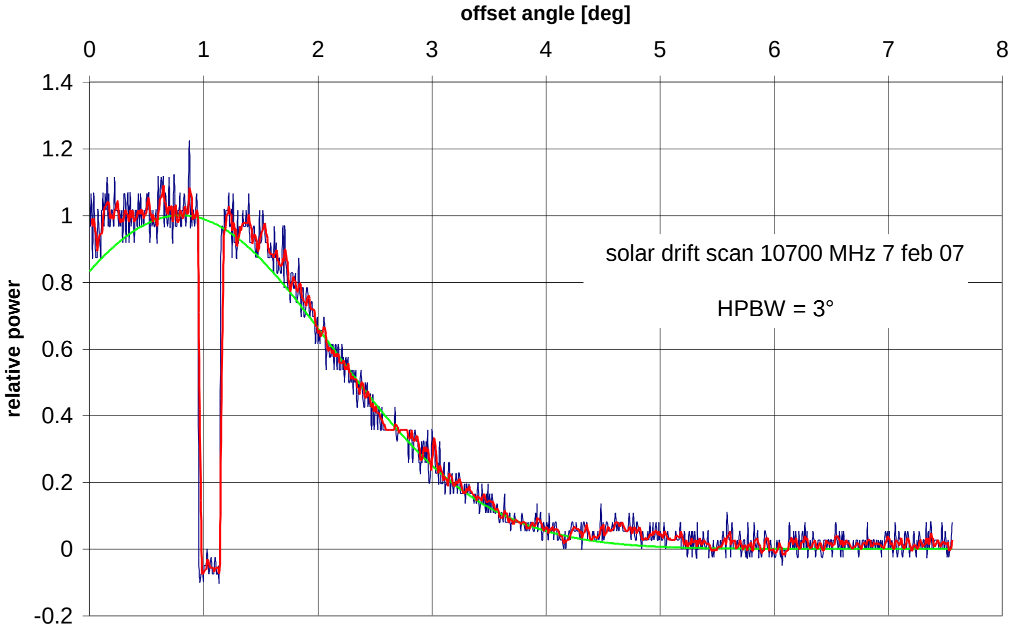
4 Observations and the measurement system:

4.1 Solar drift scans I: a first look

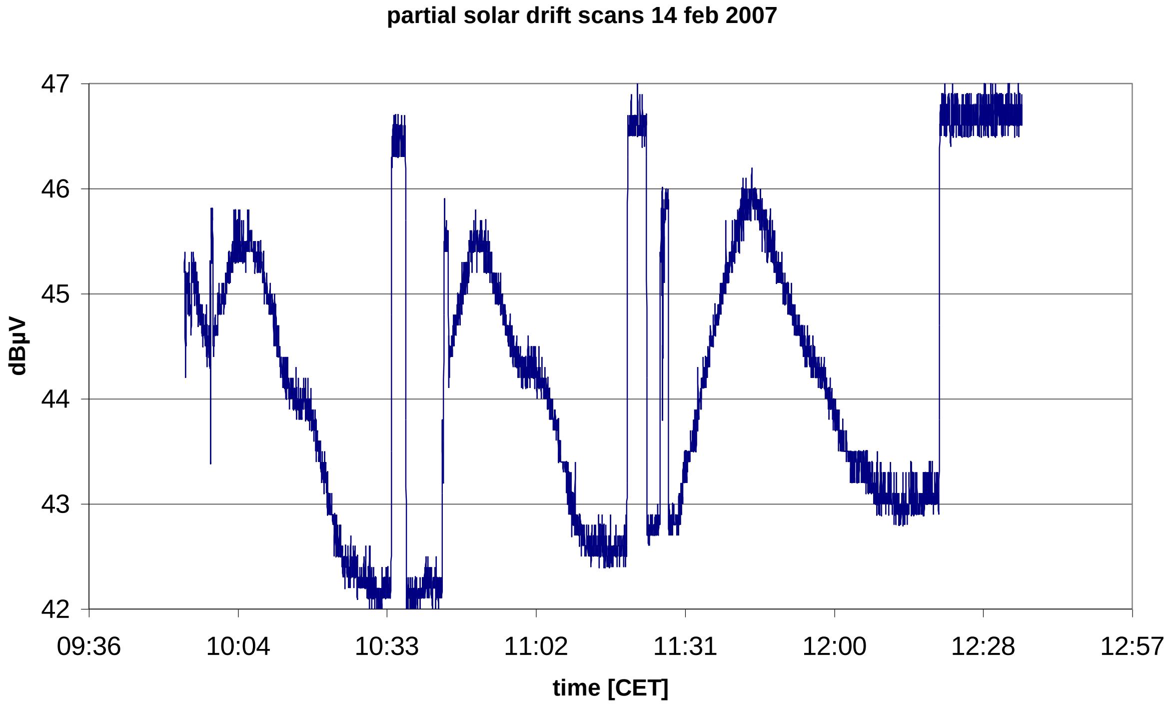
Our first solar scan followed the successful search for the Sun around its predicted position: We noted that the maximum value was only 3 dB above the background level, while the data taken with the prototype showed about 10 dB.



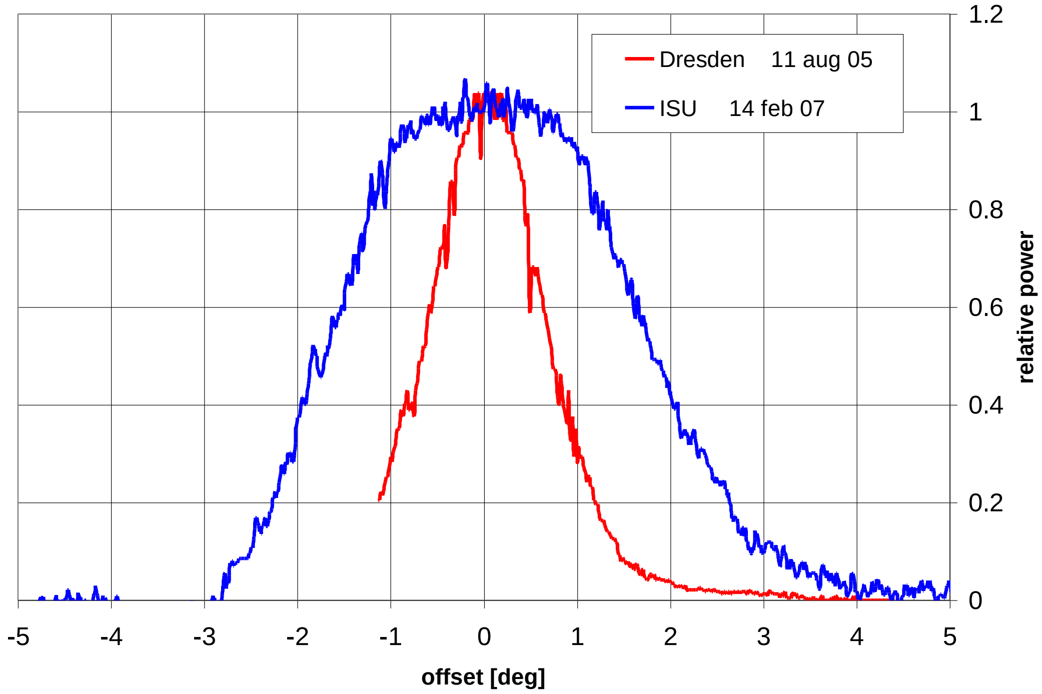
A later, more complete drift scan allowed a first estimate of the width of the antenna pattern: a rather large value for the half-power beam width (HPBW) of 3° was found, while from a 1.2m diameter dish one should have expected about 1.4°.



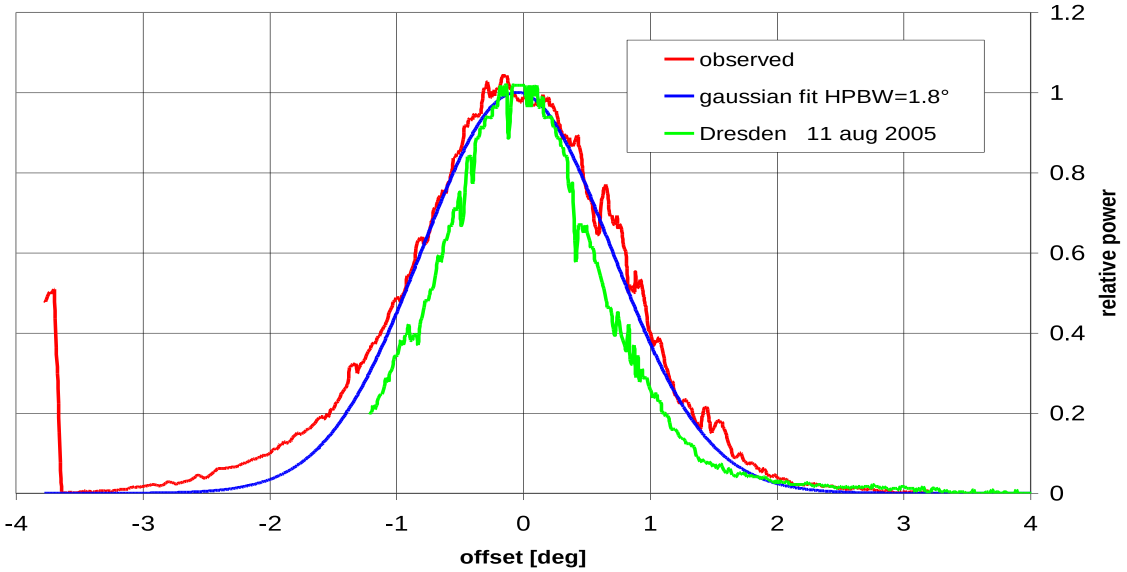
Moreover, it had been noted that the profile was not symmetrical, and that it showed a “hump” on the outgoing part, i.e. indicating that the western side of the antenna pattern behaved oddly. This was even more puzzling, because the strength of this “hump” seemed to vary strongly between observations.



Finally, a full drift scan, and a detailed comparison with a measurement by the prototype revealed that our antenna was significantly out of focus:

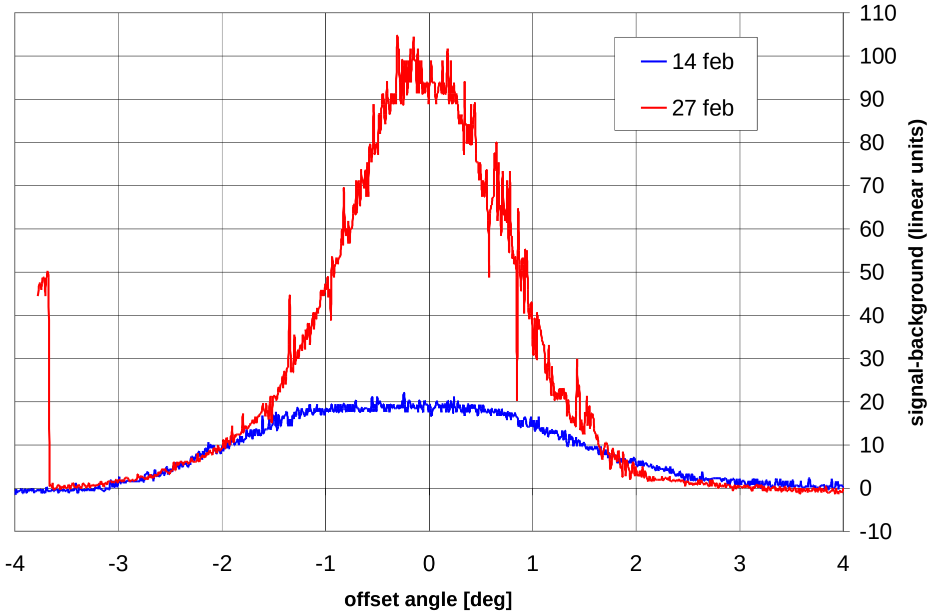


This lead to the discovery that the arm which carries the LNB was bent upwards, evidently a result from the antenna's two falls. After straightening of the arm, the antenna pattern became as narrow as it should be:

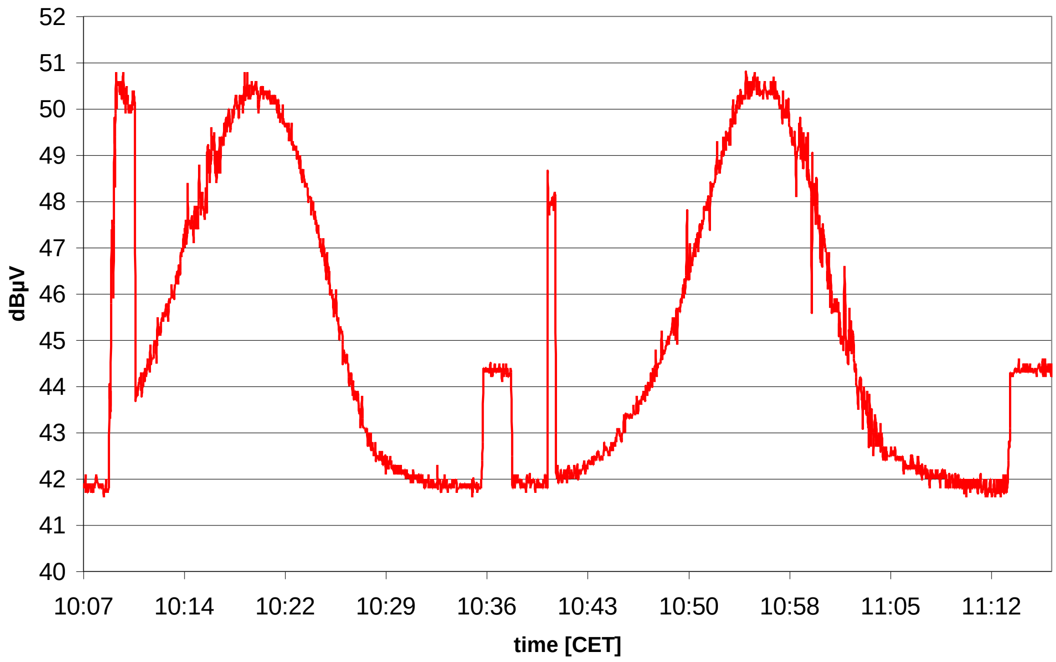


The remaining slight difference may be taken as within the tolerances of the production, and is certainly well acceptable for our purposes.

A more direct comparison of the antenna pattern before and after the repair is shown below, where we plot the difference of linear signal power above background (in arbitrary units). The improvement is especially prominent in the centre of the beam. For offset angles larger than about 1.5° the beam pattern remain the same on the eastern lobe – if one neglects the displacement of the peaks by about 0.2° – but the "hump" is apparent in the western lobe. This unsmoothed tracing shows several strong short term fluctuations with those on the eastern slope pointing upward, but the ones on the western slope downwards. These excursions of the measurements are undoubtedly due to gusts of wind which evidently come from easterly direction and push the antenna beam towards the west.

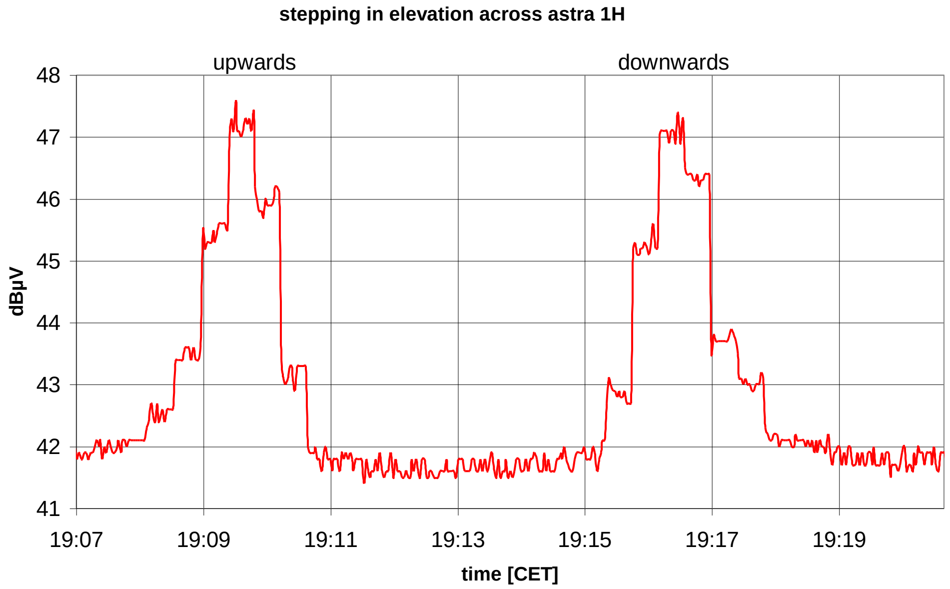


As a consequence of the narrower beam, the solar signal came up to 8 dB above the background, as seen in the two full solar drift scans of Feb. 27th:



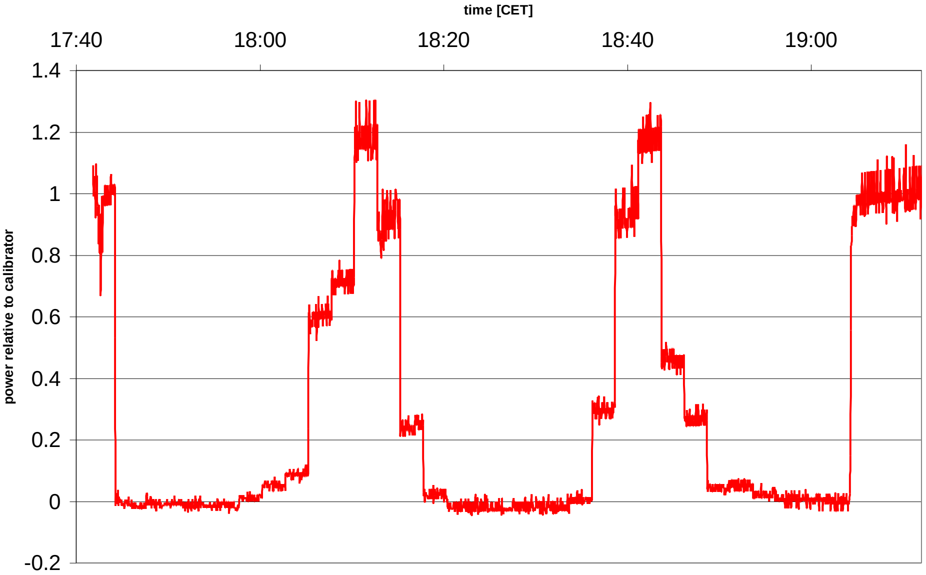
4.2 Elevation scans across a satellite: antenna pattern and repeatability of positioning

Several attempts were made to scan in elevation across the strong satellite Astro 1-H in order to test whether the positioning system would reach the same positions, irrespective of the direction in which the stepping was done. One of these observations – from Feb. 12th - is shown below:

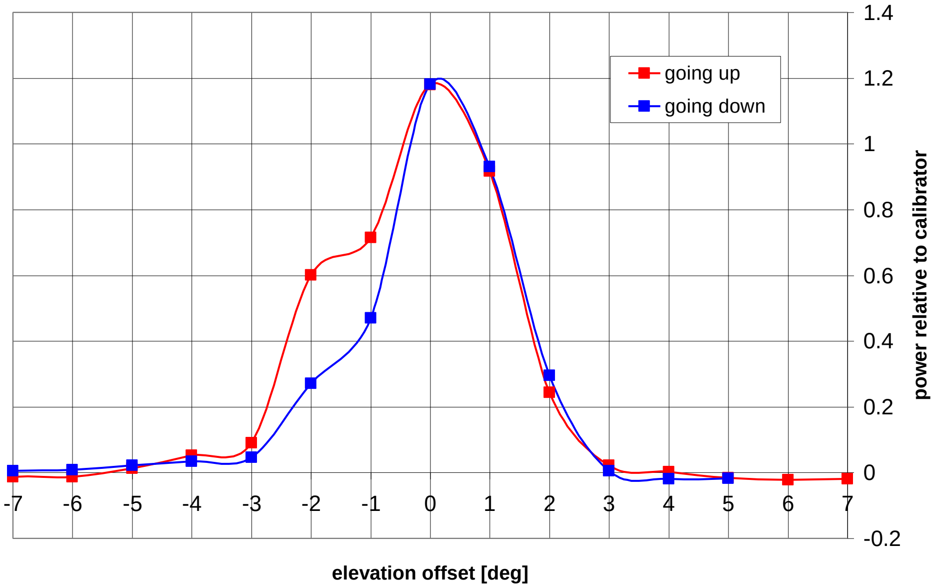


This was done with a reduction of 1/50, so that about 20 samples were taken at every position. Unfortunately, we did not record the elevations at each step, as we naively assumed that the steps were done in 1° intervals. One notes that the two profiles are not exact mirror-images of each other, as one should expect for a precise repetition of the positions. However, both profiles seem more or less consistent with each other, if one accepts the positional uncertainly of better than 1°.

In another (upwards-downwards) sequence on Feb.13th, which had also been flux calibrated,



a strong asymmetry is evident, which affects the upper side of the antenna beam, that is when the antenna is pointing below the satellite's position. In the figure below the average measurements over the 80 samples at each position (stepping with 1/300) are shown. The HPBW in vertical direction seems to be also about 3°, as one should expect for a circular dish. However, a consistent skewing of the pattern was taken as another hint that the dish was out of focus.



We note that the positions are well reproduced in both directions, which indicates a positional accuracy of better than 1°, as expected from the specifications. However, in later scans, we chanced to note that the step-width is not strictly constant at 1°, but occasionally steps of 2° are taken.

4.3 Flux calibration

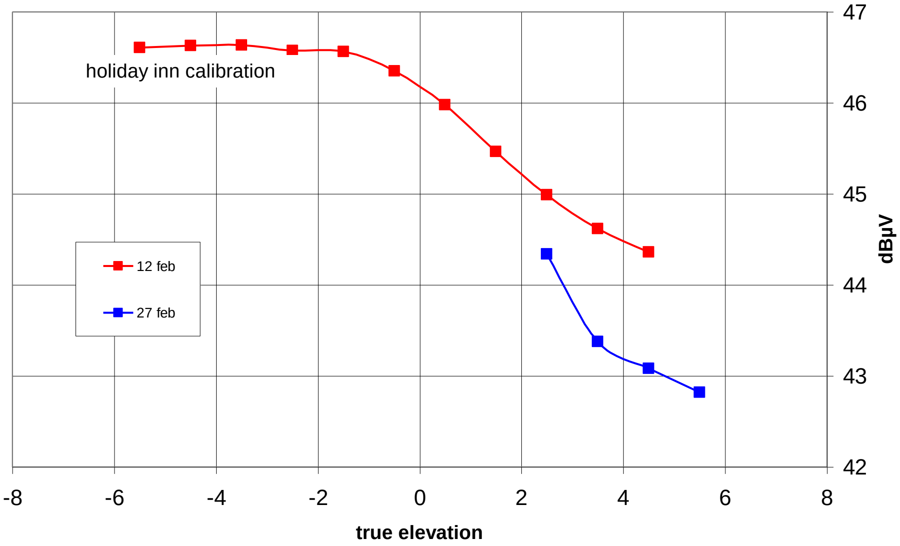
Because a radio telescope deals with signals rather close to the internal noise floor, one of the most essential aspects is the calibration of the overall system in terms of absolute fluxes. For satellite TV equipment working on 10 GHz this is particularly easy to realize: Any warm opaque body emits thermal radiation which is easily detectable by the present available apparatus.

If one points a LNB towards a person, the walls of a room, or anything at room temperature, one notes a signal, e.g. measurable by a SatFinder indicator. Only when one points the LNB to the sky, a strong drop of the signal is noticed. As seen at 10 GHz, the sky is dark, but everything else on Earth is bright. It is also an interesting experiment to point the LNB through a glass window towards the sky: No drop in signal is found, because glass is opaque at this frequency and thus the pane is as bright as a thick wall!

This property of all earthly bodies to have a temperature close to 300 K can be used to calibrate the telescope:

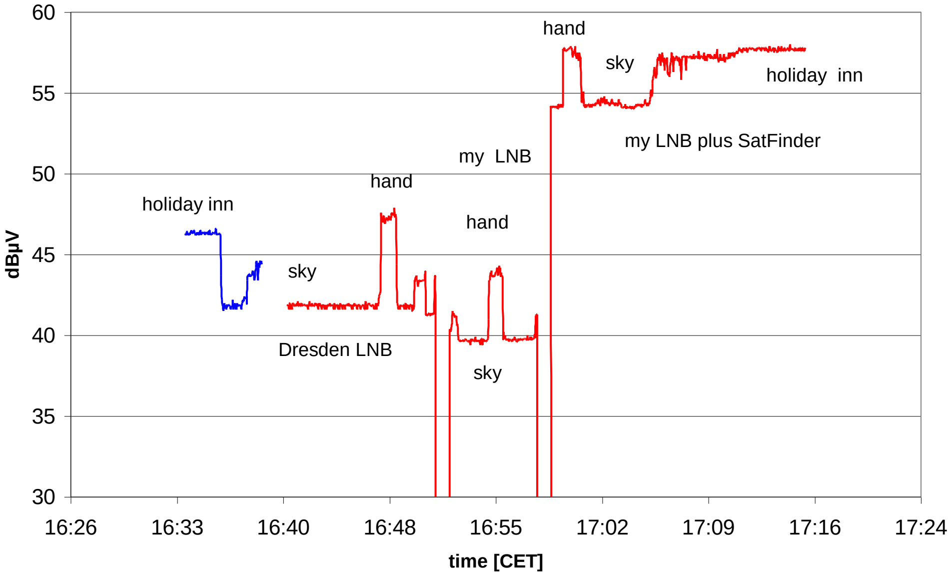
- one covers the LNB's horn antenna with one's hand
- one points the telescope towards the ground, a large wall or building, so that the telescope beam is completely filled by this source

In our installation, we found out that when tilting the instrument towards its minimum elevation (0° - which can be achieved by manually using the down-key on the Yaesu controller, in order to circumvent the 5° acceptance threshold of the software), the telescope pointed about 5.5° below the horizon. We preferred the nearby building of the Holiday Inn hotel to take the calibration measurements. The figure below shows the increase of the signal as the elevation angle is lowered; the data of Feb. 12th (i.e. before the repair of the LNB arm) exhibit saturation for angles below -1°, thus ensuring a good calibration.



As it is also practice in professional observational astronomy, we try to take one calibration before and one after each measurement, such as a solar drift scan. It has been found rather convenient to move the telescope from the calibration spot to the target, or sometimes make a short excursion to measure the sky background.

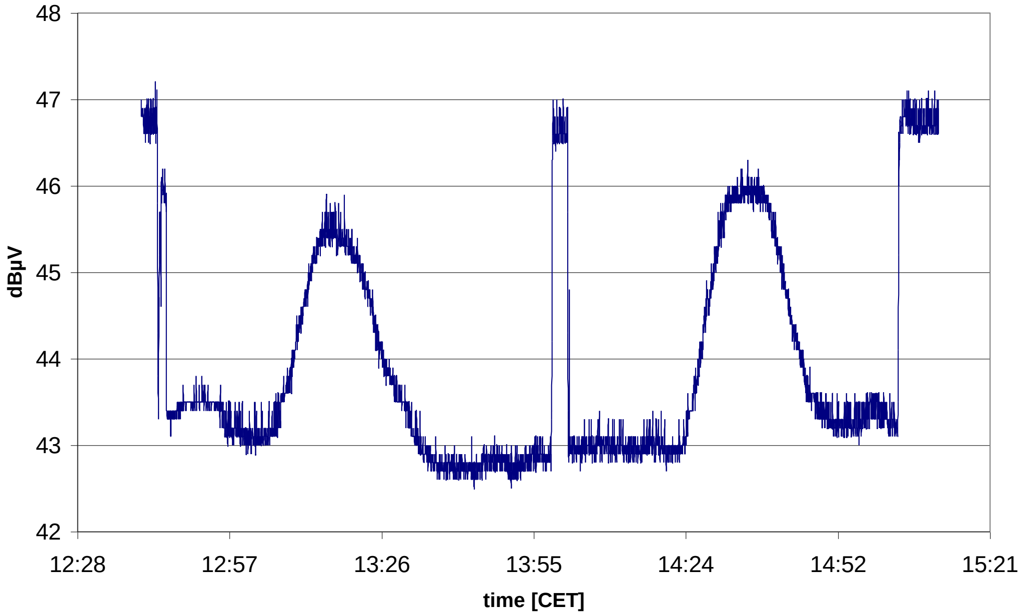
On Feb. 12th we conducted tests on the influence of the LNB, measuring the signal from hand calibration and background of the empty sky for the original (“Dresden”) LNB, another LNB of similar noise figure, and the latter one also followed by a SatFinder. It was found that the hand calibration always gave a signal of 3 to 5 dB above sky background, and that the hand calibration is close to the Holiday Inn calibration.
The two drop-outs of the signal are caused by the exchange of the LNBs and give proof that the noise floor of the AMA measuring receiver is below 30dBµV. This verified that the measured background level is dominated by the contribution from the LNB, and that the cable loss of about 10 dB is in no way detrimental to the quality of the data.
Moreover, the gain of the amplifier in the SatFinder was measured to be +14 dB. This would have been available if we had found need to compensate the cable losses.



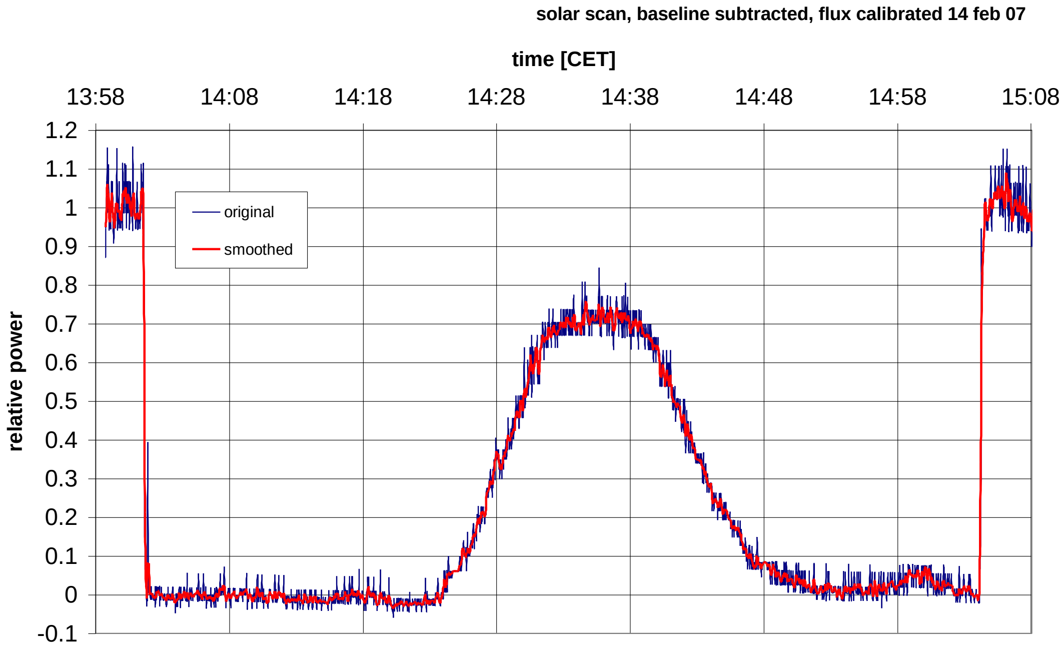
Unfortunately after its repair, the antenna pointed higher and we had lost our easy calibration facility. However, we found that it was very easy to mount the antenna dish with the LNB arm upside-down, and to adjust the elevation axis so that the offset dish can again be pointed somewhat below the horizon.

4.4 Solar drift scans II: full interpretation

Two full solar drift scans, from Feb.14th, along with the calibration measurements before and after the scans are shown below. In these original data variations of the calibration level and, more strongly, of the background level are evident.



Interpolating linearly the background and calibration levels between the start and the end of each scan, we subtract the background from all measured data. These difference powers are then normalized in terms of the calibration value.
The result is shown below:



From the width of the profile at half power one gets a HPBW of 3.75°; this implies that the Sun with a diameter of 0.5° fills only 1/56th of the antenna beam. Assuming a calibrator temperature of 300 K, the maximum of the profile gives an antenna temperature of 210 K. Correcting for the antenna coverage factor, one arrives at a solar brightness temperature of 12000 K. This is the temperature of the solar transition layer, between chromosphere and corona, the layer from which radio waves at 10 GHz can escape, as the layers become optically thin for free-free absorption.

During the entire time, several partial and full drift scans across the Sun were obtained. The successful and more complete ones are listed below, along with the essential data and the results of the quantitative analysis:

Date, time	Telescope	HPBW deg	Source dBμV	Backgrd dBμV	Antenna Temp.	Solar Temp.
7 Feb., 13:00	ESA-Dresden	2.7	45.7	42.85	--	--
12 Feb., 10:38	ESA-Dresden	3.5	46.4	42.0	219	9260
14 Feb., 13:17	ESA-Dresden	3.5	45.7	42.7	180	7610
14 Feb., 14:35	ESA-Dresden	3.5	46.5	43.1	210	8880
19 Feb., 15:53	ESA-Dresden	(3.5)**	45.1*	42.0	171*	7230*
19 Feb., 14:35	ESA-Dresden	(3.5)**	45.0*	42.3	195*	8240*
21 Feb.	Repair of LNB arm					
27 Feb., 10:56	ESA-Dresden	1.8	50.2	41.8	(1050)	(12200)
16 Mar., 12:40	ESA-Dresden	1.9	49.8*	41.8	(870)*	(11000)*
16 Mar., 13:25	ESA-Dresden	1.5	49.8*	41.8	(810)*	(6400)*
29 Mar., 16:21	ESA-Dresden	1.5	50.1	41.8	(930)	(7400)
24 Apr.	Inverted mounting of ESA-Dresden dish					
24 Apr., 10:10	Small Antenna	2.5	64.6*	62.4	195*	4370*
24 Apr., 18:36	ESA-Dresden	1.5	50.2	42.0	990	7980
26 Apr., 15:00	ESA-Dresden	1.5	50.0	41.7	1035	8460
30 Apr., 10:10	Small Antenna	3.2	65.3	62.2	285	10450
30 Apr., 11:15	ESA-Dresden	1.8	50.2	42.0	1050	12190

All observations are done on 12500 MHz, except the one on Feb.7th which was done on 11250 MHz.

* These observations missed the true maximum.

** the antenna pattern is rather asymmetric. Hence, it is difficult to give a reliable value for the HPBW.

Values in parentheses are estimated based on flux calibrations with the same instrument configuration.

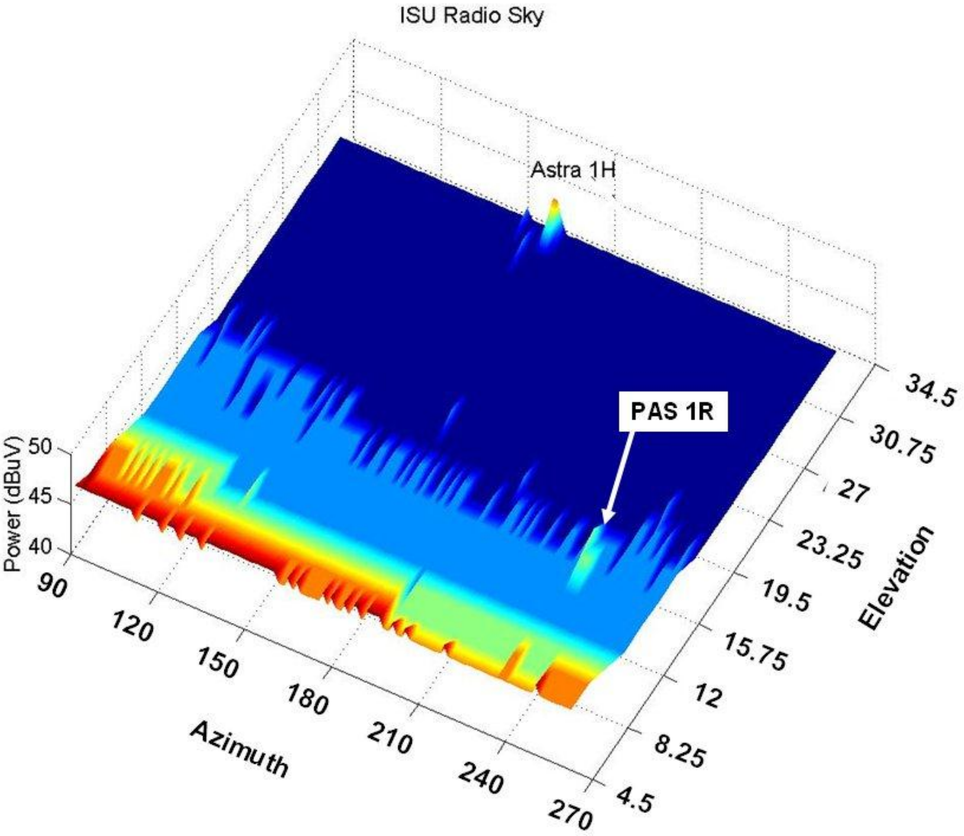
For comparison, we also performed scans with the Small Antenna, a 60 by 70 cm offset dish, positioned manually, but using the AMA receiver and computer to record the data.

In the period before the repair of the LNB arm on 21 Feb. the 1.2m antenna showed a beam much broader than expected, and the solar signal was much lower (only about 3 dB above background) than seen in the prototype (about 8 dB above background). Nonetheless, values for the solar temperature were in reasonable agreement with the expected value of about 10000 K. This demonstrates that even if the dish is badly focused, as the result of wind damage or perhaps some mishandling, it can produce useful and meaningful results. However, it had been noticed that the antenna pattern deviates from a nice symmetrical shape, and thus there would be uncertainties how to measure the HPBW which is crucial to deduce the solar temperature. Variations are undoubtedly due to differences in background subtraction and calibration. One could foresee that closer inspection of the measurement and analysis would reveal possible improvements. In view of the simplicity of the instrumentation and the approach, these results are excellent, and demonstrate the advantage of using a measurement receiver!

4.5 Sky Scans I: Satellites

The main feature of the man-made objects in the sky is the so-called Clarke-belt: All geostationary satellites are seen from an observer on the ground in a great arc across the sky. We use this fact to determine our transformation formulae for the positioning system, for which we obtained the positions by searching in the sky for individual satellites. However, we thought that it would be a nice idea to present a radio image of the sky, which showed this band of satellites like a string of bright pearls …

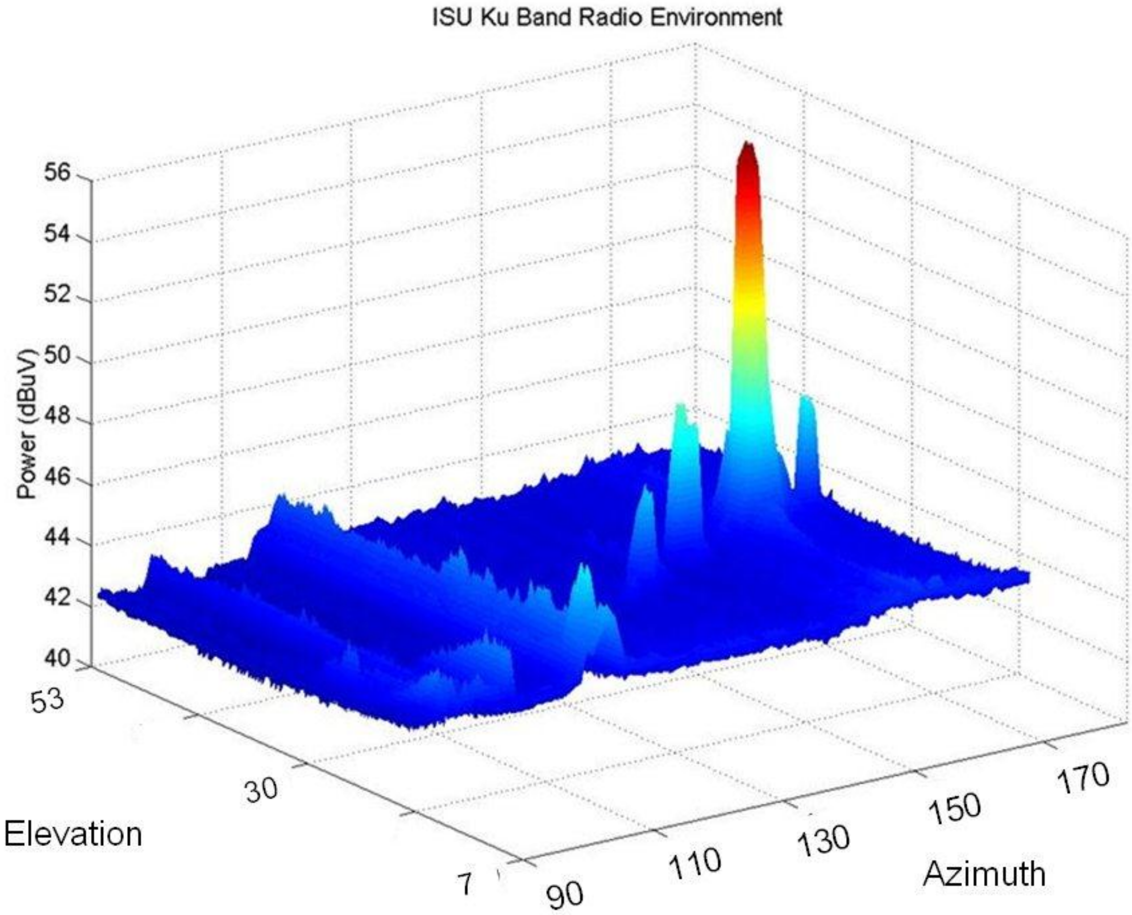
Marc Cornwall came up with this idea, and worked out how to conduct such a sky survey in an efficient manner. As a first attempt, he scanned the sky for each elevation, going from East, true azimuth 90°, to West (270°), using the slow motion option in azimuth. This gave in one evening's work a most promising overview of the sky, shown below as a false colour map:



Apart from the strong satellite Astra 1H nearly due south, and a weaker satellite at true elevation of 15° and true azimuth 240° (probably PAS-1R), no other of those satellites which we had used for the calibration of the positioning system shows up as prominently as we would have guessed. Evidently this scan was too coarse: stepping in elevation by 2° and azimuth scan in slow motion.

A more detailed and more sensitive survey is currently under way (by Marc Cornwall), which takes observations by stepping for every azimuth in elevation and observing at each position for a sufficient amount of samples. It is a very useful feature of the positioning system to allow this kind of semi-automatic stepping, which makes it possible to undertake this survey.

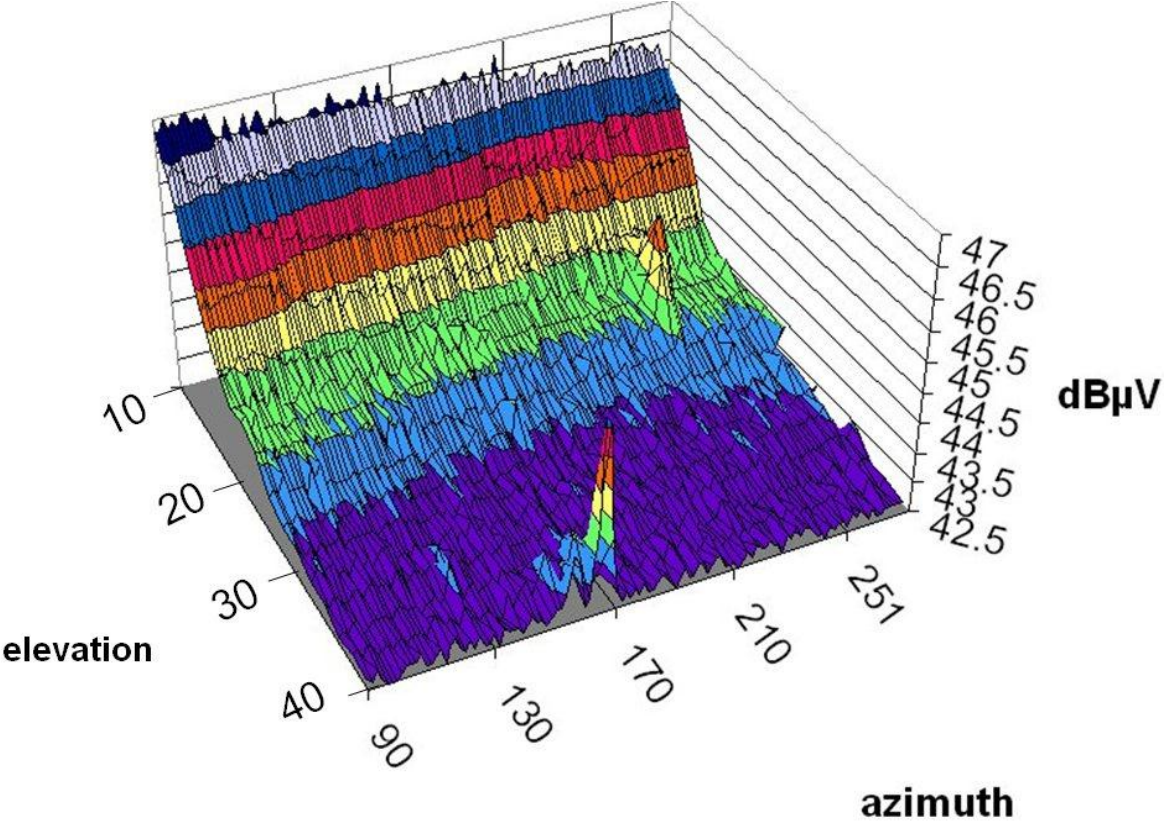
As can be seen from the data obtained until March 20th, shown below, several satellites are detected which outline well the Clarke belt:



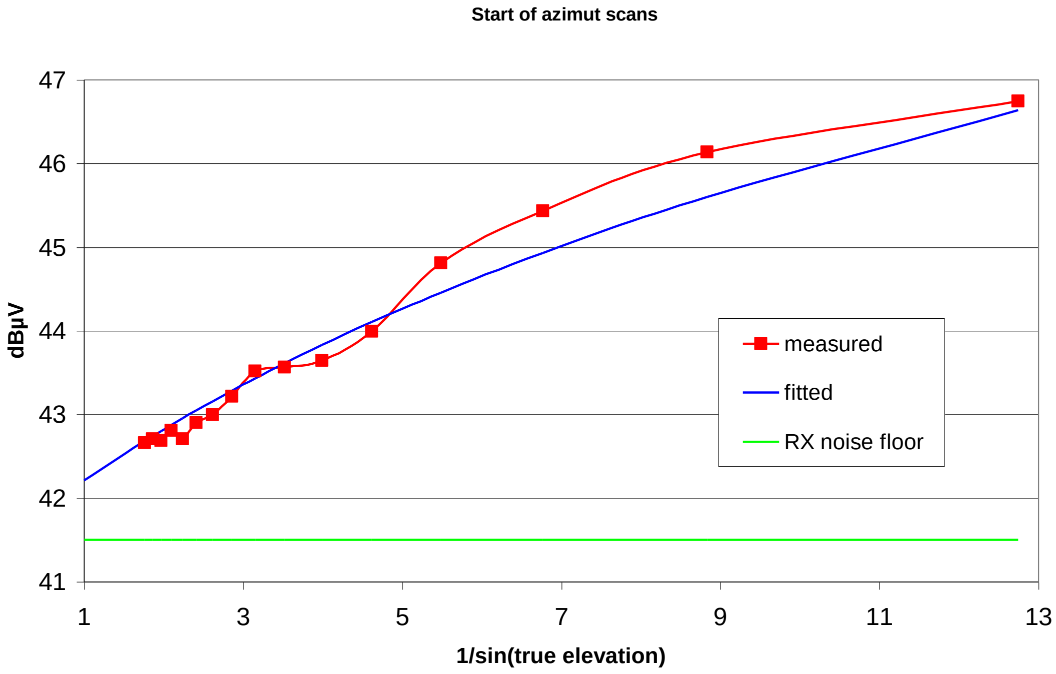
Moreover, one notes an elevated background level at several azimuths. Since all scans have been done at the same frequency and with the same polarization, it is strongly suspected that variations in the local weather – cloud cover or humidity – might be the reason for this.

4.6 Sky scans II: Separating Sky and Receiver Noise

One important feature of the sky scan of the first attempt is the observation that the background increases towards the horizon:



In a simple modelling one may represent the background as the sum of the receiver noise (essentially the LNB front end) and a sky component. This sky contribution may be thought of as thermal emission from the troposphere, which can be considered a nearly plane-parallel layer of gas, into which the antenna looks under a certain elevation angle. The path length through such an homogeneous atmosphere is inversely proportional to sin(elevation).
It is thus profitable to plot the measured background level against 1/sin(elevation).
Extrapolation to 1 – i.e. the zenith – yields the sum of receiver noise and sky noise.



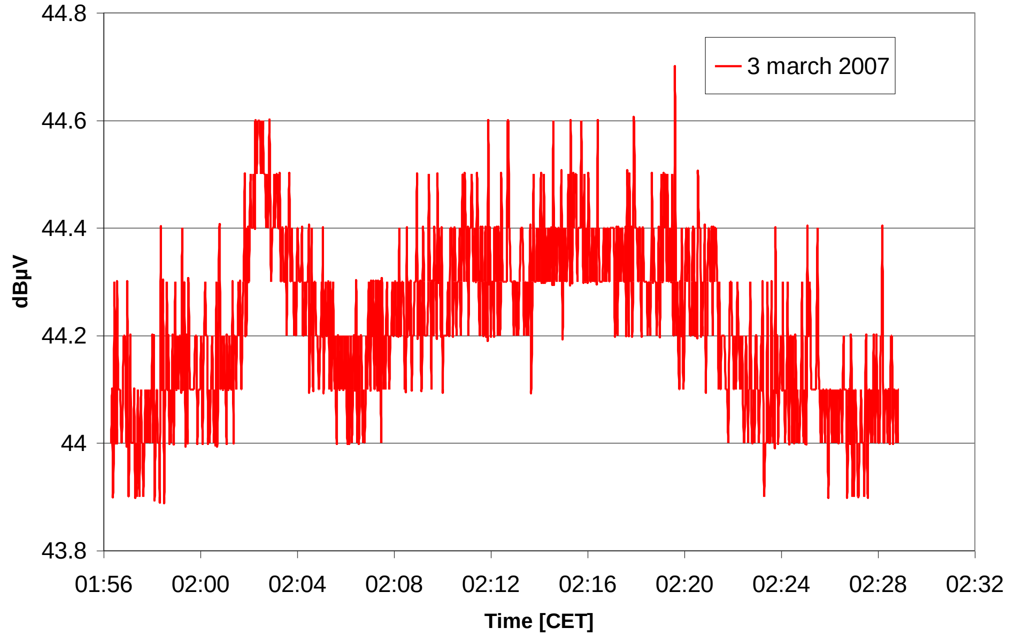
The figure above shows the data from the start (in easterly direction) of each azimuth scan (by Marc Cornwall), and compared to the best-fit values for the receiver noise of 41.5 dBµV and sky noise at the zenith of 34 dBµV. As is confirmed by other scans, the contribution from the receiver noise dominates the background.

A more careful analysis should also take into account the pick-up of the emission from the ground which enters via the wings of the antenna’s main lobe.

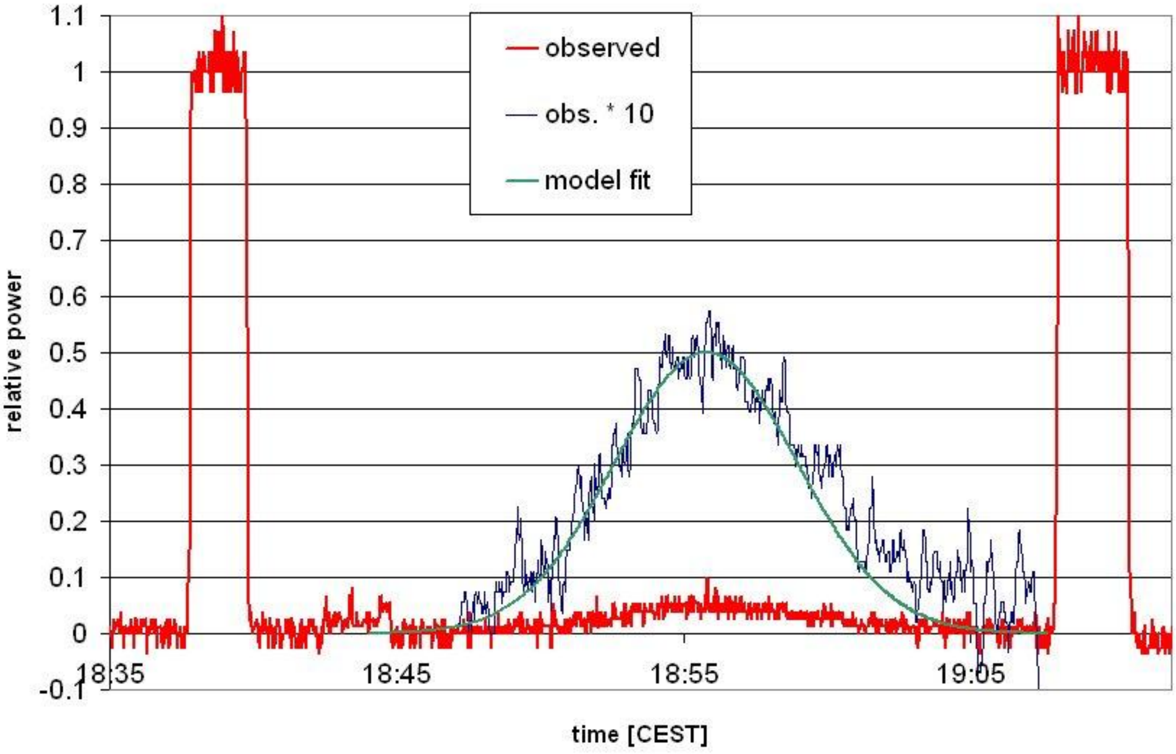
4.7 Moon

A first attempt to detect the moon was done during the January Full Moon, but was abandoned, because we had already established that the solar signal was not as strong as in the prototype.

After the repair of the LNB arm, the Full Moon at the beginning of March was used with more realistic hope. Marc Cornwall and Aravind Saini S. were able to detect a weak enhancement of the signal, every time they came close to the predicted lunar position. One of the results is shown below. The broad hump is the drift scan taken after an enhanced signal had been found at 02:03. Evidently, the scan somewhat missed the true maximum.

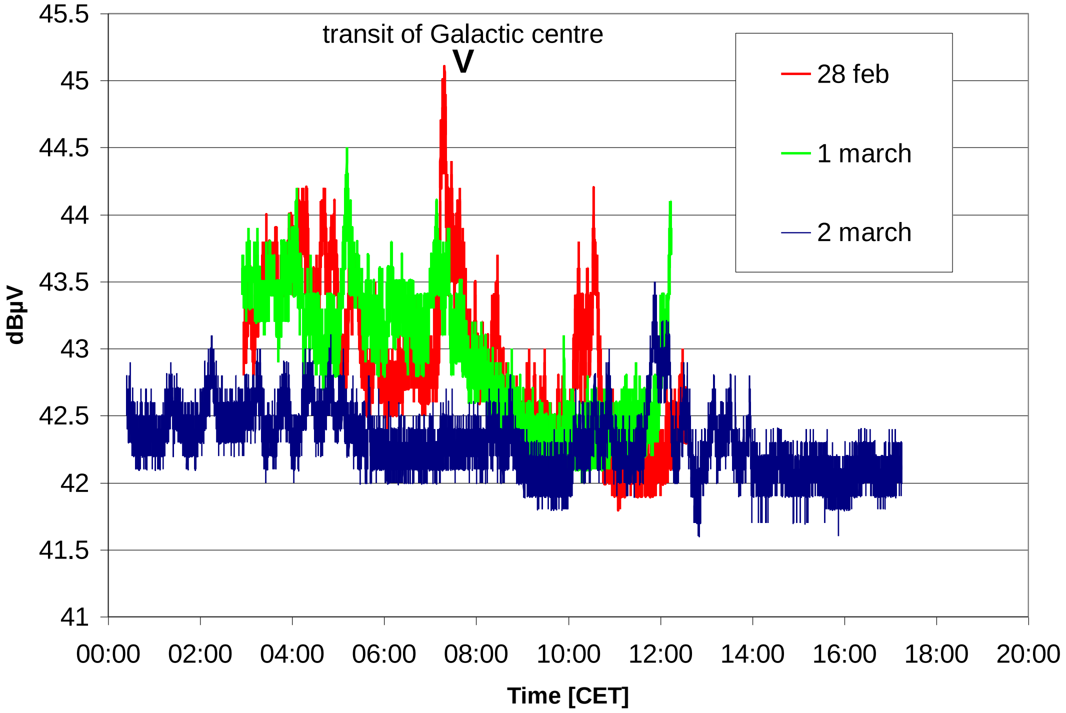


The following full scan was obtained on 26 April, when the moon was still 7 days before Full Moon. Since the signal is barely above the background, the expected position was manually searched, until one position was found which gave a consistently higher signal (of +42.5 dBµV) than the background (+42.0 dBµV) taking into account the normal fluctuations of about 0.2 dB. This occurred shortly before 18:45. Then the telescope was positioned somewhat to the West and slight above. A successful transit occurred at 18:55. The flux calibration on the Holiday Inn hotel gives an antenna temperature of 15 K. From the fit of the drift profile, a HPBW of 1.8° is deduced, in agreement with the solar drift scans. Assuming a lunar angular diameter of 0.5°, one obtains an averaged temperature of the lunar surface of 211 K. A second scan one hour later gave the same results.



4.8 An attempt on the Galactic Centre

Although emission from the Galactic Centre is dominated by non-thermal radiation, and thus the flux decreases with frequency, an optimistic extrapolation of the fluxes from lower frequencies indicates that this source might be as bright as the Moon. At this time of the year, it would transit at about 08:00 local time, and hence we took the chance of making an attempt to detect it. Since the emission is rather extended, we performed scans lasting several hours, and pointed at the expected culmination position.



The results of three consecutive nights (by Marc Cornwall and Aravind Saini S.) show a variety of fluctuations of the sky background, but none can safely be attributed to celestial origin. There are fluctuations which have a rise-time much faster than the drift time of a celestial source through the antenna beam. There are also variations of longer time-scale, but as they are not present in a consistent way, we must also dismiss them as non-astronomical features. Most probably all structures visible in the above figure are, for instance, variations of the noise floor of the LNB, variations of the receiver gain, perhaps caused by changes in temperature and supply voltage. The analysis of the data collected has not yet been finished, and will give rise to further measurements.

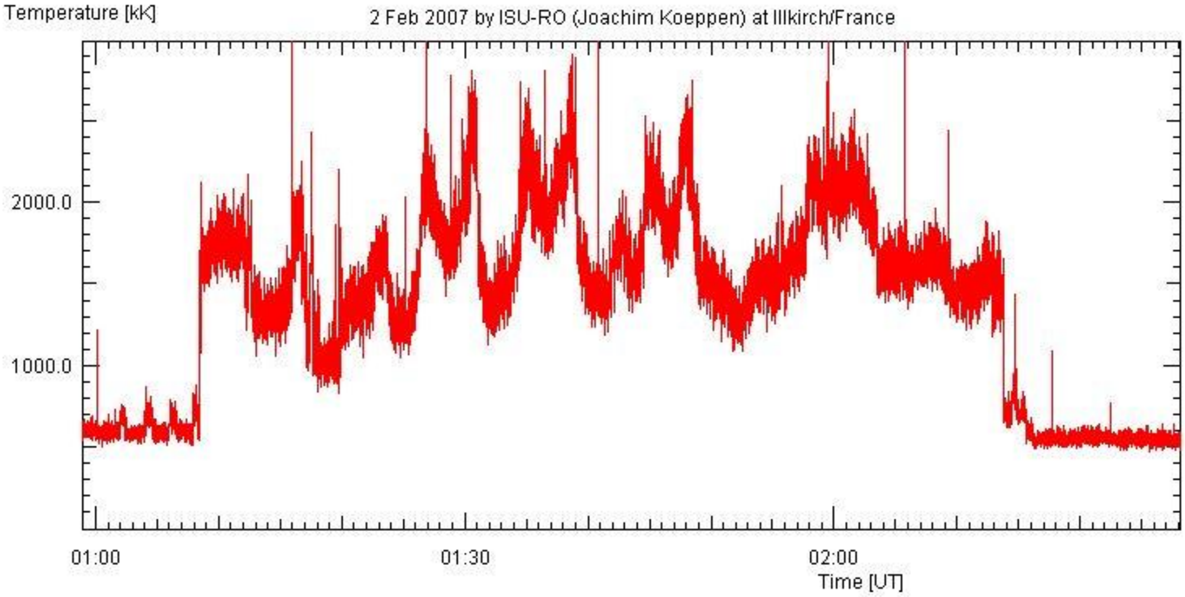
Nonetheless, this attempt showed that the apparatus would be capable of long-term observations and surveys.

4.9 Recommendations

- It would be highly desirable to automatically name the log-file of a newly started measurement with the date and time. Preferentially, in the same fashion as in the SkyPipe software: 0702271501.txt for an observation run started at 15:01 (local time would be O.K.) on Feb. 27, 2007. This could be an option for the user to choose.
- While after some time one can easily operate the software, perhaps some features from SkyPipe could be adopted to enhance the user-friendliness … it takes a while to realize that one can select an existing file (by “configuration” and “open device”) and look at its plot by “graphic snapshot” … An additional button or the distinction between “Load file” and “Start new file” would be more direct and transparent.
- It would be useful to have the option to record the current position for each measurement taken. In the heat of the excitement during difficult observations, students do forget keeping a detailed log of what they were doing. Thus, a more comprehensive automatic record would help in the reconstruction. Also, in continuous and stepped sky scans this would remove uncertainty and guesswork of the real positions of the data.
- While the user gets accustomed to clicking the “graphic snapshot”, a real-time, scrolling display, such as realized in SkyPipe, would be a most valuable improvement.
- The present system of writing data to file was proven to be fail-save, as we once experienced an instantaneous loss of power, but without losing any data!
- The feature which allows appending measurements to a file is very useful
- The analogue indication of the signal strength by the bar-graph is very useful. It would be very helpful, if the user could set the minimum and maximum values to suit his operating conditions.
- We never used the slider marks.
- The counter for the number of samples is very useful for staying on one position sufficiently long to obtain good data averages
- At this initial period, we never considered that the students start modifying the software, as the available time was too scarce to enter any serious programming activity.

4.10 Side effects

Luckily, we have not experienced any interference by other electronic equipment to our observations. However, the operation of the ESA-Dresden telescope is not without interference to other installations: It was consistently noticed that during the time of operation of the telescope, the RadioJove receiver on 20 MHz, with its dipole antenna hanging in about 15 m distance from the ESA-Dresden indoor equipment, picked up rather strong noise signals. Tests indicate that this happens when the AMA receiver is controlled by the computer. The figure below shows one of the night-time periods of observations. The lowest ever-registered background at ISU is about 70 kK, however in recent times the background has increased to 500 kK. But during operation of the ESA-Dresden telescope the noise goes up to 2500 kK, which would wipe out even strong radio bursts from the Sun.



4.11 Observations planned for the future

For our next year's personal assignment activities, we are considering the following subjects:

- Systematic solar drift scans: How accurate are the data? Does the solar temperature show genuine variations? Are other factors involved, such as the local weather …
- Scans of the Moon at various phases.
- Construct the 2D antenna pattern by keeping the antenna strictly fixed at a southerly direction and observing the successive midday passages of the Sun across the antenna beam during a period of several weeks, during which the Sun also moves in declination on its yearly round – preferentially close to the times of the equinoxes
- Explore the frequency dependence: Although the telescope covers only the region between 10 and 12 GHz, one could expect noticeable differences in the solar flux (1.6 dB), as it increases with the square of the frequency. With an accurate and stable flux calibration, this should be measurable. As the receiver's noise floor increases with frequency, it would be interesting to find out whether the signal-to-noise ratio can be optimized at some frequency.
- Detailed link budgets for TV satellites, and how they depend on local weather (cloud cover, humidity).
- Investigate and optimize the accuracy of the flux calibration. Try out various calibrators (ground, building, plywood board …) and improve the accuracy by measuring the calibrator's temperature.
- Construct the 2D antenna diagram by combining solar drift scan data with scans across satellites, using different scan orientations, and pointed measurements.
- Optimize the positioning procedures to minimize the effects of the backlash
- Improvements and extensions of the telescope software.

5 Assessment:

5.1 Comparison with the "primitive" approach

It seems useful to compare the advantages and disadvantages of the sophisticated ESA-Dresden telescope with the "simplistic" approach of a 60 cm dish antenna, a LNB, SatFinder, and manual recording of data:

The simple approach requires only plugging together the various components and applying power, its smaller antenna is easily carried from its storage in the office out on the terrace, and within a very few minutes there one can show to students the signal maxima from satellites and the Sun, let them navigate themselves the antenna dish and feel by this activity how narrow the antenna beam is. Having found the Sun, one leaves the antenna in position, and watches the decline of the signal on the SatFinder dial. Thus a quick demonstration takes about 15 minutes. Flux calibration is done by tilting the antenna towards the ground. If one wanted, one could record the measurements as a function of time – one reading per 30 seconds is sufficient – and plots the results. Rough estimates for the antenna's beam width and the solar temperature are obtained, which demonstrate the principles.

However, a severe limitation exists in the form of the strongly non-linear display of the SatFinder: in order to give a very sensitive indication of the peak of the signal, the dial from 1 to 10 covers a range of only 0.4 dB (as measured with the aid of the AMA receiver), and its variable "sensitivity control" would be a hindrance for any calibration efforts.

By contrast, the ESA-Dresden telescope offers these features:

- accurate measurement of the signal
- automatic recording of the measurements
- remote control of the orientation of the antenna
- measurement of the antenna's position
- facility to make scans and stepped scan across the sky
- … and other features one could envisage to incorporate into the software

The principal limitation of doing radio astronomy at 10 GHz is the paucity of astronomical sources bright enough for detection by a 1 m class telescope: There is the Sun (with about 9 dB above background) and the Moon (about 1 dB). All other sources are much weaker, primarily because of their non-thermal spectra.

One way to tackle weaker sources is to use long integration times, which requires not only that the telescope must track the celestial motion of the object with sufficient accuracy and smoothness, but also that one must be able to regularly orient the telescope off-source to measure and integrate over the background. The designers included the "slow rotation" feature, which execute steps of apparently 1° at longer time intervals, and demonstrated that this technique would be able to track the Sun; however, the measurements do show a repetitive structure caused by the steps of this technique. This might well pose a severe limitation for long integration times. Also, we have noticed that sometimes the position changes by 2°. The other requirement of accurate deflections off-source and accurate returns to the source position seems to be too stringent a demand for the rotator/controller-system, which was not designed for such purposes.

Thus we are left with the Sun, and – for a big challenge – the Moon. For the Sun, most of the sophisticated features of the ESA-Dresden telescope are not vital: To find the position of maximum signal from the Sun, and then to place the telescope "a bit to the west", neither the measurement of the position nor the remote control are early necessary. An automatic data recording every 3 seconds is also not essential to determine the height of the maximum and the width as half power, which are needed for the analysis. One may also see some merit of recording data yourself by hand.

So, with the exception of the accurate measurement of the power levels, all functions of the solar drift scan could be accomplished in a satisfactory fashion by the "primitive" approach. The latter also has the advantage that it does not require the effort and the time for installation necessary for the ESA-Dresden telescope.

However, these further features of the ESA-Dresden telescope make possible a number of interesting experiments and observations, which are collected in Appendix A, and most of which we have already been able to try out.

5.2 Applications: in what form and in which context?

The output of a radio telescope is not an image … therefore it is not as suitable for viewing demonstrations as is an optical telescope. Demonstrations of the properties of radio waves at 10 GHz and the sources in the sky (satellites and the Sun) for groups of up to about 15 persons can be envisaged with a small satellite dish and SatFinder. The ESA-Dresden telescope – of which the visitor would see only the indoor units – would not lend itself for such an activity. The same argument also applies the NASA's Radio JOVE installation: Solar radio bursts simply do not occur in compliance with the teacher's or presenter's schedules … one can only show recorded data and sound files. Neither is there a guarantee that a real signal appears during the time available for a workshop activity lasting a few weeks – the first solar radio burst detected at ISU was picked up at the very last day of the observation period … the next came half a year later!

This is in contrast to the VLF receiver of NASA's INSPIRE project, which enables to listen to radio emission from lightning any time of the day. Moreover it provides new sounds and phenomena to the listener every time it is switched on – an ideal instrument for demonstrations to small and large groups!

The ESA-Dresden telescope is primarily an instrument to perform measurements and surveys of the sky. To operate it, a single operator or a team of not more than two students seems sufficient and appropriate. In a larger group, this would lead to boredom and distractive activities among the members not directly involved. To operate the complex system properly, obtain useful data, and get meaningful results of the interpretation of the data, a certain amount of training and appropriate time for familiarisation with the instrument is absolutely mandatory. Thus, introducing one or a number of teams does take some time. Furthermore, any observation requires time – even a single solar drift scan takes at least 20 min – and it needs to be repeated for confirmation. Analysis of the data may need even more time, because of development of computer skills and techniques. Thus, the best format for observational projects would be that of individual projects for duration of a dedicated concentrated week, several weeks, and even months.

These observations could well be organized as several projects running in parallel, with the teams using the telescope according to a fixed schedule – like in a professional observatory – or by coordination on a personal basis. During all that time, the teacher or supervisor is necessary to provide support and guidance, and also to ensure that the instrumentation is kept in proper condition.

In which teaching environments can the telescope be used? From the impressions by and about the three students, the following conclusions can be draw:

- Secondary schools
    - Normal curriculum: hardly conceivable, because of the time required to make pupils familiar with the equipment, the duration of a typical observation, and the time for the teacher to prepare a demonstration.
    - Voluntary activities and projects (e.g. TIPE in France): this seems to be a good possibility, opening an interesting experience to individual pupils.
- Planetarium/Museum/Observatory open days:
    - Displays or short demonstrations: not suitable
    - Afternoon or weekend activities: much more suitable, especially if undertaken by a group of people meeting several times over weeks or months
- University education:
    - Use as an experiment for laboratory work at the medium level (after B.Sc.) in physics could be envisaged.
    - As an experiment for advanced level of laboratory work in physics it remains too basic and with too limited a scope in physics.
    - Could be useful for the astronomical institutes for introduction to practical observational work, in particular because it can be operated anytime of the day and independent of the cloud cover, thus complementing existing optical telescopes.
- ISU:
    - Demonstration during a lecture: hardly possible, because of the time necessary to perform one solar drift scan.
    - Summer Session physics activity: not recommendable for such an intense environment because there is hardly the time for a student to master the instrument and get some meaningful observations done. Also, the class of typically 10 persons would be too large for productive work.
    - Experiments with the ‘simple setup” of a small dish with SatFinder, and demonstrations with the LNB would be possible and are useful. This would also be suitable for Summer Session activities.
    - Personal Assignment (2 months) works well, and leaves room for student’s own ideas and exploration
    - Optional Workshops with one start-up afternoon and a few subsequent meetings: seems conceivable, and will be tried

5.3 Costs

The ESA-Dresden telescope is rated at about € 6000. This seems a price that a normal public school would not think easily of spending on an instrument which deals with a subject which is not part of the formal curriculum and which would be only covered in optional classes or workshop activities. The vital AMA receiver alone costs € 3000, which places the telescope clearly out of reach of public schools. The rotator/remote control unit takes another € 1200.

For the "primitive" approach one would need a satellite dish (€ 100, if bought new), a LNB (€ 5), a SatFinder (€ 10), and a small power supply (€ 10). And this already would permit to observe and even analyse drift scan of the Sun.
One may envisage a "middle way": provide a mechanical and manual way to orient the antenna and to indicate the position angles, improve the electronics to measure signal power more accurately, and if necessary use an analogue-to-digital converter to pass data to a computer. In this way, one could improve the "primitive" approach to be able to reach some of the features of the ESA-Dresden instrument. In Appendix B we give some details of how such an instrument could be realized, and at a much lower cost.

5.4 The teacher's involvement

The ESA-Dresden telescope is quite a sophisticated instrument. From our experience of its installation and operation, we tend to believe that the teacher responsible for this instrument and the activities must be a very enthusiastic and dedicated person, and willing to sacrifice a substantial amount of time, thoughts, and effort. This is particularly true during the first phases of the installation, the tests of its performance, and the initial observations. Even when the instrument is once functioning normally, a certain amount of attention is required. From discussions with acquaintances in this profession, it appears that the daily life in a school with the various duties there is hardly time for a teacher to commit himself in such an intense engagement, even if the interest was there. But when such an interested and resourceful teacher is given access to this instrument, it will certainly be of great use and benefit for this person and the students!

5.5 Suggestions for accompanying measures

Based on the experiences of the writer with the RadioJove and INSPIRE projects, it would seem helpful to accompany activities with the ESA-Dresden radio telescope by

- A dedicated Web site: At the present time, web pages with explanations to our three students are available under http://astro.u-strasbg.fr/~koppen/10GHz/ . It is planned to extend and transform these pages into a web site for ISU students and potential users of the ESA-Dresden telescope or a similar instrument.
- Providing users with a platform to share experiences and exchange information and news: The mail server for the RadioJove project is an excellent example to link all interested persons to spread the news of a promising solar eruption, share data for comparison, to discuss technical problems, and for the newcomer to obtain expert advice. With the complexity and the capabilities of the ESA-Dresden instrument, such a network would undoubtedly be of great help to aid teachers to make full use of the device
- Archive of observational data: Since the 10 GHz region is not subject to solar activity, such an archive of recorded data is not necessary. However, such a common site – on a small scale – might be helpful to the first generation users as a means to compare with their own data and system performance.

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Appendix A: Suggestions for Observational Projects

We describe a number of observational projects, giving practical details of the execution and also estimates of the time and effort necessary.

A.1 Experiments with the LNB and SatFinder

To give an introduction to the properties of radio waves in the 10 GHz region, it is useful to connect an LNB via a SatFinder to the AMA receiver to provide power and permit additional measurements.
-- Pointing the LNB to various objects in a room shows that all these objects having the same temperature, emit the same amount of thermal radiation.
-- Even pointing to a candle flame will not reveal obvious differences, because the flame covers only a very small portion of the beam of the LNB's horn antenna.
-- Pointing at the sky through an opened window shows a drop in signal. Because of its design, this drop is much more drastic on the SatFinder than on the AMA receiver. We found: ground +68.3dBµV, sky +64.4dBµV.
-- Closing the window will cause the surprise that the signal is as high as if the LNB is pointed towards a wall: normal glass is not transparent at 10 GHz, and thus the LNB sees it as a warm body.
-- If one holds a metal plate a couple of cm in front of the LNB aperture and varies that distance, one observes systematic fluctuations of the signal: the metal plate acts as a reflector, and standing waves are established between it and the LNB which affect the matching of the antenna. Hence the noise floor changes. The distance between two maxima is one half-wavelength.
-- Pointing at the Sun will not cause any noticeable enhancement of the signal; only a (parabolic) reflector of sufficient size will do that. Why not try a Chinese wok?
-- These activities can be extended to other experiments showing the properties of the waves: reflection, refraction, diffraction
-- By pointing at the ground, the sky, and intermediate positions, the SatFinder indications are compared with the values from the AMA receiver (in analyser/video mode), which permits to "calibrate" the SatFinder's scale. For example, we found: full scale 10 = +66.2dBµV, scale 5 = +66.0dBµV, scale 1 = 65.8dBµV.

A.2 Pointing at Satellites and the Sun

The simplest experiment is to orient the telescope towards one of the satellites and observe on the AMA receiver (in video mode) the video and listen to the audio transmission; in this way, one can identify the satellite, measure its signal strength, and observe the spectrum (in analyzer mode). Next, one searches for the Sun, and observe that the video is nothing but a 'snowy' picture of noise and that the spectrum is a pure continuum. One may also compare the signal strengths.

This experiment can also be done by attaching the AMA receiver directly to a small satellite dish, which can be oriented manually by the students. We did this quick demonstration at the beginning of the students' work, and despite the solid fog during that day, we had no difficulty to locate the Sun and satellites, and the students evidently appreciated this direct experiment! This is suitable for quick demonstrations, even under winter conditions.

A.3 Solar drift scans

One of the major experiments is to point the telescope towards the position where the Sun will be about 15 to 30 minutes later, and then take measurements of the signal, as it increases when the Sun enters the antenna beam and it decreases when the Sun exits the beam. These observations should be preceded and followed by a flux calibration. Especially near mid-day these observations are easy, because the Sun moves horizontally in the sky, and thus one can search for the Sun, and then move a few degrees towards the west to take aim.

The overall time is 30 to 60 minutes, because one must also capture the sky background well away from the Sun. Instead of a full solar scan, one could do a half-scan, by searching for the maximum emission from the Sun, and then let it drift out of the antenna beam. Thus, a simple demonstration could be done in about 15 to 20 minutes.

The analysis of the data requires determination of the background, by averaging over a sufficiently long stretch of data points, as well as that of the calibration measurements. In case of strong time variations, some interpolation between these values must be considered. All the data must then be background-subtracted and normalized to the calibration level.
One important point is that all data must be converted from dBµV into a linear measure of the power, such as

linear_value = 10.0 ^ (dBµV / 10)

• Horizontal antenna pattern

Since the Sun's diameter of 0.5° is smaller than the beam width of the antenna, we may treat – for a first approximation – the Sun as a point source, and hence the measured profile is nothing but the antenna pattern in (essentially) horizontal direction. The first step of the analysis thus yields the antenna beam width: One takes the background-subtracted data, and finds the times before and after maximum at which the power is half its maximum value. At its celestial declination δ the Sun moves by 1° across the sky in $4/\cos(\delta)$ time minutes, thus one can compute the angle with respect to face-on incidence.

The value found for the HPBW can be compared with the theoretical formula for a diffraction-limited, uniformly illuminated circular dish antenna

HBPW = 80° * wavelength / diameter

Furthermore, one could compare the measured profile with the theoretical antenna pattern (e.g. text books by Kraus, Balanis).

For a more in-depth analysis, one may also consider that the Sun is not a point source, but a disk of 0.5° diameter, so that the measured pattern is the result of convolving the true pattern with the intensity distribution of the Sun.

- **The temperature of the Sun**

The ratio of the maximum power to the power measured from the calibrator allows derivation of the antenna temperature. We may assume that the calibrator has about 300 K, or better, one measures the temperature of the body.

Then, the ratio of the solid angles of antenna beam and Sun – which are equal to the square of the ratio of HPBW and solar angular diameter - permits to convert the antenna temperature into brightness temperature. This is the temperature of the transition layer between chromosphere and corona, about 10000 … 20000 K.

For improvements, the current angular diameter of the Sun is applied, rather than the simple estimate of 0.5°. Furthermore, the angular motion of the sun across the sky must be corrected from the knowledge of the current solar declination, instead of the mean value of 0.25°/min.

One could imagine a study of measuring this temperature during several days, in particular during different levels of solar activity. This will also teach about the accuracy of all the calibration and data reduction, and permit to estimate the errors involved.

A.4 Vertical antenna pattern: elevation scans across satellites

Scanning or stepping in elevation across the position of a satellite permits to measure the antenna pattern in vertical direction. Since the dish has a circular shape, the HPBWs should be the same.
Furthermore, such a study checks the accuracy of the positioning system, in particular to detect backlash by scanning in both directions over the source. With the stepped positioning possible by the software, this could be done quite with ease, provided one had a better confidence that the steps are taken with the same step-width preferentially specified by the user.

To get reliable average values for the flux at each position, one would require about 20 to 80 samples, which implies “speed reductions” of 1/50 to 1/300.

Moving across a position at slow speed gives first impressions of results. Depending on how many sample one takes at a position, a stepped scan can take between a few minutes and about one hour.

The analysis requires identifying the positions, and taking the average values for each position.

A.5 The Clarke belt: position measurements

The positions of the geostationary satellites follow a great arc in the sky, the so-called Clarke belt. By systematically locating TV satellites in the sky, and measuring their positions, one can construct a map of this belt. This teaches also some practical items, how to align satellite TV antennas to a particular satellite, and how many are available in the sky.

Since the belt can be computed for any location on Earth, a comparison of the measured positions allows to determine the latitude and – given the identification of some of the satellites – the longitude of the observer.

Locating and measuring would be an activity for up to one hour, depending on the explorative spirit to hunt for the more exotic satellites that are not dedicated to the local area.

A.6 The image of the Clarke belt: sky surveys

A more ambitious and time-consuming challenge consists in the construction of a sky map showing the band of satellites by their intensity against the sky background. Such an approach requires systematic scans of the sky, the data of which can be displayed in a false-colour map.

Using the slow motion in either azimuth or elevation permits to cover the southern sky within a few hours. However, because the short time spent at each position might not suffice to get a measurement everywhere, one would miss numerous objects.

This technique not only requires a lot of time, but also diligence and discipline to execute all observations in the same manner. Moreover, some expertise in dealing with software to do the presentation of the data is required. Thus, it may be a challenge for a dedicated group, or a task for an advanced level.

In case of buildings or structures that extend substantially above the horizon, one can make a ‘radio map’ of that (warm) building seen against the cold sky.

A.7 The luminous sky: elevation scans over the sky

A simple elevation scan across the sky will show that the sky background is not constant, but increases towards the horizon. The data can be obtained by a slow scan or better by a stepped scan, so that at each elevation a fair number of data is collected to obtain reliable average values. It is not really necessary to cover the entire angular range to the zenith, the lower 30° are sufficient. A dedicated observation at the zenith would also be useful.

An interpretation with the simple plane-parallel atmosphere (using the 1/sin(EL) law) allows to separate between a constant contribution from the receiver noise floor and an elevation-dependent sky background.

The observations could be done in about half an hour. The analysis would not require calibration procedures or background subtraction, but merely the comparison with a simple formula.

This activity can be extended to further investigations, such as to explain any systematic deviations from the simple model prediction, a possible dependence on azimuth, or to detect any day/night difference of the sky background, or variation between clear blue skies and a solid cover of stratus clouds.

A.8 How bright is the Moon: lunar drift scans

Lunar drift scans are executed and interpreted in the same way as solar drift scans, with two differences: the Moon is a much fainter source – less than 1 dB above the background; and the best time is around Full Moon, thus perhaps only for a few days once a month. It is quite a challenge for the operator’s observational skill and the noise level of the system, but well within the capabilities of the instrument. The next steps are obvious: Can the Moon also be picked up during other times than Full Moon? Is the sky background higher during the day? Does the deduced lunar surface temperature vary with the lunar phase, that is the sun-lit fraction of the face of the Moon?

A.9 Can we see the Galactic Centre: Time Scans

Except for the Sun and the Moon, there is no other natural radio source in the sky strong enough at 10 GHz to be picked up by a 1 m class telescope. The Galactic Centre is a strong source at lower frequencies, dominating the sky background at 20 MHz. However, due to the non-thermal nature of its emission the flux at 10 GHz is at best comparable to that of the Moon. Since the galactic emission comes from a wide region centred on the constellation Sagittarius, one does not gain advantage having a narrow antenna beam.

But one could nonetheless try to detect it: The antenna is directed to that elevation in southerly direction where the maximum of the emission would expected to culminate, and then one measures the signal for several hours before and after the culmination. This is done by the computer and needs no human intervention.

At the end of the observation run, one inspects the data, looks for an expected correlation, finds unexpected features, and tries to understand them. For comparison, a second run is done, … and if one finds still some feature which might be identified with a sky object, one could do another set of runs one or more months later, when a true astronomical object should have culminated earlier!

Such a challenge – despite its low probability of success – is very useful to make students aware of what is signal, what is noise, and how one can distinguish between the two.

A.10 How stable is the background: Time Scans

Very similarly to the previous point is the long-term observation of either a source (calibration, satellite) or simply the sky background. Again, one lets the computer take long stretches of measurements, and one tries to identify systematic and random variations.

The questions can be manifold:

- How stable is the calibration? Does it vary with its temperature in the expected way?
- Does the signal from a TV satellite vary with time? Does it vary with the weather – radio waves at 10 GHz are known to be attenuated by humidity and raindrops.
- Does the sky background vary with time of the day, with cloud cover, with season? Or are there any other – perhaps artificial – sources of interference?
- How stable is the receiving system? Every receiver drifts until it has stabilized its internal temperature after being switched on. Certainly the LNB is subjected to the variations of the outdoor temperature. What can we say about the stability of the receiver's noise floor on short and long time-scales?

Most of these questions are more of a technical nature. However, by studying them, one will learn about fundamental aspects and features in the behaviour of technical systems in general!

A.11 Satellites: individual measurements

There is also the possibility of making pointed observations of TV satellites. Apart from a definitive identification on the basis of the transmitted programs, the signal strength can be measured and analysed

• Link budget

With the aid of the antenna temperature (based on the flux calibration), one can measure the absolute received flux density of a satellite

Flux_density = 1.38E-23 * T_ant / A_eff

with the effective cross sectional area A_eff of the antenna, which can be determined from the antenna HPBW. With the knowledge of the distance $d = 38000$ km and the bandwidth Δf of the transmitter, one can compute the effective isotropic radiated power (EIRP) of the satellite:

$$\mathrm{EIRP} = 4\,\pi\, d^2 * F * \Delta f$$

Taking into account that the satellite's transmission is the sum of all transponders (for ASTRA 1H the AMA's spectrum analyzer display shows about 25 channels for each sense of polarisation) which emit one TV channel with a bandwidth of about 5 MHz, one obtains for this satellite an EIRP of 170 kW or +52dBW. This agrees very well with the value of +51 dBW from the technical information on the Astra 1H satellite.

• Variations due to weather

Systematic monitoring of the signal strength of a particular satellite allows to detect variations and to correlate them with weather conditions. In particular, humidity and rain fall play a role in attenuating radio waves in the 10 GHz region.

Such a study would extend over several weeks or months and would also demand a regular monitoring of the weather – as well as verification of the overall stability of the system and is calibration.

A.12 Summary

In the Table below we give estimates for the observation times for each experiment and for their suitability for projects of various durations:

Experiment	Obs.duration	Suitable for
Experiments with LNB and SatFinder	Few min	Demos, Classroom experiments
Pointings to sun and satellites	Few min	Demos
Solar drift scans	20 … 60 min	Long demos, day projects
Elevation scans, satellite	< 30 min	Day projects
Clarke belt: positions	< 30 min	Long demos, day projects
Clarke belt: map	Sev.days	Long projects
Elevations scans: sky	< 30 min	Day projects
Lunar drift scans	< 30 min	Day projects (challenge)
Galactic Centre	Sev.hours	Projects for several days
Stability of background	Sev.hours	Long projects
Satellites: Link Budget	Few min	Short or day projects
Satellites: Variations	Sev.days	Long projects

Appendix B: Ideas for a Middle Way

Summary:

We describe a concept for a Ku-band radio telescope which could provide most the observational capabilities of the ESA-Dresden telescope that are considered useful for school activities and for demonstrations, but of a substantially reduced cost. If one uses a manual positioning system and replace the costly measurement receiver by a simpler amplifier/detector circuit followed by an analogue-to-digital converter, the estimated cost for the instrument would certainly be less than € 1000, while observations and measurements of the Sun, the Moon, and geostationary satellites can be performed for educational and outreach purposes.

Basic rationale:

Our experiences at ISU with the ESA-Dresden radio telescope suggest that the experiment with the highest educational value is that of the drift of the Sun across the antenna beam. This needs neither tracking of the Sun nor even the knowledge of the accurate position of the Sun. Especially around midday, the Sun moves horizontally across the sky, and thus a manual search for the Sun, followed by pointing the antenna a bit to the west, ensures that a full drift scan can be accomplished. While a remote control of the positioning is a very nice convenience that permits to place the antenna on the roof, out of immediate access, as well as to observe in adverse weather conditions from a dry and warm room, it is not absolutely vital for conducting observations or demonstrations. Or course, semi-automatic operations and systematic scans are greatly aided by computerized and remote controlled positioning, which constitutes a major portion of the cost, with the rotator motors and their control costing more than € 1000.

For the “primitive” approach one would need a satellite dish (€ 100, if bought new), an LNB (€ 5), a SatFinder (€ 10), and a small power supply (€ 10). However, since the SatFinder is designed to aid in the optimal pointing of a dish to a satellite, it indicates the small range of about 2 dB in signal over a scale from 0 to 10, and it depends on the setting.of a ‘sensitivity’ control. Thus, this instrument does not give a reliable measure of the relative power or voltage, which is essential if one wants to determine the antenna’s HPBW and the antenna temperature of the Sun. Using a measurement receiver is the ideal situation, but prohibitively expensive - the AMA receiver is rated at € 3000.

In what follows, ideas are presented to reduce the costs of the telescope while permitting its use in school and for demonstrations.

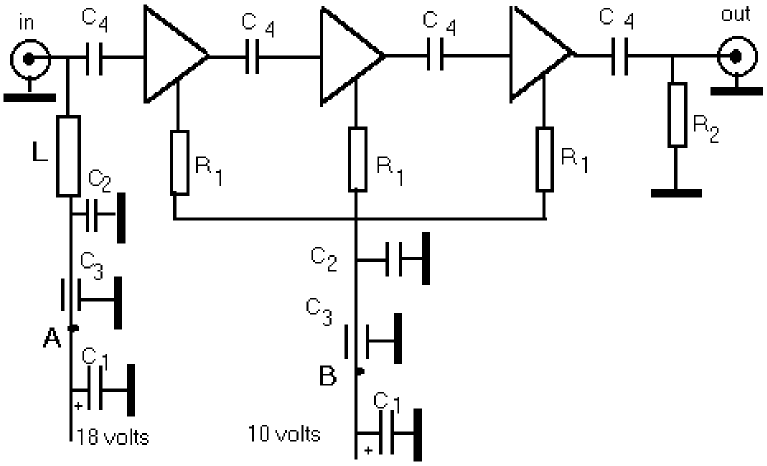
Mounting and positioning system:

This could be greatly be simplified by using a simple mechanical mounting with circular protractors for the azimuth and elevation dials which would allow manual positioning with sufficient accuracy for almost all applications. A good example for such an arrangement has been in operation by the amateur radio astronomer R.Ulivastro in southern France. While this is quite basic and is to be replaced by an electronic position indicator, it appears as a viable option to reduce the costs of the telescope.

If one takes the costs of the ESA-Dresden mounting as a guide for the costs, a sum of around € 200 would seem reasonable.

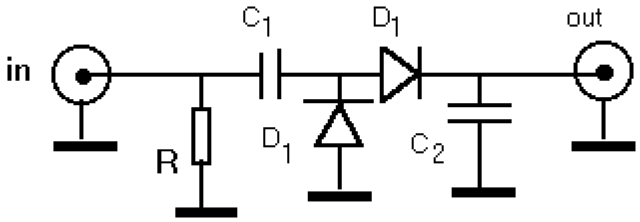
Electronics:

This could be greatly simplified by using a broad-band amplifier, followed by a detector. The amplifiers would be constructed with micro-monolithic integrated circuits (MMIC), as implemented in the Classroom Radio Telescope by Capitolo & Lonc (1999):



with suitable MAR-6 (16 dB gain, 3.0 dB noise figure) or MAR-8 (22.5 dB gain, 3.3 noise figure) at € 5.60 each. One could also use ready-made standard 18 dB amplifiers to be put in the cable and available at € 20 from conventional retailers or supermarkets, or less from electronic mail-order firms.

Since the LNB outputs about +50 dBµV (over the 8 MHz bandwidth of the AMA receiver's detector), one may expect to measure about +70 dBµV over the 800 MHz bandwidth of the entire satellite I.F. band. Thus, three MMICs of about 16 dB gain would amplify the signal from the LNB's noise floor to about +120 dBµV or 1 V, sufficient to obtain from a simple diode rectifier a linear relation between R.F. amplitude and rectified voltage.



The detector can use 1N34 Germanium diodes (the Classroom Radio Telescope) or Schottky diodes such as BAT 43.

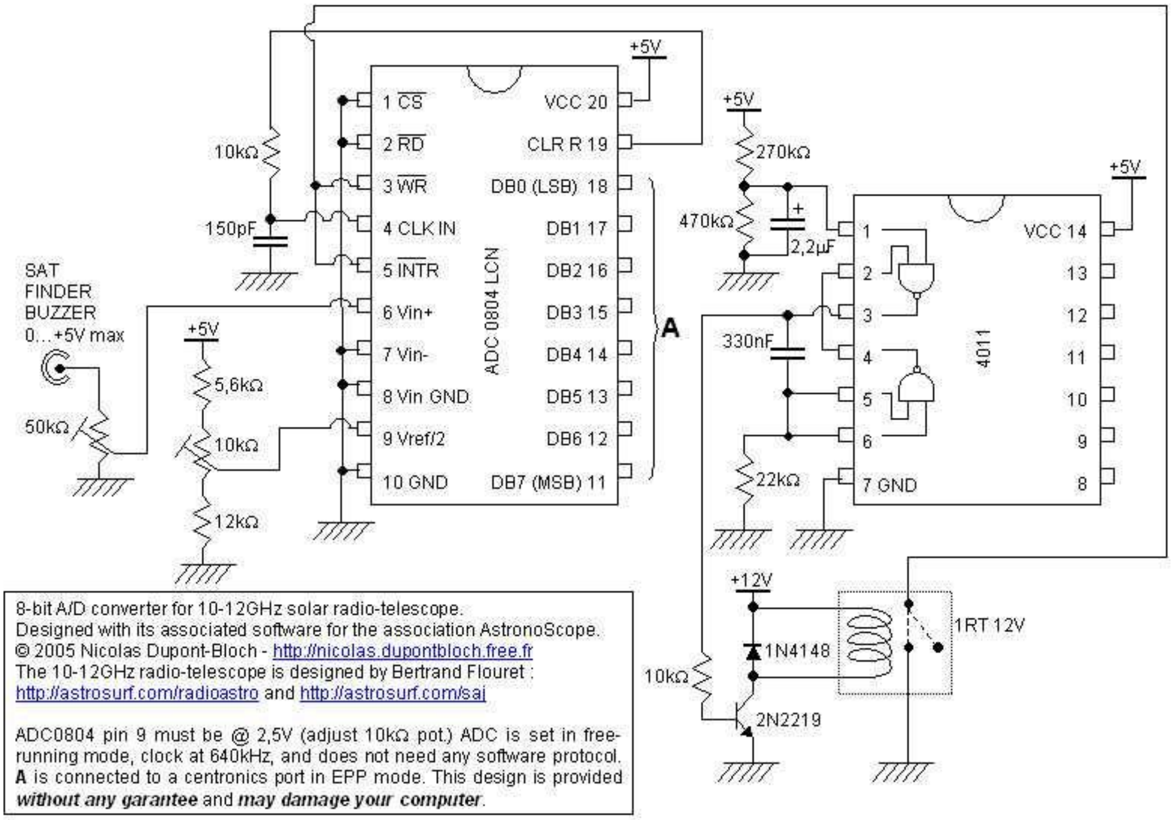
If one takes three cable amplifiers, and estimates roughly the costs for the other small parts and the power supply, a sum of less than € 100 seems realistic. Alternatively, producing a small printed circuit board for the MMICs and their associated SMD components would be of the same costs, if not less.

Measurement:

The voltage from the detector can be fed into an analogue-to-digital converter which interfaces to a computer. In order not to load the detector, the DC voltage should be measured by a high-impedance device. This could be a digital voltmeter with computer interface (Cleary 1999), or one of the approaches using a one-chip ADC, taken by amateurs and published on the Internet: for instance, the help pages for the SkyPipe software (http://www.radiosky.com/dcla2d.html) show a simple circuit based on the MAX 187 chip. The Cyclops project uses the following circuit by Dupont-Bloch (2005), from whose website the appropriate software may be downloaded:
The costs for this instrument are:

ADC 0804 LCN	€ 1.75
MOS 4011	€ 0.18

and all the other components certainly less than € 10.



8-bit A/D converter for 10-12GHz solar radio-telescope.
Designed with its associated software for the association AstronoScope.
© 2005 Nicolas Dupont-Bloch - http://nicolas.dupontbloch.free.fr
The 10-12GHz radio-telescope is designed by Bertrand Flouret :
http://astrosurf.com/radioastro and http://astrosurf.com/saj

ADC0804 pin 9 must be @ 2,5V (adjust 10kΩ pot.) ADC is set in free-running mode, clock at 640kHz, and does not need any software protocol. **A** is connected to a centronics port in EPP mode. This design is provided ***without any garantee*** and ***may damage your computer***.

Overall costs:

- The manual positioning system would permit: Drift scans of the Sun and the Moon, as well as measuring positions of the Sun, the Moon, and satellites in the Clarke belt
- The simplified receiver would provide a d.c. signal which is proportional to the noise voltage and thus permit a reliable measurement of the received power.
- The computer interfaced ADC would allow registration of results on the computer, for instance with a modified version of the RadioAstro software.
- The overall system can be properly flux-calibrated by pointing the telescope to the ground or nearby buildings as sources of 300 K thermal radiation.

Antenna	€ 140 or less	Design Description
LNB	€ 7 or less	Design Description
Coaxial cable (50 m)	€ 30	Design Description
Mounting + Positioning	€ 200	estimated from Design Description
Receiver electronics	€ 100 or less	www.reichelt.de
ADC computer interface	€ 10 or less	www.reichelt.de
➔ total	about € 500	