Scientific Constraints on the Allowable Subreflector Motions for the AT Antennas

J.R. Forster 29.2.84

Estimates for the gain loss and coma associated with axial and transverse movement of the subreflector are given in AT/21.1.1/039 and references therein. The specifications for allowable motions include only frequencies up to 22 GHz. In order to assess the need for motorization of the subreflector, specifications for 44 and 115 GHz are needed.

The original specifications are given in AT/10.2/023 appendix I (originally ASTDOC15A). Section 7 (Beam Stability While Tracking) gives rms values for allowable gain and phase variation while tracking. The gain variation within the -3 dB point of the primary beam was used to specify the allowable axial motion in AT/21.1.1/039, and the specified variation at the first sidelobe was used to determine allowable transverse shifts.

A transverse shift produces a pointing error and beam asymmetry (coma). An axial shift reduces the foreward gain and broadens the beam. The shifts are caused by thermal and gravitational deformation, and are generally a systematic function of the elevation angle. Random shifts due to wind are expected to be much smaller. The pointing offset and gain loss versus elevation angle can be mostly calibrated and corrections applied on line. However, the loss of signal due to defocussing cannot be recovered and any uncorrected gain or pointing errors result in decreased dynamic range in synthesized maps. In this note an attempt is made to assess the effect of moderate (<4 mm) subreflector movements.

Axial Movement

From Table 1 of AT/21.1.1/039 a 4 mm axial shift reduces the on-axis gain at 10, 22, 43 and 115 GHz by 0.1, 0.7, 3 and 2 dB. The reduced loss at 115 GHz is because the smaller effective aperture gives a smaller magnification factor for the Cassegrain system. From a signal to noise viewpoint these losses are very high at 22 GHz and above. Considerable improvement is gained if axial movement is less (the loss is approximately halved for each mm less).

To the degree that defocussing causes a gain change without distorting the beam this effect is self-calibratable. However, for a 3 dB loss the half-power point expands by about 12% and the -10 dB point expands by nearly a factor 1.6. The resulting intensity variation for a source at the half power point of the primary beam (assuming the on-axis gain has been corrected) is about 15%. This is similar to the effect

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There is little to recommend a relaxation of the allowable axial motion at the higher frequencies. Although the system and atmospheric noise is roughly proportional to frequency above 22 GHz, any gain loss reduces the sensitivity - and sensitivity is what is needed at the higher frequencies. It seems that the most reasonable specification on axial motion is to set a maximum allowable gain loss at all frequencies. The specification at 44 GHz will then limit the allowable axial motion. If -1 dB is chosen, the allowable motion is 2-3 mm and the primary beam varies by 2-3% at the half power point, and ≈12% at the -10 dB point. Beam variations are then in the range produced by transverse shifts of the subreflector, and the sensitivity is reduced by a maximum of about 20%.

Even if the subreflector is axially stable to ±2 mm there are arguments for providing motorized control. One reason is to simplify the initial focussing procedure for the AT receivers. Another is to allow for errors in the axial positions of the feeds. A third is to allow optimization of the focus position at both bands of the compact wideband feed horns. This can even be effective for L/S band where the S-band best focus is about a metre ~~L-band best focus is 75 cm and the S-band focus is 105 cm~~ below the nominal focal point. With 4 cm of subreflector travel and a ~~"magnification factor"~~ feed to subreflector travel ratio of 25.5 the focal point can be moved by 102 cm.

Perhaps the most compelling reason for providing remote control of the subreflector position is this: almost certainly the dynamic range obtainable with the AT over large fields will be limited by the stability of the primary beam. Since high quality images over large fields of view is a prime objective of the AT, provision for correcting any known sources of abberation should be designed in from the beginning.

Transverse Movement

Table 2 of AT/21.1.1/039 gives the variation in gain of the 1st sidelobe due to a transverse shift of the subreflector. For a ±4 mm shift the ~~(tune)~~ gain change in sidelobe level for 10, 22, 43 and 115 ~~GHz~~ is 0.8, 1.4, 2.7 and 2.1 dB. The effect of such a shift (after correcting for pointing offset) is to modulate the apparent amplitude of a source located in the sidelobe. Since the coma is not symmetric, this effect is not self-calibratable. Map errors are produced when strong background sources are present in the (time varying) sidelobes. The time varying component of their flux can be distributed over the field of view being mapped, and reduce the dynamic range. The limitations on dynamic range due to "confusion" and beam asymmetry has been investigated by the ATCSG (AT/21.1.1/028) and is also discussed in AT/10.1/003 (originally ASTDOC28). Given a reasonable specification at 1.4 GHz, the specifications at higher frequencies are easily obtained. Since confusing sources are mostly extragalactic radio sources their flux density varies as $\nu^{-0.7}$. There will also be a reduction in the number of confusing sources present in the sidelobes at higher frequencies due to the decreasing beamsize. However, since it only takes one strong source to produce this effect the beamsize will be ignored. finally, the amount of time varying flux available for distribution over the map is proportional to the mean sidelobe level times its percentage variation. Formally if $\sigma(\nu)$ is the allowable fractional variation of the first sidelobe at frequency ν and P (ν) is the mean power level of that sidelobe, then the specification at any frequency can be written (in dB)

$$\sigma(\nu) = -P(\nu) + 7 \log (\nu/1.4) + \sigma(1.4) \text{ dB}$$

where $\sigma(1.4)$ is the allowable on-axis variation at 1.4 GHz. The specification for 1.4 GHz from AT/10.2/023 is -23 dB at the -3 dB point, or -26 dB on-axis. Using -26 dB for $\sigma 1.4$ we get the following results.

Freq	P (ν)	7 log $(\nu/1.4)$	$\sigma(\nu)$	±4 mm
1.4 GHz	-15.5 dB	0 dB	-10.5 dB	
2.3	-14.0	1.54	-10.5	
5	-16.0	3.9	- 6.1	-11.5 dB
10	-15.5	6.0	- 4.5	- 6.9
22	-16.0	8.4	- 1.6	- 4.2
43	-15.0	10.4	- 0.6	- 0.6
115	-12?	13.4	- 0.6?	- 2.1

Sidelobe levels are taken from AT/21.1.1/034. The last column (±4 mm) is the expected runs variations for a ±4 mm transverse shift of the subreflector (from AT/21.1.1/039 and AT/10.2/023). While the specifications are just met at 43 GHz, it should be pointed out that other beam asymmetries (e.g. struts, feed pattern) have been ignored. However, the ATCSG results encourage us to believe that the specifications are somewhat conservative, and there are other factors (e.g. bandwidth smearing) in our favour.

Conclusions

In order to avoid serious reduction in sensitivity at 22 GHz and above, and to keep beam changes from limiting the dynamic range at 44 GHz, subreflector motions must be kept below ±2 mm in the axial direction and ±4 mm laterally for any direction of the telescope axis. Owing to the many benefits of remote focussing, however, provision for (computer controlled) mechanized adjustment of the subreflector axial position is recommended.

References

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