Attach. 5

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THERMAL DISTORTION OF THE AT ANTENNAS II

G.J. Nelson and M.J. Kesteven

1. Introduction

Earlier documents (AT/21.1.1.1/009 and 010) discussed the existence of unexpectedly large thermal distortions in the AT antennas. Measurements reported therein indicated that some of the distortion was detected by the elevation encoder and therefore correctable by the servo. Another large component however involved tilting of the top of the alidade structure and could not be corrected in the same way.

It was established that differential heating by sunlight was not the prime cause of the tilts. The magnitude of the differential effects however is so great that very large temperature differences must be involved. This document discusses: -

a) several mechanisms that might contribute to the observed tilts,
b) experiments designed to verify the importance of the mechanisms, and,
c) suggestions as to how the thermal effects can be reduced or taken into account in a pointing model.

2. Differential Expansion Mechanisms

The following mechanisms have been identified as possibly important in the Culgoora antennas.

a) Differential heating of the dish by direct sunlight.
b) Differential expansion in the dish due to the constant temperature imposed on the vertex room.
c) Differential expansion between the elevation bull gear and its associated structure (mainly the east and west quadrupod legs) due to: -
    (i) a time lag in heating the counterweight and,
    (ii) the different expansion coefficient of the lead in the counterweight.
d) Differential heating of exposed members of the alidade structure by direct sunlight.

e) Differential expansion of the alidade structure because one member is located in the air conditioned pedestal room while the remainder are more or less at ambient temperature.

f) Distortion of the alidade structure caused by a temperature gradient along the path of the ducted air flow.

g) Non uniform circulation of air from the conditioner in the pedestal room.

Mechanisms (a), (b) and (c) have not been investigated in any detail to date and will not be discussed further here other than to say that (a) may affect pointing and focussing whereas (b) and (c) should mainly affect focussing.

Figure 3a is a schematic of the alidade structure and will be used in a discussion of (d), (e) and (f). The members shown in heavy lines (1-6) are enclosed in ducts through which ambient air is forced. Member 7 is not enclosed in ducting and is exposed to ambient air and sunlight. Member 8 is the structure associated with the azimuth slewing ring and is enclosed in the air conditioned pedestal room.

In mechanism (d) the exposed member 7 may be at different temperatures in the two alidade structures. A change in the length of 7 relative to other members results in a change in shape of the parallelogram 4568. Members 2 and 4 remain parallel to 8 but are translated horizontally and vertically (figure 3b). If the temperature of 7 is not the same on both alidades then the translations differ resulting in a slewing of the elevating axis in azimuth (ie a change in the azimuth encoder zero error). The magnitude of the effect is: -

$$\frac{\Delta \phi}{\Delta T} \approx 0.9 \text{ arc sec/degree}$$

where ΔT is the difference in temperature between the two alidade structures of member 7. Thus if temperature differences of the order 10° ever occur then the effect may be quite important.

In mechanism (e) it is assumed that all members except 8 are at ambient temperature. Eight (8) is at the fixed temperature of the pedestal room. The structure formed by members 1, 2, 3, 4, 6 and 7 changes in size but not in shape as the ambient temperature changes. Thus the tilt of the elevation bearing (2) as a result of an ambient temperature change is equal to the change in angle of member 7 (figure 3c). The effect results in a change in the elevation encoder zero error. This can be calculated by considering the equilateral triangle 5 7 8 in which 5 and 7 expand with ambient temperatures while 8 remains horizontal and constant in length.

The expected tilt is: -

$$\frac{\Delta d}{\Delta T} = 1.4 \text{ arc sec/degree}$$

where ΔT is the temperature difference between the pedestal and ambient. Thus for a range of 0 - 40°C in ambient and a pedestal temperature of 20°C the tilt expected from this mechanism is ± 28 arc sec. The direction of the tilt is such that the antenna points to higher than expected elevations as the ambient temperature increases.

To illustrate <u>mechanism (f)</u> figure 3a shows the ducted air flow along members of the alidade structure. In the morning when warm ambient air is heating the alidade structure members 1 and 5 will be heated more than the others. In fact an approximately linear gradient will be set up along the ducted air paths. The nett effect as illustrated in figure 3d is to produce a tilt of the elevation bearing (2) - an elevation encoder zero error - such that the antenna points to higher than expected elevations when ambient temperature is increasing with time or vice versa.

The magnitude of the effect is: -

$$\frac{\varnothing}{\Delta T} \approx 2.6 \text{ arc sec/degree}$$

where ΔT is the difference in temperature of the steel between the air intake and outlet points. The difference in air temperatures measured at the two points can be as high as 4° and ΔT is probably of the same order. The effect is reversed in sign in the evening so the diurnal range may be as high as ± 10 arc sec.

There are two consequences of non uniform circulation of air in the pedestal room [<u>mechanisms (g)</u>]. Horizontal temperature stratification occurs so that although the temperature at the intake to the air conditioner is held approximately constant, the temperature of the structure above the slewing ring (ie the base of the alidade structure) is always hotter and more variable than this.

The main effect of this is to make the result of mechanism (e) less predictable but by itself it does not produce any additional tilt.

The fact that the pedestal air conditioner blows strongly on one side of the room and not on the other can however produce an additional tilt. If one side of the room has a temperature difference of ΔT relative to the other then a tilt: -

$$\frac{\Delta \o}{\Delta T} \approx 2 \text{ arc sec/degree}$$

can be generated. When the conditioner is blowing cold air (ie summer) the effect is equal to an E-W station tilt downwards to the east and vice versa when warming.

3. Observations of the Thermal Effects

The shape of the dish - As mentioned before no experiments have yet been done to investigate the magnitude of the effects of mechanisms (a), (b) and (c). A 12 GHz AUSSAT receiver is however available and plans are in hand to detect changes in dish shape by measuring the optimum axial subreflector position as a function of temperature etc.. Pointing errors due to non symmetrical heating of the dish will be more difficult to assess. The position of AUSSAT is not currently known to sufficient precision and the effects of thermal distortions in the structure below the dish must be understood first.

Differential Sunlight on the Uninsulated Alidade Members - Antenna #5 was rotated in azimuth until one of the alidade structures shown in figure 1a was directly in the afternoon sun and the other in shade. After two hours in a light breeze temperature difference of only 1° was measured between members 7 (figure 1a) on the two structures. This results in a negligible azimuth encoder zero error of ~ 0.9 arc sec. Even under conditions of extreme calm this effect should therefore be negligible.

Difference in Temperature between Alidade and Pedestal and Gradient along Alidade Air Path - It is believed that these two mechanisms produce the largest thermally induced pointing errors on the antennas. Measurements with tilt meters confirm that a large rotation of the elevation bearings about the elevation axis accompanies changes in ambient temperature. Figure 2a shows this tilt measured on three successive days. The responses for the three days are displaced because attempts were made to significantly alter the pedestal room temperature on each day. The hysteresis effect due to the temperature gradient along the alidade ducted air path is also clearly visible. This latter effect is more obvious in figure 2b where the daily range in ambient temperature was smaller and no change in pedestal temperature was induced.

It is not possible to directly compare the above observations with the predictions of the previous section because the mean temperature and temperature gradient in the alidade structure are not readily measured. Instead the temperatures Ti and To of the air going in and coming out of the alidade ducts respectively were monitored. The average temperature of the alidade differs from ambient (Ti) by an amount indicated by the change in air temperature through the duct. Thus $T_{\mathrm{Alidade}} = Ti + k_1 (To - Ti)$.

The gradient ΔT_A in alidade temperature along the air path will also relate to To - Ti but in addition will depend to some extent on the past history of Ti. As a crude approximation we can however write $\Delta T_A = k_2 (To - Ti)$. Using the expressions presented in section 2 the total tilt at the elevation bearing is therefore: -

$$\begin{aligned}
\Delta \varnothing &\approx 1.4 \; [\, Ti + k_1 (To - Ti) - T_{\mathrm{Pedestal}} \,] \\
&\quad -2.6 \; [\, k_2 (To - Ti) \,] \\
&= (1.4 - 1.4 \, k_1 + 2.6 \, k_2) \, Ti \\
&\quad + (1.4 \, k_1 - 2.6 \, k_2) \, To - 1.4 \, T_{\mathrm{Pedestal}}
\end{aligned}$$

Fitting linear relationships of this kind to the data in figures 2a and 2b results in residuals of 5" and 2" respectively (figures 2c and 2d). The former data is probably also affected by gradients induced in the pedestal room during attempts to make large changes in the pedestal temperature (eg points shown by crosses in figure 2c were recorded while cooling the pedestal air from 38C to 12C). The smaller residuals in the second case (figure 2d) indicate the extent to which the effects might be modelled under more normal operating conditions. The fit would presumably also be better if actual steel temperatures were measured rather than inferring these from measurements of air temperatures.

The alidade thermal effects described here can be removed by modelling using observed air or steel temperatures as described above. Alternatively the tilts might be measured directly with tilt meters (this may be difficult due to the effects of wind, antenna motion and rotation about the non vertical azimuth axis) or they might be largely removed altogether by passing air conditioned pedestal room air through the alidade ducts rather than ambient air. An experiment to evaluate this latter approach is underway. Jeff Schafer from Macdonald Wagner points out that doing so will result in movement of the elevation bull gear relative to the drive pinions. We estimate that the movement will only be ~ 0.7 mm for an extreme temperature difference of 20° between the bull gear and the alidade structure. This movement will be checked experimentally but if it is as small as expected should cause no problems.

Another partial solution is to reduce the hysteresis effect due to the temperature gradient along the air path by merely increasing the flow of ambient air. The flow required to achieve an appreciable reduction will be checked experimentally. This procedure imposes no additional load on the pedestal air conditioner, results in no differential motion between bull gear and pinion and aims to remove the least predictable part of the tilt. It leave the more predictable effect due to differing alidade and pedestal temperatures to be removed by direct measurement or by temperature measurement and modelling.

Temperature Gradients in the Pedestal Room - Temperature differences between the top of the pedestal room and the air intake of the conditioner as high as 10°C are common during hot days. In addition at such times the structural members behind the air conditioner are typically 2° warmer than those in the direction of the outgoing air.

Experiments with a large fan mounted ~ 2 m above the floor and blowing upwards resulted in all points in the pedestal room being at the same temperature ± 0.5C. The uniformity of pedestal room temperature will again be measured while the experiment to control the temperature of the alidade legs with pedestal room air is being carried out. In this experiment air is drawn from near the top of one side of the room and returned with a large downward velocity on the other side. It is expected that this will result in sufficient mixing without the addition of an extra fan.

Recommendations

We adopt the philosophy that it is better to remove problems than to simply allow for their effects. Thus subject to the outcome of current experiments described above we recommend that the alidade structure be maintained at constant temperature by passing air from the pedestal room through the existing ducts and returning it in a manner that promotes mixing of the air in the pedestal room. The rate of air flow required and the adequacy of the resulting mixing will be determined experimentally. The alidade ducts are well sealed and insulated so that the extra load on the pedestal air conditioner will not be too great. If the conditioner cannot maintain a constant temperature through the year we recommend that the pedestal room temperature by varied between summer and winter to reduce the extreme loads to acceptable levels. Temperatures as low as 13°C in winter and as high as 27°C in summer are not unreasonable.

The modifications should be designed and the installation supervised by Macdonald Wagner. We should specify the air flow required and the manner of extracting and returning the air to promote mixing in the pedestal room.

G.J. NELSON & M.J. KESTEVEN