Scattering of Solar Flux by Panel Grooves

James W. Lamb

***Abstract*— The amount of scattering of solar radiation by grooves machined into the surfaces of the MMA antenna panels is estimated. Circular cross-section grooves are found to be much more effective than triangular grooves since they scatter over a wider range of angles. The groove pitch should be comparable to or smaller than the wavelength at the highest operating frequency, or about 100—300 μm, and have a radius of ~0.7 mm.**

I. Introduction

The requirement that the MMA antennas are able to directly observe the sun and sources close to it means that the solar radiation must be scattered at the primary to reduce the thermal loading on the secondary and the receiver cabin. Painting the surface would result in too high a loss, even in the millimeter band (see for example the measurements quoted in [1]). A technique successfully applied at BIMA [2] is to leave fine grooves from the machining process in the panel surface. It has been assumed that this is equally applicable to the MMA. However the antenna area has now been increased by a factor of 2.25 relative to the 8-m design, and it is a factor of 4 greater than the BIMA antennas. Furthermore, because of the better atmosphere and higher elevation, the solar flux will be significantly greater in the Atacama high desert than at Hat Creek.

In order to quantify the problem we make some simple estimates for two different groove cross-sectional shapes. An assumption is that the grooves are cut in a tangential direction relative to the primary or secondary surface, but a similar analysis could be applied for radial or other grooves. The results are not expected to be very different. Grooves with triangular and circular cross-section are compared.

II. Solar Power

Most of the solar radiation falls in the range with wavelengths longer than 4 μm. Geometrical optics calculations should therefore be valid. The solar flux at the Chilean site is taken to be 1290 W m^{-2}. This yields a maximum insolation on the antenna of 0.15 MW. It is preferable to reflect as much of this as possible, rather than thermally loading the antenna. For aluminum the emissivity, ε, will be of order 0.25—0.4 depending on machining and age. A specular primary would therefore produce a flux of 200—250 kW m^{-2} on a 750-mm diameter secondary. Heat concentrated on the feed legs while observing a source close to the sun could be much higher.

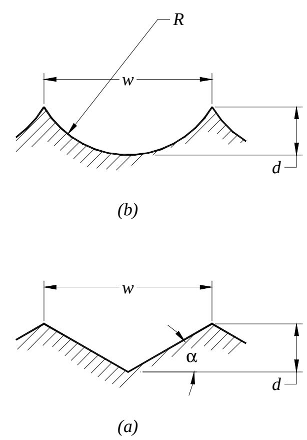

Fig. 1. Parameters used to characterize the groove cross-sections for *(a)* a triangular groove, and *(b)* a circular groove which is approximated as a parabolic curve.

III. Groove Scattering

Fig. 1 shows the two groove geometries with the appropriate parameters. For the millimeter and submillimeter bands we need to consider diffraction effects if the groove pitch, w, is comparable to a wavelength, and Ruze losses [3] if w is greater than a half wavelength or so. At the highest frequency the wavelength is $\lambda_{min} \approx 300$ μm. We will assume that the maximum contribution to the surface error budget is to be $\varepsilon = 3$ μm.

A. Triangular Grooves

To satisfy the surface error constraint for wide grooves ($w \geq 150$ μm) we require

$$d \leq \frac{\varepsilon}{0.289}\ . \tag{1}$$

If the blaze angle is $\alpha = 5°$, then the width is $w \leq 230$ μm which is quite close to the diffraction limit. For angles greater than about 8° the width will be less than $\frac{1}{2}\lambda_{min.}$

With the sun on axis, these grooves will scatter the solar radiation in a cone around the secondary. In the plane of the secondary the power will be distributed in an annulus of width d_s, the diameter of the secondary, and radius

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Owens Valley Radio Observatory, California Institute of Technology, Big Pine, CA 93513, USA

$$r = 2\alpha f \;, \tag{2}$$

where f is the primary focal length. The secondary will be at the center of the annulus and therefore receive very little of the power.

If the antenna is pointed away from the sun by an angle 2α the secondary will again be illuminated. However, compared to the on-axis case with no grooves, the solar radiation is reduced by an amount

$$\eta = \frac{d_s}{16\alpha f} \,, \tag{3}$$

giving $\eta = 0.11$ for a 750-mm secondary and a 5° blaze angle on the groove. The resulting flux at the secondary is then 22—28 kW m^{-2}, or 20 times the flux incident on the primary. A 10° blaze angle would be a factor of two better.

By using a 45° blaze angle the groove would be a retro-reflector. However, having two reflections would increase the solar loading on the primary by 60—75%.

B. Circular Grooves

Cutting grooves with a tool of radius R to a depth d produces a pitch of

$$w = 2\sqrt{2Rd} \;. \tag{4}$$

The slope angle is uniformly distributed over a range

$$\begin{aligned} &0 \le \alpha \le \alpha_{\max} \\ &\alpha_{\max} \approx \frac{4d}{w} \end{aligned} \tag{5}$$

which is twice that of a triangular groove having the same aspect ratio. The Ruze criterion now gives

$$d \le \frac{\varepsilon}{0.298} \,, \tag{6}$$

essentially the same as for triangular grooves.

Now the solar energy is distributed within a cone, and at the secondary this is a circle of radius

$$r = 2\alpha_{\max} f \;. \tag{7}$$

Note that this is about twice the size for the triangular groove, and the energy is uniformly distributed within a circle rather than being in an annular region. The corresponding reduction in solar flux is therefore

$$\eta = \left(\frac{d_s}{4\alpha_{\max} f} \right)^2 \,, \tag{8}$$

which gives $\eta = 0.0015$ for the same width and depth of groove used for the calculation of the triangular groove, a 65 times improvement. At the secondary the flux density is reduced to 305—380 W m^{-2}. Since this depends on $(d/w)^2$, while η in Eq. (3) varies as d/w, scattering by circular grooves can be improved more easily with small changes in parameters than the triangular ones.

IV. POWER AT THE SECONDARY FOCUS

Since the secondary subtends about 5° at the Cassegrain focus and the grooves scatter by a similar amount, the power will be distributed in a region of diameter $\ge d_s$ in the plane of the receivers. The density will therefore be less than or similar to the flux at the secondary. Grooves could of course be machined into the secondary mirror also.

V. SURFACE RESISTIVITY

Since the skin depth is small compared to the groove dimensions (≤ 1 µm), the effective resistance increases with the surface area relative to a smooth surface [4]. This increase will be small for the shallow grooves proposed here, and up to 40 % for a blaze angle of 45°.

VI. FEASIBILITY

We suppose that the grooves in the surface will be a result of the cutting marks of the tool used to machine the panel or secondary mirror surface. From [5] we find the recommended feed rate for turning aluminum with a cut depth less than 1 mm is 180 µm per revolution. For face milling it is 250 µm for wrought alloys and 200 µm for cast alloys. Obviously these are quite close to what is required for good scattering.

The tool radius for the circular grooves used in the above analysis is $R \approx 0.7$ mm, also reasonable.

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