SPIRE

Technical Note

Edge-diffraction: sun-shield via M2 edge.

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CONTENTS.

Summary.
A calculation is made for the amount of sun-shield radiance diffracted into the used beam at the M2 edge. The result is a stray-light level at 0.2 % of the telescope mirrors background, in the worst case λ=0.5mm.

1. Introduction.

In SPIRE there is no significant Lyot stop for longer wavelengths, i.e. the instrument pupil undersize with respect to the telescope has no allowance to block edge-diffraction, and this is so in order to preserve high throughput across all wavelengths (Ref.1).

Consequently the beam from the instrument (single detector) is significantly clipped by the telescope pupil (edge of M2), and the background due to the clipped part is acceptable since the M2 surround has low emissivity/temperature (made up of sky & spider legs).

However, this clipping & lack of Lyot stop also means that radiance from well outside the beam , entering it via diffraction at M2, will pass through to the detector. The main source for such diffraction is the inner surface of the sun-shield, and an example path is shown in fig.1 (in colour).

2. Geometry.

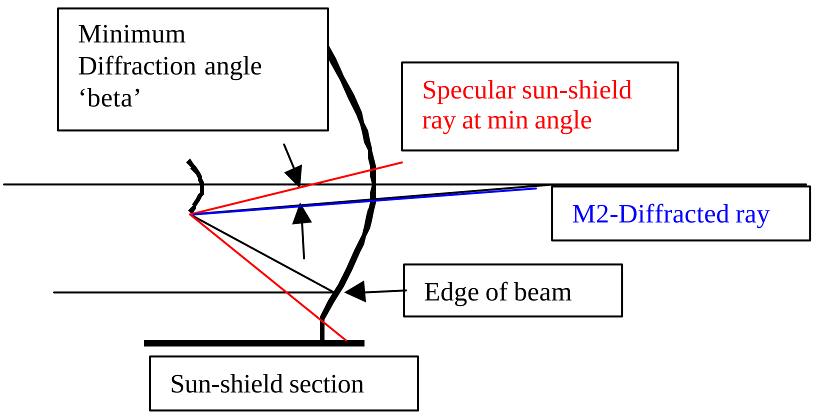

Fig.1. Section view of FIRST sun-shield geometry (ref.2).

The sun-shield is made of two flat surfaces, & each of these extend behind the telescope primary. There is also a flat surface between the edge of the mirror optical surface & the sun-shield, but this will be largely reflecting and so will simply image the sun-shield surface. With this geometry the minimum diffraction angle is determined by the separation of the edge of the used beam, as defined by the pupil & FOV position, and the edge of the primary mirror optical surface (i.e. the conic surface), as defined by FIRST unvignetted FOV plus M1 oversize margin. The equivalent angle in the space between M1 & M2 is shown as 'beta' in the figure. The corresponding worst-case position of the M1/sunshield boundary is calculated as:

Y = o + (a-r).L

Where o = M1 oversize in mm = 17mm.
r = SPIRE FOV worst case = 13.5 arcmin for outer corner.
a = FIRST unvignetted FOV radius = 15 arcmin.
L = FIRST entrance pupil distance from M1 = 17 m.
(ref.5), giving
Y=24mm

3. Analysis method.

In order to use a standard format for analysing edge-diffraction, it is convenient to work in 'object space', i.e. to image both the source surface & the diffracting edge to the space ahead of the telescope (ref.3). This geometry is shown in fig.2. We consider first the case of bare detectors, and the result for horn detectors can be obtained by multiplying the result by the edge taper.

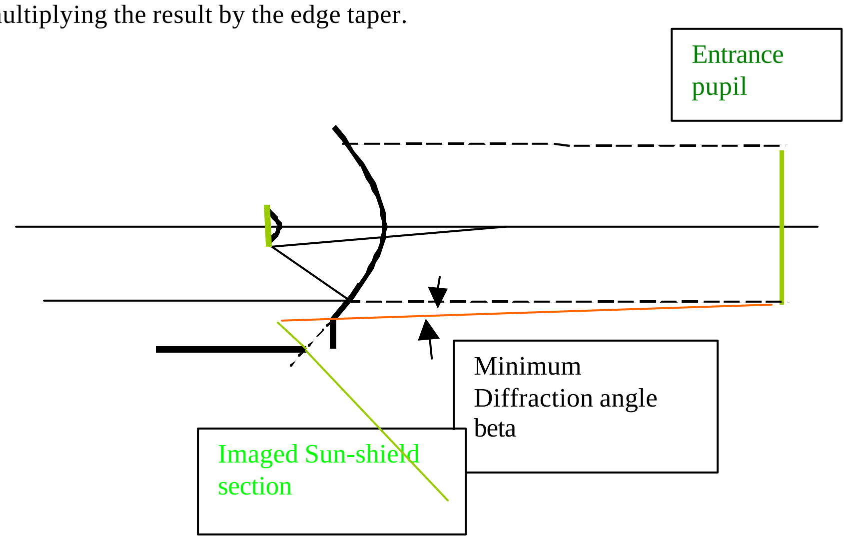

Fig.2 Sun shield & M2 as imaged in M1.

Furthermore, to determine the diffraction radiance at the detector (or telescope focal plane) the whole telescope optical system may be replaced by an equivalent ideal lens of focal length f = FIRST focal length, placed at the entrance pupil, which is at approx f/2 behind the telescope M1 :

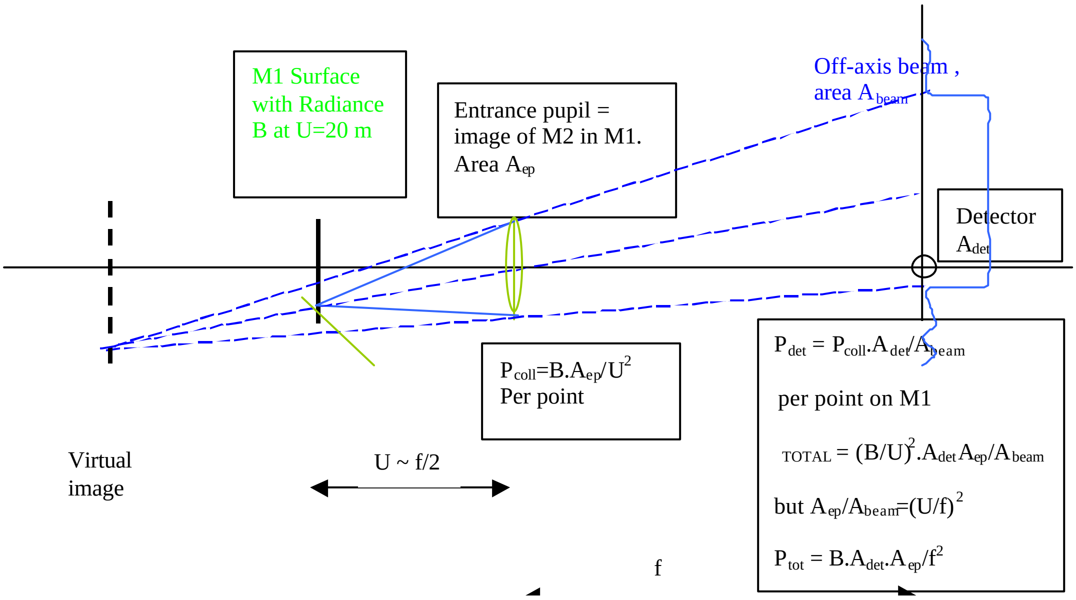

Fig.3. Equivalent lens system

With the entrance pupil being close to f/2 behind the M1, the point source on M1 has a virtual image at a distance of –f from the EP. The beam area at the detector plane is then $A_{beam} = A_{ep}.(2f/f)^2$.

The power collected by the EP is

$$P_{coll}=B.A_{ep}/U^2 \quad \text{per unit area of M1}$$

This is spread over the beam area, and the power collected by the detector is

$$P_{det} = (P_{coll}/A_{beam}).A_{det} \quad \text{per unit area of M1}$$
$$= B.A_{det}/f^2$$

If this is approx. the same for all points on M1, the total power is P_{det} x A_{ep} , which is the same result as for an extended source at infinite distance.

3.1. Off axis beam.

Here only the ‘wing’ of the beam lies on the detector.

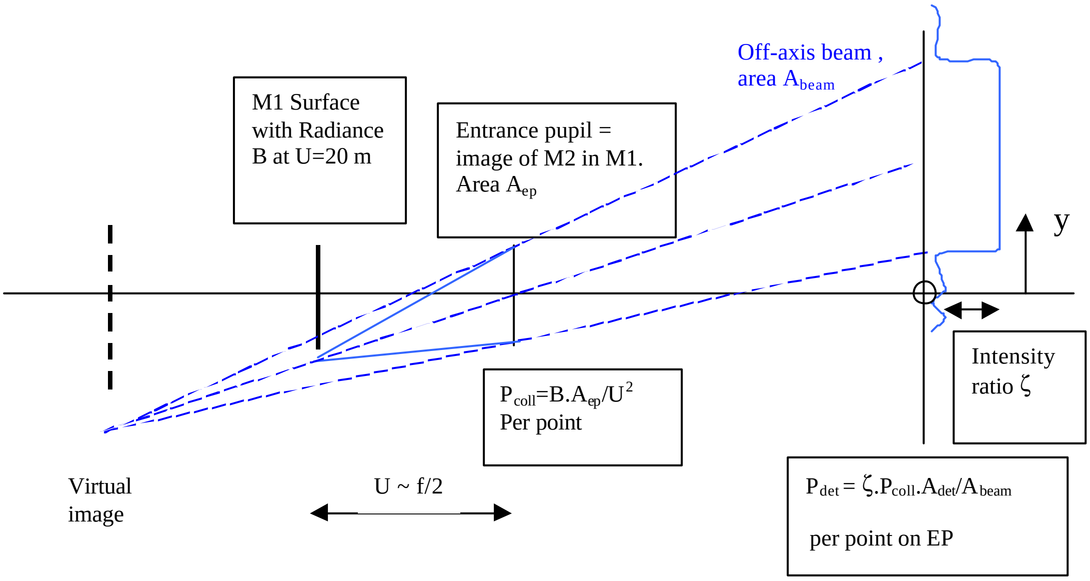

Fig.4. Off-axis case.

Calculating the power detected now requires the ratio ζ of the intensity in the beam's wing to that in the specular beam. In the near-field as required here APART is said to use an altered BDDF but the formula for this is not found in the literature.

So we have to calculate the near-field beam pattern explicitly. Although this can be done e.g. with ASAP, to get the high numerical accuracy needed here in a beam diameter >> λ, a direct evaluation of the diffraction integral is used for the point source spherical wave on a circular aperture (Born & Wolf, p.450)

The input field at distance r from the point is :

$$E = \exp(j.k.r)/r$$

Figure 5 shows the field modulus at the output plane, at which r = 2f = 70 m, so the peak of |E| = 1/70 = 0.014.

At the minimum off-axis distance of the sun-shield edge (0.025 m, for outer corner of FOV) the intensity ratio is $\zeta \sim (0.1)^2$.

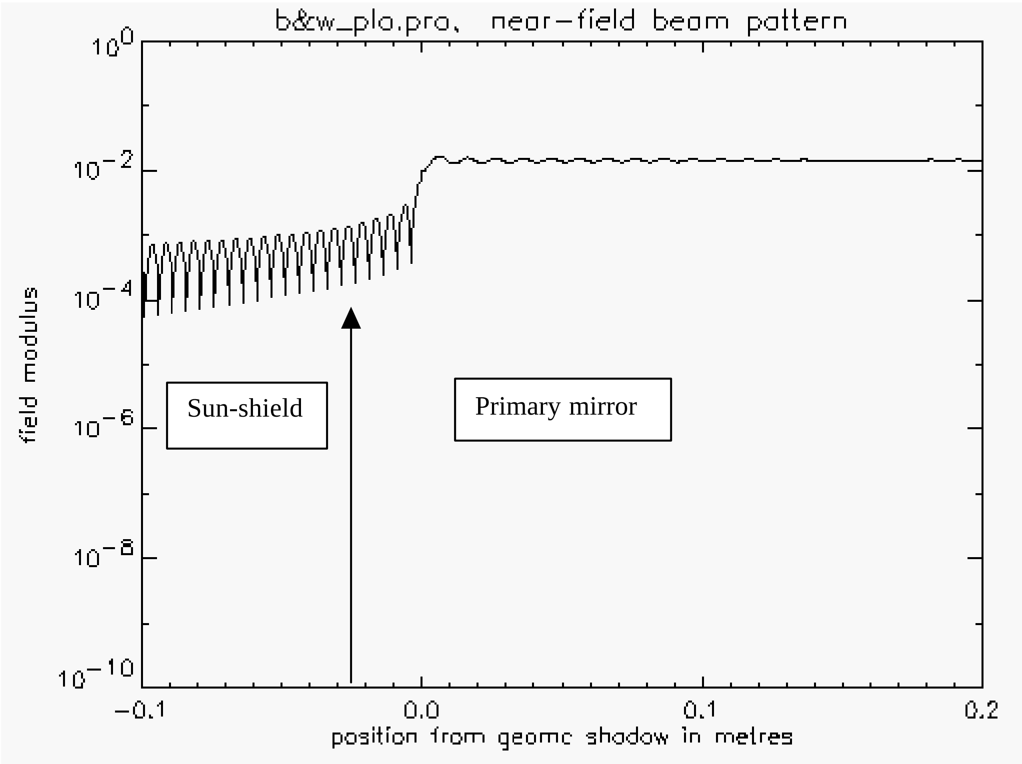

Fig.5. Beam pattern in detector plane of fig.2, for case where the geometric shadow lies on the optic axis (i.e. at y=0).

The power of the beam within the primary mirror is estimated as

$$P1 = |E|^2 . \pi D^2/4$$

Where |E|=1/2f = 1/70

And that outside of its edge is

$$P2 = \int_{y1}^{y2} |u(y)|^2 .2p .(D/2 + |y|)^2 .dy$$

where from the figure the limits are y1=-0.025m and y2=-∞.

4. Results.

The calculation is made for the following parameters:

Beam (entrance pupil) diameter D=3500mm
Mirrors: ε_m=0.01 T_m=74 K.
Sun-shield: ε_{ss}=0.04 T_m= 170 K.
(ref.2)
Sun-shield surround factor χ=1/3

The telescope edge-clearance parameters are listed above.

The wavelength used is the middle of the longest wavelength channel, λ=0.5mm.

The beam pattern above & y2=-0.6m gives a ratio P2/P1 = 0.0005.

The sun-shield stray light as a fraction of the mirror emission is this figure multiplied by the emissivity ratio (0.04/0.01), while the perimeter fill factor (1/3) and spectral radiance factor (2.5) approximately cancel. This gives a final result:

Sun-shield signal/M1 signal = 0.002 at λ=0.5mm.

5. References.

Ref.1. 'Trade off in beam shape & size in telescope'RAL-N-0118, & PDR July'99.
Ref.2. 'FIRST payload module/focal plane unit straylight model' RAL N-0101.1
Ref.3. 'Application of general diffraction analysis to the design of non-standard Lyot stop systems…'.Opt Eng.Vol.36,No.10,pp.2793-2808 (1997).
Ref.4. 'Lectures on mm-wave optics', no.17. D.H.Martin.
Ref.5 "Optical design of the ultra-light-weight FIRST telescope" SPIE Vol.4013. SPIRE-REF-PUB-000409 & SPIRE-REF-PUB-000411