Sensitivity of the TMU alignment

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Introduction

We will calculate how sensitive the telescope efficiency is to the tertiary mirror unit (TMU) alignment. The JCMT receivers do receive radiation but it actually does not matter if we think of the receiver as a transmitter or receiver. Since it is simpler to think of the problem in transmission, we will do that.

Model

The receiver sends out a Gaussian shaped beam, which hits the secondary mirror unit (SMU). The beam width is such that the power at the edge of the secondary is about 1/10 of the power (-10dB) at the center when the beam is perfectly aligned. The calculation below is not very sensitive to the edge taper so we will only consider a taper of 10dB. We will compute the power intercepted by the secondary when perfectly aligned and when the beam is offset from the center of the SMU. Neglecting diffraction and vignetting the drop in relative intercepted power is equal to the drop in efficiency.

Geometry

The TMU is about 7.5 meter from the TMU. If the TMU angle is changed by 1 degree, the reflected beam direction will change with 2 degrees. Thus, if we move the TMU from the perfect alignment by the angle *angle* the beam will be displaced on the SMU by

$$motion = 7.5 * \tan(2 * angle) \quad [m]$$

If we move the TMU with 1degree, the beam will shift 0.262m on the secondary or about 70% of the 0.375m radius. Hence, 1 degree is a large move of the TMU. Actually, we are only half as sensitive to a TMU x (or Azimuth) angle error due to the TMU mounting (the effect is most extreme when the TMU is parallel with the cabin floor, changing the TMU Azimuth will then not have any effect at all. At 45degrees, there is a factor of two).

Calculation

The power in a cross section of the beam when it reaches the secondary can be described by the equation

$$f(x) = \frac{\ln(T)}{\pi} \cdot \exp(-\ln(T) \cdot x^2)$$

Where we have normalized the length scale so the secondary radius is one and 1/T is the drop of power at edge of the secondary. Integrating from x=0 to 1 gives 1-1/T, this is the power intercepted by the SMU when we have perfect alignment. If the beam is offset by the (normalized) distance of z from the center of the SMU, we get the intercepted power:

$$\frac{\ln(T)}{\pi}\int_0^1\int_0^{2\pi} r\cdot\exp\left[-\ln(T)(r^2+x^2-2xr\cos(t))\right]drdt$$

Combining the above, we calculate:

TMU error(deg)	Relative efficiency
0.0	1.000
0.1	0.997
0.2	0.988
0.3	0.974
0.4	0.954
0.5	0.927
0.6	0.895
0.7	0.856
0.8	0.812
0.9	0.763
1.0	0.709

Conclusions:

The drop of efficiency due to a 0.2 degree TMU alignment error is negligible (0.4degree in TMU x or Azimuth). In practice, even a 0.4degree miss alignment will be hard to se in efficiency data. Apart from error in aligning the TMU, we will also see effects due to deformation in the telescope and equipment. The SMU is moved to compensate for the dish deformation with elevation. The total motion is of order 8mm equivalent to a 0.03degree TMU motion – this is a negligible loss of efficiency. Deflections in the TMU unit itself are likely small. More likely is that we have deflections in the receiver itself, either in the warm optics or due to deflections in the Cryostat. A deflection if about 2mm will correspond to a TMU error of 0.1 degree. A few millimeters shift could occur – causing a variation in the TMU angle of order 0.1degrees. The sensitivity to mirrors angles is of the same order as for the TMU itself.