Physical Optics Analysis of the Cold Load Optics for the GBT 4mm Receiver

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The 4mm dual-beam receiver for the GBT, which is under development, will cover the 67-93 GHz frequency range. The primary scientific goal is spectroscopy; however, VLBI observation will be supported over a part of the band. A compact feed horn with a sinusoidal profile taper is used in this receiver. The outside diameter of the horn is 1.03”. The spacing between the feeds is 10.4” giving a beam separation of about 4.7 arcminutes. The calibration strategies and design are driven by the specification to maintain better than about 3% relative calibration of the instrument [1]. The calibration scheme consists of chopping between two (hot and cold) loads and the sky. The system gain is determined by use of the ambient and cold load calibration, while the sky-load is used to monitor the atmosphere. A preliminary optics design to reflect a 20K cold load into one of the feed horns was arrived at by Roger Norrod [2].

Figure1 shows the schematic of the optics. There are two back-to-back offset parabolic mirrors, one positioned above one of the feeds and the other positioned above the cold absorber. The mirrors have a focal length of 1.9685” and the center-to-center distance is 5.2”. The half-angle subtended by the offset paraboloid from the focus is 22°. Figure 2 shows the location of the mirrors and the cold load with respect to the dewar top plate. This figure also shows Zemax ray trace results where the phase center of the feed at F1 gets translated to F2 located above the cold load. The projected aperture of the parabola is 3.43” perpendicular to the feed axis and 3.18” perpendicular to the plane waves. The first mirror is located at distance of 3.94” from the feed and is in its near-field region. The parabolic mirrors are also located in the near-field region of each other. In order to verify the ray trace results, a physical optics (PO) analysis of the quasi-optical scheme was carried out and results are presented here.

The analysis was done using a reflector antenna electromagnetic code which facilitates computation of the radiation pattern of a multiple reflector system using the PO technique. Parameters of the multiple reflectors can be input in a single data file and radiation pattern of the entire system can be calculated in one step. The surface currents on the reflector surface are obtained from the feed illumination or preceding reflector pattern and then integrated to determine the radiation pattern of the antenna. Measured feed patterns in the E- and H-planes were used in the analysis. Analysis was done at 68, 80 and 92 GHz and for both horizontal and vertical polarizations. The origin of the coordinate system is at v2 (Figure 1) with z-axis pointing towards v1 and y-axis pointing up. The output beam from the second reflector is along the negative y direction and hence it is complicated to calculate the beam pattern in several planes. The output beam of the two-mirror system is calculated only in the yz-plane (plane of the reflectors). Figures 3a shows the reflected beam from the second reflector (blue) along with the feed patterns in the E-(red) and H- (green) planes at 68 GHz. The polarization is horizontal (into the plane of the paper). The reflected pattern agrees well with the input feed pattern down to -15 dB from the peak of the beam. This indicates that ray tracing is a good approximation for the given geometry of the reflectors. The lobe at 180° is due to reflector edge diffraction or the equivalent of Poisson/Arago spot in optics. Figure 3b shows the beam from the mirror system for vertical polarization (along the y-axis) and again there is good agreement with the input feed pattern.

Results for both polarizations at 80 GHz and 92 GHz are shown in Figures 4 and 5, respectively. There is excellent match of the reflected beam at 92 GHz with the feed pattern down to the -25 dB level from the peak of the beam. These results show that the two-mirror optics scheme essentially translates the feed pattern from F1 to F2 and into the cold absorber.

REFERENCES

[1] D. Frayer, R. Maddalena and F. Ghigo, “Calibration Plan of the GBT 4mm Receiver”, October 26, 2010.

[2] https://safe.nrao.edu/wiki/bin/view/GBT/ColdLoadMirrors

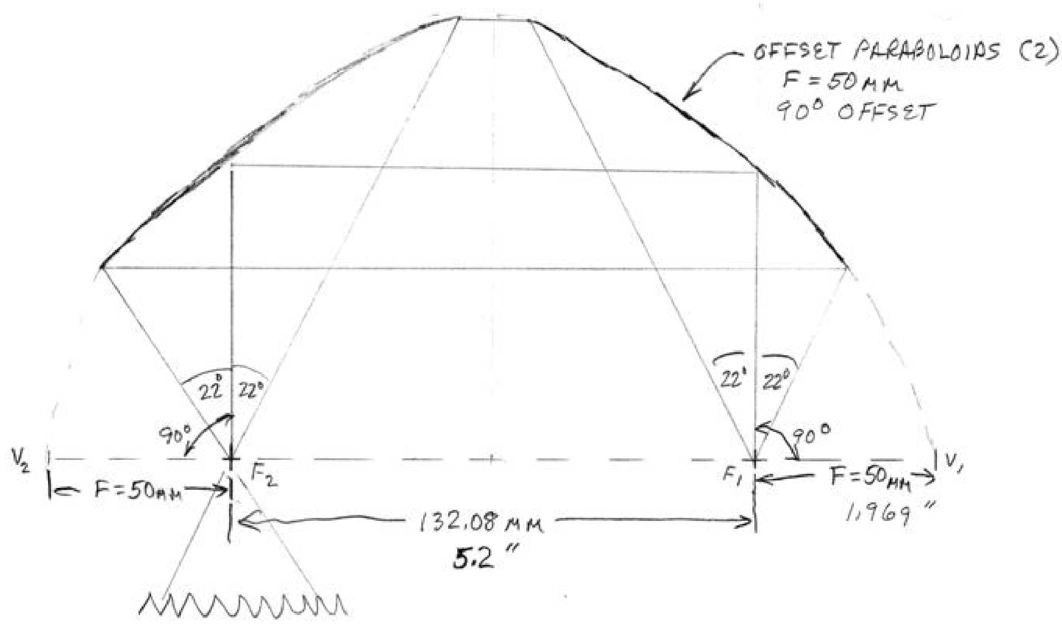

Figure 1. Geometry of cold load optics

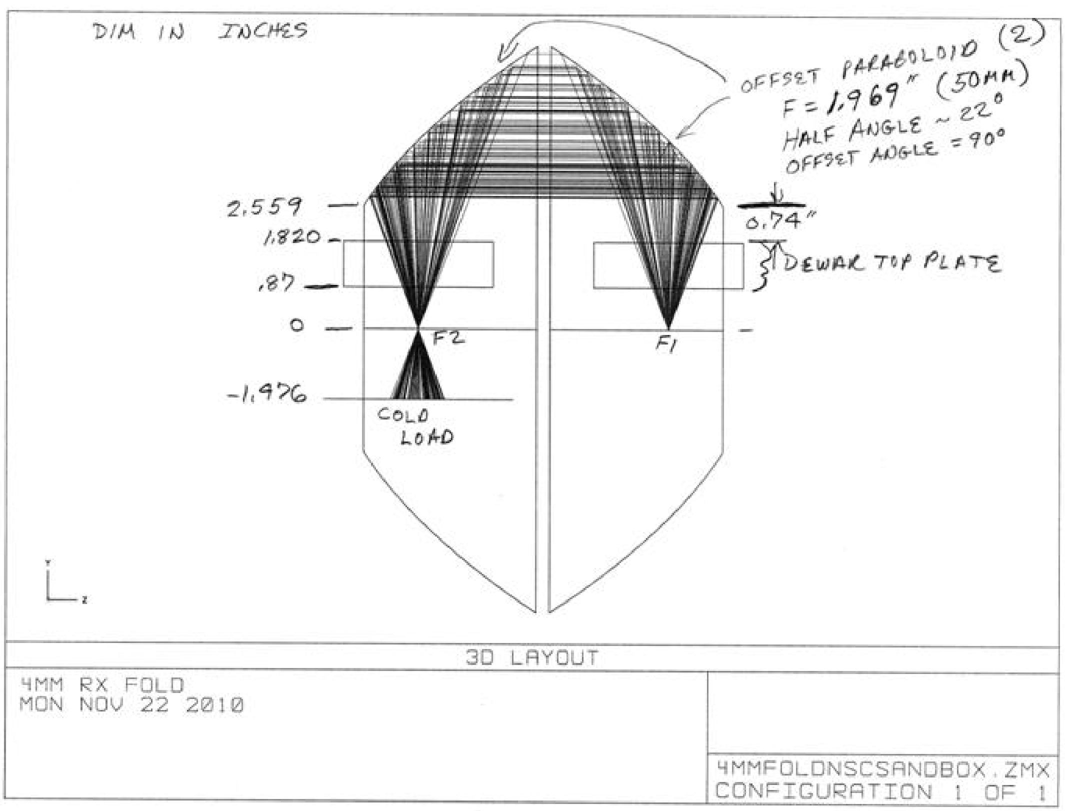

Figure 2. Zemax ray tracing results

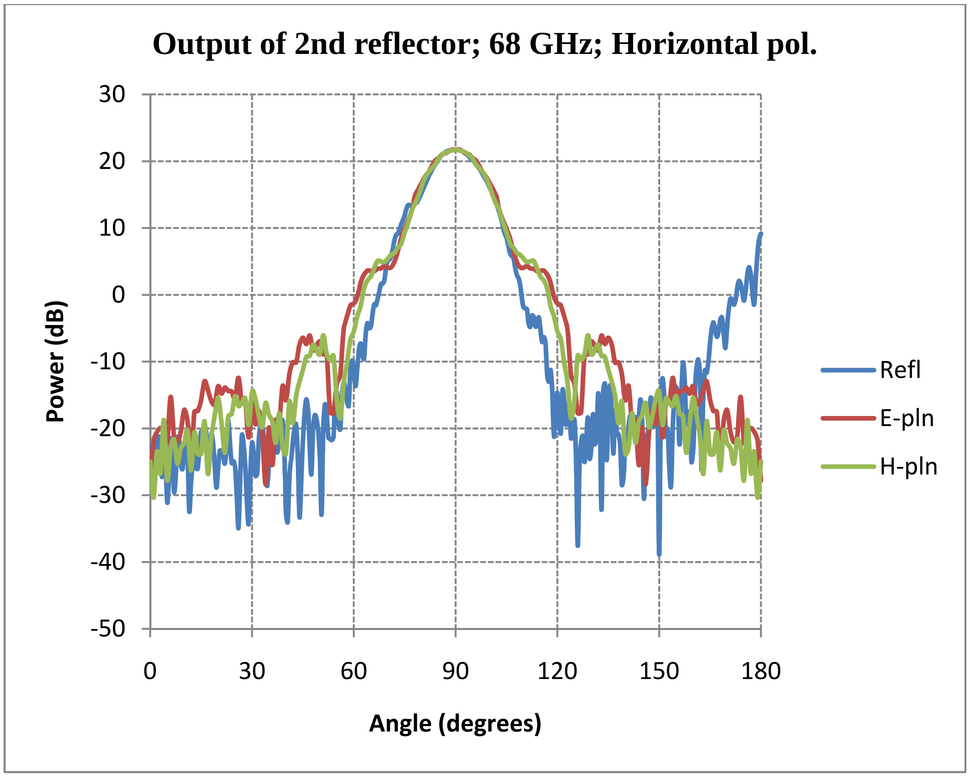

Figure 3a. Reflected beam for horizontal polarization and feed patterns at 68 GHz

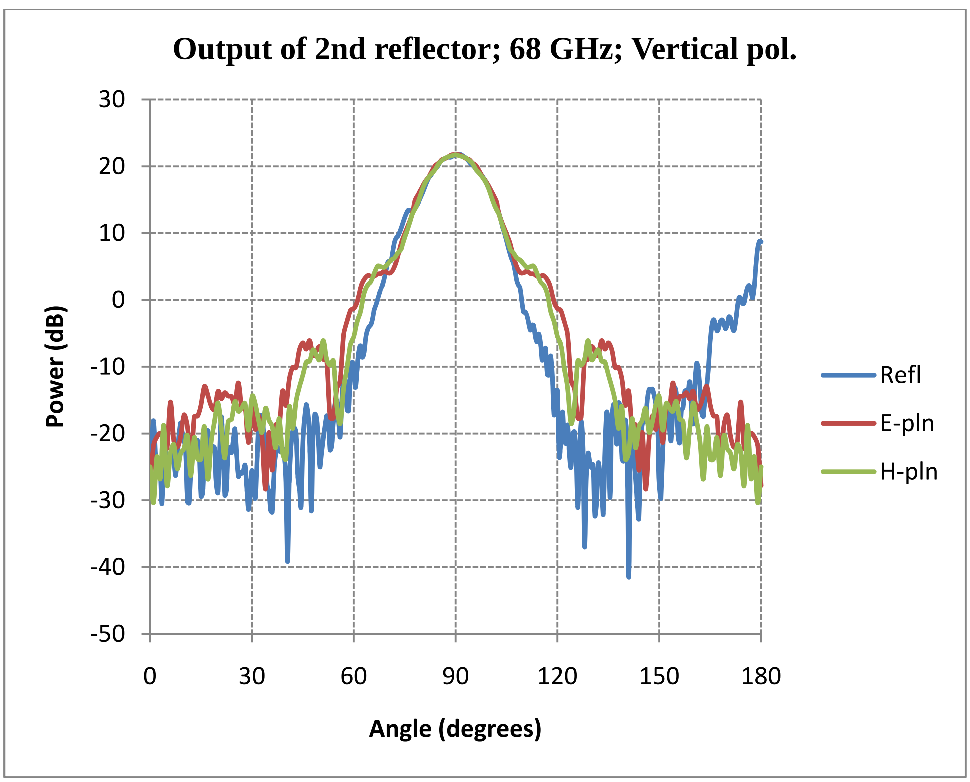

Figure 3b. Reflected beam for vertical polarization and feed patterns at 68 GHz

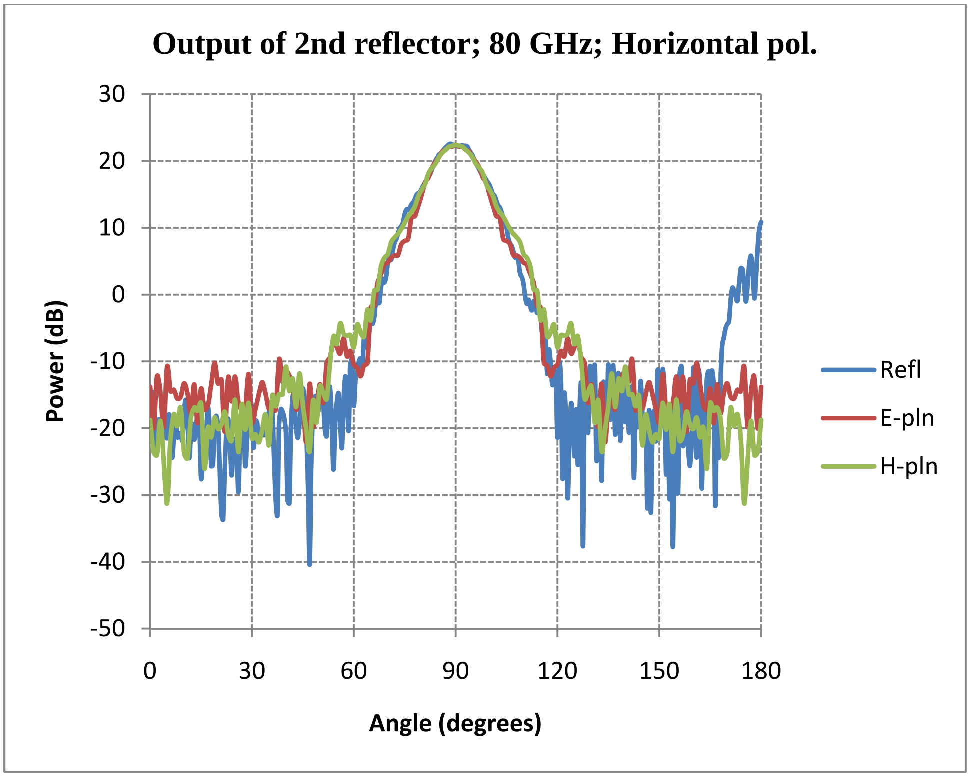

Figure 4a. Reflected beam for horizontal polarization and feed patterns at 80 GHz

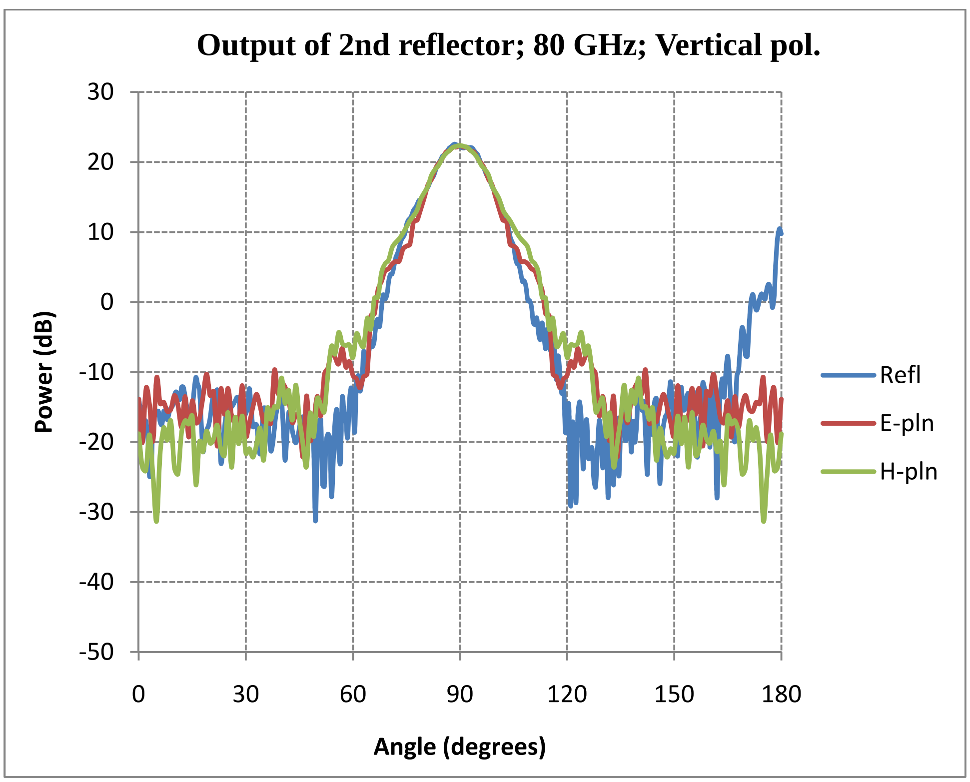

Figure 4b. Reflected beam for vertical polarization and feed patterns at 80 GHz

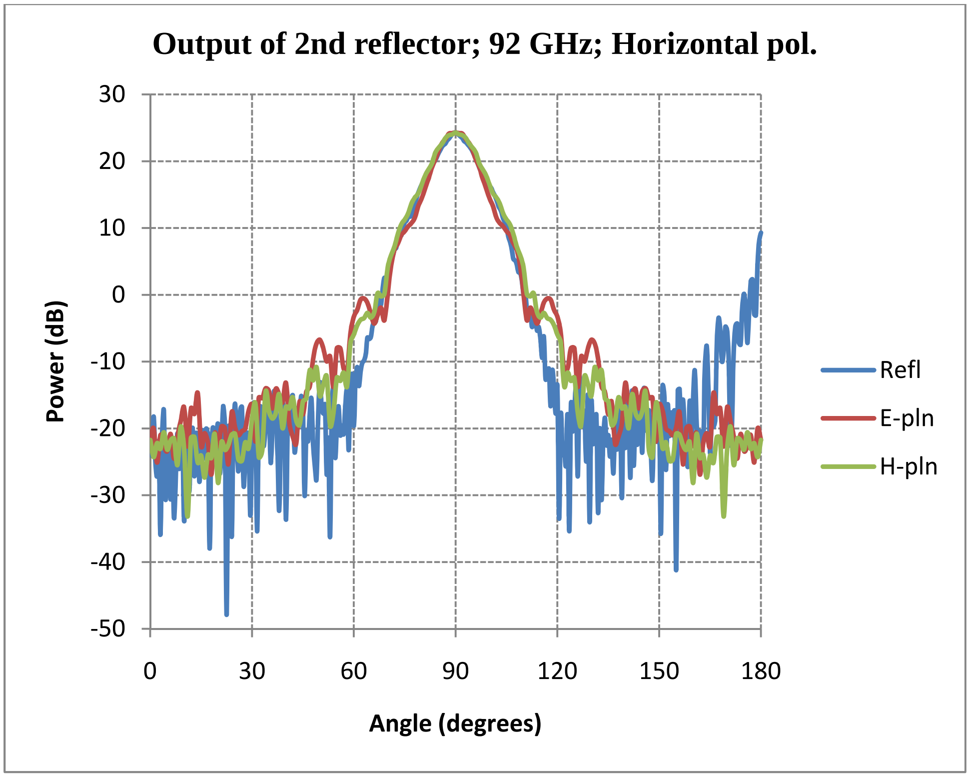

Figure 5a. Reflected beam for horizontal polarization and feed patterns at 92 GHz

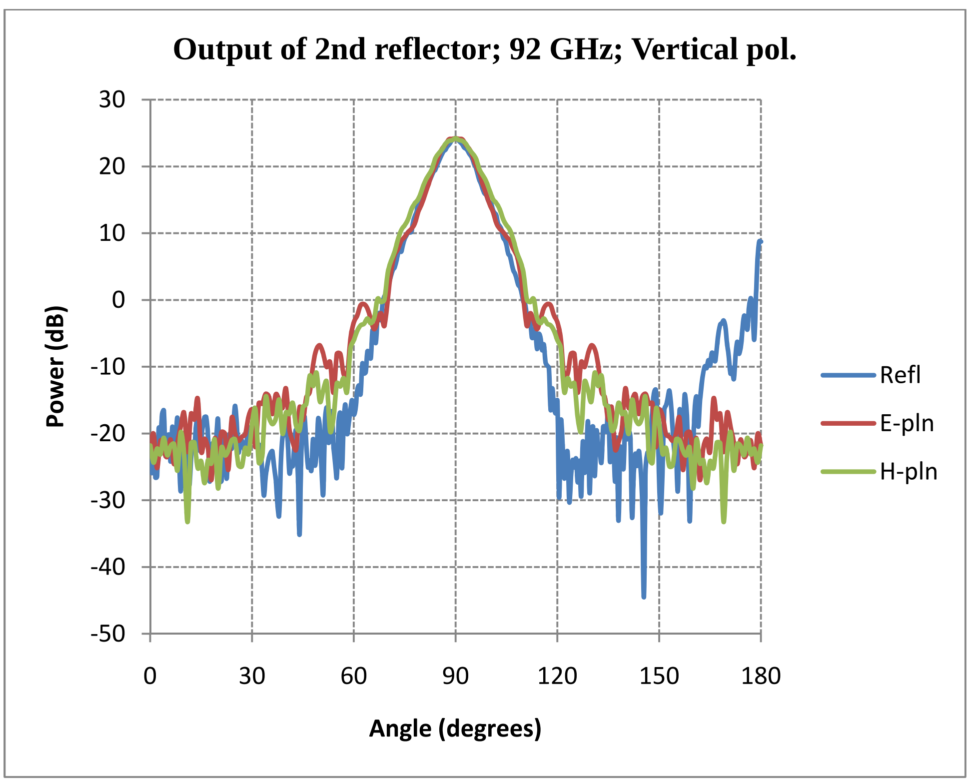

Figure 5b. Reflected beam for vertical polarization and feed patterns at 92 GHz