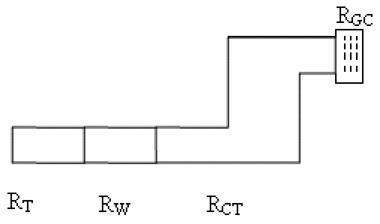
H. Marks 19/07/2009
F: 3462

Report no. 40
Report on the Evaluation of the New Resonator

1. Description and model



The round trip reflectivity of the resonator can be measured directly from the $S_{11}(f)$ measured. Alternating, with the approximation of neglecting higher order modes excitation, one can measure the contribution of the components, and assume a multiplicative relation of the round-trip reflectivity of the components:

$$R_{RT} = R_T \cdot R_W \cdot R_{CT} \cdot R_{GC}$$

The resonator round trip loss is then:

$$R_{MT} = 1 - R_{RT}$$

All measurements were made by constructing a Fabri-Perot resonator using grid #610 attached to the mode exciter. In each case the reference for determining the absolute value of S_{11} was a shorting plate placed instead of the #610 grid. When we were not sure about the reference we assume the following:
Power reflectivity of grid 610 is 92% (this value fits all the curves well). The principal variable for the theoretical curve is τr_2. The experimental curves have been put on a linear scale and multiplied by an arbitrary factor until both curves match.

The experimental curves were matched to the theoretical curve of a Fabri-Perot resonator

$$\Gamma = |S_{11}|^2 = \frac{[r_1 - \tau r_2]^2 + 4\tau r_1 r_2 \sin^2\left(\frac{\delta}{2}\right)}{(1-\tau r_1 r_2)^2 + 4\tau r_1 r_2 \sin^2\left(\frac{\delta}{2}\right)}$$

$$T = |S_{12}|^2 = \frac{(1-r_1^2)(1-r_2^2)}{(1-\tau r_1 r_2)^2 + 4\tau r_1 r_2 \sin^2\left(\frac{\delta}{2}\right)}$$

Where $\delta = 2k_z L \approx 4\pi f L / c \quad (L = ...)$ $r_1 = \sqrt{r_1}$ is the amplitude reflection coefficient of the input coupling mirror (in most cases grid # 610), $r_2 = \sqrt{r_2}$ is the reflectivity of the mirror at the other end (when it is a short $r_2 = 1$, an τ is the amplitude round trip reflectivity along the resonator excluding the mirrors.

2. Measurements of components

From curve matching we found:

Waveguide (R_W)

R_W Roundtrip reflectivity of Waveguide alone: $R_w = r_w^2$ = (0.977^2) = 95.45%

Straight Talbot together with Waveguide

R_{T+W} Roundtrip reflectivity of straight Talbot + Waveguide: $R_T = ..$ = (0.97^2) = 94.09%

Straight Talbot (calculated)

R_{T+W}/ R_W = 0.9409/0.9545 = 0.9858 => R_T of Straight Talbot = 98.58% (L_T=1.42%)

Con-focal Talbot

R_{CT} Roundtrip reflectivity of con-focal Talbot splitter with a short in place of the rotating grids R_{CT} = (0.89^2)/ /0.92 = 79.21% => Losses of L_{CT} =20.79% (see figure 1 below).

With rotating grids at the end (R_{GC}*R_{CT}) Roundtrip reflectivity of con-focal Talbot splitter = 0.839^2 = 70.39% => Losses of 29.61% (see figure 3 below).

Rotating 3 Grid System

R_{GC} can be calculated by itself by (R_{GC}*R_{CT})/ R_{CT} = 88.87% => Losses of L_{GC}= 11.13%

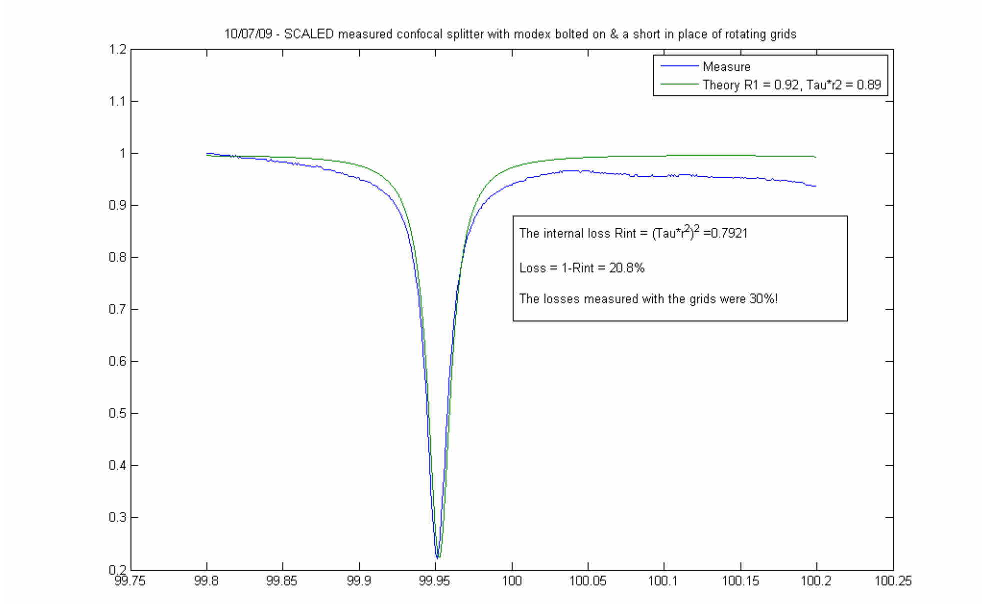


Figure 1: Theoretical and experimental curve of the confocal splitter alone with the mode exciter bolted with grid 610 and a short placed where the rotating grids were.

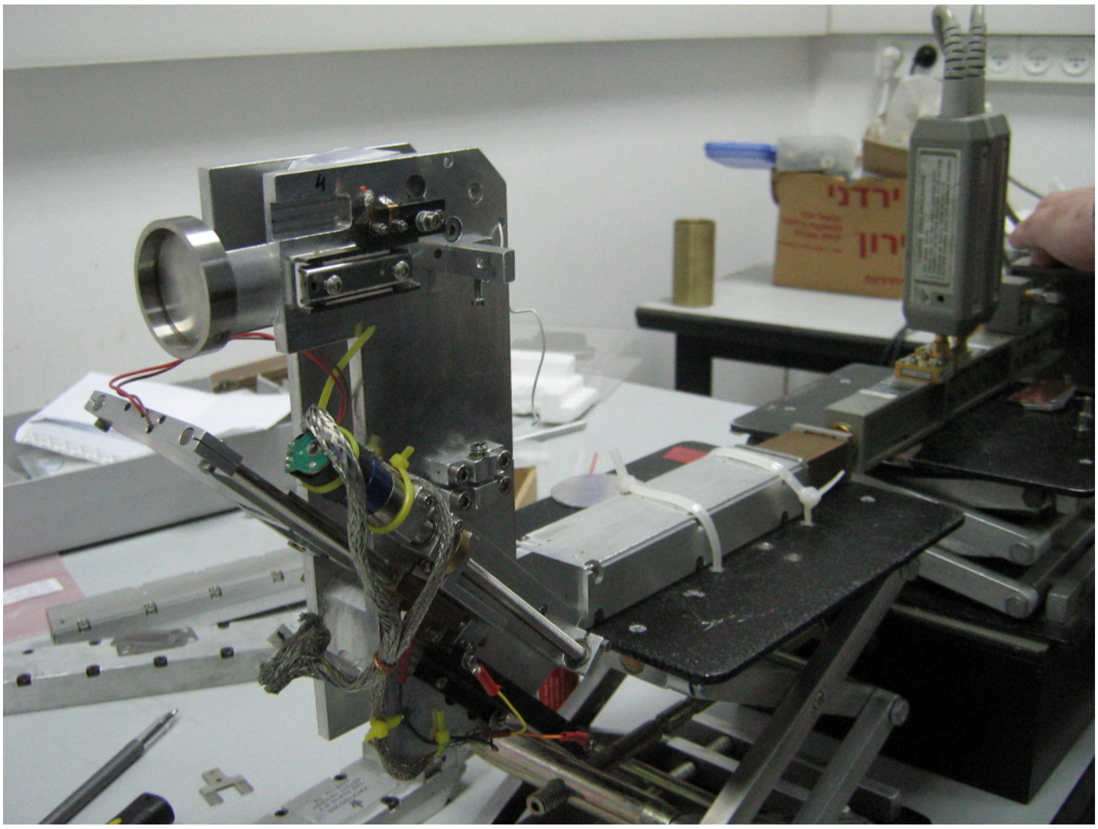


Figure 2: Picture of the setup used to produce the graph in figure 1.

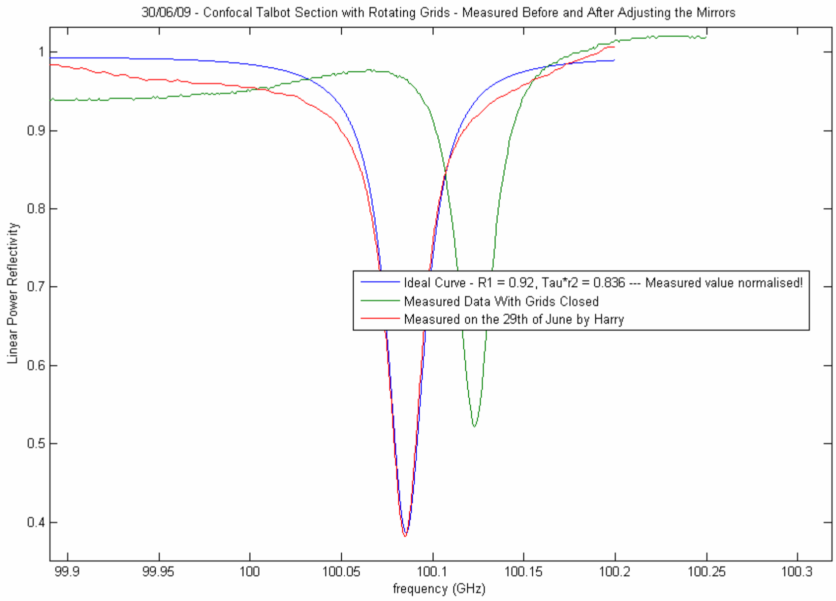


Figure 3: Theoretical and experimental curve of the confocal splitter alone with the mode exciter bolted with grid 610 with the rotating grids closed.

3. Measurements of the entire system

3.1. From Rotating Grid Side

With the rotating grids and straight Talbot reflector R_T in place $r_1 = \tau^* r_2 = 0.76$ => Roundtrip Reflectivity of whole system $0.76^2 = 0.5776$. This measurement was made at critical coupling (see fig. 3). Losses in the entire cavity are 1-0.5776 or 42.24%.

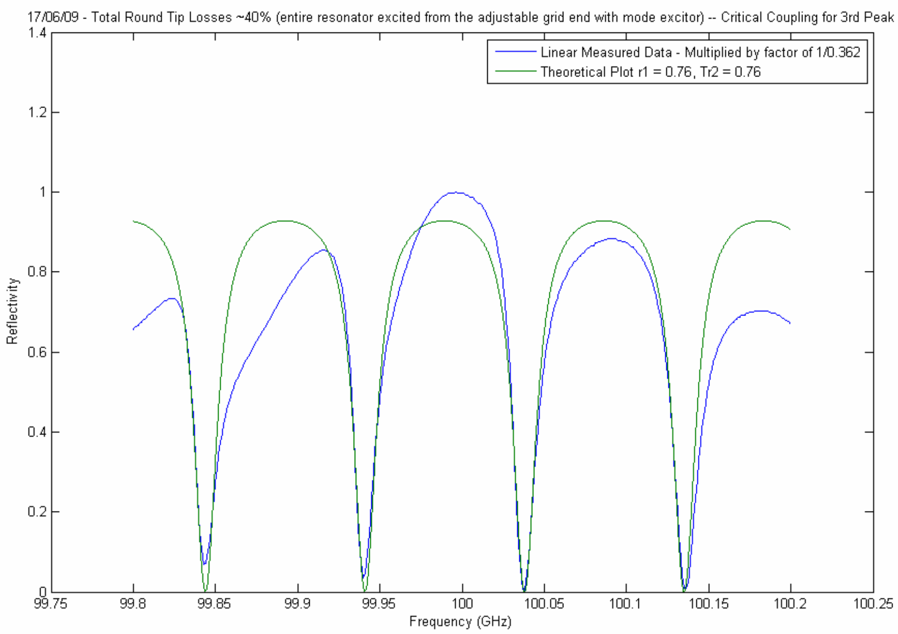


Figure 4: Third trough critically coupled used to determine internal losses of whole system.

3.2. From Entrance Side (Without Straight Talbot Section):

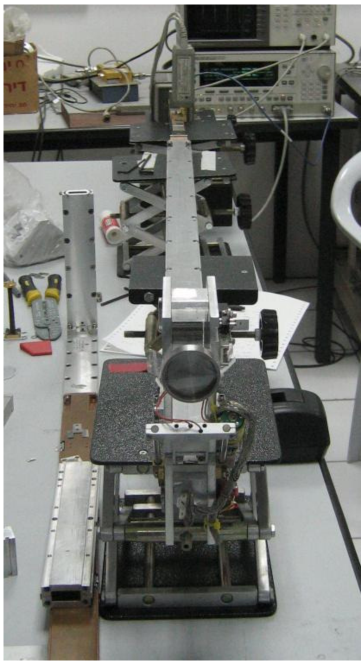
$R_{W+CT} = 0.85$ (1)

Including the reflectivity of straight Talbot section = 0.85*0.9858 = 0.8379

$0.8379^2 = 0.7021$

Therefore Total Losses = 1 – 0.7021 = 29.79%

Figure 5: Shown to the right the measurement of the whole system excluding the straight Talbot section and the rotating grids.



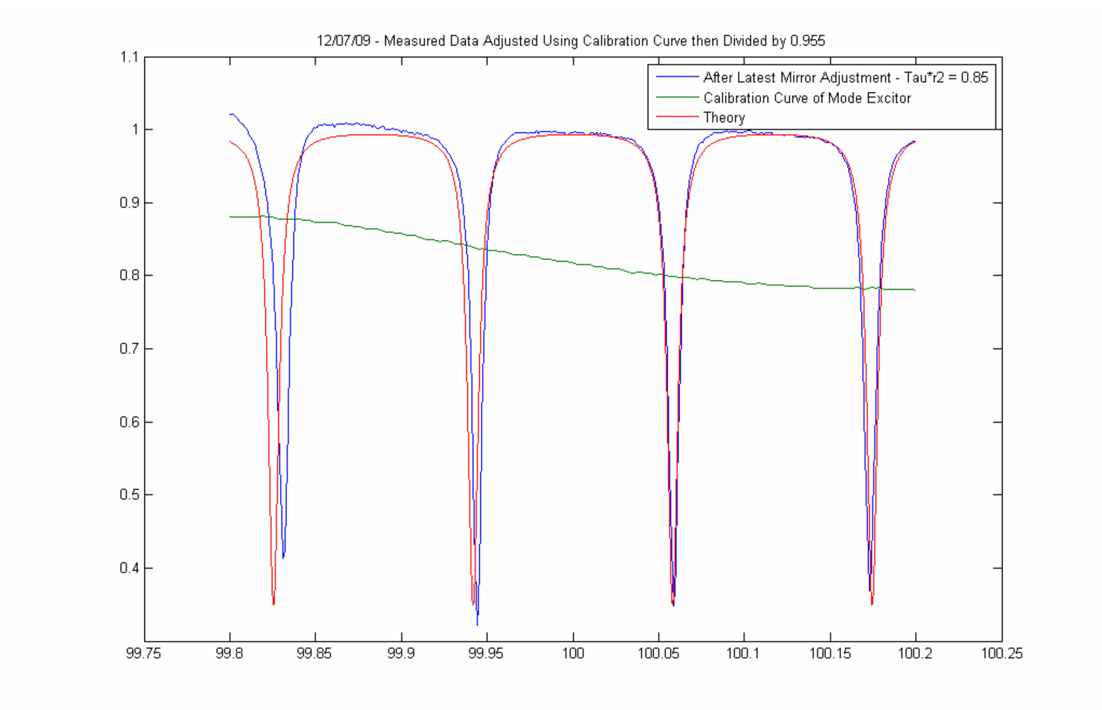


Figure 6: Whole system measured without the straight Talbot section, and also without the rotating grids, as shown in figure 5.

3.3. Measurement of the entire system with grids replaced

Attaching the mode exciter to the waveguide through the #610 grid with the rotating grids closed the roundtrip reflectivity was measured once more. This is shown below in figure 7.

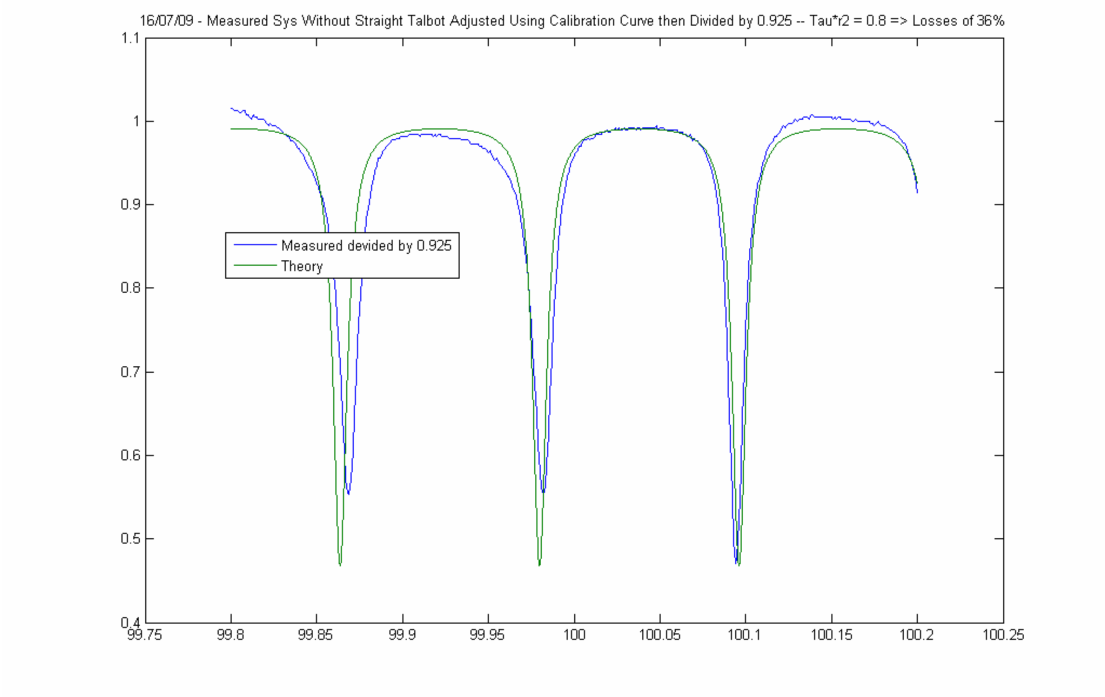


Figure 7, matching theoretical and measured plots of reflectivity with the rotating grids closed and the straight Talbot section removed.

We can see from figure 7 that the losses in the whole system excluding the straight Talbot section are 36%. Taking into account the straight Talbot we multiply the roundtrip reflectivity of 0.8 by 0.9858 (as in section 3.2 above), and subtract this from one, hence we find losses of 37.8%. Comparing this with section 3.2 by subtracting the two total losses we can see that the grids may be responsible for 37.8-29.79 = 8% of the losses.

4. Measuring the grids alone

To confirm that the rotating 3-grid system was indeed the source of losses in the system we made the following measurements. First we performed a calibration of the mode exciter (see figure 8a), then we pointed the mode exciter directly into the grid system with the grids closed (figure 8b) and measured the reflectivity, finally we inserted an Al disc into the cavity of the grid system such that the disc/short was in contact with the grids and the reflectivity was measured again (figure 8c shows the cavity without the disc, and 8d with the disc/short). The results of these measurements are shown in figure 9. In figure 9 we can see that the grids reflect at least 30% less radiation than the Al disc placed in front of the grids. This confirms the tendency shown in sections 2 and 3 that the rotating grids are a significant source of error.

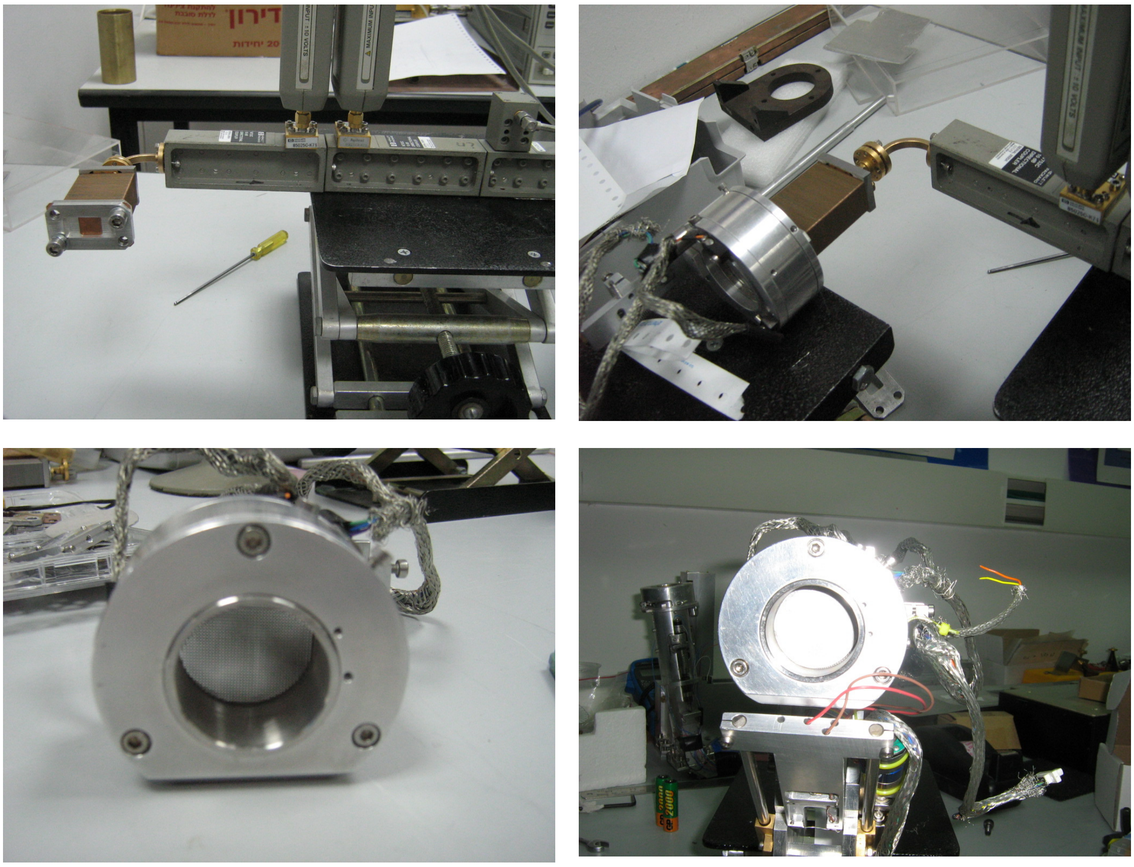


Figure 8: 8a calibration of the mode exciter (top left). 8b, measuring the reflectivity of the rotating grids in the closed position (top right). 8c, inside the cavity of the rotating grid system the wires of the adjustable grid can be seen (bottom left). 8d, a circular Al disc is placed in front of the grids in the cavity to form a short.

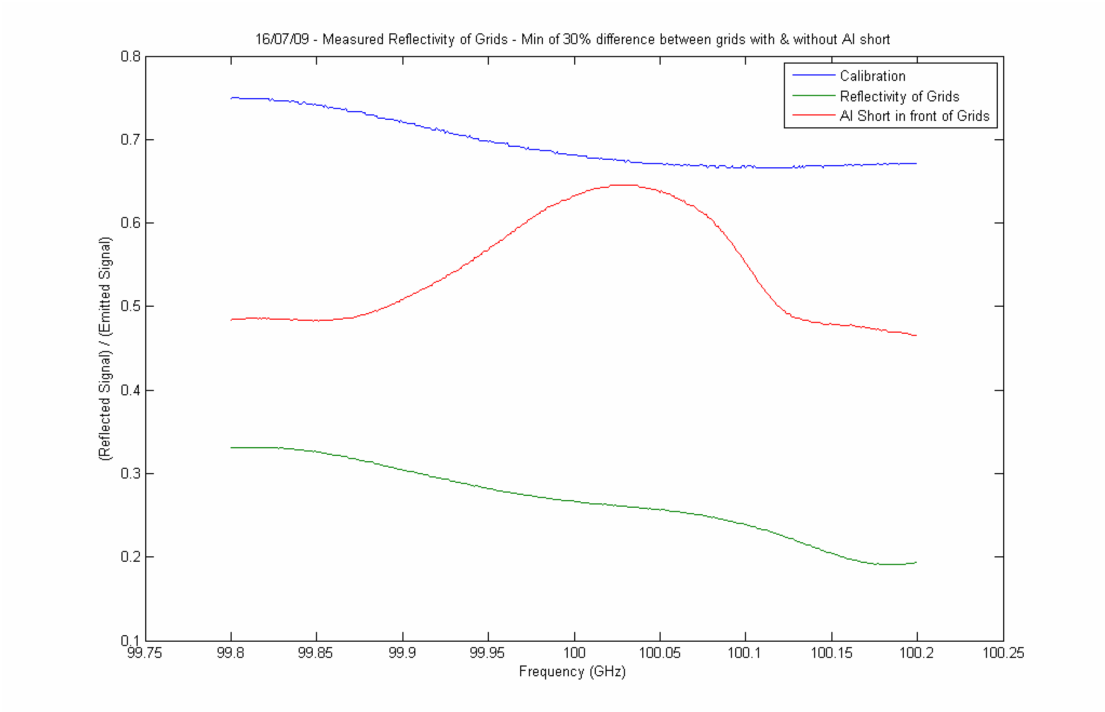


Figure 9: Top curve is the calibration curve of the mode exciter, the middle red curve is the reflectivity of an Al short placed in front of the rotating grids and the bottom green curve is the reflectivity of the 3 grids when closed.

5. Optical measurements and some notes on the mirrors

In contrast to the mirrors machined in Russia, those produced in the Weizmann institute have not been polished. This makes optical measurements difficult due to dispersion caused by the roughness of the surface.

The mirrors produced in Russia have continuous curvatures whilst the mirrors we will insert have a stepped or polygonal shape. However, to a rough approximation the polygonal structure does follow the equation describing the appropriate parabola. However, nobody has simulated how this deviation from the planned structure will affect the path length and hence phase of the waves.

Additionally the distance between the central points of both mirrors (through which they rotate) has been confirmed to be correct to an accuracy of ±1mm.

6. Conclusions

Estimates of the losses due to the rotating grid system range from 8-11%. This is larger than expected and is thought to be due to errors made in the construction of the system. Comparisons of the mirror systems (not presented in this report) show that the smooth continuous surfaces manufactured in Russia have fewer losses (diffraction) than our current polygonal mirror system. These two sources of losses are due to deviations between the specifications demanded by our theoretical calculations and that produced by the work-shop.

It has been decided that in order to rectify these problems without delaying the operation of the laser the offending items should be inserted into the system, whilst new parts are ordered so that the old parts may be replaced at a later date. Despite the losses of the poorly manufactured parts we expect that lasing should occur.

The remainder of the resonator components all function according to specification with relatively low losses.