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Procedure	**LIGO-T1200475**	**8/Oct/2012**

Use of Green Beam for IR QPD Path on Transmission Monitor Telescope

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1. Summary

Though TMS red QPD path is pre-aligned in the lab before installation in the chamber, this is done using irises and a retro reflecting mirror on the TMS ISC breadboard. In other words, the red path is never adjusted in the lab in relation to the TMS telescope optics nor ETM. Because of a short lever arm available on the ISC breadboard, this could easily lead to an error on the order of 10^-3 rad or more, which can make the red beam fall off of the QPDs. In the case of H1 TMSY, from the observation of the green beam reflected into the QPD path, it is apparent that the red beam will NOT hit the red QPDs.

Once the TMS is installed in the chamber and the ALS table is available, we need to inject a green beam into TMS, and use the beam retro reflected by the ETM to align the red QPD path. Even though the red telescope axis is slightly different from the green one due to dispersion and the wedge in the ETM and the ERM, the position error due to this will be about the same as the QPD diameter for one of the QPDs and smaller for the other, therefore it is reasonable to expect that we can find the red beam once the system is in vacuum and the red light resonates with the arm.

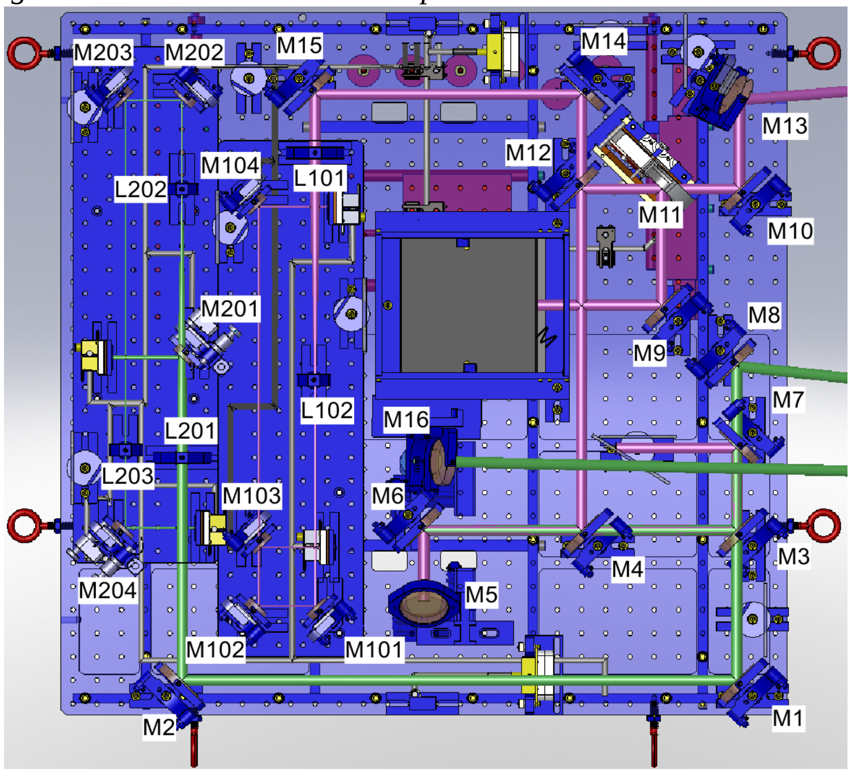
2. References

1. "ISC Transmon Assembly", D1000484-v9, https://dcc.ligo.org/cgi-bin/DocDB/ShowDocument?docid=9663&version=9

3. TMS ISC breadboard layout

Figure 1 shows the top view of the TMS ISC breadboard. In the figure, ETM is in the north. IFO beam comes from the north under the breadboard, is shot up and emerges from the hole under M5. Subsequently it is reflected by M6, M4, M12 and M15 before it reaches the red QPD sled. Between the furthest red QPD (which we call QPD2) and the HR coating of the ETM, the only four transmissive elements are the ETM substrate, ERM substrate and two lenses (L101 and L102).

Figure 1: TMS ISC breadboard top view.



4. Dispersion and wedge in ETM and ERM

Though the red and the green mode inside the arm should be reasonably colinear, when we propagate both of the modes into the TMS ISC table they diverge because of the wedge and the dispersion.

The refractive index of fused silica is about 1.4496 for 1064 nm light and 1.4607 for 532 nm.

The wedge specification of ETMs is 0.07+0.03-0.00 degrees vertical, thick side down. The worst case in real world is 0.08 degrees, as all of the manufactured ETMs were measured to be between 0.07 and 0.08 degrees. Red beam propagating toward the TMS from the ETM diverges from the green beam by about 15 micro radians due to this.

ERM wedge specification is 0.04+0.04-0.03 degrees horizontal, and H1 ERMY was measured to be 0.04 degrees. Red beam diverges from the green by about 7.7 micro radians due to this.

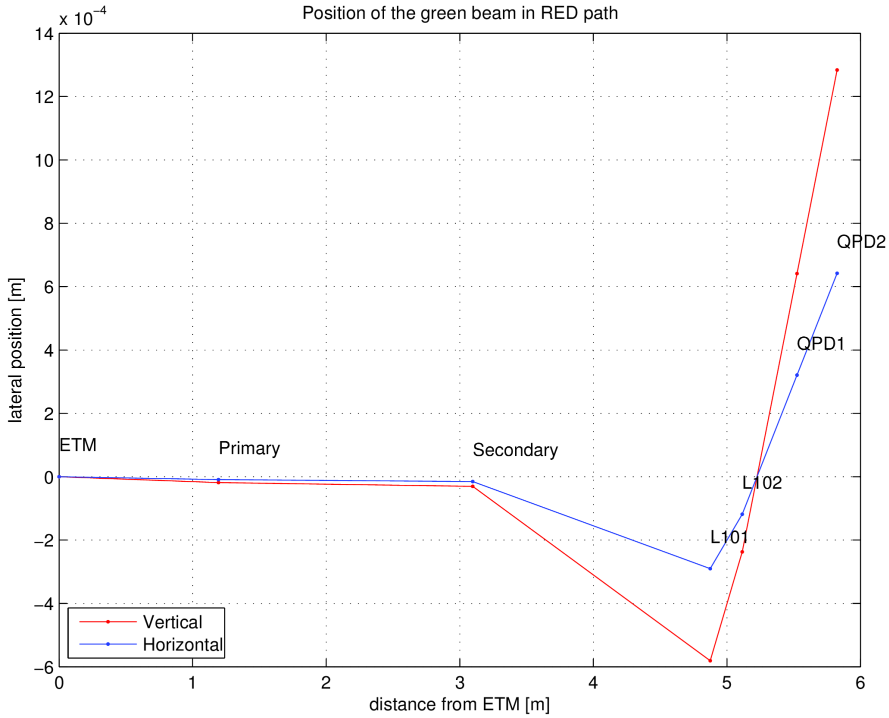


Figure 2: Propagation of the green beam in relation to the red. Note that the vertical flip caused by the periscope right after the secondary is not taken into account in this plot. For example, at the QPD2, the green beam is actually 1.3mm lower than the red beam.

Figure 2 shows the beam position of the green beam in relation to the red, in the red QPD path (see redpathAlignment.m in the same DCC number for details). In this calculation, the distance from the secondary mirror to the first lens could have a few centimeters error as it was roughly estimated from the drawings, not as-built pictures. Also the ERM was put in the same position as ETM. The dispersion in the lenses was not taken into account. These were quite negligible compared with the effect of the wedge in the ETM/ERM.

As you can see, at QPD2 the beam position of the green beam could be as large as 1.3 mm vertical and 0.6 mm horizontal (RMS of 1.4mm)

Note that the vertical dimension is flipped by the periscope (M5 and a mirror below the breadboard). The plot doesn't take this into account. The green beam is deflected down more by the ETM, which is correctly represented by the plot, but after the periscope (somewhere between the secondary and L101) the positive value means that the green beam is lower than the red beam.

5. Aligning red path using the green beam

The dichroic (M4) is known to reflect some green beam, and the red high reflectors like M14 and M15 are not entirely transparent to the green beam either. In the first installation of TMS, a green beam was observed on M15. The beam then hit one of the mirror/lens holders and didn't hit the QPDs. This means that the red path was not in a good shape as was, and that we're very likely able to use the green beam as the alignment marker for the red path.

We should be able to visually align the green beam on the lenses and QPDs. If the centering is perfect at this stage, one can expect that the red beam will hit the lenses somewhat low, and at QPD2 the red beam will be higher by 1.3 mm, and at QPD1 it will be 0.6 mm high. The red beam still hits both of the QPDs as the QPD diameter is 3mm, and we will be able to center the QPDs further by using picomotors on M4 and M14.