SCUBA-2 FTS Project Office
University of Lethbridge
Physics Department
4401 University Drive
Lethbridge, Alberta
CANADA
T1K 3M4

Tel: 1-403-329-2771
Fax: 1-403-329-2057
Email: brad.gom@uleth.ca
WWW: http://research.uleth.ca/scuba2/

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Document Prepared By:	B. G. Gom FTS Project Manager	Signature and Date:	03/11/08
Document Approved By:	D. A. Naylor FTS Project Lead	Signature and Date:	03/11/08
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Change Record

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0.1	7/11/06	All	CDR draft
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0.3	3/11/08	All	Update to reflect new CMM alignment strategy

Contents

Introduction

"Good, fast and cheap – pick any two." *Anon*

Aligning FTS-2 poses several challenges. There are 18 mirrors, of which 10 are plane and 8 have complex polynomial surfaces, and two beamsplitters. The input focal surface is curved and the FTS-2 must return this far from ideal beam to the SCUBA-2 feed optics with as little distortion as possible. Optical modelling has shown that positioning (decentre and defocus) to the level ±0.5 mm is required for the internal optical components; angular alignment of the components themselves to ±0.1° is required. High precision optical mounts, with orthogonal adjusters will be used throughout to minimize cross-talk between adjustments of the various optical components.

Based on extensive experience using FTS at the JCMT, the team has developed many useful mechanical and optical alignment tools to assist in the rapid alignment of several previous FTS (containing up to 11 mirrors and two beamsplitters) to the JCMT. In the early years the alignment process often took two nights, but over time this was reduced to much less than an hour. This experience will be vital in solving the challenges in aligning FTS-2.

FTS-2 will be assembled, integrated and its performance verified in a laboratory that has been dedicated for this purpose. The anticipated alignment procedures are summarized below, but are subject to change as we iterate the alignment process during the AIV campaign.

1. Alignment tools

The following is an initial list of alignment tools will be used in the integration phase. Other tools will be added as required:

- Mechanical: Precision spirit level, precision height gauge, portable CMM, bars of calibrated length and metal reference brackets.
- Optical: Patterned LED image generator, viewing screen, photomixer source, pyroelectric detector.

2. Framework Alignment

As in all optical systems, carefully establishing the reference frame for the optical system simplifies the alignment process. The top surface of the reseach grade optical breadboard serves as the primary reference plane. Two reference posts of fixed height will be mounted to the breadboard, so that they do not interfere with the optical beam, and serve as primary fiducial references for locating the brackets that hold the fixed mirrors of the interferometer; their precise location is arbitrary so long as they are both within the reach of the CMM arm without relocating the CMM, and that the distance between all optics datums is within the CMM reach from at least one reference.

The optical breadboard is first made level by adjustment of its height micro-locks while viewing a spirit level located at the centre of the breadboard. Flatness of the breadboard surface will be confirmed by CMM measurement and precision straight-edge. Manufacturing specifications for the breadboard give a flatness of 0.1 mm.

The moving mirror translation stage axis defines the horizontal axis of the interferometer (perpendicular to the elevation bearing axis). Once the stage is loosely mounted on the breadboard, the stage axis is aligned parallel with the long edge of the breadboard (and centered on the short edge) by measuring the position of the platform at both extremes of its motion. One the stage is aligned, locating blocks are fastened to the breadboard so that the stage can be removed and replaced later without requiring re-alignment.

After alignment of the stage, the moving mirror assembly is mounted to the platform. A dowel pin hole is provided at each end of the moving mirror assembly which together define the axis of the assembly. The assembly axis is aligned to the stage axis by measurements with the CMM. The tolerance on this alignment is low, since the corner-cube retroreflectors compensate for any tip\tilt in the orientation, provided that there is not enough shear to cause spillover on the mirrors. Once the assembly is aligned, the adjustable locating bushings are tightened down so that the assembly can be removed and replaced in future without requiring re-alignment.

The plane of the beamsplitters defines the second reference plane of the FTS, perpendicular to the breadboard reference plane and parallel (collinear) with the telescope elevation bearing axis. The beamsplitter plane represents the zero-path-difference (ZPD) location of the center of the moving mirror assembly, and is centered along the long edge of the breadboard (975 mm from either end). The support structure for the beamsplitters is mounted to the breadboard and aligned to the proper location using the CMM relative to the breadboard surface and the moving mirror axis. Three adjustment screws are provided for each beamsplitter to locate the beamsplitters at the required coordinates within the tolerances specified in the optical model (+/- 0.5 mm, +/- 0.1°). Alignment beamsplitters should be used for the initial alignment, and replaced with the actual beamsplitters after the full FTS is assembled and aligned to prevent accidental damage. Once the alignment is complete, locating blocks are fastened to the breadboard to allow the beamsplitter mount framework to be removed and replaced without requiring re-alignment.

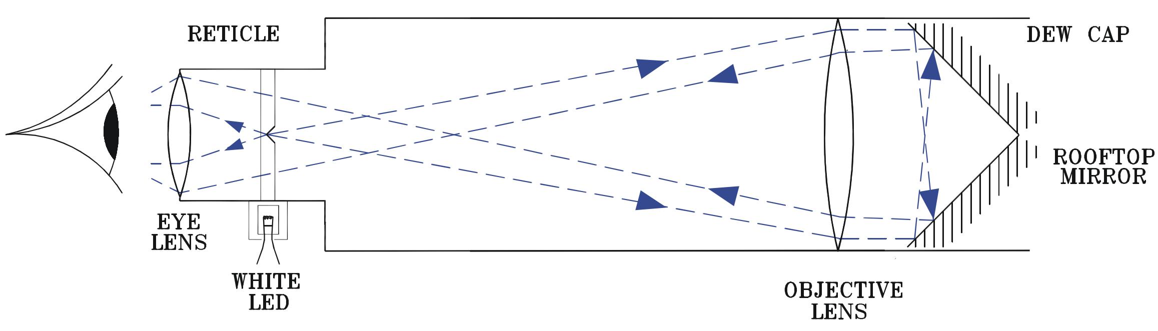
The two towers holding the fixed mirrors of the interferometer can now be bolted to the optical breadboard. These assemblies are located using the CMM to confirm the location of each mirror mount relative to the CAD model. Tolerances at the mirror locations are +/- 1 mm since there is sufficient adjustability in the optical mounts. Locating blocks are bolted to the breadboard along the tower edges to aid re-assembly.

The pickoff mirror unit translation stage is suspended by a set of rails supported by the two optics towers. The rails are aligned mechanically and then the pickoff translation stage is mounted. Final alignment of the translation stage is done after the pickoff mirror assembly has been mounted, since measurements of the pickoff mirrors is required. Since the translation stage may be used for alignment of the pickoff mirror unit in the horizontal direction over a small range (~10 mm), the alignment of the pickoff translation stage axis must be parallel with the breadboard surface and perpendicular to the telescope elevation bearing axis, with a tolerance which ensures the pickoff mirror assembly is located with a tolerance of +/- 0.5mm over the adjustment range. The tolerance on the vertical position of the translation stage is +/- 0.5mm, and is adjusted using shims. The tolerance on the stage location along the elevation bearing axis is +/- 0.5mm. The location of the stage along the horizontal axis perpendicular to the bearing is not critical; the desired in-beam location of the pickoff mirrors is adjusted using the stage travel, and this travel offset from the home position is stored for use in the control software setup sequence.

3. Optical Alignment

Alignment using lasers is not practical due to the surface finish and aspherical curvature of the FTS mirrors. Since the alignment tolerances on all the FTS optics (+/- 0.5 mm XYZ and +/- 0.1°) is relatively large, a portable CMM with ~0.05 mm resolution can be used to locate all the optics via direct measurement relative to a fixed datum on the breadboard. All powered mirrors have conical locating divots in the corners which have a known relationship to the mirror surfaces, which will serve as measurement points for the CMM. All powered mirrors in the FTS have adjustment in 6 degrees of freedom, and the adjustment should in principle be maintained after removal and reinstallation of the optics. There is no required alignment sequence for the powered mirrors.

The back-to-back corner cube mirrors, consisting of 6 plane mirror segments, will be assembled and aligned independently of FTS-2. Each roof-top pair will be first aligned, to an accuracy of ~2”, using an auto-collimation technique that was developed for use with an earlier FTS (Naylor and Schultz, in Optics and Photonics News, Engineering and Laboratory Notes, **11** (2000)). The figure below illustrates how the reicule image projected by the telescope is retroreflected by a rooftop mirror, which is perfectly aligned when the reflected image is coincident with the actual reticule.



Since the shear require by the corner cubes in the FTS-2 design is larger than the practical exit aperture of the existing alignment telescope, either a larger aperture telescope (~10 inch) must be used, or a large dual-surface plane mirror must be used. In this scheme, the reference plane mirror is aligned to be perfectly perpendicualr to the telescope axis, and then the corner cube assembly is aligned so that the reflected images from both sides of the reference plane mirror are coincident (see below). The resulting accuracy of the FTS-

2 corner cube is expected to be <10”, which is well within the tolerance from the optical model.

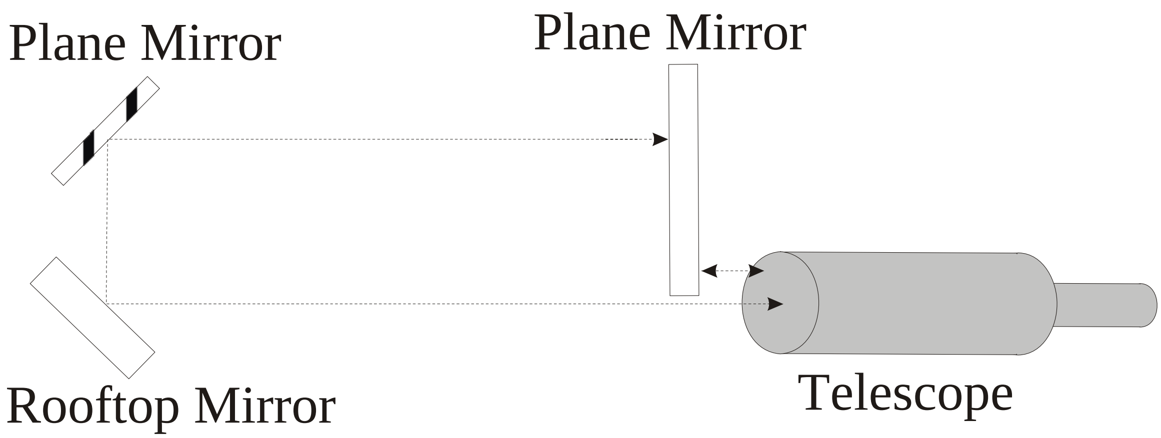


Fig.2 Auto-collimation of corner cube assembly using reference plane mirror. The telescope is aligned perpendicular to the reference plane mirror, and then the reflected sheared beam from the corner cube is aligned with itself by adjusting the corner cube mirrors.

4. Interferometric alignment

Mechanical alignment of the interferometer mirrors using a CMM should be sufficient to optimize the alignment of the interferometer, however, it may also be possible to use visible wavelength techniques to verify the alignment if the reflectivity of the powered mirrors is good enough.

The inherently high degree of symmetry in the FTS-2 design will be exploited during its interferometric alignment. We propose to construct an LED alignment tool consisting of ten bright LEDs mounted in a two identical cross patterns (of 5 LEDs), shown in figure 3, each representing the centre and extremes of the field points of the JCMT viewed by FTS-2. These LEDs will be mounted in a curved block to match the curved focal surface provided by the JCMT as the beam exits the elevation bearing. The LED alignment tool and viewing screen will then allow the location, and symmetry, of the intermediate images to be measured and at this point the input beamsplitter will be aligned by viewing the overlap of the fields at the pupil image plane located at ZPD. A semi-silvered Mylar beamsplitter will be manufactured for this purpose. With the back-to-back corner cube module removed, the symmetry of the design with the pupil image located at ZPD will provide an auto-collimation mode in which light from each input returns to both inputs and any alignment errors quickly become evident.

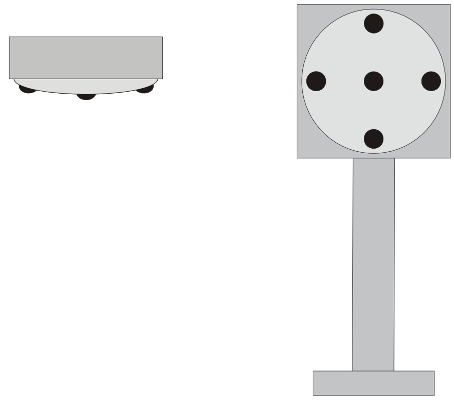


Fig.3 Schematic of LED alignment tool. Top view (left), side view (right)

With the alignment of the first half of FTS-2 confirmed, the back-to-back corner cube module will be installed and the alignement of the second half of the interferometer can be checked in an identical fashion. The final image, located before the return pickoff mirror, is readily accessible and its location and orientation can be measured and compared with its expected value.

5. Alignment with JCMT beam

A mechanical stop will be bolted to the N1 support frame to locate the corner of FTS-2 nearest the telescope and the membrane. With the FTS-2 hoisted into place the pickoff mirrors will be retracted from the beam and the JCMT optical laser alignment tool will be positioned to direct its collinear horizontal exiting beams through two alignment plates attached to each side of the vertical frame of the FTS-2 facing the JCMT bearing and mirror N1, respectively (Fig 4). The optical breadboard will be levelled (by adjustment of the microlocks located within the breadboard) so that the beam exiting in the direction of the telescope intersects cross hairs made of thin wire mounted on the end of the bearing tube. Minor adjustments of the FTS-2 breadboard, accomplished by nudging bolts attached to the mechanical stop, will be made as require while the FTS is still suspended by the crane to ensure that the beam exiting the outgoing alignment plate of the FTS strikes N1 on the latter's optical axis. In this step we assume that there exists an alignment mark indicating the point where the optical axis meets the surface of N1

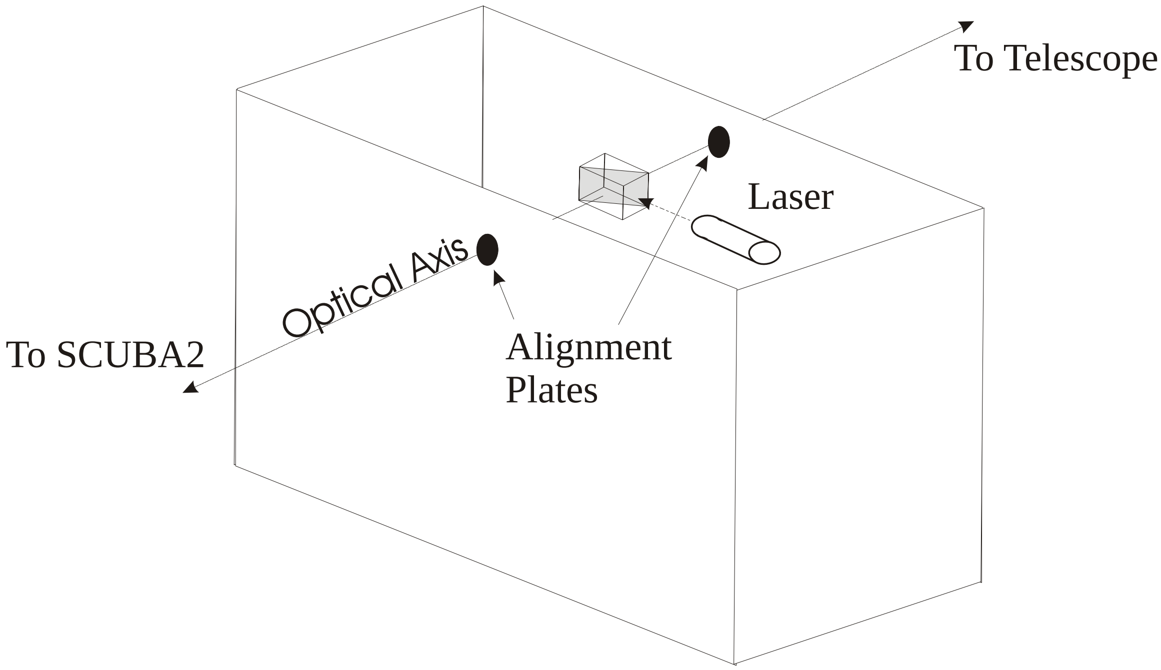


Fig.4 Alignment of FTS-2 to JCMT and SCUBA-2

6. Infrared alignment to the JCMT Scuba-2 optics

An infrared alignment tool consisting of a cross hatched pattern of heated wires that are mounted to a dielectric curved surface which again represents the curved focal surface provided by the JCMT as the beam exits the elevation bearing, will be used to validate the final focus of FTS-2 as seen by SCUBA-2. This step will be used primarily as an end to end test of light incident on FTS-2 being detected by SCUBA-2. It will be to evaluate image quality through the FTS-2, as it will highlight any distortions. Moreover, it will provide a useful interferogram signal that can be used to test the processing software. The final optimization of FTS-2 image will involve astronomical point sources.