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## Contents

# Introduction

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

Aligning and validating the performance 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 show that alignment to the level ±0.2 mm is required on the placement of optical components; angular alignment of the components themselves to ±0.5° is required. High precision optical mounts, with orthogonal adjusters, to minimize cross-talk between adjustments of the various optical components, will be used throughout.

Based on extensive experience using FTS at the JCMT the team has developed many powerful 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 alignment process often took two nights, but over time this was reduced to much less than an hour. This experience will be vital in the challenges posed by FTS-2.

FTS-2 will be assembled, integrated and its performance verified in a laboratory that has been dedicated for this purpose.

# 1. Alignment tools

The following alignment tools will be used in the integration phase:

- Mechanical: Bubble level, precision height gauge, metal reference brackets
- Optical: Laser/penta-prism/corner-cube 3-D orthogonal axes generator, auto-collimating telescope system, patterned LED image generator, viewing screen, infrared source, gas cell.

# 2. Internal Alignment

As in all optical systems, carefully establishing the reference frame for the optical system simplifies the alignment process. One corner of the research grade damped breadboard will form the alignment reference frame. A mechanical alignment aid consisting of a precision height gauge and metal guides reference the coordinates of the horizontal plane with respect to one corner of FTS-2.

The optical breadboard is first made level by adjustment of its height micro-locks while viewing a bubble level located at the centre of the breadboard (the position of ZPD within the interferometer). An laser alignment tool (Fig 1) consisting of a diode laser, penta-prism, cube beamsplitter and reflecting corner cube will, after auto-collimation from a plane parallel mirror placed face-up at the position previously occupied by the bubble level (a small bath of mercury could also be used to establish the local vertical, but we believe that the bubble level will be of sufficient accuracy, ~10”, and is less of a hazard), be used to establish the orthogonal axes of FTS-2.

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 (Ref Naylor optics notes). The same technique will be applied to the alignment of the full corner cubes. Since the shear require by the corner cubes in the FTS-2 design is larger than the practical exit aperture of the alignment telescope, a precision corner cube reflector (PLX Inc) will be used to aid this process. The resulting accuracy of the FTS-2 corner cube is expected to be <10”.

The other mirrors of FTS-2 will be initially positioned by dead-reckoning using the mechanical alignment aid described above and shown schematically in Fig 2. To aid this process, a small divot will be left in the surface of each of the complex mirrors denoting the point at which the optical axis strikes the surface. Together with the alignment tool this will allow locating of the mirrors to an accuracy of ~0.1 mm.

The inherently high degree of symmetry in the FTS-2 design will be exploited during its alignment. An LED alignment tool consisting of ten bright LEDs mounted in a two identical cross patterns (of 5 LEDs), each representing the centre and extremes of the field points of the JCMT viewed by FTS-2, will be placed at the entrance to FTS-2 (Fig 3). 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 used in this process. With the back-to-back corner cube module removed, the symmetry of the design, with the pupil image located at ZPD, will provide an autocollimation mode in which light from each input returns to both inputs and any alignment errors quickly become evident. Identifying the responsible culprit will use standard optical methods such as the knife edge test to locate the intermediate foci.

With the first half of FTS-2 aligned the back-to-back corner cube module will be installed and the second half of the interferometer aligned 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 using the knife edge test.

# 3. 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 removed from the beam and the optical laser alignment tool (Fig 1) 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. 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 to ensure that the beam exiting the outgoing alignment plate of the FTS strikes N1 on the latter's optical axis.

# 4. 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 representing 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 to evaluate image quality through the FTS-2, as it will highlight any distortion (barrel/pincushion). Moreover, it will provide a useful interferogram signal that can be used to test the processing software.