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Document Title:	**FTS-2 Test Plan**
Document Number:	**SC2/FTS/TST/002**
Issue:	**Version 1.0**
Date:	**7 November 2006**

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Change Record

Issue	Date	Section(s) Affected	Description of Change / Change Request Reference / Remarks
1.0	7/11/06	All	CDR version

Contents

Introduction

This document presents the SCUBA-2 Fourier Transform Spectrometer (FTS-2) Test Plan, which describes the test procedures designed to ensure that the FTS-2 development process meets all of the requirements set out in the FTS-2 Functional and Performance Requirements document (SC2/FTS/SRE/001). This document will be updated during the final design and integration phases.

The table below summarizes the various test activities, their owners and reviewers.

Test	Gating	Owner	Reviewers	Status
Prototype				
Optical mounts	Load handling and alignment tests	U of L	U of L	Done
Translation stage	Calibration, PID tuning	U of L	U of L	Done
Pickoff mirror unit	Positional accuracy	U of L	U of L	Preliminary
Mirror actuators	Positional accuracy	U of L	U of L	Done
DR engine	Processing speed	U of L	U of L, JAC	Done
RTS Client SW	Communication tests	U of L	U of L, JAC	Done
Production				
Beamsplitters	Optical performance tests	Cardiff	U of L	
Framework	Load handling, dimensions, mass	U of L	JAC	
Optical alignment	Laser alignment tests, single pixel focus tests.	U of L	U of L	
Component functionality	Translation stage, pickoff mirror assembly, optical mount, functional tests	U of L	U of L, JAC	
DR software	FTS engine testing in main DR pipeline	U of L	JAC	
Control SW	OCS / RTS interface tests	U of L	JAC	
System performance	Single pixel detector optical tests	U of L	U of L, JAC	
Commissioning				
Functionality	FTS-2 subsystem functional tests	U of L	U of L, JAC	
Performance	Sensitivity tests	U of L	U of L, JAC	
Calibration	Spectral calibration tests	U of L	U of L, JAC	
Alignment	Alignment and imaging tests	U of L	U of L, JAC	
Operation				
Calibration	Periodic instrument calibration tests	JCMT	JAC	
Diagnostics	Monitoring of diagnostic parameter logs	JCMT	JAC	

1. Prototype Tests

As many aspects as possible of the FTS-2 design were prototyped and tested prior to the CDR, as described below.

1.1. Optical Mounts

Custom optical mounts based on a spherical bearing will be used for all the large FTS-2 internal optics. Prototypes were constructed and tested successfully as described in SC2/FTS/MEC/002. Motorized actuators were also tested as part of this process; however, revision of the pickoff mirror unit design has led to the selection of smaller, piezo-based actuators. These actuators have higher resolution than the prototype units, and should not affect the performance.

1.2. Translation stage

The operation of the Aerotech translation stage has been tested using the provided Aerotech software. Final tuning of the PID parameters requires that the mass of the corner cube assemblies be known, and will therefore take place during the FTS integration phase. Testing will involve recording the stage position jitter for the range of operating speeds and accelerations suitable for the designed observing modes.

Previous experience with these translation stages has shown that the metrology is extremely reliable, and is not likely to affect the system performance.

1.3. Pickoff mirror unit

The pickoff mirror unit was redesigned shortly before the CDR and there was not time to prototype it. The unit consists of 4 spherical bearing mirror mounts bolted together, suspended from a translation mechanism. While the mirror mounts are expected to behave like the prototype mount, a sample actuator will be acquired to confirm the load capabilities and resolution. The translation system will consist of two precision rails which support a carriage suspending the pickoff mirror assembly, driven by a precision lead screw. Prototyping of the translation system is not deemed necessary. Repeatability of the pickoff mirror positioning will be driven by the lead screw parameters, and is expected to be easily within the optical tolerances. Testing during the integration phase will confirm that the positional accuracy and repeatability is within tolerances (< 0.2 mm).

1.4. Mirror actuators

Zaber Technologies actuators were fully tested during the mirror mount prototyping, and were shown to have acceptable backlash levels. New Focus Picomotor model 8301 piezo actuators have since been selected for the pickoff mirror actuators due to their more compact size. Specifications for these units indicate that nearly arc second resolution should be achievable. The incremental motion provided by these actuators is smaller than the tested Zaber units, but more importantly, the design of the piezo actuators ensures that they do not move when power is removed or applied, and will therefore not need to be indexed during each power up of the FTS-2 instrument.

1.5. DR engine

All modules of the FTS-2 processing engine have been successfully tested by the U of L for functionality, accuracy, and speed. Optimization of the phase correction and deglitching algorithms is continuing, and this code will be tested with simulated data and data from the SPIRE instrument tests. Results of the processing benchmarks are provided in the FTS-2 DR Engine document (SC2/FTS/SOF/001).

1.6. RTS Client SW

The FTS-2 RTS client PC and interface card have not yet been purchased, and the RTAI implementation of the RTS client interface software is not yet available from the JAC. However, the FTS-2 RTS client software has been prototyped and tested by the U of L in order to test the communication links with the FTS motion controller. Performance of the communication system is satisfactory. Final testing of the RTS system can proceed when the interface software is available, but is not expected to reveal any issues with the FTS hardware communication.

2. Production Phase Tests

Most aspects of the FTS-2 instrument can only be tested in the actual production phase since prototyping is either too costly or not possible.

2.1. Beamsplitters

Beamsplitters of the required size and composition have been produced by the Cardiff labs, although testing of the actual FTS-2 units will be required to confirm the performance before FTS-2 is delivered. Testing will consist of FTS measurements of the beamsplitter efficiency across the SCUBA-2 spectral windows in the Cardiff labs. The tolerance for the R/T efficiency and phase characteristics is TBD.

2.2. Framework

The framework provides support for all the system components above the breadboard level, but more importantly, provides registration for the optics positions. Careful measurements of the manufactured framework components and the final assembled system will be required to ensure the mirror locations will be within the optical design tolerances.

2.3. Optical alignment

Alignment of the FTS-2 internal optics will be performed during the integration phase according to the FTS-2 Optical Alignment document (SC2/FTS/OPT/005). Some testing of the optical alignment will be testable without an imaging array, but full verification of the alignment will only be possible when the system is integrated with SCUBA-2.

2.4. Component functionality

There are three motorized components in the FTS-2: the pick-off mirror drive unit, the ambient blackbody calibration units and the interferometer translation stage.

The positional accuracy of the pick-off mirror translation stage assembly will be measured by repeated (at least 50 cycles) insertion and retraction of the mirrors against a dial gauge mounted to the breadboard. Positional errors must not exceed 50 μm.

The operation of the ambient blackbody calibration unit will be verified by repeated (at least 50 cycles) insertion and retraction of the unit in front of each input port. Since the function of the calibration unit is to provide a constant flux to FTS-2 the positioning of the unit is not critical. Positional errors must not exceed 5 mm.

The positional accuracy of the interferometer translation stage will be measured by repeated motion control sequences with reference to a dial gauge mounted to the breadboard. Cumulative positional errors must not exceed 1 μm after 1000 motion command sequences.

2.5. DR software

A suite of test software has been developed to test the DR pipeline modules using simulated data. The final form of the DR test routines requires input from the JAC.

Simulating Data Files

The program, test_drpipeline/MakeNDF.java, is used to make a NDF data file compliant with the SCUBA-2 data file format. By default, the output data file consists of an interferogram with three spectrum bands. This program has some adjustable parameters, such as the noise intensity, the sampling jitter, the position and the intensity of a glitch, etc. The program is called as follows:

```
java -cp .:${CLASSPATH} MakeNDF output_datafile
```

Testing Individual DR Modules

The performance of the DR pipeline engine can be tested using diagnostic software developed by the U of L. The software can be called either by direct Java calls (TestDRPipeline and TestSpectrum), or by using a pre-built GUI. The TestDRPipeline Java method reduces an input interferogram cube (real data or data generated by MakeNDF) into a fully reduced spectral cube. The TestSpectrum method extracts each individual spectrum from the cube into a subdirectory for analysis using standard spectral display routines.

The GUI based test package (named TestDRTunup.java) displays diagnostic plots of the interferogram, spectrum, phase fitting result and Phase Correction Function, which allows the performance of the data reduction to be readily assessed. The usage of the software is described in the document, FTS-2 Tune-up Tool (SC2/FTS/SOF/007).

Testing Drama Pipeline Interface

A Java program (TestDramaServer.java) and a Drama program (ditscmd) are used to test the Drama interface between the FTS-2 data reduction engine and the SCUBA-2 pipeline. TestDramaServer uses Java class Drama2FTS to start a data reduction Drama task ‘Drama2FTS’:

```
java -Xmx350M -cp .:${CLASSPATH} TestDramaServer
```

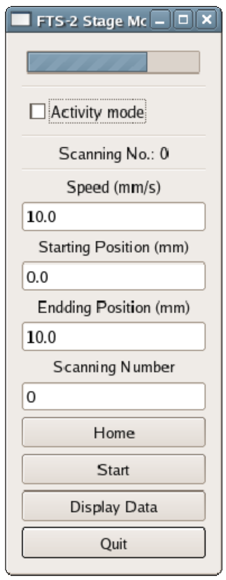
The file, test_drama/DramaClient.txt, lists some examples to demonstrate how to use ditscmd to call the three actions of the above Drama2FTS server.

2.6. Control SW

The FTS-2 control software will be tested with all the FTS-2 subsystems in order to identify potential communication problems and failure modes.

Stage Control

A C/GTK+ program, TestSoloist.c, has been written and used to test the stage motion and the MOD-Bus communication between the control PC and the Soloist box. The program accepts the scanning speed, scanning distance, and number of scans as inputs. A graphical display shows the current position of the stage, and a plot of the recorded stage positions can be generated using GnuPlot. An external interrupt signal is used to trigger the position sampling of the stage at regular intervals.



OCS Interface

- An 'Initialize' action is provided in the FTS-2 software to call the FTS-2 self-test procedure which exercises the internal mechanists and confirms normal communication and operation.
- A 'Report' action is provided to obtain the current status of the FTS-2 OCS status flags.

Details of the system monitoring parameters are still TBD.

RTS Interface

Since the RTS Drama Client separates FTS-2 from the RTS, no FTS-2-specific test is necessary.

PO Mirror Control

The actuators selected for the PO mirrors use Ethernet based controllers. Software will be developed to test the communication and operation of the mirror actuators once the controllers have been purchased, and will be integrated into the FTS-2 control software suite.

2.7. System performance

The alignment of FTS-2 will be challenging, however, the alignment procedures (see SC2/FTS/OPT/005) and their refinement can readily be tested in our laboratories at Lethbridge. While we do not have access to an imaging detector array, we do have several single pixel bolometers that, with some auxiliary optics (to re-image the FTS-2 focus onto our detector), will be used to measure the interferometric performance of FTS-2.

A short path cell containing HCl gas at low pressure provides a simple means of verifying the spectroscopic performance of FTS-2. The cell (length 22 cm) will be filled with HCl at a pressure of 5 Torr. The cell will be placed, in turn, between each output pickoff mirror of FTS-2 and immediately before an off-axis parabolic mirror which will re-image the field centre beam onto the single pixel L^3He cooled detector. The far-infrared pure rotational spectrum of HCl consists of doublets located at 20.87783 and 20.84657 cm^{-1} (separation of 0.03126 cm^{-1}), and at 41.74434 cm^{-1} and 41.68157 cm^{-1} (separation of 0.06277 cm^{-1}). This separation is ideally suited to validating the spectral performance of FTS-2 both in absolute wavelength scale and resolution.

Figure 1 shows modeled spectra for the HCl doublets to be measured during FTS-2 verification testing. Spectra are shown for various pressures of HCl gas in the cell (see color legend on figure). The other absorption features are due to the atmosphere in the remainder of the optical path. The model spectra include the sinc ILS of the FTS. These spectra are used to select the pressure of the HCl gas for the FTS verification observations.

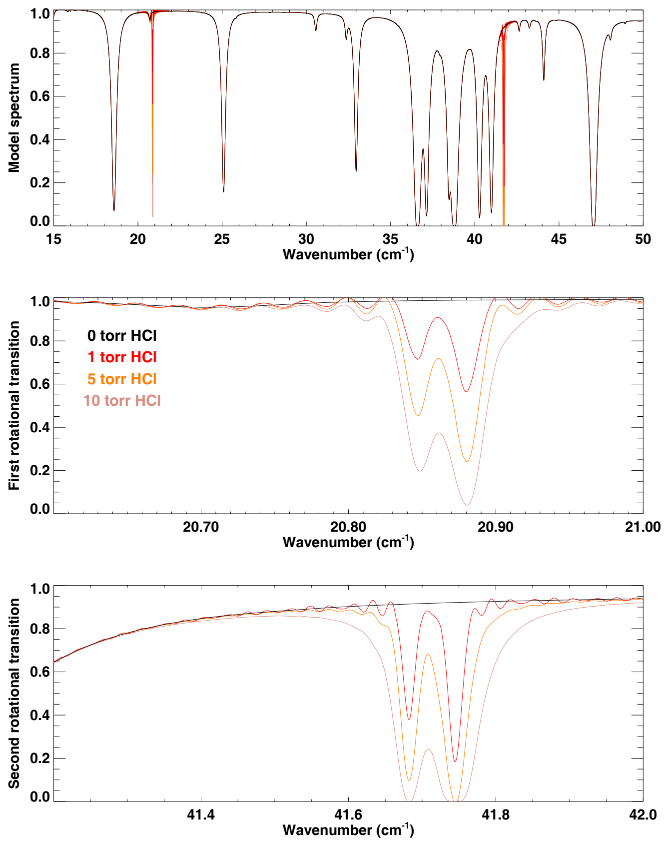


Figure 1. Theoretical pure rotational spetrum of HCl.

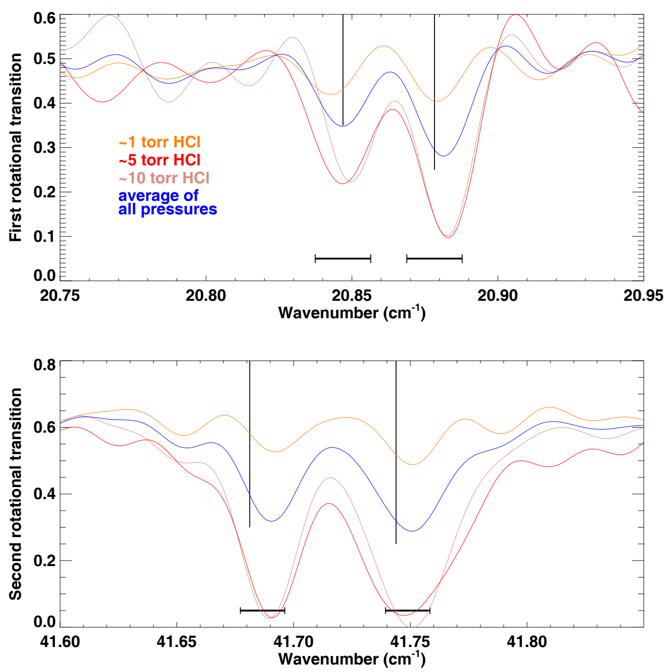


Figure 2. Observed HCl spectra in our laboratory with a ^{4}He bolometer and FTS system.

Figure 2 shows measured spectra of HCl doublet pairs measure in our laboratory using a less sensitive detector and lower resolution FTS. The horizontal bars indicate the frequency uncertainty; the vertical bars are the predicted line centres.

While the above results were obtained with an un-pumped L^4He cooled detector, for the verification of the FTS-2 spectral resolution FTS-2 we will use a L^3He cooled detector that will be two orders of magnitude more sensitive. Analysis of the resulting data by non-linear least squares fitting will yield the line centres for each pair of doublets, and hence their separation. Furthermore, the common instrument line shape profile will be extracted and used to verify the resolving power of FTS-2.

3. Unpacking test plan

- This section will be updated prior to the ARR.

FTS-2 components will be shipped in a sturdy, custom-made crate with protective foam padding. The crate should be handled with care adequate for a sensitive optical instrument. As indicated by signs on the crate, it should always be standing upright. All opto-mechanical components will be assembled on arrival.

On arrival, the FTS-2 should be inspected to check for:

- damage of the shipping crate (dents or cracks).
- completeness of parts list.

It is recommended that personnel from the University of Lethbridge perform the initial inspection.

After carefully removing the packaged optical components and safely storing them, temporarily in a clean environment, the FTS-2 base and framework components can be lifted from their crate(s) using the supplied lifting harness with nylon straps. The FTS-2 breadboard can then be placed on top of its closed shipping crate for assembly, integration and verification.

The optical system must be aligned, the electronics initialized, and the software installed before the instrument can be tested. These steps need to be done by trained personnel. The installation procedure for the software will be detailed in the user manual.

3.1. Functional and performance testing

After delivery to the JCMT, the functionality and performance of FTS-2 will be verified. The verification will be performed by David Naylor and Brad Gom with assistance from Baoshe Zhang. Given the size of FTS-2, the assembly, integration and verification (AIV) will take place on the observing floor. The verification procedure consists of the assembly of the test system, the alignment of the optical components, the functional testing of the motorized components and finally verification measurements with the integrated system, similar to those described above.

All necessary tools and alignment fixtures for the AIV will be provided as a deliverable to the JCMT.

4. Commissioning test plan

- This section will be updated prior to the ARR.

The FTS-2 Commissioning Plan (SC2/FTS/INST/001) describes the task breakdown and tentative schedule for the commissioning phase. Commissioning will consist of 2 parts: assembling and aligning the FTS system, and functional tests of the installed system.

Once FTS-2 has been aligned on the observing floor of the JCMT it will be hoisted into its final position where it will be aligned to the telescope and the SCUBA-2 feed optics, as described in (SC2/FTS/OPT/005). Alignment to the JCMT beam will be done using a laser tool, followed by alignment of the pickoff mirrors by IR measurements using the SCUBA-2 arrays. In principle, if the FTS system is mounted within the required tolerances, the final alignment to the SCUBA-2 optics will only involve adjusting the pickoff mirrors remotely while monitoring the image registration and quality.

Instrument performance tests for the commissioning phase are still TBD.

5. Routine operation tests

- This section will be updated prior to the ARR.

5.1. Calibration

5.2. Diagnostics