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:	Brad Gom 18/11/09
Document Approved By:	D. A. Naylor FTS Project Lead	Signature and Date:	David A Naylor 18/11/09
Document Released By:	D. A. Naylor FTS Project Lead	Signature and Date:	David A Naylor 18/11/09

Change Record

Issue	Date	Section(s) Affected	Description of Change / Change Request Reference / Remarks
1.0	7/11/06	All	CDR version
1.1	30/01/07	2.6	Delta-CDR Version Control SW testing was done during Craig Walther's visit Jan 2007.
2.0	30/10/08	All	ARR version Changed planned system performance tests
2.1	18/11/09	All	Added status and time estimates to planned tests

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				
Framework	Load handling, dimensions, mass	U of L	JAC	Done
Lifting Harness	Engineering drawings and load test	U of L	JAC	Done
Beamsplitters	Optical performance tests	Cardiff	U of L	Done
Translation stage	PID tuning and metrology	U of L	U of L	In progress
PO Translation stage	Repeatability tests	U of L	U of L	Done
Optical alignment	CMM measurements, single pixel on-axis tests.	U of L	U of L	In progress
BB Shutters	Repeatability tests	U of L	U of L	
DR software	FTS engine testing in main DR pipeline	U of L	JAC	
Control SW	OCS / RTS interface tests	U of L	JAC	Done
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 will be used for all the large FTS-2 internal optics. Prototypes for the spherical bearing based mounts 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 mount performance.

1.2. Translation stage

The operation of the Aerotech translation stage has been tested using the provided Aerotech software. Previous experience with these translation stages has shown that the metrology is extremely reliable at spatial resolution far better than required for interferogram sampling, and is not likely to affect the system performance.

1.3. Pickoff mirror unit

The pickoff mirror unit consists of 4 spherical bearing mirror mounts bolted together, suspended from a translation mechanism. The spherical mount design was tested for backlash and repeatability before the mirror unit was constructed. Static friction in the spherical bearing is the only potential source of backlash in the mirror tilt adjustment, since the piezo actuators provide a minimum incremental motion of < 30 nm, which translates to < 0.1 arc second.

The pickoff mirror translation system will consist of an Aerotech leadscrew driven translation stage. Prototyping of the translation system is not deemed necessary. Repeatability of the pickoff mirror positioning is expected to be easily within the optical tolerances, since the repeatability will be driven by the lead screw parameters and stage optical limit sensor which are well above the required accuracy. 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 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 Java 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 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. This section lists specific component tests that have been identified for lab testing.

2.1. Framework

The framework provides support for all the system components above the breadboard level, but more importantly, provides registration for the optics positions. After the CDR, the mirror and mount design was changed to make the mirror alignment less dependent on the assembled framework dimensions. CMM measuring equipment will be used to locate the mirror surfaces directly, instead of requiring mirror pivots to be located precisely by the framework. The framework components will be tested after machining to confirm manufacturing tolerances have been met, and the framework will be aligned and measured with the CMM during assembly.

Test Outcome

- Measurement and tolerance report from component manufacturers
- Measurements of mechanical datum locations for the breadboard, beamsplitter mount, and mirror support framework against CAD model

Test Duration

~2 days

Status

- All critical mechanical components were delivered with full inspection reports. The FTS framework has been assembled, and all critical components have been measured to be within the limits of the optics adjustability.

2.2. Lifting Harness

The lifting harness attaches to mounting points on the FTS-2 breadboard and provides an eye hook on a levelling yoke for use with the JCMT crane.

Test Outcome

- Load tests with dummy mass
- Stamped engineering drawings

Status

Complete.

2.3. 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 University of Cardiff labs. The tolerance for the R/T efficiency is 50% +/- 1%. Very small phase effects have been measured in the SPIRE FTS which may show up in FTS-2 when using the dual-port cancellation.

Test Outcome

- Beamsplitter R/T efficiency across SCUBA-2 bands
- Beamsplitter phase measurements (optional)

Test Duration

~2 hours for tests and analysis, plus 1 day setup

Status

- Tests of sample beamsplitters were performed at the U of L in May 2008 to determine self emission effects as observed in the SPIRE FTS. The final beamsplitter units are expected to have identical performance to the test units, and will not impact the spectrometer performance. Beamsplitter efficiency and phase tests with FTS-2 will not be done in the lab unless we have free liquid helium available.

2.4. Translation Stage

Final tuning of the motion controller 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, and optimizing the PID paramters to ensure that the interferogram spatial sampling is as uniform as possible at the 200 Hz sample rate.

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. Testing that cumulative positional errors do not exceed 1 μm after 1000 motion command sequences will confirm that the encoder does not miss pulses.

Test Outcome

- Parameter file for Soloist controller with tuned PID settings
- Plot of position and velocity overshoot for motion corresponding to basic scan modes
- Repeatability test results

Test Duration

~1 day for tests and analysis

Status

- The stage PID loop has been tuned using the built in optimization features of the controller software. The PID values will be provided in the FLASH memory of the controller, and in the parameter file provided with the software.
- Plots of the stage metrology during the basic scan modes have not yet been completed.
- Repeatability tests have not yet been done, but are not expected to be an issue.

2.5. Pickoff Unit 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 stationary dial gauge. Positional errors must not exceed 50 µm at the home location of the stage, and the encoder must not miss pulses.

Test Outcome

- Repeatability measurement of the translation stage home location.

Test Duration

~1 day

Status

- Repeatability tests are complete.

2.6. 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. Initial alignment will be performed using a CMM to measure the mirror surface locations within the tolerance specified in the optical model.

Once the optics have been aligned mechanically, the input and output image plane geometry could be confirmed using a visible wavelength point source, since it is difficult to do this with submillimeter detectors and sources. This test will involve placing a point source at the 5 field point locations defined the optical model, and measuring the location of the focus in the intemediate and output image planes, with and without a mylar alignment beamsplitter installed. The accuracy of this test will likely be limited by the surface finish of the aspherical optics in the interferometer arms, which will not be polished to optical quality.

Tests of the submillimetre image quality might be possible using the U of L microbolometer array and a strong line source. This would allow measurements to be done using the actual beamsplitters, and with less loss due to the mirror finish.

Test Outcome

- Measured coordinates of each mirror surface and beamsplitter

- Measured coordinates of the output image plane for field coordinates in the INO optical model

Test Duration

~2 days for initial CMM measurement and alignment; 1 day for subsequent re-alignment
~2 hrs for corner cube alignment
~1 day for optical or THz image quality tests

Status

- Initial alignment of the fixed mirrors has been done using a Romer portable CMM arm with 5 foot reach. Alignment accuracy is less than anticipated due to problems with the arm, but all datum points are now aligned to within ~0.15 mm of their required locations.
- Alignment of the corner cube assembly was successfully achieved using an alignment telescope and temporary optical jig. A more robust jig will be built before comissioning.
- Optical\THz imaging tests have not yet been done.

2.7. Blackbody Shutters

Operation of the ambient blackbody calibration units will be verified by repeated (at least 50 cycles) insertion and retraction of the units in front of each input port, followed by measurement of the shutter angle in the open and closed position. Since the function of the calibration unit is only to provide a constant flux in the arm of the interferometer, the positioning of the unit is not critical (+/- 2.5°). Opto switches will ensure proper opening and closing of the shutters, and mechanical wear is not expected to be a concern.

Test Outcome

- Repeatability measurement of the shutter open and closed positions.

Test Duration

~1 day

Status

- Prototype BB shutters have been tested using the final acuators and electronics
- Final BB shutter units have not yet been tested

2.8. 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, which is created by inserting a simulated interferogram into an output file of the SCUBA-2 simulator. 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` *`input_file output_file`*

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 FTS-2 Tune-up Tool document (SC2/FTS/SOF/007).

There are additional DR modules which are implemented as SMURF routines. These routines are tested by running `./sc2fts` from the `/star/bin/smurf/` directory. The user is prompted to enter an input file, an output file, and a list of parameters:

```
/star/bin/smurf$ ./sc2fts
IN - Input data files > in.sdf
OUT - Output data file > out.sdf
PARSLIST – Parameter list: eg.op1.key1=value1, op2.key2=value2, ...>
ADDWCS.none=1,TRANSCORR.AM=1.5,TRANSCORR.PWV=0.8,TRANSCORR.Tau=Tau
```

In the parameter list, `value1` is assigned to the parameter `key1` of the routine `op1`. The current routines include:

- IFGMFLATFIELD – Interferogram Flat Field
- ADDWCS – World Coordinate System
- FREQCORR – Frequency Correction
- PORTIMBALANCE – Port Imbalance
- TRANSCORR – Transmission Correction
- SPECTFLATFIELD – Specral Flat Field
- GROUPCOADD – Group Co-add

Any number of routines can be called through the parameter list. Upon successful completion, the output file will be created and no error messages will be reported.

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.

Test Outcome

- TBD

Test Duration

TBD

Status

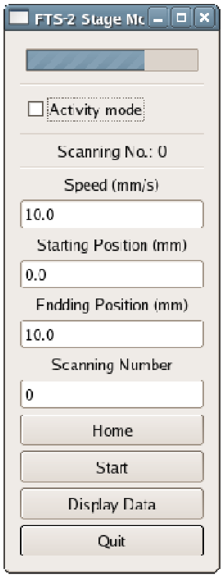
TBD

2.9. Control SW

The FTS-2 control software has been tested with all the FTS-2 subsystems\controllers 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.



This program tests all of the MOD-Bus functions performed by the Soloist, confirming that the internal Soloist programs operate correctly, the MODBus interface is working, and the control PC network connection is working. The following Soloist programs are tested:

- HOME – home the stage and zero the encoder
- RESET – reset the Soloist controller
- DISABLE – disable the stage motor
- ENABLE – enable the stage motor
- POSITION CAPTURE – start the triggered position capture mode
- LINEAR MOVE – move the stage to a given position
- CURRENT POSITION – read the current stage position

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:

Drama Parameter	Value(s)
MODE	'RAPID_SCAN','STEP_AND_INTEGRATE','DREAM','ZPD_MODE', ''
SCANVEL	mm/s
INBEAM	'FTSMIROR', ''

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 has been developed to test the communication and operation of the mirror actuators, and will be integrated into the FTS-2 control software suite and engineering interface during the system integration phase.

Test Outcome

- TBD

Test Duration

TBD

Status

TBD

2.10. Interferometer 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 that would be useful for interferometric tests, 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.

Test Outcome

- Single-pixel on-axis interferogram to confirm expected line shape
- Single-pixel off-axis interferogram to measure self-apodization (this is a rough test since the source and detector will not match the telescope and SCUBA-2 optics)
- Reflections and stray light checks

Test Duration

~2 days

Status

- Not yet started

3. Unpacking test plan

FTS-2 components will be shipped in sturdy, custom-made crateswith protective foam padding. All crates should be handled with care adequate for sensitive optical instrument. All crates should be stored and moved in the orientation indicated by signs on the crates. All opto-mechanical components will be assembled on arrival.

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

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

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

Pre-assembly tests:

- Test pickoff mirror controller communication with PC
- Test pickoff mirror actuators by stepping each and observing mirror angle
- Test pickoff translation stage controller communication with PC
- Test pickoff translation stage homing cycle and end-of-travel limits
- Test Soloist communication with PC
- Test FTS translation stage homing cycle and end-of-travel limits.

Post-assembly tests:

- Align and confirm all mirror coordinates against lab measurements
- Test pickoff assembly retraction
- Test rooftop assembly motion
- Test blackbody shutter operation

Once all mechanisms have been tested and mechanical alignment is complete, the instrument can be hoisted to the mounting location and aligned according to

SC2/FTS/OPT/005. After installation and final alignment, the control SW tests outlined in section 2.9 can be repeated.

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 an optical target to define the axial position and angular alignment, 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