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-2 Project Manager	Signature and Date:	Brad Gom	06/07/05
Document Approved By:	D. A. Naylor FTS-2 Project Lead	Signature and Date:	David A Naylor	06/07/05
Document Released By:	J. Molnar Canadian Project Manager	Signature and Date:		06/07/05

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Introduction

This document summarizes the equations for estimating the time required to map a given area when using the FTS-2 instrument. These equations are based on the FTS-2 noise model which calculates the NEP/NEFD for the FTS-2/SCUBA-2 system due to the added loading when the extra FTS-2 optics are in the beam. A PDF version of the model can be found at:
http://research.uleth.ca/scuba2/documents/analysis/SCUBA-2_noise_analysis_FTS_80K.pdf
The survey time equations are derived in the following file:
http://research.uleth.ca/scuba2/documents/analysis/FTS_mapping_speed.pdf

The following sections describe the 2 sets of equations for estimating the survey time based either on system NEP and survey noise temperature, or system NEFD and survey photometric depth in mJy.

1. NEP-based Calculation

Starting from the "FTS_mapping_speed.mcd" Mathcad file, where we use the observing time equation from Serabyn et al. (1995), the mapping time for FTS-2 in terms of NEP and noise temperature is:

$$t = \frac{A}{FOV \cdot \eta} \left(\frac{NEP}{k \cdot \Delta f \cdot \Delta T \cdot 2 \cdot \eta_{tot}} \right)^2$$

Where:

t	is the time in seconds
A	is the map area in deg^2
FOV	is the FTS-2 field of view in deg^2 (assume 2.8E-3)
η	is the mapping efficiency (assume 0.6)
NEP	is the FTS-2 noise equivalent power in W/√Hz
Δf	is the spectral resolution in Hz
ΔT	is the 1-sigma noise temperature in K
η_{tot}	is the overall system optical efficiency per pixel (~0.025 at 850 μm)

The η_{tot} term includes the pixel coupling efficiency to the telescope, η_{tel}, the atmospheric transmission, *skytrans*, the transmission of the optics, t_{sys}, and the Ruze equation.

	450 μm	850 μm
η_{tel}	0.466	0.147
skytrans	0.464	0.829
t_{sys}	0.226	0.226
Ruze	0.709	0.908
η_{tot}	0.0346	0.025

For 850 µm this reduces to:

$$t_{850} = 2.089 \times 10^{48} \cdot \frac{A}{FOV \cdot \eta} \left(\frac{NEP}{\Delta f \cdot \Delta T} \right)^2$$

For 450 µm this reduces to:

$$t_{450} = 1.093 \times 10^{48} \cdot \frac{A}{FOV \cdot \eta} \left(\frac{NEP}{\Delta f \cdot \Delta T} \right)^2$$

Current estimates for the FTS-2 NEP are $7 \times 10^{-17}\, W/\sqrt{Hz}$ and $50 \times 10^{-17}\, W/\sqrt{Hz}$ at 850 and 450 µm, respectively, as derived from the radiative transfer noise model.

Changing units, we get:

$$t_{850} = 5.8 \times 10^{32} \cdot \frac{A}{FOV \cdot \eta} \left(\frac{NEP}{\Delta f \cdot \Delta T} \right)^2$$

$$t_{450} = 3.0 \times 10^{32} \cdot \frac{A}{FOV \cdot \eta} \left(\frac{NEP}{\Delta f \cdot \Delta T} \right)^2$$

Where:

- t is the integration time in hours
- Δf is the spectral resolution in MHz

For example, mapping a 1 deg^2 area to a 1K ΔT with 150 MHz resolution will take ~4.5 minutes at 850 µm or ~121 minutes at 450 µm.

Note: the above values are expressed in terms of per pixel and do NOT include the time taken to fully sample the image at 450µm.

2. NEFD-based Calculation

The FTS-2 NEFDs can be calculated from the NEP as follows:

$$NEFD = \frac{NEP}{\eta_{\mathrm{mod}} \cdot \eta_{tot} \cdot A_{tel} \cdot \Delta \nu}$$

Where

- η_{mod} is the efficiency due to flat-fielding and baseline removal. (assume 1/√2 as worst case)
- η_{tot} is the system optical efficiency from above
- A_{tel} is the telescope primary area
- $\Delta\nu$ is the frequency bandpass

The resulting NEFD is 64 $mJy/\sqrt{Hz}$ for 850 µm and 165 $mJy/\sqrt{Hz}$ for 450 µm.

The mapping time in terms of NEFD becomes:

$$t = \frac{A}{FOV \cdot \eta} \cdot \left(\frac{NEFD \cdot \eta_{\mathrm{mod}} \cdot A_{tel} \cdot \Delta \nu}{k \cdot \Delta f \cdot 2 \cdot \Delta T} \right)^2$$

We can convert ΔT into an equivalent flux, D, for wavelength, λ, and beam width, θ, (15" for 850 µm and 7" for 450 µm):

$$D = \frac{2 \cdot k \cdot \Delta T}{\lambda^2} \cdot \frac{\pi}{4} \cdot \left(\frac{\theta \cdot \pi}{3600 \cdot 180} \right)^2$$

For 850 µm, the conversion is 15.875 Jy/K and at 450 µm it is 12.335 Jy/K

The mapping times become (MKS units):

$$t_{850} = \frac{A}{FOV \cdot \eta} \cdot \left(\frac{NEFD \cdot \eta_{\mathrm{mod}} \cdot A_{tel} \cdot \Delta \nu}{k \cdot \Delta f \cdot 2 \cdot \frac{D}{15.875}} \right)^2$$

$$= 6.322 \times 10^{20} \cdot \frac{A}{FOV \cdot \eta} \cdot \left(\frac{NEFD}{\Delta f \cdot D} \right)^2$$

$$t_{450} = \frac{A}{FOV \cdot \eta} \cdot \left(\frac{NEFD \cdot \eta_{\mathrm{mod}} \cdot A_{tel} \cdot \Delta \nu}{k \cdot \Delta f \cdot 2 \cdot \frac{D}{12.335}} \right)^2$$

$$= 1.527 \times 10^{21} \cdot \frac{A}{FOV \cdot \eta} \cdot \left(\frac{NEFD}{\Delta f \cdot D} \right)^2$$

With the spectral resolution expressed in MHz, the integration time. in hours, becomes:

$$t_{850} = 1.76 \times 10^5 \cdot \frac{A}{FOV \cdot \eta} \cdot \left(\frac{NEFD}{\Delta f \cdot D} \right)^2$$

$$t_{450} = 4.24 \times 10^5 \cdot \frac{A}{FOV \cdot \eta} \cdot \left(\frac{NEFD}{\Delta f \cdot D} \right)^2$$

Where NEFD and D are in $mJy/\sqrt{Hz}$, and the other variables are the same as before.
Note: the above values are expressed in terms of per pixel and do NOT include the time taken to fully sample the image at 450µm.

Table 1. Estimated FTS sensitivities per pixel.

	850 μm		450 μm	
Resolution (MHz)	180	3000	180	3000
Resolution (cm^{-1})	0.006	0.1	0.006	0.1
NEP (W/√Hz)	$7 \cdot 10^{-17}$	$7 \cdot 10^{-17}$	$\sim 5 \cdot 10^{-16}$	$\sim 5 \cdot 10^{-16}$
1-σ ΔT in one hour integration (mK)	12	0.7	~62	~3.7
1-σ flux per hour (mJy)	192	11	~770	~46

3. Sensitivity per beam

When account is taken of the additional sampling of the 450 um image required to fully sample the focal plane, and noting that the 850 um image is four times oversampled, the above equations expressed in terms of sensitivity per beam (14" at 850 um and 7" at 450 um) become:

$$t_{850} = 1.45 \times 10^{32} \cdot \frac{A}{FOV \cdot \eta} \left(\frac{NEP}{\Delta f \cdot \Delta T} \right)^2$$

$$t_{450} = 1.2 \times 10^{33} \cdot \frac{A}{FOV \cdot \eta} \left(\frac{NEP}{\Delta f \cdot \Delta T} \right)^2$$

or equivalently:

$$t_{850} = 4.4 \times 10^{4} \cdot \frac{A}{FOV \cdot \eta} \cdot \left(\frac{NEFD}{\Delta f \cdot D} \right)^2$$

$$t_{450} = 1.7 \times 10^{6} \cdot \frac{A}{FOV \cdot \eta} \cdot \left(\frac{NEFD}{\Delta f \cdot D} \right)^2$$

Where t is the integration time in hours, and Δf is the spectral resolution in MHz

The above calculations are based upon using one quadrant of the SCUBA-2 camera. When the focal plane is fully populated, if the complementary outputs of FTS-2 can be successfully combined, a further improvement of a factor of √2 will be realized in the sensitivity.

Table 2. Estimated FTS sensitivities per beam

	850 μm		450 μm	
Resolution (MHz)	180	3000	180	3000
Resolution (cm^{-1})	0.006	0.1	0.006	0.1
NEP (W/√Hz)	$7 \cdot 10^{-17}$	$7 \cdot 10^{-17}$	$\sim 5 \cdot 10^{-16}$	$\sim 5 \cdot 10^{-16}$
1-σ ΔT in one hour integration (mK)	6	0.36	~124	~7.5
1-σ flux per hour (mJy)	96	6	~1542	~93