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MCU / BSM DM Mechanism
Integration and Test Report

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1 Introduction

This document aims to report about the MCU QM0 electronics and the BSM Development Model integration which was performed at ATC premises during October 14th and 15th 2003.

2 Goals of integration

The integration aimed to verify that MCU was running in open and closed loop on both chopper and jiggle axis with the same performances than the dSpace control system used by ATC during lifetime tests and to validate the control scheme and parameters on both side (MCU and dSpace).

The integration did not aim to fine calibrate the absolute position since this step shall be necessary only on the Flight model.

For DM integration, the absolute position was roughly measured using a laser beam hitting the BSM mirror cold down at around 4K and reflected on a wall at a distance of about 6.7 meters.

3 General experiment set up

The experiment set-up consisted in :

- a 233 MHz PC equipped with Labview program to send commands to MCU Mac board and to receive telemetry bsm packets,
- a MCU assembly including a MAC board QM1 model, a BSM 40mA QM0 model and a QM1 model backplane,
- a harness compliant with configured SPIRE pin-out definition and including 10 Ohm resistors on motor lines to be representative with flight model cold harness resistance,
- the BSM DM model put in a cryostat equipped with a window
- a laser beam projected on BSM mirror through the window and reflected on a distant wall.

4 Measured performances vs. requirements

This is a recall of main performances to be achieved. The measured values during MCU/BSM integration do not differ significantly as compared with the results of performances tests presented during Instrument hardware Design Review by ATC on July 9th and 10th 2003.

Requirement item	Specified value	Measured value on DM(peak)	Conformance
Angular Travel Chop Jiggle	+/-2.53° (+/-130 arcsec sky) +/- 0.573°	+/- 2.51° With 40mA analogue board. +/-0.6°	Shall be compliant with 50mA analogue board QM1 model
Minimum chop throw	+/- 0.1°	TBD	TBD
Minimum step size Chop Jiggle	2 arcsec sky (=0.038 °) 0.039°	0.0002° (ADC accuracy) 0.0001° (ADC accuracy)	Ok Ok
Position accuracy	0.004°	0.0002° (ADC accuracy)	Ok after linearisation process to be done on FM
Position resolution	0.0005°	0.0001° (ADC resolution)	ok
Stability	0.2 arcsec sky (=0.004°)	0.0006° (short term)	ok
Settling time Chop Jiggle	20ms 100ms	~ 20ms ~ 60ms	Ok Ok
Frequency Chop Jiggle	Up to 2Hz Up to 0.5 Hz	Max frequency: 40Hz but power dissipation not measured Max Frequency 10 Hz	Ok

5 Detailed results

5.1 Chopper Axis Measurements

5.1.1 Open loop measurements

The following table gives the relationship between chopper target position, motor current sent to DAC and estimated position in open loop. This table implies that the chopper position scale factor parameter (see SetCPositionScaleFactor in command list) is set to default value of 3051. With this setting there is the same digital value sent to DAC as the target position reference parameter.

motor current and dac output = f(openloop reference) with default position scale factor parameter

after inner scale factor

MCU position scale parameter= **3051** **3,05176E-05**

open loop reference (32768=0)	dac value	dac volt output	motor current(mA)	estimated position(°)
0	0	-10	-40	-2,51159794
20000	20000	-3,8964844	-15,586	-0,97864021
32768	32768	0	0	0
35000	35000	0,6811523	2,7246	0,17107808
40000	40000	2,2070313	8,8281	0,55431751
45000	45000	3,7329102	14,932	0,93755694
46000	46000	4,0380859	16,152	1,01420483
47000	47000	4,3432617	17,373	1,09085272
48000	48000	4,6484375	18,594	1,1675006
49000	49000	4,9536133	19,814	1,24414849
50000	50000	5,2587891	21,035	1,32079638
60000	60000	8,3105469	33,242	2,08727524
65532	65532	9,9987793	39,995	2,51129134

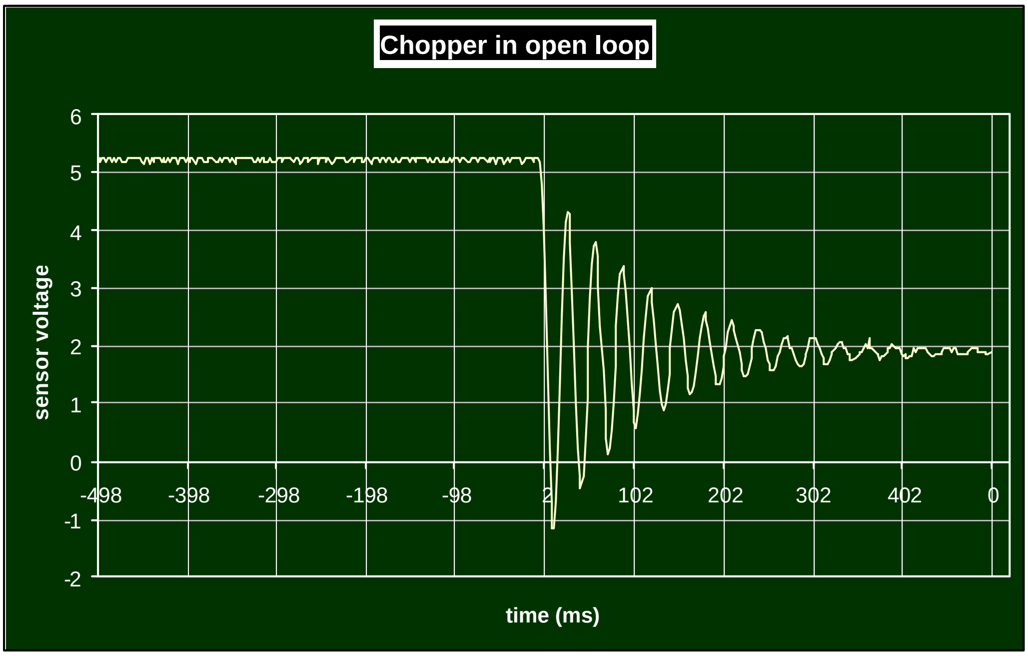
flex stiffness:	0,073	Nm/rad
motor cst	0,08	Nm/A
pwr amp max current	0,04	A/10V

Table 1 : correpondance between motor current, dac output and target position with default position scale factor

To calibrate the chopper we first send an open loop current on DAC. The chosen value is **20000** corresponding **to -1°** displacement with a **–15.5 mA** motor current in the analogue board (see table 1). For this, we perform the following commanding scenario (after the power switch on and the boot on RAM program):

Wait between commands	Commanding scenario	Command sent by DPU	Action
1ms	SetCSensorPwr,on	90C00001	Switch on the 1mA current to be sent to sensor
1ms	SetCPositionScaleFactor,3051	90D60BEB	Set the open loop constant between target position and DAC value =1/32768 in order to control in open loop with DAC units (see table 1).
1ms	SetCRateLimit,1000	90D103E8	Apply the slew rate limit to avoid too fast step response in open loop and too much oscillations.
1ms	SetChopLoopMode,3	90C20003	Set the loop mode in open loop mode (no sensor)
1ms	SetChopTargetPosition,20000	90C34E20	Perform a step to 20000,ie –15,5mA or –1°
1ms	SetTelemetryPacket12Sample,8	91C20008	Start BSM Packet telemetry at 8*400^{us} rate.

The open loop step position is captured on oscilloscope. To be able to operate in open loop, some damping must be added by mean of backemf provided by the motor coil.



5.1.2 Open loop scaling

The measurements taken by BSM telemetry packet are:

- Sensor ADC value: **21276**, ie 3.51 volts; (at 0 position: 29741, ie –0.92 volts). The sensor sensibility is therefore around 3.51-0.92= **2.58 V/deg**.

expected position(°) =f(sensor ADC) =f(target position)

	target position	sensor volts	position(°)
mr sensitivity(V/deg)	55000	6,78466797	2,65216717
	50000	5,25878906	2,055692006
0,06	40000	2,20703125	0,862741678
bsm gain 1	30000	-0,84472656	-0,330208651
	20000	-3,89648438	-1,52315898
19,38	15000	-5,42236328	-2,119634144
bsm gain 2	11000	-6,64306641	-2,596814275
2,2			
difference			
1			
MR ADC scale (V/deg)			
2,55816			

This value is compliant with the magneto resistance measured sensibility of 60,4 mV/° amplified by a factor of 2.2*19.38= 42.63 by the analogue BSM board (0.0604*42.63= 2.575 V/°).

- Motor current ADC value: **19973** (there is so a difference with **20000** demanded at DAC level)

- Motor voltage ADC value: **6892**

Now we have to calibrate the backemf feedback to allow open loop with some damping.

5.1.3 Scaling the back emf

The goal of the back emf is to apply speed feedback control by mean of the motor voltage measurement. This feedback shall damp the axis natural oscillation. The useful information is the motor backemf voltage which is proportional of the motion speed. The undesired information is the R*I voltage which is the voltage drop in both coil and harness. The following procedure aims to remove the useless information RI:

1. Determine the ratio between motor current and motor voltage as measured on telemetry:

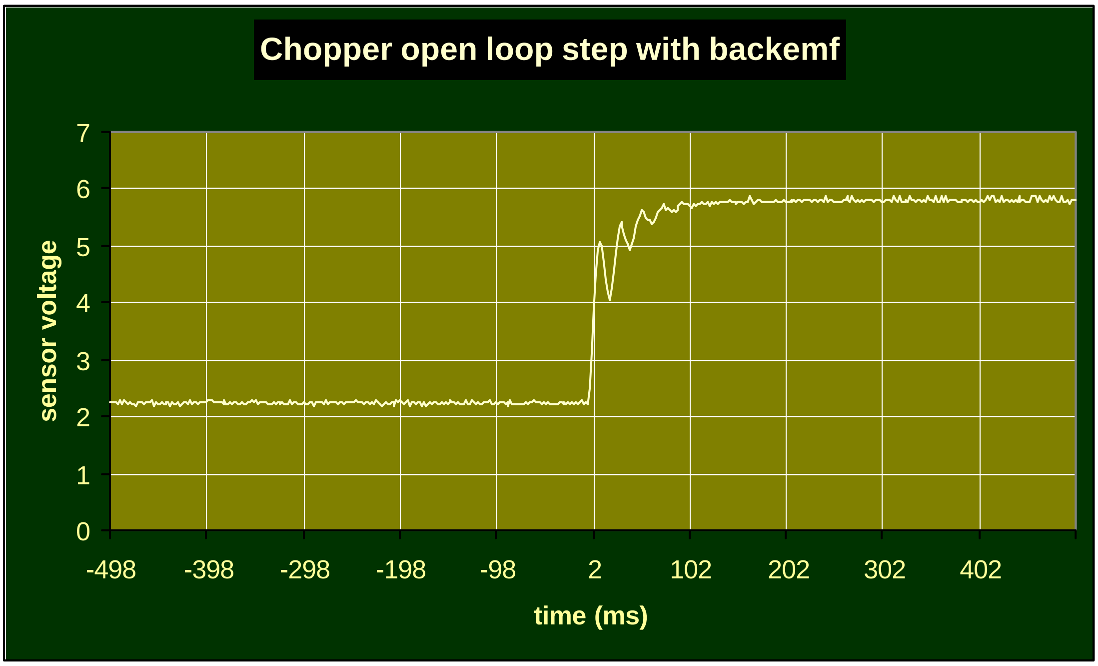
(Motor Voltage-32768)/(Motor current-32768)= -25876 / -12795= 2.02

backemf		
		at 0
max current measured	19973	32768
max voltage mesured	6892	32768
ratio V/I	2,02235248	
parameter (Rmot)	**20224**	

2. Send the command corresponding to SetCMotor resistance,20224: **`90D34F00`**

3. Now apply some gain of the feedback: SetCMotorbackEmfGain,500:**`90D201F4`**

Going to a new target position, the result is an open loop damped as shown next figure.



5.1.4 Chopper closed loop step response

The closed loop operation need to adjust PID parameters according to dSpace preliminary control results. The following table gives the correspondance between dSpace and MCU 16 bit integer parameter due to necessary scale factor conversion :

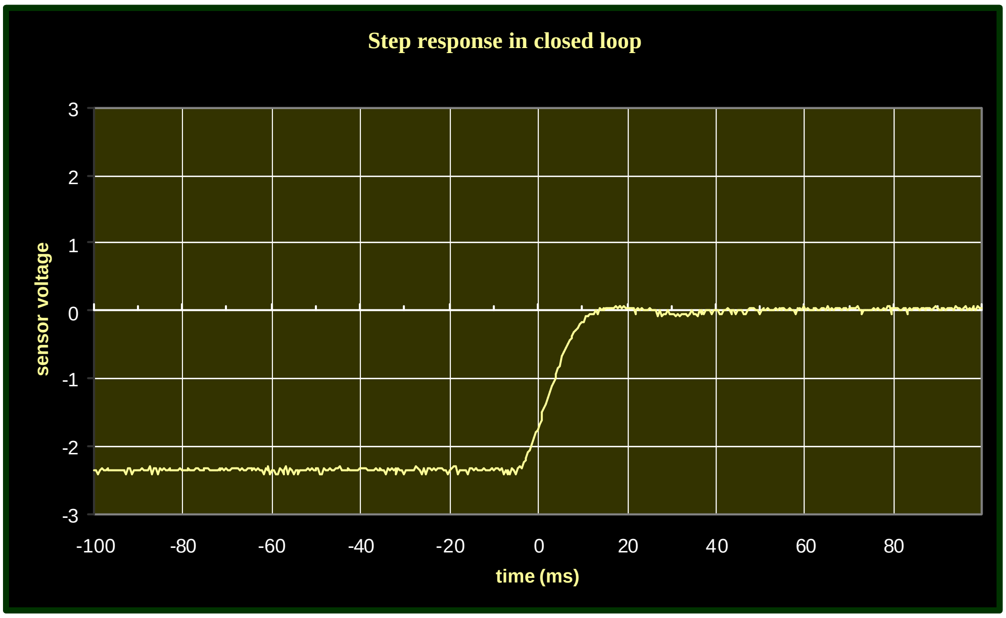
PID Parameter	ATC parameter	ADC/volts	mr deg/volts	ADC/deg	conversion dSPACE->MCU	parameter fixed scale factor	parameter in MCU
PROPORT	**4,17**	3276,8	0,39090596	8382,58	0,000497	1E-08	**19898**
DERIVATIVE	**0,014**	3276,8	0,39090596	8382,58	1,67E-06	1E-10	**6681**
INTEGRAL	**275**	3276,8	0,39090596	8382,58	0,032806	1E-06	**13122**
INTEGRAL LIMIT	**0,04**	3276,8	0,39090596	8382,58	4,77E-06	1E-06	**12407**

In addition, the feedforward gain must be adjusted according to the open loop results.

To operate clo sed loop control we first send the following commanding scenario from the present open loop configuration.

Wait between commands	Commanding scenario	Command sent by DPU	Action
1sec	SetChopTargetPosition,32768	90C38000	Go to the 0 position to send 0 on dac (safety)
1ms	SetCKp,19898	90C84DBA	Set the PID proportional gain
1ms	SetCKd,6681	90C91A19	Set the PID derivative gain
1ms	SetCKi,13122	90CA3342	Set the PID integral gain
1ms	SetChopLoopMode,1	90C20001	Close the loop on the sensor
1ms	SetCRateLimit,800	90D10320	Decrease the slew rate limiter of the step
1ms	SetChopTargetPosition,20000	90C34E20	Go to the target position in step mode

The dynamics taken by oscilloscope on sensor signal shows a settling time of about 20ms.



Remark: noise level is not representative due to oscilloscope probe measurement. See position stability and noise chapter for actual data as read out by ADC converters.

5.1.5 Position stability/ noise in closed loop

During a steady position of chopper axis in closed loop, the position noise is +/- 5 ADC unit, ie +/- 1.54 mV. The chop sensor signal has a sensibility of 2.55V/deg. The chop position noise is therefore **+/- 0.0006°.**

Note: the Y axis unit is the ADC digital value obtained from telemetry.

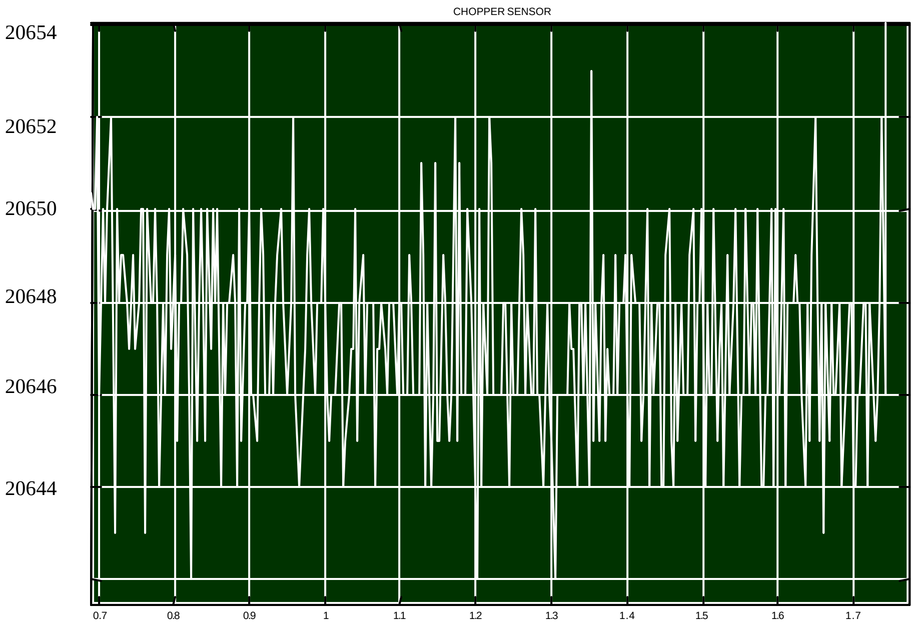


Figure 1: Chopper sensor ADC signal at steady position

5.2 Jiggle axis measurements

5.2.1 Open loop

The following table gives the relationship between jiggle target position, motor current sent to DAC and estimated position in open loop. This table implies that the jiggle position scale factor parameter (see SetJPositionScaleFactor in command list) is set to default value of 3051. With this setting there is the same digital value sent to DAC as the target position reference parameter.

motor current and dac output = f(openloop reference)

MCU position scale factor parameter	**3051**	
after scale factor	**3,05176E-05**	
flex stiffness:	0,56	Nm/rad
motor cst	0,16	Nm/A
pwr amp max current	0,04	A/10V

open loop reference (32768=0)	dac value	dac out	motor current(mA)	estimated position(°)
0	0	-1	-40	-0,65480946
20000	20000	-0,3896484	-15,586	-0,25514548
32768	32768	0	0	0
35000	35000	0,0681152	2,7246	0,0446025
40000	40000	0,2207031	8,8281	0,14451849
45000	45000	0,373291	14,932	0,24443449
46000	46000	0,4038086	16,152	0,26441769
47000	47000	0,4343262	17,373	0,28440089
48000	48000	0,4648438	18,594	0,30438409
49000	49000	0,4953613	19,814	0,32436728
50000	50000	0,5258789	21,035	0,34435048
60000	60000	0,8310547	33,242	0,54418247
65532	65532	0,9998779	39,995	0,65472953

5.2.2 Jiggle sensor scaling

Before closing the loop, the magnetoresistor sensor scale factor must be known. This scale factor shall be used to adjust the necessary feed forward gain and to have a relationship between desired position (°) and sensor signal 16 bit parameters (which, in closed loop without static error, shall be the same as the target position). At cold, the magneto resistors have a sensibility of 130mV/°. After amplification in the BSM analogue board of 2.2*19.195, the overall sensitivity as seen by ADC is 5.48 V/°.

position(°) =f(sensor ADC) or f(target position in closed loop)

	Target position	volts	position(°)
mr sensitivity(V/deg)	20000	-3,32641602	-0,605929942
0,13	22500	-2,56347656	-0,466955184
	25000	-1,80053711	-0,327980427
bsm gain 1	27500	-1,03759766	-0,18900567
19,195	30000	-0,2746582	-0,050030913
	32500	0,48828125	0,088943845
	35000	1,2512207	0,227918602
	37500	2,01416016	0,366893359
	40000	2,77709961	0,505868116
bsm gain 2	42500	3,54003906	0,644842874
2,2	30900	0	0
1			
MR ADC scale (V/deg)			
5,48977			

5.2.3 Step response in closed loop

The same procedure of tuning has been applied on jiggle axis as chopper axis. Crude tuning of the PID allow to perform a settling within 60ms instead of 100ms required. However some additional time to fine tune this axis should improve the dynamics but at the price of the motor current solicitation. The commanding scenario is identical as the chopper one.

6 Conclusion

The MCU/BSM DM integration did not show difference in the dynamics of the control between ATC lifetime operation using dSpace, and PID+Feedforward algorithm implemented in the MCU DSP.
This integration confirms the system performances achieved during lifetime tests using dSpace instead of MCU as presented during Instrument Hardware Design Review held July 9thand 10th 2003 (see ATC BSM Viewgraphs).

Final performances and position calibration shall be done on FM (and Spare) during another integration process.