FIRST / SPIRE

MCU Design Description

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Acronyms

AD	Applicable Document
AVM	Avionics Model
BOL	Begin Of Life
BSM	Beam Steering Mirror
CQM	Cryogenic Qualification Model
EGSE	Electrical Ground Support Equipment
EOL	End of Life
ESA	European Space Agency
FIRST	Far InfraRed ans Sub-millimetre Telescope
FM	Flight Model
FPU	Focal Plane Unit
FTS	Fourrier Transform Spectrometer
FTSE	FTS warm Electronics
FTSP	FTS Preamplifier for the position encoder signals
H/K	House Keeping
H/W	Hardware
I/F	Interface
LAM	Laboratoire Astrophysique de Marseille
MAC	Multi Axes Controller
MCU	Motorization Control Unit
N/A	Not Applicable
RAL	Rutherford Appleton Laboratory
RD	Reference Document
ROE	Royal Observatory of Edinburgh
S/C	Spacecraft
SM	Spare Model
SMEC	Spectrograph MEChanism
S/W	Software
TBC	To Be Confirmed
TBD	To Be Define
TBW	To Be Written
TC	Tele-Command
TM	TeleMetry
WE	Warm Electronics

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1 INTRODUCTION

1.1 Purpose and Scope

The purpose of this document is to describe the electronics design for the control and monitoring of the FIRST/SPIRE FTS Mechanism (**SMEC**) associated with the Beam Steering Mirror mechanism (**BSM**) control.
The control electronics unit of the 2 mechanical subsystems is called **MCU (Motorisation Control Unit).**

The **MCU** is part of the **DRCU** and has electrical and mechanical interfaces with it.

1.2 Applicable and reference documents

1.2.1 Applicable documents

AD1	Operating Modes for the SPIRE Instrument (SPIRE-RAL-DOC-000320)
AD2	FIRST/Planck Packet Structure Interface Control Document (SCI-PT-IF-07527)
AD3	Spire Spectrometer Mirror Mechanism Subsystem Specification (SPIRE-LAM-PRJ-000460)
AD4	FIRST / Planck Instrument Interface Document Part B (SCI-PT-IIDB/SPIRE-02124)
AD5	DRCU Electrical Interface Control Document (SAp-SPIRE-CCa-24-00)
AD6	SPIRE Instrument Requirements Specification (IRD) (SPIRE-RAL-PRJ-000034)

1.2.2 Reference documents

RD1	Beam Steering Mirror Control Software Requirements (Spire-ATC-Draft)
RD2	Beam Steering Mirror Warm Electronics (Spire-ATC-Draft)
RD3	Beam Steering Mirror Electronics Electrical Interface (Spire-ATC-Draft)

2 SYSTEM OVERVIEW

The **MCU** is dedicated to the control and monitoring of the following **3** axis of the SPIRE instrument:

- the Spectrometer Mechanism (SMEC). The control is based on a scan at a configurable speed,
- the **chopper** and **jiggle** axis of the **B**eam **S**teering **M**irror subsystem . The control is a position step control pattern.

Furthermore, the MCU shall provide H/K data of the 3 axis for telemetry and scientific interferogram calibration and detector synchronisation purpose.

The trajectory control of the 3 axis is performed by a 21020 DSP on the basis of PID controllers associated by feedforward for trajectory generation and filtering for notching of mechanism modes.

The software shall be based on a master scheduler on the principle of time sharing without the use of a specific multi tasking kernel. The tasks to be performed shall be called on the basis of a software interrupt generated by the inner DSP timer, allowing interlaced tasks such as FTS and BSM control algorithms, command polling, etc…

The DSP software, in order to be as simple as possible, will time share within one single 100 micro sec (TBC) cycle task :

- the SMEC control task
- the chopper control task,
- the jiggle control task,
- the communication and other various internal DSP tasks.

The scan parameters are put in memory for configuration purpose by mean of the command serial line described hereafter.

2.1 General architecture

The MCU control electronics includes:

- the **MAC Board**: common digital control board based on a **21020 DSP**

- **a SMEC Board**: analog electronics for the power amplification of the actuators and acquisition electronics for sensors preamplification and conditioning of the SMEC subsystem

- **a BSM Board**: analog electronics for the power amplification of the actuators and acquisition electronics for sensors preamplification and conditioning of the BSM subsystem

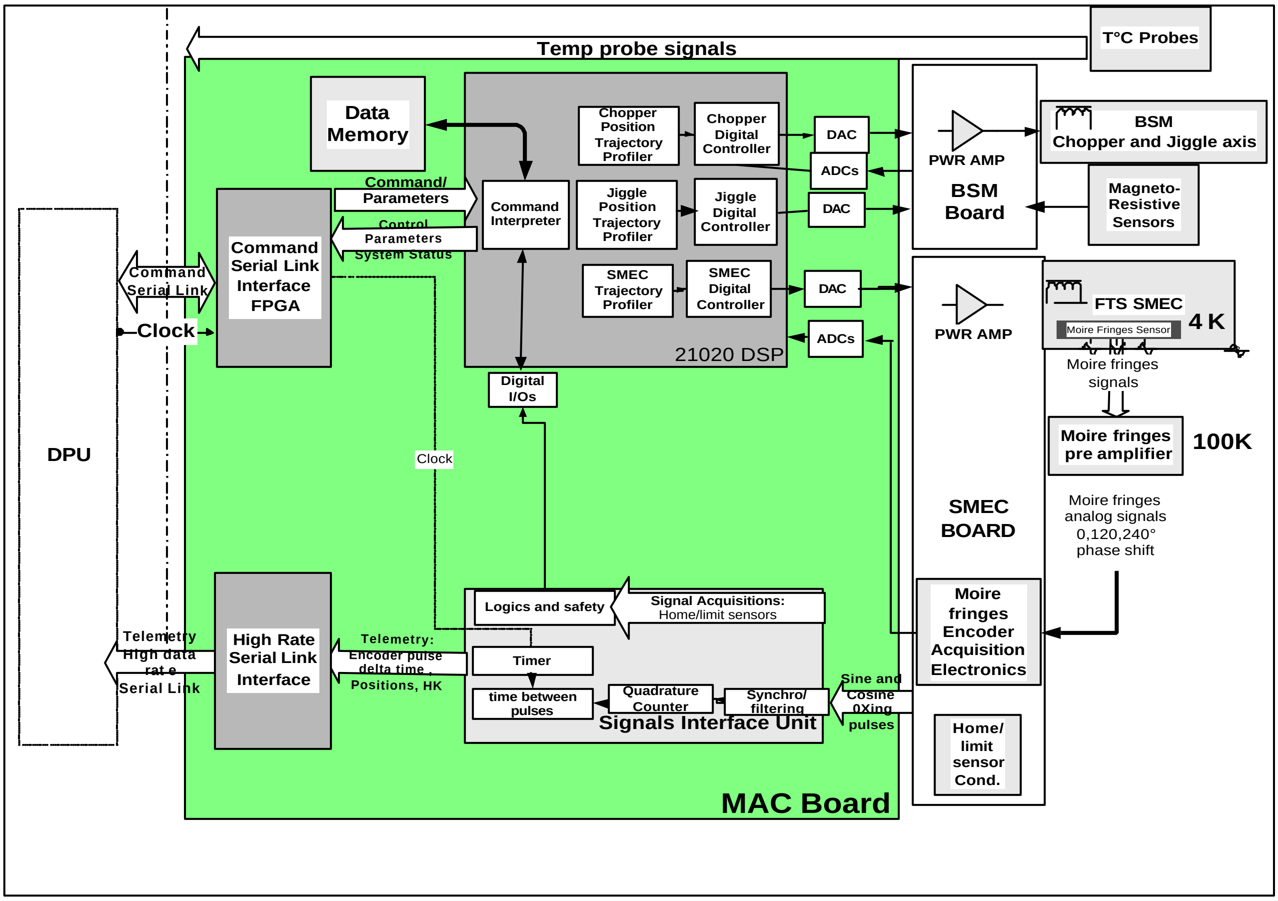


Figure 1: Control system architecture

2.2 Communication and telemetry principles

The MCU communication with DPU shall be done through 2 serial lines :

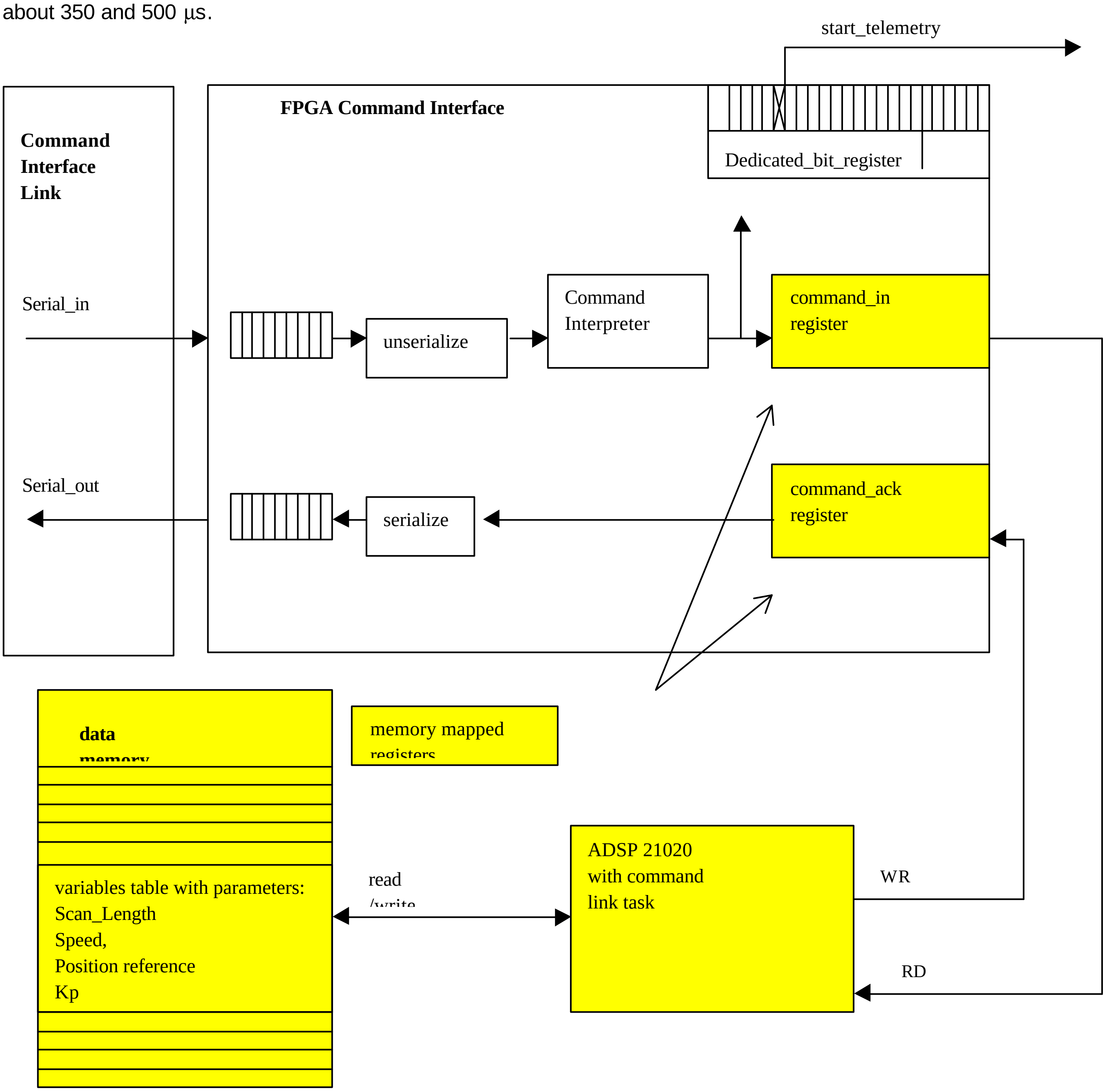
- Low rate command interface link 300 kbits, based on 32 Bits word. By mean of a FPGA dedicated to serial interface, the commands and parameters are decoded and put in a register to be read by the 21020 DSP

- High rate telemetry interface link 1Mbits, based on 16 bits.

On the basis of this principle, the MCU DSP shall read the command register every cycle of the common time sharing monitoring of the 3 axis (ie 100 micro seconds).

2.2.1 Low rate Command interface

The MCU shall receive a 32 bits word for each command. The 32 bit word shall include (i) 2 bits for subsystem id (ii) 8 bits for command type (e.g. set scan_length), (iii) the rest for the parameter itself.
The MCU communication FPGA shall decode if the command concerns its subsystem, since all systems shall be adressed.
If yes, the MCU FPGA put the parameter value after header decoding in a register. The DSP reads pediocally the interface register et put in its own memory the parameters according to a table pointer.
For every command, a handshake is done with DPU, so that only one command can be sent at one time until the parameter of the control shall be taken into account.
-With this handshake, a first assesment shows that two commands can be sent in about 320 micro second (TBC). The handshake shall consist of only one 32 bits word return. Since the DSP readout of the command is done periodically every 100 µs, the maximum delay for a command to be taken into acount is between about 350 and 500 µs.



2.2.2 High rate Telemetry serial link

Some specific values such as position and motor current samples are delivered on a fast mono directional serial link to provide data for telemetry purpose.

The telemetry shall use a 1Mbit/s 16 bits serial link.

For the sharing of telemetry channel:

- there is only one common FPGA connected to one high rate serial link,

- this FPGA shall have two communication mode :

  - **jiggle mode** : the telemetry data are the BSM axis with some additional SMEC information. In this mode the telemetry is synchronized by a clock
  - **scan mode** : the telemetry data are the delta time SMEC position with some optional BSM information. In this mode, the telemetry rate depends on the SMEC encoder pulses counts, ie the scan speed in an asynchronous way.

For the SMEC the telemetry packet as defined in the DRCU Electrical Interface Control Document (AD5), shall consists in a delta time between two zero crossing of a sine optical encoder signal, ie every 1 micron in the scan. At the nominal speed of 500 micron/sec, the delta time between two encoder pulses shall be delivered at a rate of 500 Hz.

The value of 1 micron is to be considered as a minimum value and shall be programmable. The possible values shall be, for example, 1, 2, 4 or 8 microns (TBC).

3 SMEC AXIS TRAJECTORY AND CONTROL

3.1 Scan in closed loop operation

The SMEC axis is controlled by a digital PID with a ramp reference to insure a scan with configurable length and speed. The scan may be single with a flyback at the end or a double scan (single and return) with the same common speed and length.

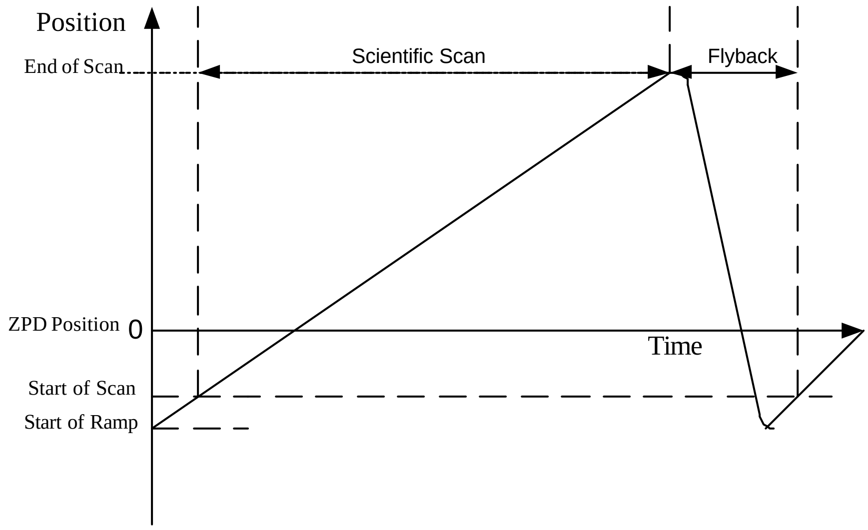


Figure 2: SMEC Scan characteristics

Scan characteristic	Specification (Initial Requirement)	Comment
Scan length	- 0.3 cm min to 3.2 cm max	Programmable length Value referred to the home position
Scientific Scan Length resolution	0.5 µm	based on a 16 bits parameter reference
Max scan speed	2000 µm/s	
Min scan speed	200 µm/s	
Nominal scan speed	500 µm/s	The nominal speed is the basis for velocity stability requirements
Speed reference resolution	0.03 µm/s	based on a 16 bits word reference parameter
Stability of the velocity scan	(1% -goal 0.5 % rms).	on the basis of a filtered velocity fluctuation by a 29 Hz / 3rd order low-pass filter
Flyback duration	less than 10% of the scientific scan	including acceleration phase

Table 1 : SMEC scan specifications

3.1.1 Home and limit position acquisition

The home and limit positions acquisitions are based on 3 magnetoresistive sensors with same conditioning electronics as BSM ones, with few microns resolution. The sensors shall define the:

- upper limit
- lower limit
- home position

3.1.2 Optical Encoder Position Acquisition

The position is determined from the 3 sine optical encoder signals after pre-amplification, conditionning and a sine / cosine signals format conversion to be read directly by the DSP via 2X 16 bits ADC for fine position on the basis of an arctan computation in the DSP. The complete absolute position is then computed by addition of an incremental value of 2 µm every encoder cycle. Since that, the sampling time of the DSP does not depend on velocity (it is not the case with a 1/T speed counting between encoder pulses with some problems at very low speeds). Furthermore, the arc tangent computation of the position is dedicated for a fine and continuous position control, avoiding speed jitter that should be generated by encoder pulses if these signals enters directly in the control loop. The number of sine/cosine samples to be acquired to arctan computation is given by :

$$N = \text{Sine period} / (\text{Speed} * t_{sampling}), \text{ with Sine period} = 2\ \mu m$$

By the mean time, the encoder pulses generated by the encoder electronics are entering an Encoder Unit Interface (FPGA) for pulses counting and crude position determination. The incremental position count is done in the FPGA for in order to verify the trajectory controlled by the DSP and acts the role of a watchdog. Furthermore, the Encoder Unit Interface includes error signals generation for whatever problem occures during the trajectory (limit switches reached, etc...). If one on the logics signal is high, the DSP is interrupted and put in safe configuration.

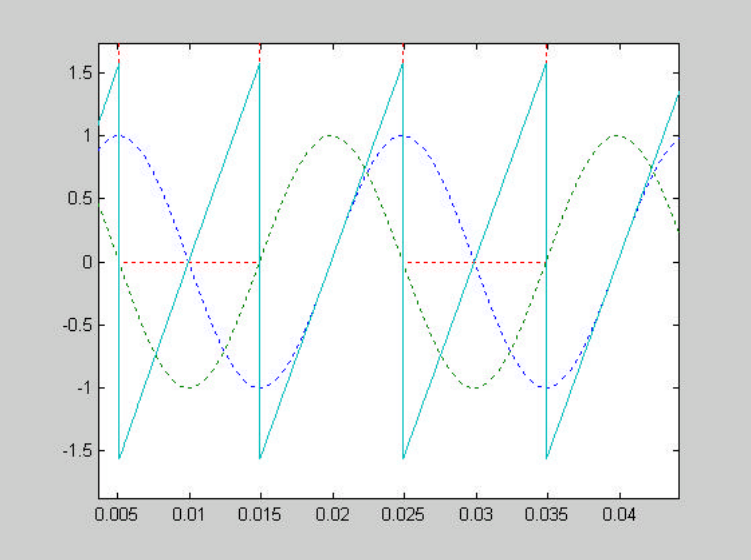


Figure 3: Fine position (solid line) derived by arctan computation

3.2 SMEC Position data for telemetry

In order to reconstruct interferograms, the detector readout data must be concatenated with position sampling data.

There is no absolute time tag in the SMEC Control System, but an extra signal on the timer of the Encoder Interface Unit is implemented.

For this purpose, the SMEC control electronics provides the time elapsed between encoder pulses corresponding to, for example, 6 µm displacement (ie 3 encoder engraving wave of 2 µm), by mean of a timer triggered by an external clock. This is done by the Encoder Interface Unit on the basis of a zero crossing every 3 cycles as seen on the next figure.These data are then delivered to telemetry high data rate serial link.
The value of the number of encoder cycles is programmable with a minimum value of 1 micron corresponding to the zero crossing of an elementary sine wave of the moire fringe optical encoder.

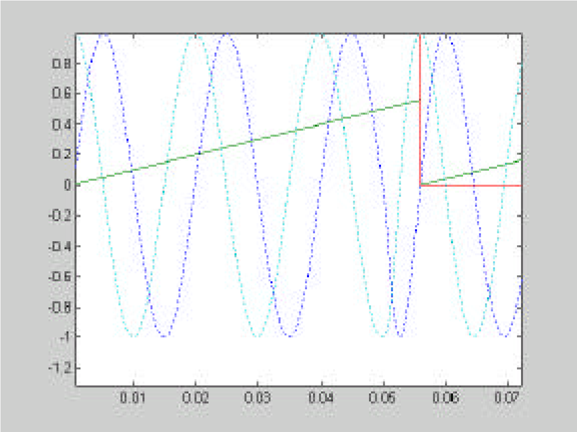


Figure 4: Time count (solid line) between encoder pulses for telemetry

3.2.1 Synchronization with DPU

The measurement of the delta time elapsed between 2 or more encoder zero crossing starts on the receipt of a specific synchronization signal. This synchro signal reset the internal timer of the delta time count in the Encoder Interface Unit FPGA. This function is implemented to allow synchronisation with detector data frames acquisitions. Since that the first delta time value provided to telemetry is representative of the time delay between the synchro signal provided by the DPU/DRCU and the first optical encoder pulse of the scientific scan. The delta time counter is incremented by the Low Speed Serial link clock set to 330 kHz. The counter range is defined to 32 bits.

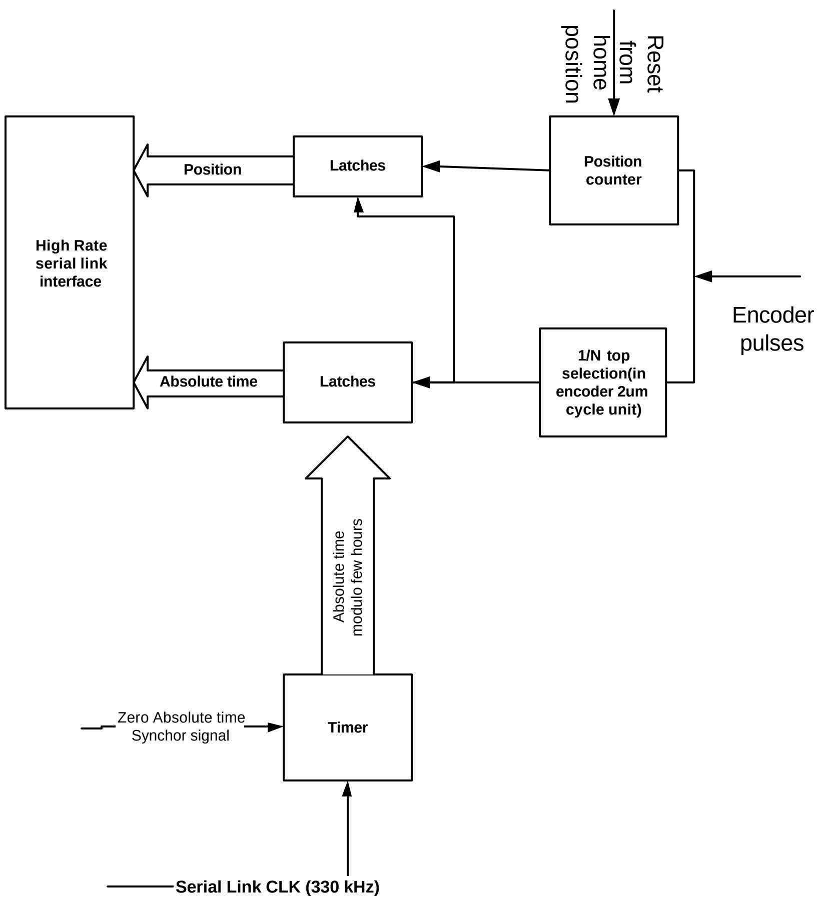


Figure 5 : Principle of position sampling timer synchronization with DRCU

Position data characteristic	As designed specification (Initial Requirement)	Comment
Position data sampling	1 µm (5 µm)	Provides a time count every 2 encoder main pulses (encoder engraving of 2 µm) Initial requirement based on the mini scientific wave length (200 um) divided by : - 4 (interferometer arm ratio) x - 5 (position data over sampling for calibration)
Position data accuracy	0.01 µm (0.1 µm)	Resolution given by the optical encoder after systematic non linearity correction
Position data synchronization	time count start between pulse triggered by external signal	allows to reconstruct the trajectory starting from a reference start signal to be synchronized with start of detector samples

3.2.2 Position data for telemetry sampling rate

The position for telemetry sampling data rate depends on the FTS SMEC velocity.
Consequently, le telemetry to be provided shall be asynchronous and not synchronised by a dedicated clock, the encoder pulses assuming to latch the delta-time counter.
The values of the sampling rate are proportional to the speed as specified in the following table. The sampling rate depends also proportionnaly on the length between the encoder pulses zero-crossing (eg every 2 or 4 sine waves).

Scan speed (mm/s)	Position data sampling rate (Hz) for 1micron delta time
200	200
500	500
1000	1000

Table 2 : Telemetry rates for zero crosing every 1 micron on the optical encoder

4 PRINCIPLE OF OPERATION OF BSM CONTROL

4.1 Requirements

The BSM is used to steer the optical beam of the SPIRE photometer channel over the detector arrays. The beam steering mirror will be used to perform jiggle mapping (to produce fully sampled images for feedhorn arrays, and to improve image quality) and perform chopping (to remove background and background variations and perform fine pointing corrections). This peaking up mode will be used to quickly ensure that point sources are well centred on individual detectors

The BSM comprises a flat mirror which is mounted on a two axis pivot system. This pivot system allows precise angular motion of the mirror over a small range of angular travel in two orthogonal axes. Electrical actuators are used to provide motion of the mirror. Magnetoresistive sensors are used to measure the mirror position to allow control of the mirror position. Control of each axis is done by a digital conventional PID (3-term) controller - with corrections for cross-coupling between axes- in the MAC Board.

Position profile specification	Axis	Value
Angular Travel	Chop (around Z axis in telescope coordinates)	±3°
Angular Travel	Jiggle (around Y axis)	±0.72°
Minimum step increment (demand)	Chop & Jiggle	0.01°
Angular measurement resolution	Chop & Jiggle	0.002°
True angular position accuracy	Chop & Jiggle	0.04°
Angular position repeatability	Chop & Jiggle	0.004°
Maximum chop axis frequency at max amplitude	Chop	5 Hz
Maximum jiggle axis frequency at max amplitude	Jiggle	1 Hz
Settling time to within 5% (TBC) of demand position (Chop axis)	Chop	10 msec
Settling time to within 5% (TBC) of demand position (Jiggle axis)	Jiggle	50 msec

Table 3: BSM Control system specifications

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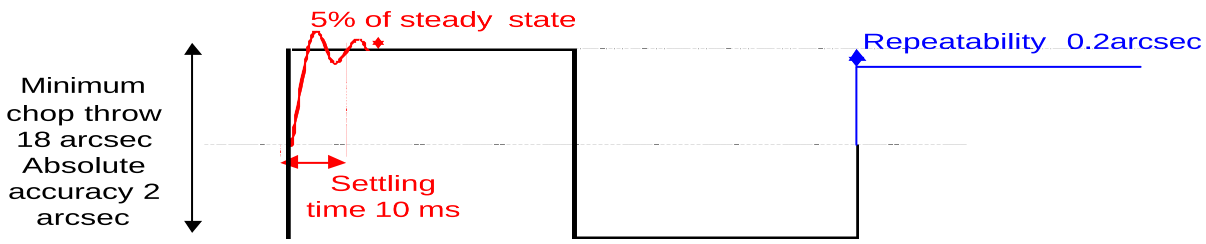


Figure 6: BSM Trajectory specification

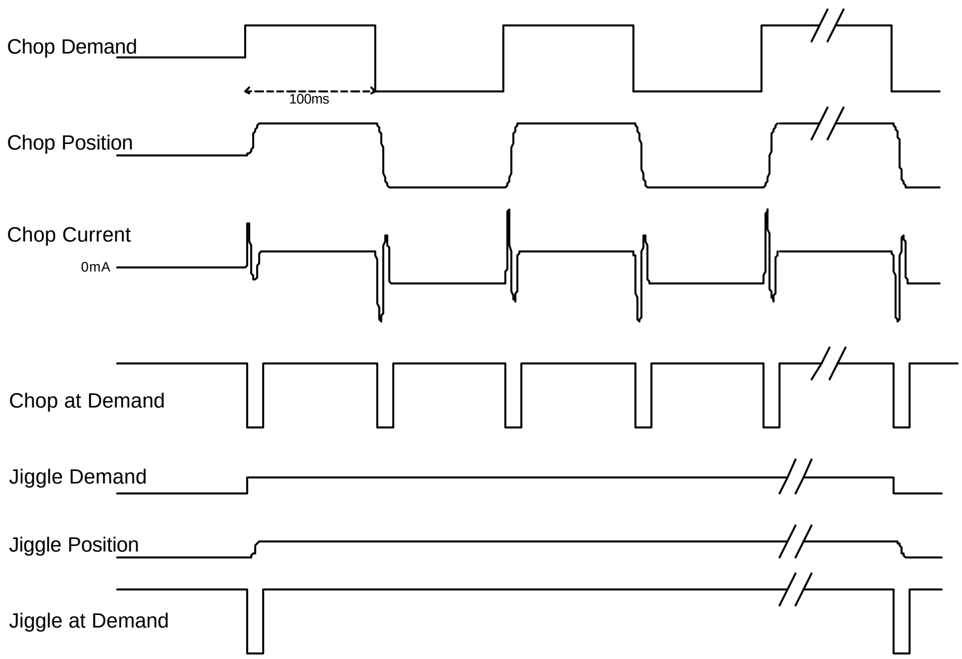


Figure 7 : BSM Control system chronogram

4.2 BSM Modes

- Off
- On
  - On axis in Chop (z) at angle θ_c=0
  - On axis in Jiggle (y) at angle θ_j=0
  - Moving to position (θ_c ,θ_j)
  - Holding in position (θ_c ,θ_j)

- TBC modes - which could be all software driven by master controller, by sending stream of positions to BSM controller
  - Chopping on z axis
  - Jiggling on z axis
  - Jiggling on y axis

4.3 Command/Parameter list

Chop axis:

- Set point
- Proportional Term
- Integral Term
- Derivative Term
- TBC : Waveform : 1024 points - default is to drive by a series of set point commands from the DPU processor

Jiggle axis:

- Set point
- Proportional Term
- Integral Term
- Derivative Term
- TBC : Waveform : 1024 points - default as above

Status Parameters

- Chop axis position
- Chop axis motor current
- Chop axis position error
- Chop axis moving flag
- Jiggle axis position
- Jiggle axis motor current
- Jiggle axis position error
- Jiggle axis moving flag

4.4 Telemetry data list

- Chop and Jiggle axis positions to housekeeping @ 20 ms rate.

5 MAC OPERATION

The MAC Board may be operated by a set of commands according to the following table.

Mode #	Mode Name	Action	Possible Next Mode	On Command
0	Off	The set of boards is not powered. No function available	On	Power On
1	On	The set of boards (main or redundant) board is powered .	Off	Power Off
1.0	Booting	• The software is initialized after reset. • The software is downloaded from Prom memory to SRam memory	Downloaded	MAC Reset On
1.1	Downloaded	• The communication is available. • The status of the system is available. • Waiting for commands • Goes initially to Open loop mode	Booting	MACReset On **'ResetMAC'**
1.1.0	Open Loop	• Waiting for Advanced Configuration Commands (Control gains,etc ...) • Goes initially to open loop standby	Close Loop	'**CloseLoop**'
1.1.1	Close Loop	• nominal control loop mode using a digital PID controller at 100 µs sampling rate • Goes initially to Stand By mode	Open Loop	**'OpenLoop'**
1.1.1.0	CLoop Stand By	Waiting for motion configuration: (Scan Length, etc..)	Motion init	**'Init Motion'**
1.1.1.1	CLoop Motion Init	Searching for limits and diagnostics	Ready	End of Motion initialization
1.1.1.2	CLoop Ready	Waiting for motion commands and configuration	Scan	'**StartMotion'**
1.1.1.3	CLoop Scan	Motion underway: scan for the SMEC, chopping and jiggling for BSM	Ready	End of Motion '**StopMotion**' **'ResetMotion**

5.1 Command format

A command is a 32 bits word with the following allocation:

Bits 29-28	Bits 27-20	Bits 19-18	Bits 17-0
MCU header	Command type	Axis id.	Parameter

Axis id:

- 0: all axis
- 1: SMEC axis
- 2: Chopper axis
- 3: Jiggle axis

5.1.1 Bufferized commands and parameters

Some commands should not take immediate effect on the control. These commands are called **bufferized commands**. They are taken into acount when a specific **Update** command is sent. This is useful for a configuration set definition such as the scan speed and length before a validation of the configuration. The parameters that are bufferized are :

- ClearPositionError,
- Acceleration,
- deceleration,
- Position,
- Velocity,
- Scan length
- PID parameters,
- MotorCommand.

5.1.2 Digital Servo Filter commands

Command type	Action
SetKp	Proportional gain of the digital PID controller
SetKd	Derivative Gain of the digital PID controller
SetDerivativeTime **GetDerivativeTime**	Sets the sampling time to calculate the derivative term in number of servo cycles
GetDerivative	**Only in Closed-loop mode**:Returns the derivative of the current position error as calculated by the servo filter. The derivative value is defined as the previous position error substracted from the current position error.
SetKi	Integral gain of the digital PID controller
GetIntegral	Returns the current integrated position error of the servo.Can be used for Integration limit survey
SetIntegrationLimit **GetIntegrationLimit**	Loads/Reads the integration saturation for the intergral compensation of the servo
SetPositionErrorLimit **GetPositionErrorLimit**	determine/reads the position error value that causes an error on the servo
ClearPositionError	In case of the position error exceeds a thresold, the motion is stopped for further diagnostic. This command is used to reset the position error by forcing the position refernce to be equal to the actual position counter.
GetPositionError	Returns the difference between the actual position and commanded position
SetMotorBias **GetMotorBias**	Sets a bias voltage of the digital servo.Used for a static effort cancel out on the mechanism
SetMotorLimit **GetMotorLimit**	Sets a saturation on the output of the motor output command issued by the servo filter
SetSampleTime **GetSampleTime**	Sets the cycle time for the servo of the specified axis
SetNotchParam Axis i	Parameters for notch filtering of mechanical modes

5.1.3 Trajectory Profile commands

Command type	Action
SetPosition	specifies the trajectory detination For BSM= position step level (um) For the SMEC : moves the SMEC by a step by step way. Unit= 1 um Range: 5.5 cm: 55000 values B0-B21: position reference from the home position
GetPosition	Allows the measurement of a position step by step. Usefull for engineering mode to get position for step response. B0-B21: actual position from the home position
GetCommandedAcceleration	returns the current commanded acceleration value for the specified axis.
GetCommandedPosition	The commanded position is the instantaneous position value output by the trajectory generator
GetCommandedVelocity	The commanded velocity is the instantaneous velocity value output by the trajectory generator.
SetAcceleration	Load the max acceleration of the motion
GetAcceleration	
SetActualPosition	loads the actual position register and at the same time the commanded position
SetJerk	Loads the acceleration variation limitation on the trajectory of the specified axis
GetJerk	
SetScanLength **GetScanLength**	Load / update a table defining a spectrometer scan. The scan is defined as a start position, ie a number of position sensor fringes move
SetScanSpeedRef **GetScanSpeedRef**	Load/Read the desired speed of the control scan reference speed: 16 bits if value=0 the servo is in position mode
SetProfileMode Axis i	**'SetProfileMode'=0 =>** Mode= **Position_Closed_Loop** **'SetProfileMode'=1** => Mode= **Scan_Closed_Loop** The number of scan to be performed is within parameter

5.1.4 I/O and Encoder signals related commands

GetCaptureValue	Returns the contents of the Position Capture register
GetActualPosition	reads the contents of the encoder's actual position counter
SetCaptureSource	Defines which signal is used for encoder counter initialization (Home,Limits switches,Current position)
SetEncoderSource	Set the tyep of encoder feedback. Can be incremental mode using sine cosine A/B signals, or arctan computation
SetEncoderRatio **GetEncoderRatio**	Converts the number of encoder pulses in scan length micron units
GetSignalStatus	Returns the signal status register: Encoder A,Encoder B,Home,Positive limit,Negative Limit
SetLimitSwitchMode	Enables or disables the limit switches sensing

5.1.5 DSP Software related commands

GetTime	retuns the number of cycles since last reset
GetVersion	Returns software version number
Reset	restores the chipset to initial default conditions
ResetEventStatus	reste the event stus and related error bits for re-initialisation
Update	Updates in the chipset the buffered parameters (eg PID parameters)

5.1.6 Communication related commands

GetHostIOError	returns the IO Error code
SetIOPollingTime	Set a maximum time between 2 commands before a IO Error code is generated, meaning a communication problem
NoOperation	No effect on the chipset.It is usefull as a 'null' operation to verify communication with the Motion Processor
SetPortMode **GetPortMode**	Determines the instructions set that can be executed.When set to Limited, only the base instructions may be used

5.1.7 Motion and control modes related commands

Command type	Parameter	Action
GetEventStatus		reads the event register for a specified axis.
GetActivityStatus	Axis#	reads the Activity Status Register. This Stuatus Register can only be read and no bit cna be cleared since the word is refreshed by the chipset.
GetCurrentMotorCommand		Returns the current motor command for the specified axis. In closed loop, this is the output of the servo filter. In the open loop mode it is the contents of the motor output command register.
SetMotionCompleteMode		establishes the source for the comparison which determines the motion complete status
GetMotionCompleteMode		
SetMotorMode		Determines the mode of operation: open loop,closed loop,back EMF loop
SetMotorMode	Axis#	**'SetMotorMode'= 1** => Mode = **Closed_Loop** **'SetMotorMode'= 0** => Mode = **Open_Loop**
GetMotorMode		The error / internal mode status word allows the DPU to identify problems B0-B3: idem set_SMEC_mode B4-B21: error/internal mode status
SetSettleTime		Sets the time that the specified axis must remain within the tracking before the axis settled indicator is set to 1
GetSettleTime		
SetStop		Stops the specified axis in abrupt or smooth mode
GetStop		
SetAutoStopMode		Defines the conditions onwhich the motion sould stop
SetBreakpoint		Defines an action of a specified event
GetBreakpoint		Reads the register defining breakpoint conditions

5.1.8 Trace and telemetry related commands

The trace mode allows to record up to 4 data in a memory allocation for further read out of servo loop values. The trace table is , after recording, read by a dedicated command on the low rate serial command line (point to point).

Command type	Parameter	Action
GetTraceCount		Returns the number of points stored in the DSP Trace Buffer it defines the length of telemetry sample
GetTraceStatus		B0= 1 when in synchronous mode, **0 when in asynchronous encoder pulses mode**
SetTraceMode		The trace may be in rolling on or one shot time
SetTracePeriod		Sets the time period, expressed in ms, between successive trace points. or the number of encoder zero crossing to be sampled in asynchronous mode
SetTraceStart		0=Immediate start of the trace 1= Stop on next Update command 2= Event Status Register 3= Activity Status register 4= Signal Register Bit + mask of the register fro trace trigger
SetTraceStop		0=Immediate stop of the trace 1= Stop on next Update command 2= Event Status Register 3= Activity Status register 4= Signal Register Bit
SetTraceVariable		Specifies up to 4 variable to be put in the DSP trace register and sent to telemetry channel. It consists in the telemetry data mux selection
TelemetryCounterReset (broadcast)	1 dedicated bit	Starts the telemetry counter on a broadcast synchronized signal

5.1.9 HK on the command line related commands

This commands allow to recover some data for H/K in order to build a table representative of the inner state of the servo control.

Command type	Parameter	Action
GetActualVelocity	Axis #	Get the instantaneous velocity
GetScanMeanSpeed	Axis #	actual scan mean measured speed: 16b Allows to verify the velocity scan error
SetMeanSpeedMeasure	Axis #	Length of the speed sample used for Mean Speed measurement
ReadAnalog	Value to be read	Returns a 16 bits value representing the value of a specified analog input

5.1.10 Event Status Register

Bit	Name	Description
0	**Motion Complete**	Set when a trajectory profile/scan is complete
1	**Position wrap**	Set when the actual motor position exceeds 7FFF.. (the most positive position) and wraps to 8000... (the most negative positin)or vice versa
2		
3		
4	**Motion error**	Set when the actual position differs from the commanded position by an amount more than the specified maximum position error
5	**Positive limit**	
6	**Negative limit**	
7	**Instruction error**	Set when an instruction error occurs

5.1.11 Activity Status Register

Bit	Name	Description
0		
1	**@ Maximum velocity**	Set to 1 when the trajectory is @ maximum velocity. This bit is determined by the trajectory generator, not by the actual encoder position.
2	**Tracking**	Set to 1 when the axis is within the tracking window
3	**Current profile mode**	on 3 bits: velocity scan, position step, trapezoidal
4	**Axis setteld**	
5	**Motor Mode on/off**	
6	**Position capture**	
7	**In-motion**	
	In positive limit	
	In negative limit	Set to 1 when the negative limit switch is active

5.1.12 I/O Error code register

Bit	Name	Description
0	**No error**	
1	**Processor reset**	
2	**Invalid instruction**	
3	**Invalid axis**	
4	**Invalid parameter**	
5	**Block out of bounds**	
6	**Bad serial CKS**	
7	**Not primary port**	
8	**Invalid parameter change**	
9	**Invalid move within limits**	

6 MAC SOFTWARE

6.1 21020 DSP Software principles

The DSP software is in 21020 assembly language without the use of a specific off-the-shelf real time operating kernel. The assembly language is choses because Analog Devices provides directly specific libraries to produce PID, filtering, arctan computation with a high efficiency (and even readability). For this reason C coding is not foreseen since the software shall be simple, dedicated to pure signal processing (ie realisation of IIR Filters with product/sommation operations) without complexe command interpreting nor complex mode of operations.
The main tasks to be realized are called by a Master scheduler which is a routine interrupted by a software interrupt generated by the inner timer of the DSP.
Mainly, the software does not use other interrupt, excepted for the the following functions :

- watchdog interrupt to recover from a loss of control of the DSP,
- interrupt when the command / parameter buffer between the WE interface chip and the DSP is full, indicating that the flow of data entering the DSP is too high.

Code uploading in the DSP is not foressen, the DSP beeing only used for control, in substitution of analogue electronics, with very poor load regarding communication / command interpreter. Code uploading would imply a very heavy software management task.

6.1.1 Watchdog mechanism

- The DSP resets periodically a counter implemented in the telemetry FPGA.
- This counter is incremented on the basis of the telemetry FPGA internal clock.
- If the DSP does not ensure the counter reset, the telemetry FPGA automatically resets the DSP.

6.1.2 Digital I/O polling

The DSP comprises an digital I/O area for the following signals :

- reach of the home limit

- trajectory count error

6.1.3 Reset

The reset of the DSP shall be activated on the following events :

- no watchdog signal
- communication FIFO full

6.1.4 ITs

the ITs are used for emergency in case of :

- Limit sensor reached
- Error in the trajectory detected by the encoder interface FPGA

6.2 MAC Software architecture

The software is designed to be as simple as possible. For this purpose, there is an only task running every time defined by the digital servo sampling time parameter. The digital servo sampling time is defined by the MMS (Mac Master Shceduler).

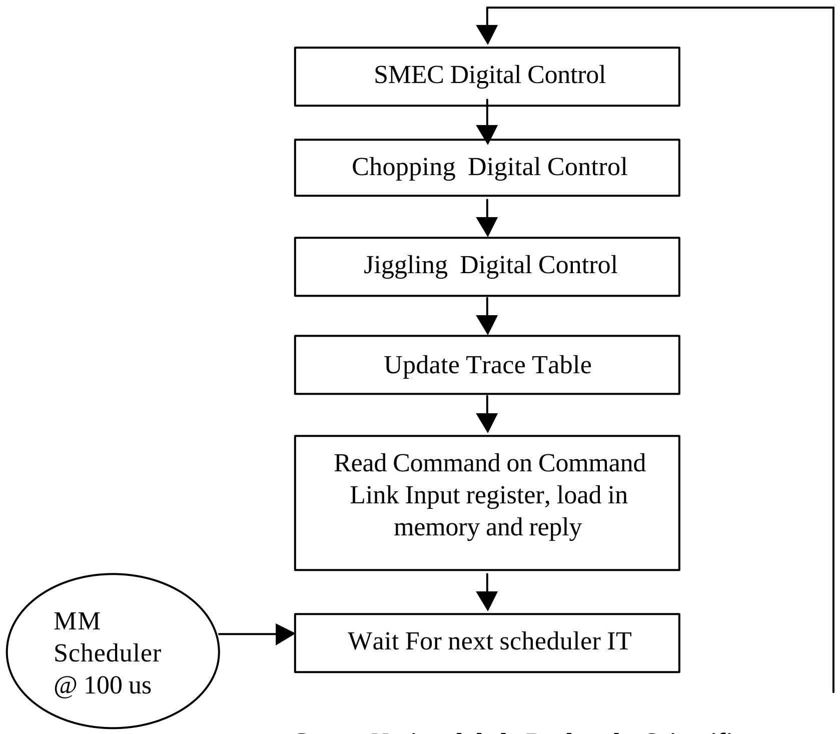
6.2.1 MAC Master Scheduler (MMS)

The principle of the MMS is the management of the main cycle to be performed in the MAC DSP.

The main cycle is set by default to 100 us (TBC), but is configurable.

The MMS uses the internal clock of the DSP , incrementing an internal counter set to deliver an interrupt every 100 us triggering the start of the main task.

6.2.2 MAC Main task



6.2.3 SMEC and BSM axis Control Algorithms

- Read Digital I/O (Home, Upper and Lower limits)
- Compute control status
- Compute servo loop

6.2.4 SMEC Servo Loop algorithm

- Step 1 : read sinus and cosinus (1 DSP cycle = 50 ns)
- Step 2 : read cosinus (1 DSP cycle = 50 ns)
- Step 3 : filtering sinus (T1 = 40 DSP cycles = 2 µs)
- Step 4 : filtering cosinus (T1=40 DSP cycles = 2 µs)
- Step 5 : compute arctangent (T2 = 120 DSP cycles = 6 µs)
- Step 6: compute current trajectory,that is the same that a speed filtering (T1=40 DSP cycles=2 µs)
- Step 7 : compute current error and "do something" if error > max error (T3=40 DSP cycles=2 µs)
- Step 8 : with error, compute output DAC for FTS motor amplifier (T4 = 80 DSP cycles = 4 µs)
- Step 9 : write output DAC (1 DSP cycle = 50 ns)

T1, T2 are roughly given and are to be exactly defined.
T3,T4 and T6 are estimated with Analog Device application notes, for example the number of cycles for a FIR Filter is given by : **number of cycles = 7 + number of taps used for filtering.**
Another example is the compute of **PID in 10 cycles** (ref : DSP-Based Motor Controller Seminar of Analog Devices)
These numbers don't include error test , overflow… so we must reserve about 20 cycles for this.
The compute of **Arctangent** is given for **82 cycles** maximum from Analog Devices (ref ADSP-21000 Family Application Handbook), but we must reserve about 40 cycles for overflow and error tests.
So, the total timing for execute step 1 to 11 can be estimated to about 17 µs.

6.2.5 BSM Chopping axis Servo loop

Nota : the BSM software is specified in the Reference Document RD1 Beam Steering Mirror Control Software Requirements (Spire-ATC-Draft)

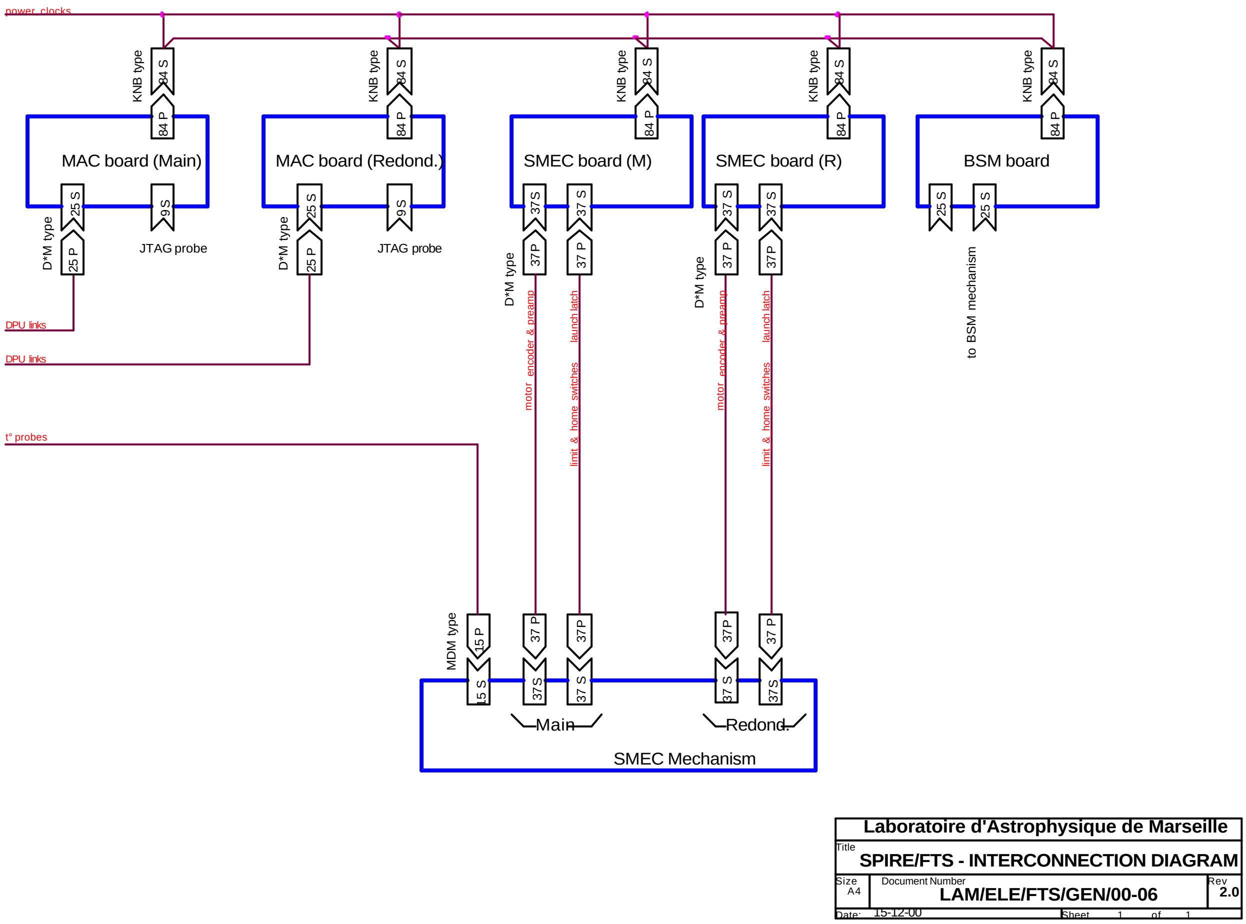
- Step 1: set analog multiplexer to BSM chop position magneto-resistive sensor (1 DSP cycle = 50ns)
- Step 2: wait 300 ns (analog mux transition time)
- Step 3: write Start of Conversion to ADC (1 DSP cycle = 50 ns)
- Step 4: wait 15 µs (ADC conversion time)
- Step 5: read position (1 DSP cycle = 50 ns)
- Step 6: compute position filter (T1 = 40 DSP cycles = 2 µs)
- Step 7: compute current error and "do something" if error>max error (T2 = 40 DSP cycles = 2 µs)
- Step 8: with error, compute output DAC for BSM Chopping axis (T3 = 40 DSP cycles = 2 µs)
- Step 9: write output DAC (1 DSP cycle = 50 ns)

So, the total timing for execute step 1 to 9 can be estimated to about 7 µs.
The steps are exactly similar to the previous task.

7 MCU ELECTRONICS DESIGN

This Section is intended to describe the features and the architecture of the Subsystem dedicated electronics (i.e. electronics circuitry and interconnection including complex circuits like FPGAs and/or dedicated micro-controllers.

7.1 Overall description.



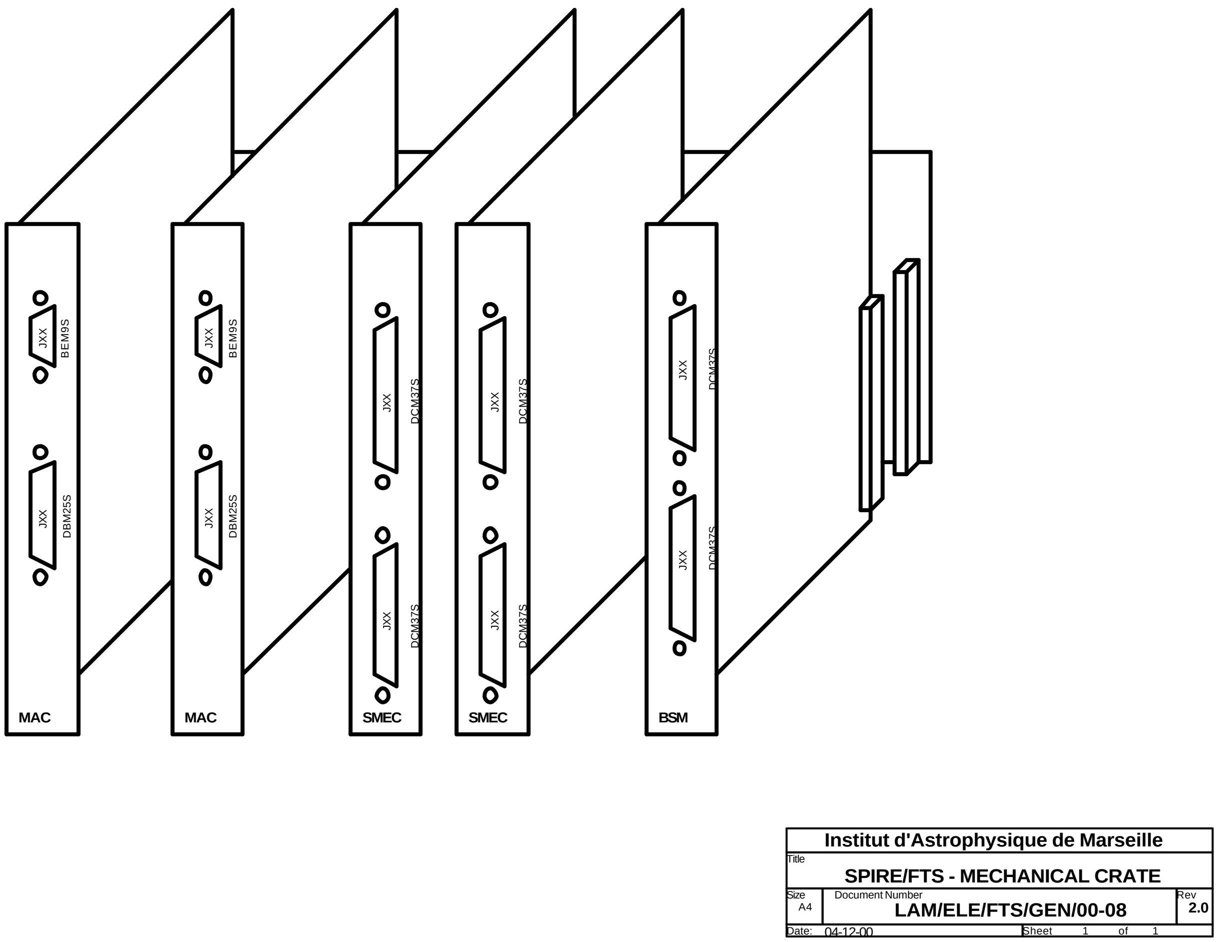
7.2 MCU Mechanical implementation.

7.2.1 Mechanism control unit (MCU)

WE includes :

- 2 Multi Axes Controllers (MAC) boards,
- 2 SMEC boards,
- 1 BSM board.

Two MAC boards, SMEC boards and BSM board are plugged on the same mother board.



Dimensions of the MAC, SMEC and BSM boards are 220 x 223 mm^2 (TBC).

7.2.2 Position encoder preamplifier box

The preamplifier box include the two preamplifiers for main and redundant channels. It is located in the SMEC mechanism, near the position encoder heads.

Dimensions are TBD

The mass of the electronics boards is estimated to 98 g.

7.2.3 Mass

Subsystem	Number	Nominal mass / unit (g)	Margin / unit (g)	Dispersion / unit (g)	Total max. mass (g)	Remarks
MAC module board	2	380	76	9	930	TBC
MAC module mechanical and thermal parts	2	TBD	TBD	TBD	TBD	
SMEC module board	2	TBD	TBD	TBD	TBD	
SMEC module mechanical and thermal parts	2	TBD	TBD	TBD	TBD	
BSM module board	2	TBD	TBD	TBD	TBD	
BSM module mechanical and thermal parts	2	TBD	TBD	TBD	TBD	
preamplifier board	2	40	8	1	98	TBC
TOTAL					**TBD**	

7.2.4 Power dissipation

Subsystem	Voltage	Average power (TBC)	Peak power / time (TBC)	Average / peak current	Remarks
MAC board DSP and logic	+ 5 V	8000 mW (TBC)	13500 mW (TBC) t = 100 ms (TBC)	1.6 A / 2.7 A (TBC)	• power peak happens during DSP boot
MAC board analogue & data converters	± 13 V	2500 mW	2500 mW	90 mA on + 13 V 77 mA on – 13 V	
SMEC board analogue electronics	± 13 V	1500 mW (TBC)	1500 mW (TBC)	58 mA on + 13 V 58 mA on – 13 V	
SMEC board PWR Amplifier	± 15 V (TBC)	45 mW on + 15V or 45 mW on - 15V	120 mW on + 15V or 120 mW on -15V t < 10 ms	3 mA 8 mA max (TBC)	• motor harness resistance at 300 K less than 600 ohms • power peak happens during acceleration of the mirror.
BSM board analogue electronics	± 13 V	1500 mW (TBC)	1500 mW (TBC)	58 mA on + 13 V 58 mA on	

				– 13 V	
BSM board PWR Amplifier	± 15 V (TBC)	150 mW on + 15V or 150 mW on - 15V	300 mW on + 15V or 300 mW on -15V t < 10 ms	10 mA 20 mA max (TBC)	• motor harness resistance at 300 K less than 600 ohms • power peak happens during acceleration of the mirror.
TOTAL		13700 mW	19420 mW		• power peaks on SMEC and MAC boards are nether at the same time.

7.3 Interfaces

7.3.1 MCU I/F with SMEC

I/F	Type	Nb. of cond.	I/O	Value	Constraints
Linear Motor Coil	analogue current	2	out	8 mA max. (TBC)	20 Ω load for total harness resistance.
	back EMF analogue voltage	2	in	10 µA max.	
Optical Encoder	Sinusoidal low level signals provided and preamplified by 3 photodiodes delivering moire fringes signals	12	in	5 µA peak (TBC)	distance from position encoder to preamplifier as short as possible.
	analogue current delivered to LED	2	out	0.5 mA DC (TBC)	
	analogue current delivered to preamplifier	2	out	200 µA DC (TBC)	
	analogue current delivered to heaters	3	out	30 µA DC (TBC)	
Temperature probe	analogue current delivered to t° probe	2	out	10 µA DC (TBC)	
	analogue t° signals provided by t° probe	2	in	TBD mV	
Home Position magneto-resistive sensors	analogue current delivered to resistors bridge	3	out	2 x 0.5 mA (TBC)	
	analogue voltage delivered by resistors bridge	2	in	+/- 50 mV	
Limit Position magneto-resistive sensors	analogue current delivered to resistors bridge	2 x 2 switches	out	0.5 mA (TBC)	
	analogue voltage delivered by resistors bridge	2 x 2 switches	in	+/- 50 mV	

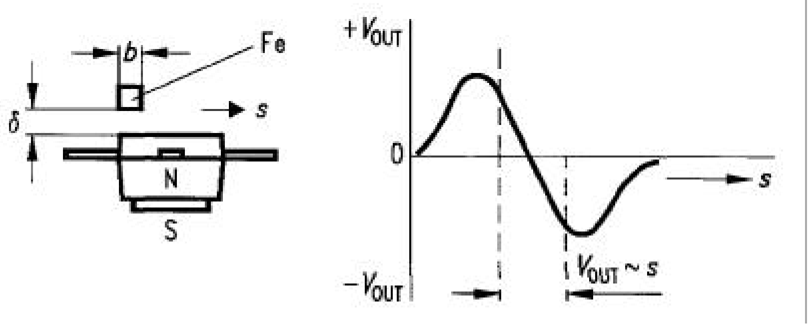
7.3.2 MCU I/F with BSM

I/F	Type	Nb.	I/O	Value	Constraints
Voice Coil Motor	analogue current	2 x 2 motors	out	20 mA max (TBC)	
Home Position magnetoresistive sensors	analogue current delivered to resistors bridge	3 x 2 bridges	out	2 x 1 mA (TBC)	
	analogue voltage delivered by resistors bridge	2 x 2 bridges	in	+/-100 mV	

Position sensor specification :

- resistance at 300K : 2 x 100 Ω nominal
- small change at 4K
- excitation current : 1 mA DC
- dissipation : 0.5 mW (constant)
- output voltage : +-0.1 V
- Hysteresis : ~ 0.05° - corrected as part of control algorithm

- Infineon (ex-Siemens) FP 212 L100-22 differential field plates sensing moving soft iron pieces
- The sensors are dual InSb/NiSb magnetoresistive elements, biased with a permanent magnet and forming part of a bridge circuit.



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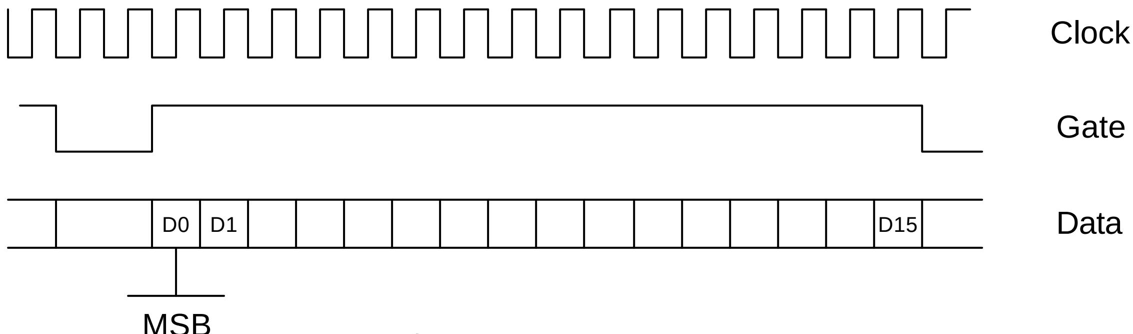
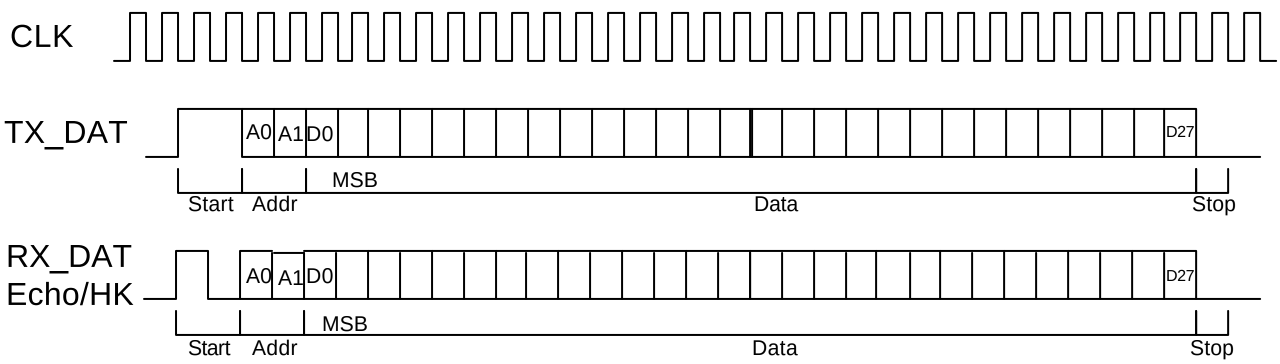
7.3.3 MCU I/F with DPU

The interface with the SPIRE DPU consists of :

- 2 synchronized serial links :
  - the command serial link for configuration order and low speed exchanges with the DPU
  - the telemetry / HK serial link for high-speed data transfer to the DPU.



High speed interface protocol



FSDPU/FSDRCU Low Speed Interface protocol

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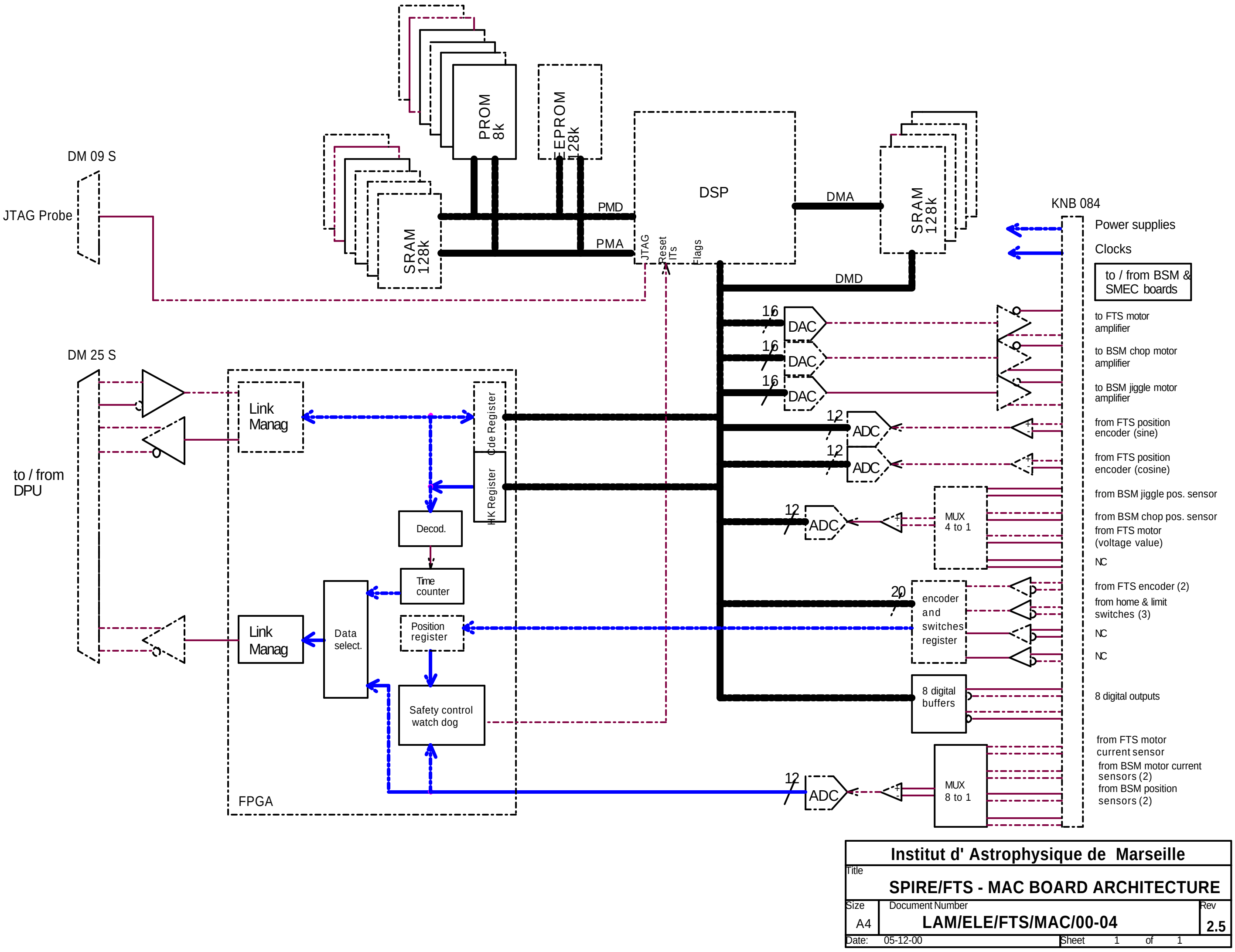
7.4 Board Design description.

7.4.1 MAC Board

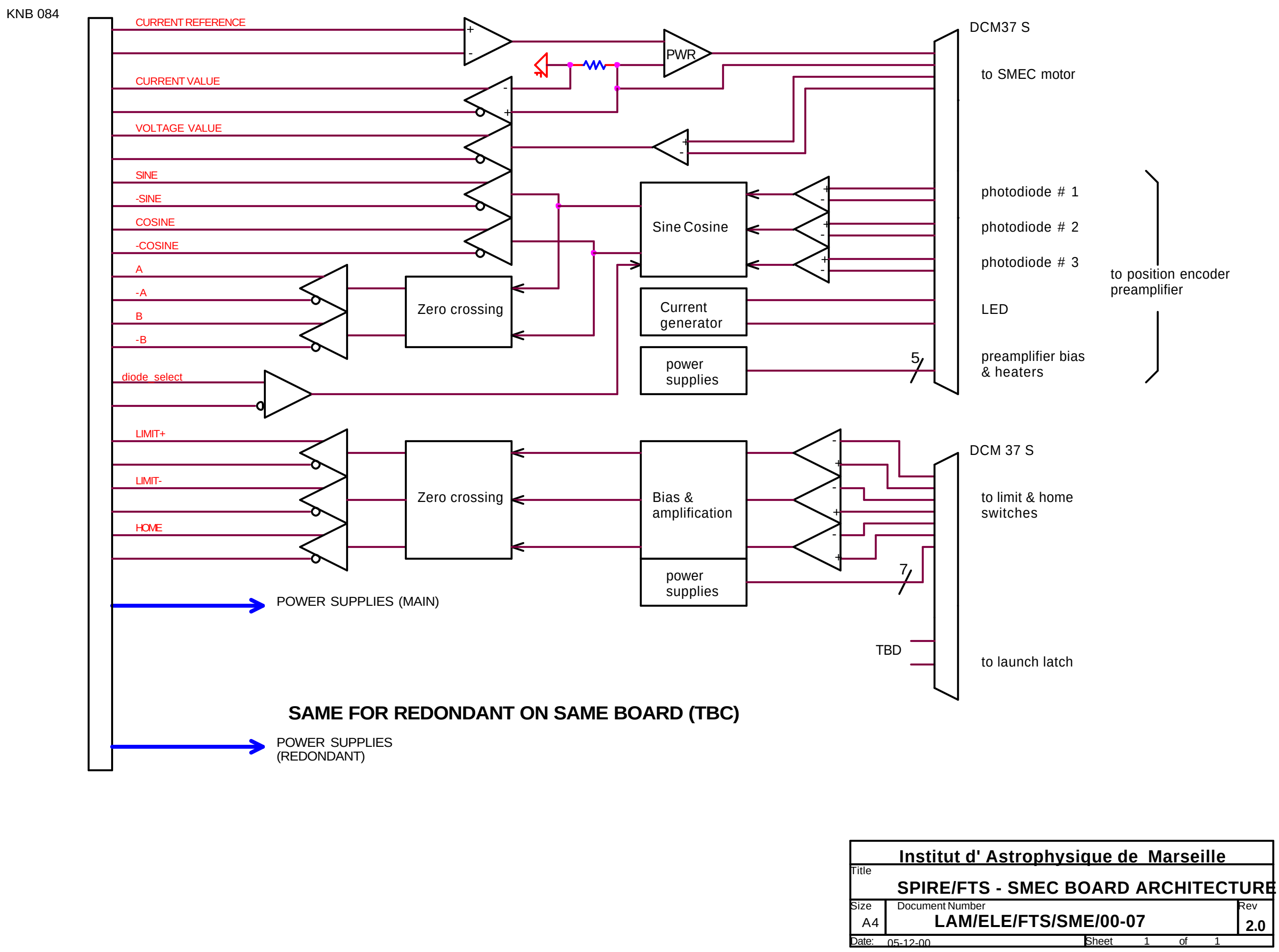


7.4.2 SMEC Board

The SMEC Board is a double europe card including all analog electronics interfacing the SMEC Subsystem. It includes:

- the motor amplifier
- the optical encoder acquisition
- the limit position sensors conditionning

Main and redundant chains are included on the same board.



7.4.2.1 MOTOR Power amplifier

The Power Amp is based on bipolar transistors (complementary pairs of 2N2905A) providing a gain of 2mA/V with abandwidth àf 3.3 kHz.

The layout is To Be inserted

7.4.2.2 Encoder acquisition electronics AND PREAMP

see SMEC Board Layout for encoder acquisition electronics.

7.4.2.2.1 Optical Encoder Preamplifier

- The preamplifier box include the two preamplifiers for main and redundant channels. It is located in the SMEC mechanism, near the position encoder heads.
- 3 TIA (IRLAB Components) with inner thermal regulation (+ 3 redundant)
- **PB: Needs 20 mn to rize from 4K to 100 K => Major issue for operations**
- 100 mwatt/TIA

7.4.3 BSM Board

- Position sensor read-out :
  - Bridge circuit with switchable DC bias,
  - Instrumentation Amplifier eg AMP 01 or OP 27,
  - Multiplexer and 12 bit A/D converter eg 9221LPRP
- Motor drive
  - Complimentary bipolar transistor pair eg 2N 5153/4 or 2N2219 / 2N 2905
- Motor Current Measurement
  - series resistor and connection to A/D converter

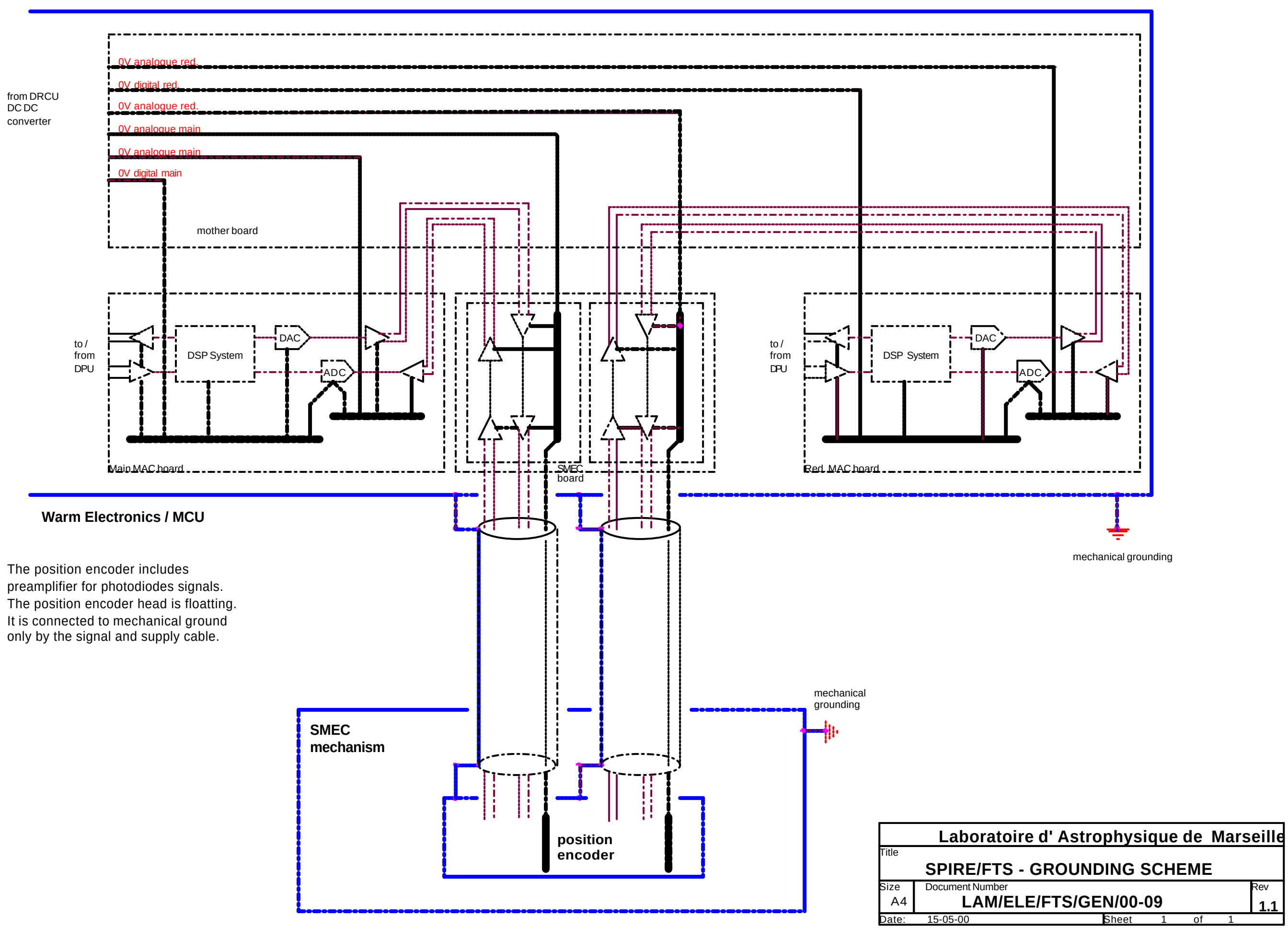
7.5 Power Supply

Subsystem	Nominal voltage	Average current	Peak current / time	Voltage stability	Voltage Noise	Remarks
MAC board DSP and logic	+ 5 V	1.6 A (TBC)	2.7 A (TBC) / 100 ms (TBC)	± 2.5 %	TBD	
MAC board analogue elec. & data converters	± 13 V	90 mA on + 15 V 77 mA on – 15 V	-	± 2.5 %	TBD	
SMEC board analogue electronics	± 13 V	50 mA on + 15 V 50 mA on – 15 V	-	± 2.5 %	TBD	includes power for preamplifiers and position encoder.
SMEC board PWR Amplifier	+/-15 V (TBC)	3 mA (TBC)	8 mA (TBC) / 50 ms (TBC)	± 5 %	TBD	motor harness resistance < 600 ohms at 300 K
BSM board analogue electronics	± 13 V	50 mA on + 15 V 50 mA on – 15 V	-	± 2.5 %	TBD	includes power for position encoder.
BSM board PWR Amplifier	+/-15 V (TBC)	10 mA (TBC)	20 mA (TBC) / 50 ms (TBC)	± 5 %	TBD	

- Two complete sets of these above power lines are needed (main power lines & redundant power lines).
- Encoder preamplifier boards (M & R) are powered by SMEC board.
- All the electrical components in the SMEC mechanism are powered by the SMEC board.
- All the electrical components in the BSM mechanism are powered by the BSM board.

7.6 Grounding Scheme.

- Motor PWR Analog ground to be added on the schematics
- The analog grounds not connected @ MCU level
- Analog/Digital grounds connected @ ADC level
- Analog ground not connected to mechanics



7.7 Use of Special Components/Component list.

See the EEE part list for the complete set of components (doc ref LAM/ELE/FTS/QUA/000201).

8 REDUNDANCY AND DEGRADED MODES

The design is oriented in order to avoid :

- single point failures by mean of dedicated redundancy,
- propagation of failures to other sub systems by mean of specific protections.

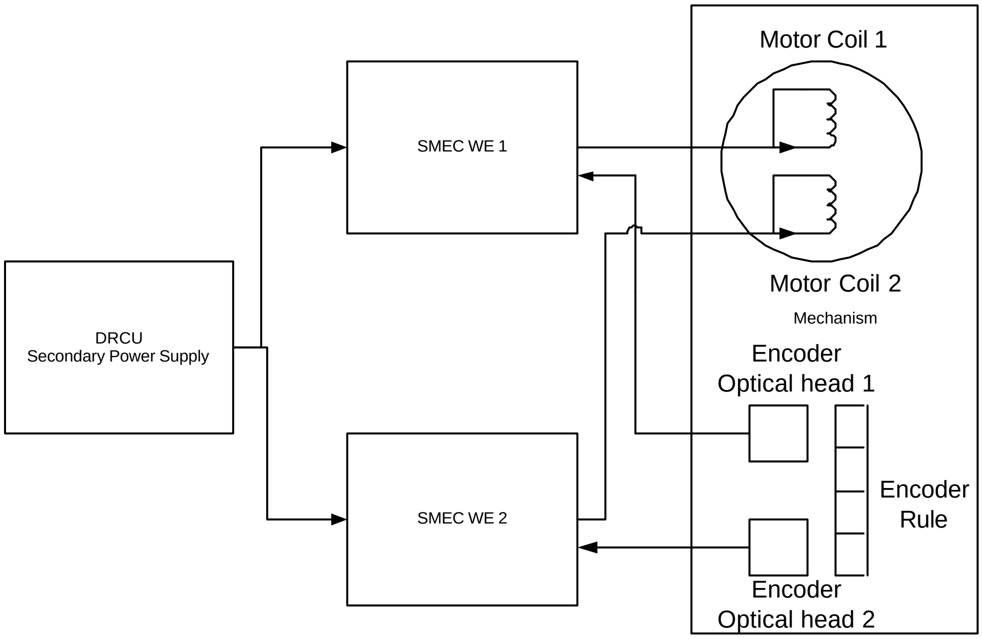
8.1 Redundancy

The SMEC Control electronics consists of 2 independent sets of boards without cross switching.
The related reliability is expressed by :

WE1.M1.OE1 + WE2.M2.OE2

Wei : FTS electronics board
Mi : motor coil
Oei : optical encoder

Note : the solution with cross switching of the components would imply non reliable complexity and single point failure with the following reliability layout : ***(WE1+WE2).(M1+M2).(OE1+OE2).Ics with*** Ics : Necessary Interface for cross switching



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8.2 Limitation of failure propagation

The limitation of the failure propagation is ensured by design as demonstrated in the following AMDEC analysis :

Subsystem/Component in failure	Event during a specific mode of operation	identification mean	Effect	Recovering Degraded mode
Interface electronics	No command can be received	the DPU has no command handshake	FTS WE out of control	
	Bad command/parameter	Checksum/No recognition of a command		Stop of the scan Status report Switch to stand-by mode waiting for another control mode operation
DSP and related interface components	Control algorithm diverging	software limits	Increase of the actuator command up to limitation	Stop of the scan Status report Switch to stand-by mode waiting for another control mode operation
	No control on the DSP	Watchdog		Emergency stop on watchdog action
Motor and related PWR amp	Short cut in the motor coil	Motor current measurement	Limitation of current value by the PWR amplifier	Use of the redundant board + motor coil.
Optical encoder and related acquisition electronics	Loss of some individual incremental pulses during closed loop operation	Difference between fiducial mark and position counter	Perturbation on the trajectory	Status report Adjust the position counter on next scan
	Total loss of incremental encoder pulses	id.	Error vs ramp reference increase -> Increase of the actuator command due to integral effect and position ramp increase -> Excessive motion speed up to speed limitation. -> Emergency stop.	Stop of the scan Status report Switch to stand-by mode waiting for another control mode operation
	Glitch on the absolute position counter (decreasing)	Additional position switch on the mechanics	The scan goes to hardware limits	Flyback operation and reset of the absolute position counter
	Glitch on the absolute position counter (increasing)	The scan ends before the nominal scan length parameter, and a difference between fiducial mark and position counter occurs at the end of flyback	The scientific scan is not achieved completely	Status report Readjust the position counter on next scan

8.3 BSM Redundancy and degraded modes

- SPIRE BSM will have 2 position sensors per axis, all permanently connected to separate analogue inputs,
- The motors will wired and driven so that failure of one coil allows operation at reduced performance

Failure Mode	Effect	Remedy	Criticality
Chop Pos Sensor 1 fails	Cannot measure Ch1 position	Use C2 pos coil	No effect
Chop Pos Sensor 2 fails	Cannot measure Ch2 position	Use C1 pos coil	No effect
Chop Drive Coil 1 fails off	Cannot move from nominal position	Use C2 drive coil on its own	Longer rise-time – lose some efficiency
Chop Drive Coil 2 fails off	Cannot move from nominal position	Use C1 drive coil on its own	Longer rise-time – lose some efficiency
Chop Drive Coil 1 fails on	Cannot move from last position	Switch off BSM controller	Cannot chop or jiggle – only scan mode
Chop Drive Coil 2 fails on	Cannot move from last position	Switch off BSM controller	Cannot chop or jiggle – only scan mode
Both Pos Sensors fail	Cannot measure position	Run open loop	Reduced accuracy of chop or jiggle – or use scan mode
Both Drive coils fail off	Cannot move from nominal position	None – 2 point failure	Cannot chop or jiggle – only scan mode
Mechanism sticks	Cannot move from last position	None	Cannot chop or jiggle – only scan mode May lose some FOV