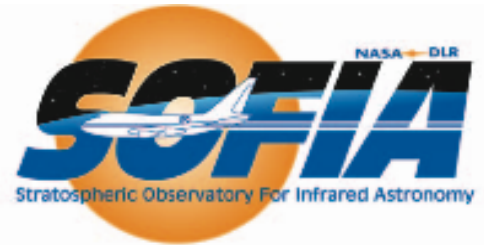


Interface Control Document

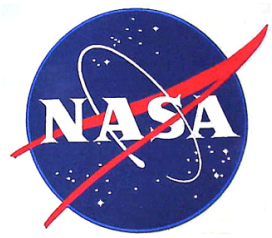
TA CHOPPER PROCESSOR / PRINCIPAL INVESTIGATOR COMPUTER DIRECT ANALOG INTERFACE

TA_SI_04

SOF-DA-ICD-SE03-038

Date: June 24, 2013

Revision: 2.1



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TA CHOPPER PROCESSOR / PRINCIPAL INVESTIGATOR COMPUTER DIRECT ANALOG INTERFACE

TA_SI_04

PREPARED BY:

Holger Jakob 4/19/2012

Holger Jakob/ DSI / Telescope Assembly Date

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TA CHOPPER PROCESSOR / PRINCIPAL INVESTIGATOR COMPUTER DIRECT ANALOG INTERFACE

TA_SI_04

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REV	DATE	DESCRIPTION	APPROVAL
Rev. 0	02/26/03	Rev. 0 of SOF-DA-ICD-SE03-038 never was issued. Rev. 0 of TA_SI_04_F was issued 26 February 2003 by releasing MAN document SOF-ICD-MG-063, titled ICD TA_SI_04, Issue 7.32, dated 14 February 2003.	Jeff Logan (USRA)
Rev. 1	05/2/11	Initial SOFIA SE&I release on OCCB-Level of the former MAN Final ICD TA_SI_04, Issue 7.32, dated 14 February 2003 (SOF-ICD-MG-063). The text of the former MAN document was carried over one-to-one, but all SOF-ICD-MG-063 document history deleted. Wording of external TTL square wave chopper synchronization signal in section 4.2.8 changed (OCCB-CCR-007) – pages 13, 14 Minor clean ups for readability and typo corrections are **NOT** denoted by vertical bars in the margin of each page	PMB
Rev. 2	4/16/12	Reassigned Chop-Cl-Out signal as Chop-Beam-Out 4.2.11, pg. 18.	PMB 4/16/2012
Rev. 2.1	6/23/13	Refined and restored requirement for 40 kHz Chop-Cl-Out signal. Clarify ambiguous, TA-centric and context-sensitive usage of “internally furnished” and “externally furnished” by adding annotation to define whether synchronization signal is furnished by TA (SCS) or SI.	PMB 6/24/2013 PRG-CCR-134

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former SOF-ICD-MG-063 into SOF-DA-ICD-SE03-038)

Table of Contents:

1 Acronyms

CIU	Cavity Interface Unit
CoG	Center of Gravity
FCM	Focus Center Mechanism
FCMU	Focus Center Mechanism Unit
FPI	Focal Plane Imager
LCU	Local Control Unit
LOS	Line of Sight
MCCS	Mission Controls and Communications System
PDU	Power Distribution Unit
PI	Principal Investigator
SI	Science Instrument
SM	Secondary Mirror
SMA	Secondary Mirror Assembly
SMCU	SM central Unit
SMM	Secondary Mirror Mechanism
SCS	Secondary Control System
TA	Telescope Assembly
TAMCP	Telescope Assembly Master Control Processor
TCM	Tilt Chopper Mechanism
TCMU	Tilt Chopping Mechanism Unit
TTL	Transistor Transistor Logic

Other acronyms used in this document are referenced in the SOFIA lexicon, PD-2009.

2 Scope

The TA chopper must provide a method to allow control of the chopper using a TTL phase input and a phase locked amplifier or an analog chopper waveform from the PI computer. This document describes the signal types, the physical connection between SI experimenters rack and SMCU and the necessary control functions.

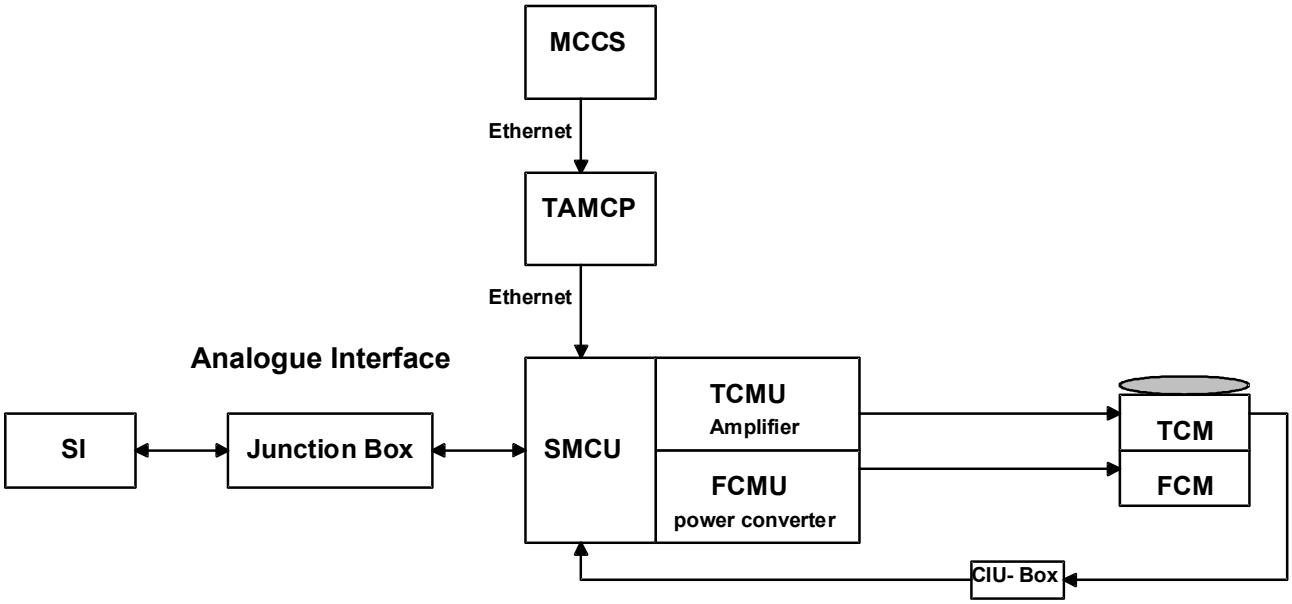

Figure 2.1: Definition of the Analog Interface within the control units for the SMA

3 Documents

3.1 General

D1	SOF-1011	SOFIA Telescope Assembly Requirements
D2	SOF-1030	SOFIA Systems Interface Requirements
D3	SOF-LIS-MG-0000.0.02	Configuration Item Data List
D4	SOF-LIS-MG-0000.0.05	Hardware Breakdown
D5	SOF-PLA-MG-0000.0.03	SRM & QA Plan
D6	SOF-PLA-MT-0000.0.04	FAR 25 Compliance Matrix
D7	SOF-SPE-MT-0000.0.01	TA Airworthiness Certification Safety and Special Factors
D8	SOF-TAN-MG-0000.0.04	Design Loads
D17	SOF-PAL-MG-0000.0.13	TA Verification Plan
D18	PD96165004-00, PA10-002	Observatory Hazard Analysis
D19	PD96100021-000, PM21	SRM&QA Plan
D20	PM12	SOFIA Observatory Integration, Test and Verification Plan

3.2 Electronics

D9	SOF-PLA-KT-0000.0.01	Software Development Plan
D10	SOF-SPE-KT-6000.0.01	Electrical Subassembly Definition and Installation Provisions
D11	SOF-SPE-KT-6000.0.02	EMC Design Specification
D12	SOF-SPE-MT-0000.0.03	TA Airworthiness Certification Design of Electric and Electronic TA Installation
D13	SOF-DF-ICD-SE03-003 (TA_AS_12)	Aircraft System / Telescope Assembly Power Interface
D14	deleted	Deleted
D15	SOF-DF-ICD-SE03-047 (TA_MCCS_F)	TA / Mission Control & Communications System (MCCS) Functional Interface
D16	SOF-DF-ICD-SE03-048 (TA_MCCS_P)	TA / Mission Control & Communications System (MCCS) Physical Interface

3.3 Reference

RD 01	PD-2003; (NASA); Feb. 1996	Interface Reference Document
RD 02	SOF-DA-ICD-SE03-007 (GLOBAL_01)	ICD – Master List
RD 03	SOF-SPE-MG-1200.0.01	Specification SMA
RD 04	SOF-SPE-MG-1220.0.01	Specification TCM
RD 05	SOF-SPE-MG-1230.0.01	Specification FCM
RD 06	SOF-SPE-MG-1240.0.01	Specification SMA LCU, Appendix 1 Software Design, Appendix 2 Electronics Design
RD 07	SOF-ICD-MG-005	Interface SMA TAMCP
RD 08	SOF-SPE-KT-1000	Telescope Optics
RD 09	SOF-DA-ICD-005 (GLOBAL_04)	Aircraft LOPA
RD 10	SOF-ICD-MG-062 (TA-SI-01)	Science Instrument Cable Interface
RD11	SOF-ICD-MG-010	TA-MG Harness / Electrical Interface
RD12	TCM Timing measurements	
RD13	SOF-DWG-MG-4300.0.00	Balancing Subassembly
RD14	SOF-DWG-MG-4300.2.72	Balancing- Mainplate Machining Cabin Side
RD15	Analog In/Out Calibration	Calibration Sheet
RD16	SOF-SPE-MG-1241.0.00	Specification Junction Box
RD17	Field Bus System	Wiring Diagrams

The given issue numbers of the above documents refer to their status at preparation of this document. Valid for the project are the latest issue of the applicable documents. However, this document will not be reissued as long as its contents are compliant also with the new issue of the applicable documents.

4 Interface Requirements

4.1 Physical

The connectors for the cables between the SI experimenters rack and the SCS are mounted in a junction box which is mounted on the front surface of the Counter Weight Plate. The Secondary Control System SCS is located at the flange assembly of the TA near the balancing system. In this position close to the SI the junction box will be part of the SCS. The following physical requirements are valid for the junction box connection.

4.1.1 Overview Junction Box

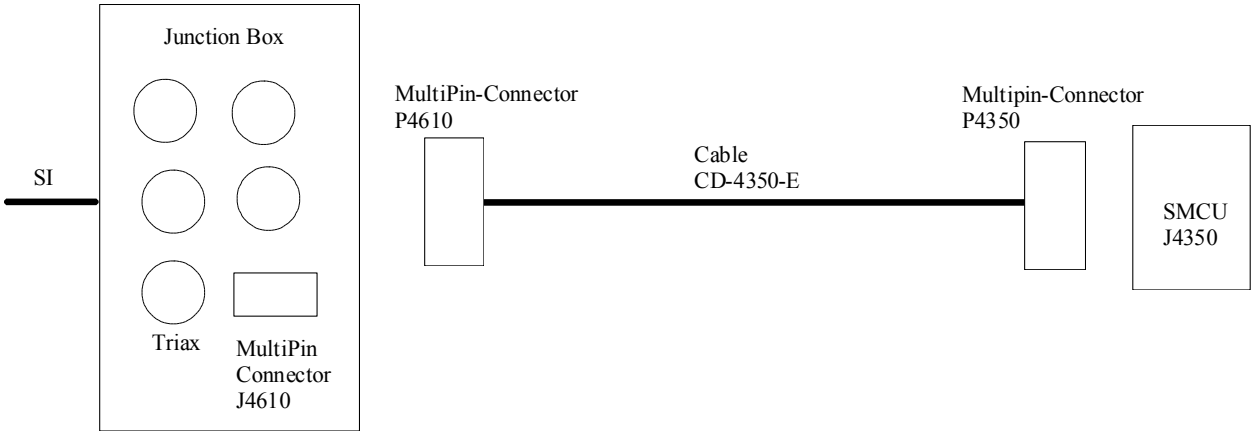

Figure 4.1: Connection SMCU - Junction Box in principle

The drawing above gives a schematic overview on the physical part of the analog interface between the SMCU and the scientific instrumentation. The SMCU is furnished with the multi pin socket J4350. The cable CD-4350-E consists of 22 single cables and an overall screen. The multi pin connector and the triax sockets are arranged on the front of the junction box. The junction box is a closed box made of Aluminum. Inside the junction box the pins of J4610 are connected with the Triax sockets.

Site of Junction Box: on Balancer Counter Weight Plate, see Figure 8.2 , RD13, RD14

Connector Pin Layout: see RD17 for connectors J4610, P4610, P4350 and J4350 and Table 8.1-1 in Section 8 for the Triax connectors in the Junction Box.

Cable: see RD11, CD-4350, and RD17 and RD11

Signal types: analog: ±10 V; recommended signal receivers: differential amplifier
TTL: optically isolated, powered from SCS For details see RD06, Appendix „Electronics Design Report“

4.2 Functional

4.2.1 Coordinate system for chopper analog signals

The SMA coordinate system is defined in the SMA specification SOF-SPE-MG-1200, chapter 5.1, see RD 03.

4.2.2 Analog waveform output axis R (Analog –R-Out)

The analog waveform output axis R represents the actual measured angle about the SMA R axis. It is an analog signal transformed from sensor signals. The 3 sensors are assigned to the 3 chopper actuators and located in the TCM between SM and chopper base in a 120° configuration around the T (LOS) axis. The signal represents the actual angle between chopper base and SM in the SMA local φ_R coordinate. Offsets performed with the FCM are not included.

Source: SMCU

Scale: 124.8 arcsec / volt

Upper Range: 1123 arcsec mirror space = 9.0 V

Lower Range: -1123 arcsec mirror space = -9.0 V

Calibration: RD15

Resolution: 0.206 arcsec (≥14bit) mirror angle

Accuracy: The above scale for a given output voltage gives a mirror angle within 10% of the actual Secondary Mirror angle about the R axis.

4.2.3 Analog waveform output axis R without FBC components (R-FBC-Out)

The FBC control (input) signal is subtracted from the signal described above under 4.2.2. The result is called „Analog waveform output axis R without FBC components“. The FBC signal is defined in SOF-ICD-MG-064. Description and specifications of the analog waveform output axis R (4.2.2) apply also for this signal:

Source: SMCU

Scale: 124.8 arcsec / volt

Upper Range: 1123 arcsec mirror space = 9.0 V

Lower Range: -1123 arcsec mirror space = -9.0V

Calibration: RD15

Resolution: 0.206 arcsec (≥14bit) mirror angle

Accuracy: The above scale for a given output voltage gives a mirror angle within 10% of the actual minus the FBC Secondary Mirror angle about the R axis.

4.2.4 Analog waveform output axis S (Analog-S-Out)

The analog waveform output axis S represents the actual measured angle about the SMA S axis. It is an analog signal transformed from sensor signals. The 3 sensors are assigned to the 3 chopper actuators and located in the TCM between SM and chopper base in a 120° configuration around the LOS axis. The signal represents the actual angle measured between chopper base and SM in the SMA local φ_S coordinate. Offsets performed with the FCM are not included.

Source: SMCU

Scale: 124.8 arcsec / volt

Upper Range: 1123 arcsec mirror space = 9.0 V

Lower Range: -1123 arcsec mirror space = -9.0 V

Calibration: RD15

Resolution: 0.206 arcsec (≥14bit) mirror angle

Accuracy: The above scale for a given output voltage gives a mirror angle within 10% of the actual Secondary Mirror angle about the S axis.

4.2.5 Analog waveform output axis S without FBC components (S-FBC-Out)

The FBC control (input) signal is subtracted from the signal described above under 4.2.4. The result is called „Analog waveform output axis S without FBC components“. The FBC signal is defined in SOF-ICD-MG-064. Description and specifications of the analog waveform output axis S (4.2.4) apply also for this signal:

Source: SMCU

Scale: 124.8 arcsec / volt

Upper Range: 1123 arcsec mirror space = 9.0 V

Lower Range: -1123 arcsec mirror space = -9.0 V

Calibration: RD15

Resolution: 0.206 arcsec (≥14bit) mirror angle

Accuracy: The above scale for a given output voltage gives a mirror angle within 10% of the actual minus the FBC Secondary Mirror angle about the S axis.

4.2.6 Analog command (Reference waveform profile) axis R (Analog-R-In)

The reference waveform profile axis R is an analog signal and represents the commanded angle between chopper base and SM in the SMA local φ_R coordinate. The signal is the counterpart to the analog waveform output axis R. Offsets performed with the FCM are not included.

Source:	PI Station
Scale:	124.8 arcsec / volt
Upper Range:	1123 arcsec mirror space = 9.0 V
Lower Range: -	1123 arcsec mirror space = -9.0 V
Calibration:	RD15
Resolution:	0.206 arcsec (≥14bit) mirror angle
Accuracy:	The actual Secondary Mirror angle about the R axis is within 10% of the angle as defined by the above scaling law for a given input voltage or 2 arcsec mirror angle, whichever is greater.

4.2.7 Analog command (Reference waveform profile) axis S (Analog-S-In)

The reference waveform profile axis S is an analog signal and represents the commanded angle between chopper base and SM in the SMA local φ_S coordinate. The signal is the counterpart to the analog waveform output axis S. Offsets performed with the FCM are not included.

Source:	PI Station
Scale:	124.8 arcsec / volt
Upper Range:	1123 arcsec mirror space = 9.0 V
Lower Range:	-1123 arcsec mirror space = -9.0 V
Calibration:	RD15
Resolution:	0.206 arcsec (≥14bit) mirror angle
Accuracy:	The actual Secondary Mirror angle about the S axis is within 10% of the angle as defined by the above scaling law for a given input voltage or 2 arcsec mirror angle, whichever is greater.

4.2.8 External (SI-provided) TTL square wave chopper synchronization signal (Chop-Sync-In)

As an alternative to the analog reference waveform profiles R and S from the PI station, all parameters, except frequency, for square wave chopping (including the identification of whether a 2-point chop or 3-point chop is desired) can be set through the MCCS (see D15), and an external TTL square wave signal sent to the SCS via the SI/SMA interface to synchronize either a 2-point or 3-point chop. In the 2-point chop mode, the frequency of this TTL input shall be between or equal to 0.5 Hz and 20 Hz. In the 3-point chop mode, the frequency of this TTL input shall be between or equal to 1 Hz and 40 Hz. Note, for the 3-point chop, the TTL input has twice the frequency of the chop waveform.

Figure 4.2 (for 2-point chop) and Figure 4.3 (for 3-point chop) show how the TTL input synchronizes the chop waveforms after every start or re-start of the TCM synchronization.

For the 2-point chop mode, the high and low state of the TTL square wave is directly related to the two chop positions of the TCM.

Figure 4.2 depicts typical 2-point chop waveforms for the SI-provided external TTL input and the response in the R-axis analog output when chopping at an angle of zero degrees. The high state of the TTL square wave signal corresponds to the high signal level of the analog waveform output under the following conditions:

(1) if the chop angle is set to 0 degree the response is in the R axis,

(2) if the chop angle is set to 90 degree the response is in the S axis.

The chop angle can be set through the MCCS (see D15). The low state of the TTL respectively will move the TCM to the other chop position and during the transition the analog waveform output will respond with a falling edge. Other chop angle orientations may lead to transitions in the negative sense of the analog waveform output.

For the 3-point chop mode (see Figure 4.3) the rising OR falling edge of the TTL square wave will trigger the next edge of the chop waveform (either rising OR falling).

Figure 4.3 shows that the TTL signal has a 180 degrees phase ambiguity for the 3-point chop. The analog outputs described in 4.2.3 and 4.2.5 can be used to monitor this phase degeneracy.

Signal source: PI Station

Signal type: TTL

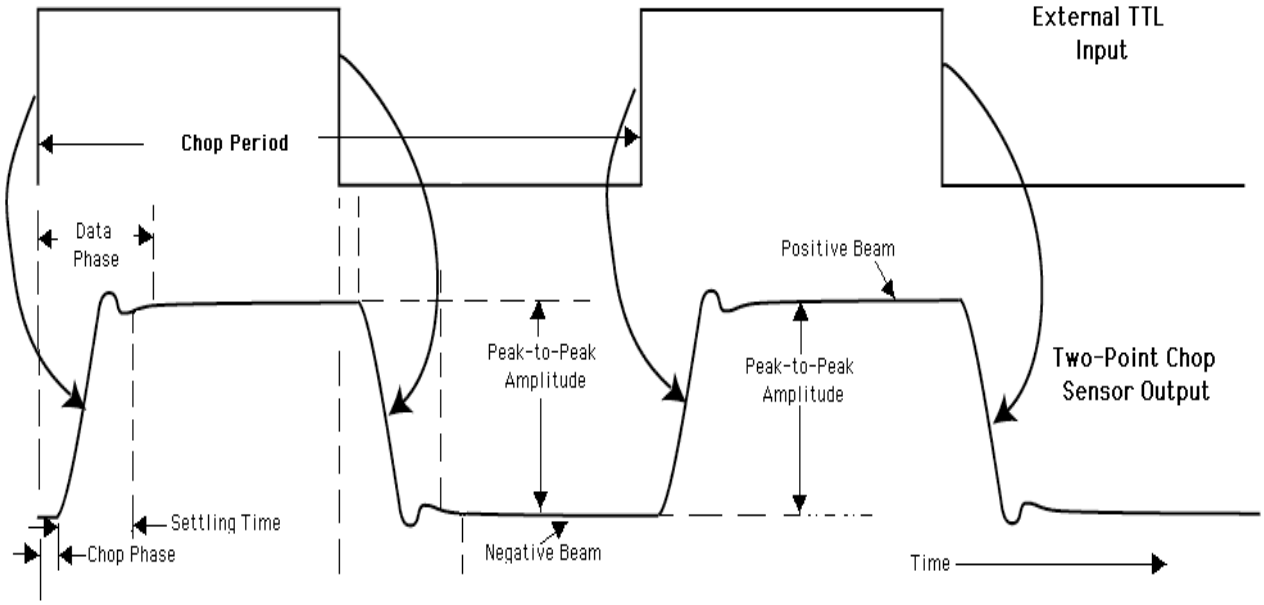

Figure 4.2: External Synch for 2-point Chop

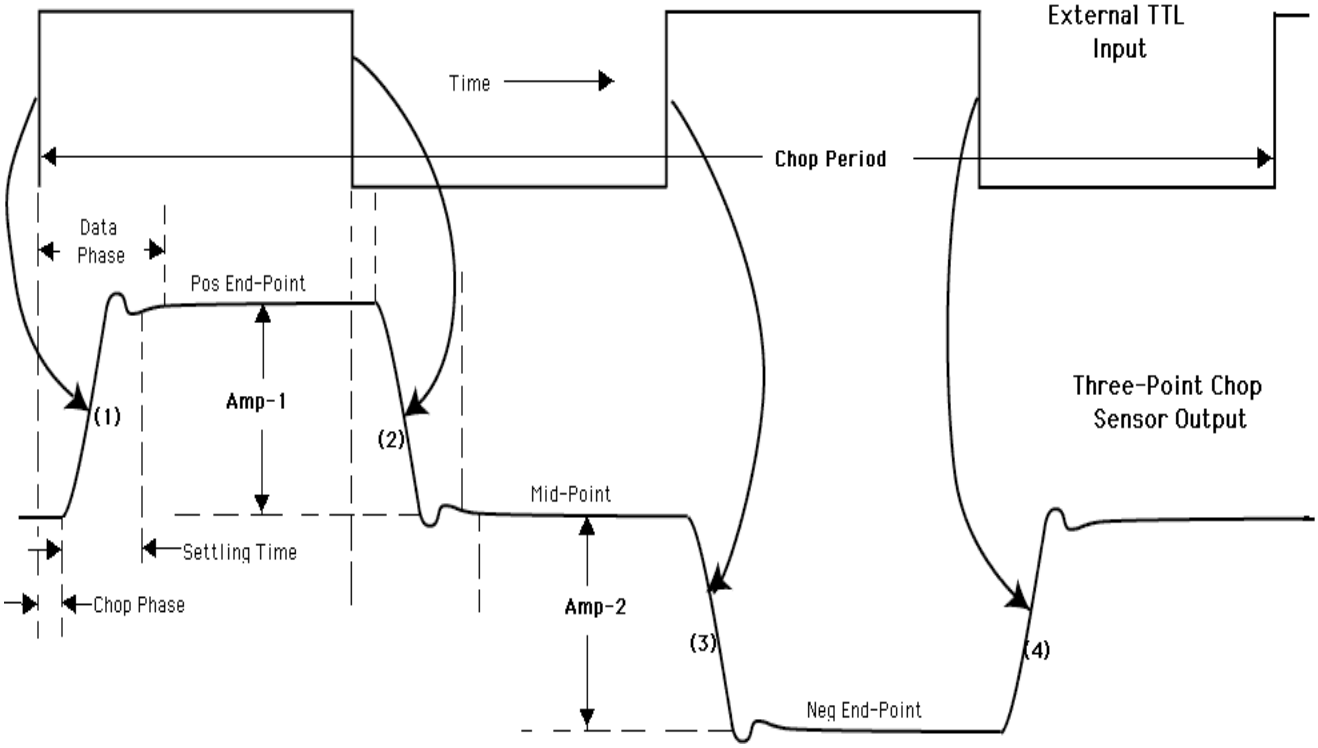

Figure 4.3: External Synch for 3-point Chop

4.2.9 Synchronization reference TTL square wave signal (Chop-Sync.-Out)

The Synchronization Reference TTL signal is a TTL square wave signal representing the chopper synchronization signal, whether or not it is furnished externally (i.e., by SI) or internally (i.e., by TA SCS).

Source: SMCU

Signal type: TTL

4.2.9.1 Chop Synchronization furnished externally (by SI)

When the synchronization is furnished externally by an SI, there are two Opto couplers, two Digital IO boards and a waveform generator between the TTL sync IN and TTL Ref OUT (see figure below).

The rise time of the Opto couplers is not negligible but it is stable. The delay of the Digital IO board is stable and small. There is a < 250 µsec jitter due to bad synchronization between the waveform generator and the input TTL sync signal due to the 4 kHz update rate of the SCS. This 4 kHz update rate represents the decimated SCS master clock.

The timing response can be described as follows:

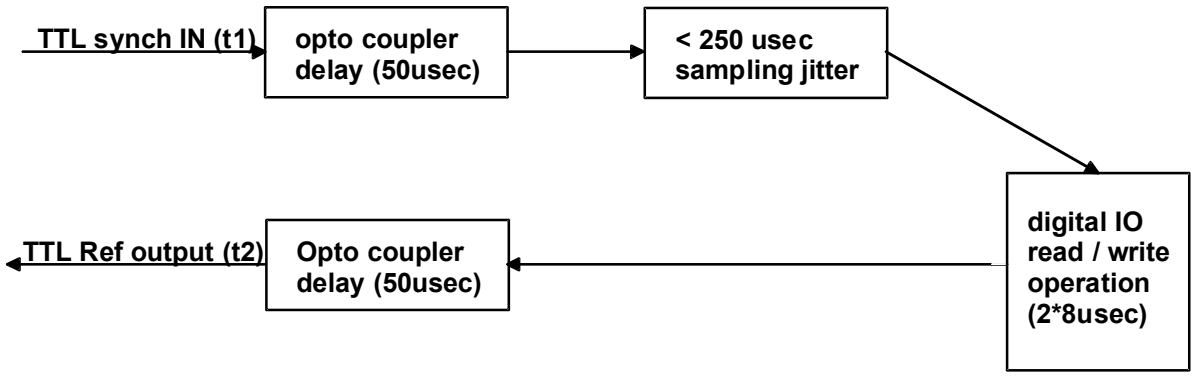

Figure 4.4: Timing

The moment between the TTL sync IN arises (t1) and the moment it is copied as an ouput to the ref TTL output (t2) is given as follows:

116 µseconds < t2 – t1 < 366 µseconds

4.2.9.2 Chop Synchronization furnished internally (by the TA SCS)

When the synchronization is furnished internally by the TA SCS, there is only one Opto coupler and one Digital IO board between the TTL sync of the chop and TTL Ref Out.

The rise time of the Opto coupler is not negligible but it is stable. The delay of the Digital IO board is stable and small.

The moment between when the internal TTL sync is generated within the SCS (t1) and the moment it is copied as an ouput to the ref TTL output (t2) is given as follows:

t2 – t1 = 58 µseconds

4.2.10 Chop phase reference output TTL square wave signal (Chop-Phase-Out)

Chop phase angle Θ is defined as the time lag or lead between the internal chop sync state transition or the external TTL square wave chopper synchronization signal (4.2.8) state transition and the onset point of the actual chop throw. Any other suitable stable reference point on the mirror position waveform can be used as the phase marker for testing purposes.

The chop phase reference output is a TTL-based square wave signal, provided for use by investigators as an adjustable chop phase reference for data-taking initiation. The signal shall be phase adjustable with regard to the sync-ref signal (4.2.9) and the phase angle difference between these two signals shall be defined as θ_{ref} (see D1, DCR0106R1, Fig 4b). This phase angle θ_{ref} can be adjusted by the chopper electronics via the parameter TCM_DES_PHASE from the MCCS (see D15). The chop phase adjustment requirement only applies to the internal-sync and external-sync modes of chopper operation.

Source: SCS

Signal Type: TTL

Adjustment range: ±180° in steps of ≤ 1°

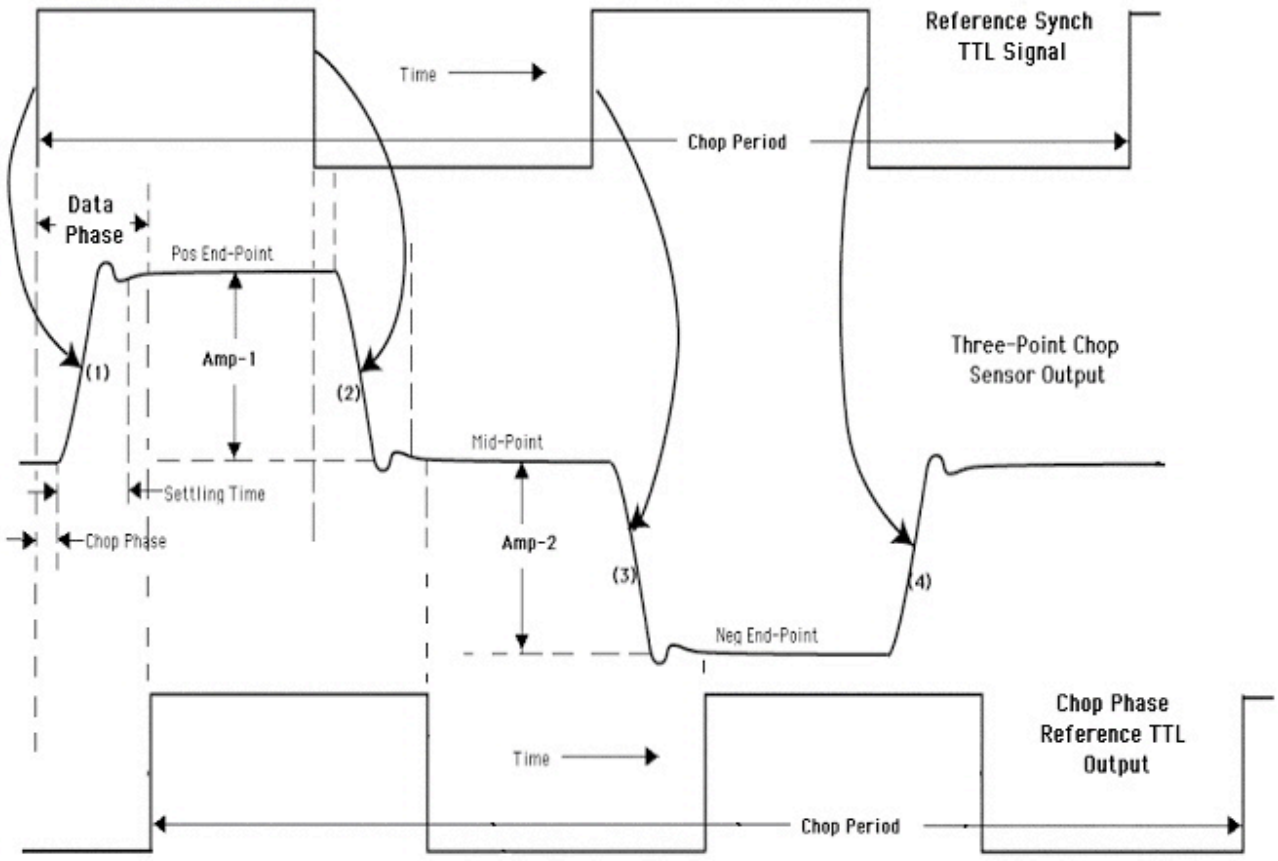

Figure 4.5: Chop Phase Reference for 3-point Chop

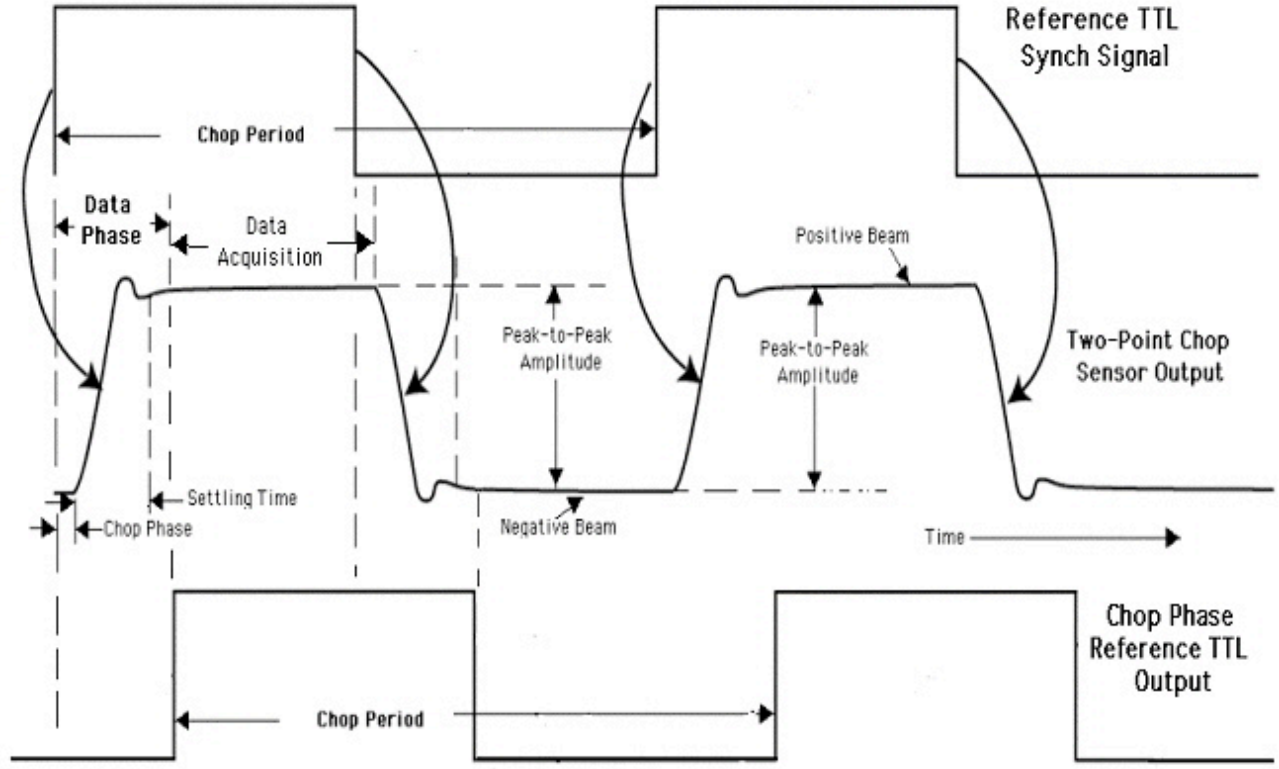

Figure 4.6: Chop Phase Reference for 2-point Chop

4.2.11 Chopper control clock signal (Chop-CI-Out)

A 40 kHz TTL signal with the same phase and frequency as the SCS master clock shall be provided tothe PI station / SIs.

Source:	SCS	Frequency:	40 kHz
Signal Type:	TTL	Destination:	SI

4.2.12 Timing Diagram

A timing diagram to illustrate the relationship between the TTL sync signal and the initiation of a chopper transition can be found in the RD06, Appendix „Electronics Design Report“.

4.2.13 TTL 5VCC (TTL 5VDC)

The TTL 5VCC_pos and TTL 5VCC_neg lines represent the output of the SMA-provided 5V power supply for use with the “open collector” TTL input and TTL output channels (see RD 06, “Appendix 2: Electronics Design”).

4.3 Environmental

Cabin environment in accordance with ICD TA_MCCS_P

4.4 Safety

This ICD does not contain interface design information attributed to the design control of hazards identified in PD96165004-000 (PA10-002, The Observatory Hazard Analysis).

See D7, D11, D12

5 Notes

5.1 Tradeoffs between chop throw and chop offset

The following ranges for chop amplitude and offset performed with the TCM are defined in SOF-1011, 3.3.14.3. :

- amplitude up to 10 arcmin peak to peak object space
- offset up to 5 arcmin in object space with amplitude reduced correspondingly

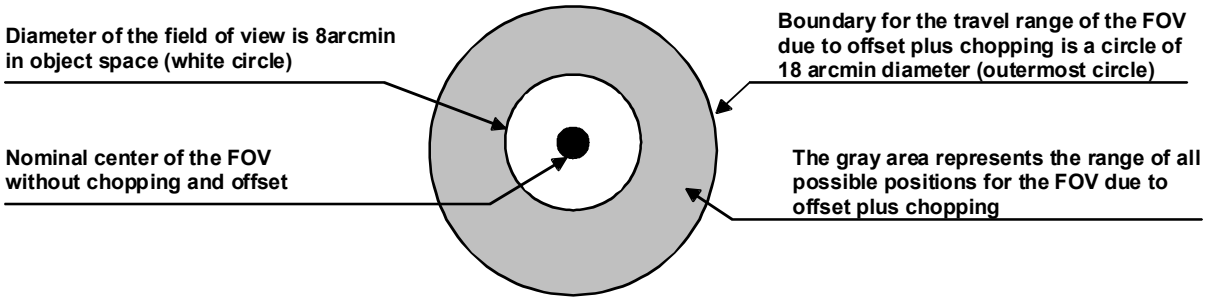

Figure 5.1: Range of the FOV for offset plus chopping

The figure explains the range for offset and chopping with the TCM. A cross section of the cone forming the optical path is displayed.

Chop offset can be performed with the TCM or the FCM. The hexapod of the FCM allows angular motions with the same pivoting point as the TCM (CoG of SM plus moving interface parts). Part of the angular motion range is necessary to compensate for mechanical tolerances during manufacturing and mounting of the SMA. Another part can be used to perform a slow motion offset. The total range of ±30 arcmin mirror angle can be split between the two functions. The max. achievable speed is about 0.3 degree/second. Note that TCM sensors do not recognize the FCM offset. The FCM offset therefore is independent from TCM offset and can only be controlled, commanded and measured via the MCCS.

5.2 Command and data element lists

Command and data element definitions for digital control of the SMA via MCCS are part of the interface document TA_MCCS_F, see D15.

5.3 Angle Conversion Factor

The mirror angle to object space angle conversion factor for the SOFIA F/20 system is approximately 3.74:1.

6 Quality Assurance

Quality Assurance will verify each hardware interface to the drawing, and participate in testing by reviewing and verifying plans and procedures; witnessing tests; and approving reports in accordance with PD96100021-000 (PM21), for the USRA side of the ICD, and SOF-PLA-MG-0000.0.03, Safety, Reliability, Maintainability and Quality Assurance (SRM & QA) Plan, for the TA consortium MG-KT-MT side of the ICD, respectively.

7 Verification

Verification plan for this interface is documented in PM12, SOFIA Observatory Integration, Test and Verification Plan, for the USRA side of the ICD, and in SOFIA TA Verification Plan, SOF-PLA-MG-0000.0.13, for the TA consortium MG-KT-MT side of the ICD, respectively.

8 Appendix

8.1 The SI/SMA Interface Junction Box (see also RD16, RD17)

J4611	BJ73 (Triax)	1	Chop_CI_Out	Junction Box	Female
		Shield 1	Chop_CI_GND		
		Shield 2	Global_Shield		
J4612	BJ73 (Triax)	1	Chop_Sync_In	Junction Box	Female
		Shield 1	Chop_Sync_In_GND		
		Shield 2	Global_Shield		
J4613	BJ73 (Triax)	1	R_FBC_Out	Junction Box	Female
		Shield 1	R-FBC_Out_GND		
		Shield 2	Global_Shield		
J4614	BJ73 (Triax)	1	S_FBC_Out	Junction Box	Female
		Shield 1	S_FBC_Out_GND		
		Shield 2	Global_Shield		
J4615	BJ73 (Triax)	1	Analog_R_In	Junction Box	Female
		Shield 1	Analog_R_In_GND		
		Shield 2	Global_Shield		
J4616	BJ73 (Triax)	1	Analog_S_In	Junction Box	Female
		Shield 1	Analog_S_In_GND		
		Shield 2	Global_Shield		

J4617	BJ73 (Triax)	1	Analog_R_Out	Junction Box	Female
		Shield 1	Analog_R_Out_GND		
		Shield 2	Global_Shield		
J4618	BJ73 (Triax)	1	Analog_S_Out	Junction Box	Female
		Shield 1	Analog_S_Out_GND		
		Shield 2	Global_Shield		
J4619	BJ73 (Triax)	1	Chop_Phase_Out	Junction Box	Female
		Shield 1	Chop_Phase_GND		
		Shield 2	Global_Shield		
J4620	BJ73 (Triax)	1	Chop_Sync_Out	Junction Box	Female
		Shield 1	Chop_Sync_Out_GND		
		Shield 2	Global_Shield		
J4621	BJ73 (Triax)	1	TTL5VCC_pos	Junction Box	Female
		Shield 1	TTL5VCC_ret		
		Shield 2	Global_Shield		

Table 8.1: Plug and socket layout of the Junction Box

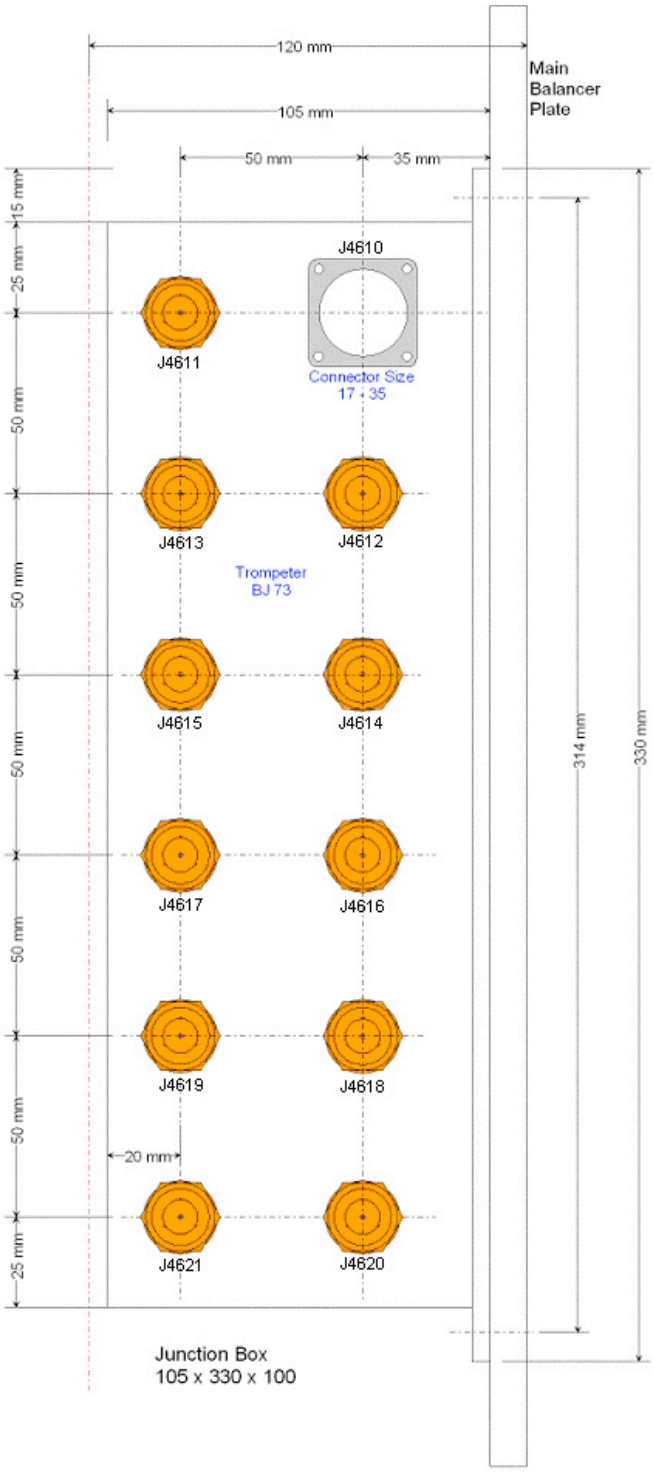

Figure 8.1: Side View of Junction Box

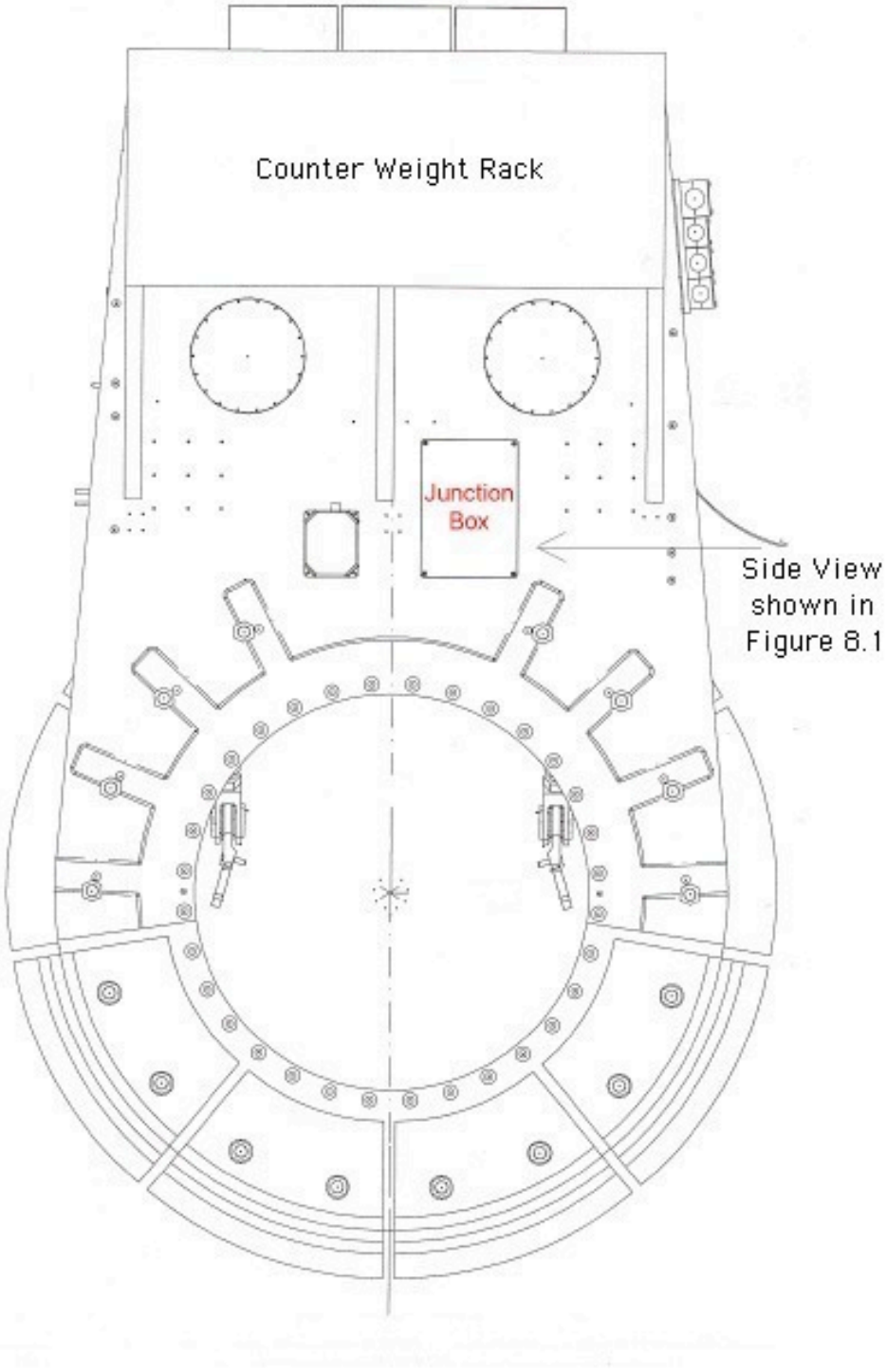

Figure 8. 2: Location and orientation of the Junction Box (see also RD13, RD14)