THE SUPERCAM ARRAY AT APEX:

INTERFACE CONTROL DOCUMENT

Version *2.0*

12 October 2014

VERSION HISTORY

Version #	Implemented By	Revision Date	Approved By	Approval Date	Description of Changes
1.0	*Craig Kulesa*	*16 July 2014*			*First complete draft*
1.1	*Craig Kulesa*	*17 July 2014*			1. Typographic edits 2. Added 10 MHz reference 3. Added timing interfaces
1.2	*Craig Kulesa*	*31 July 2014*			1. First draft of changes reflecting discussion at site visit, up to Software Section.
1.3	*Craig Kulesa*	*31 July 2014*			1. Added brief section on UPS 2. ARTEMIS helium lines
1.4	*Craig Kulesa*	*4 Aug 2014*			1. Edited software section based on 31 July discussion 2. Edited Figure 1.1 to eliminate Arizona A-cabin pickoff 3. Edited roles per discussion 4. Numerous small edits
1.5	*Craig Kulesa*	*24 Aug 2014*			1. CTI compressor is actually single phase (all 3 phases go into the compressor but one leg is unused internally). 2. First edit of software section based on initial email discussion w/ Dirk Muders.
1.6	*Craig Kulesa*	*7 Sept 2014*			1. Updated mechanical section including ICD and C-cabin installations (some contributions from Ruben and Paul).
1.7	*Craig Kulesa*	*19 Sept 2014*			1. Updated mechanical section with integrated FEA and thread analysis (RD and CK) 2. Updated electrical section including documentation of UPS module, power distribution and control, and transformer. (CK) 3. Updated software section, command and control, data calibration and processing. (CK and BP)
2.0	*Craig Kulesa*	*12 Oct 2014*			Minor tweaks following discussions. Completed summary table of interface descriptions. FINAL DRAFT.

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1 OVERVIEW

1.1 SCOPE AND PURPOSE OF THIS DOCUMENT

This ICD aims to document and track the information required to define the Supercam system interface to the APEX telescope. It will relate inputs and outputs from Supercam for all potential actions. This will give all parties guidance on the architecture of the system to be integrated in November 2014, and help ensure compatibility between system components. A **Q** emblem identifies critical questions that still needs to be addressed.

1.2 DESCRIPTION OF INSTRUMENT PACKAGE

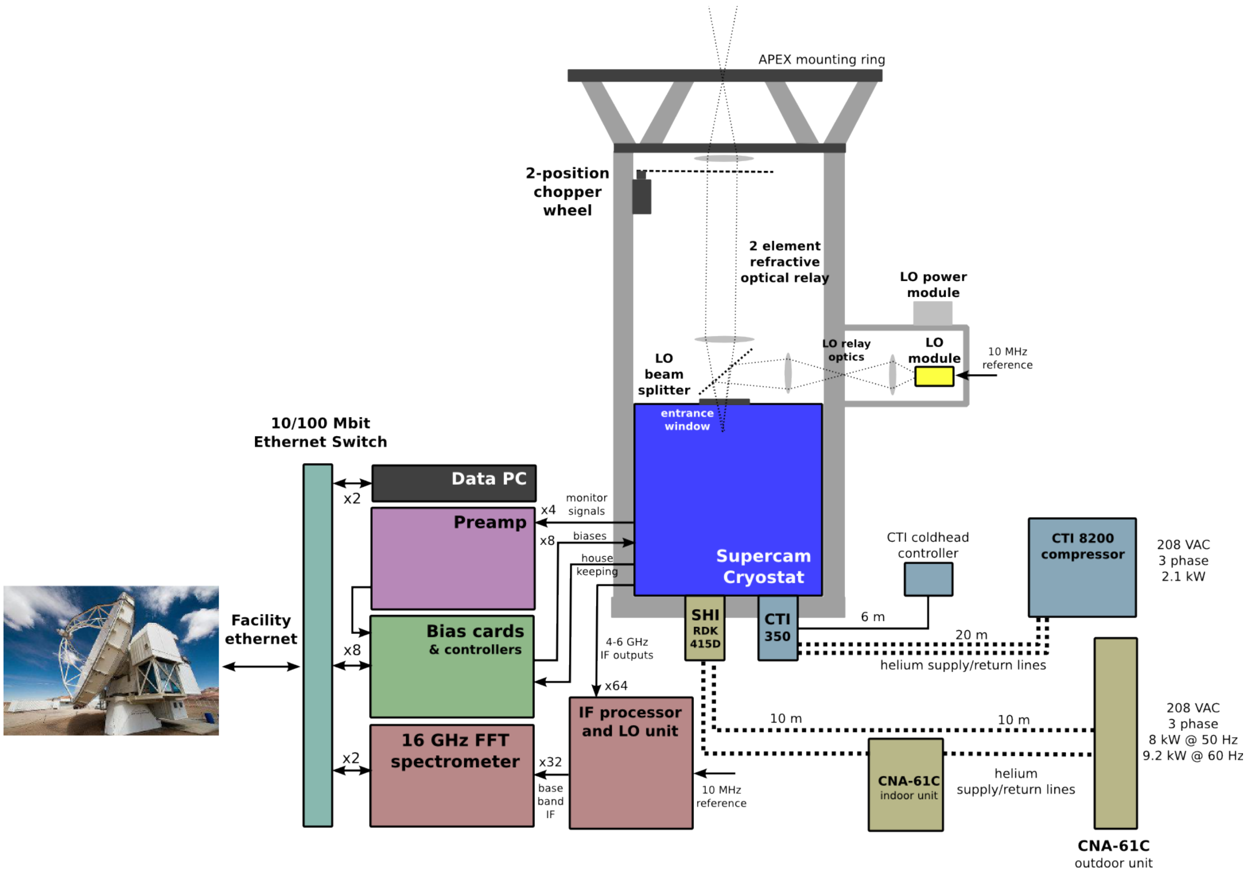

Figure 1.1: Overall block diagram of the Supercam instrument on APEX

Supercam is a 64-beam heterodyne array that operates between 300 and 400 GHz, though the power output of the current Local Oscillator (LO) restricts this range to 330-365 GHz. The baseline operating mode will observe the ^{12}CO J=3-2 line at 345.795 GHz in the upper sideband (USB). The focal plane is comprised of eight integrated blocks each with 8 feedhorns, mixers and low noise amplifiers (LNAs), cooled to ~5K through a Giffords-McMahon (GM) closed cycle cryocooler. 64 stainless-steel coaxial cables bring out the mixer IFs and are precooled to 15K with a second GM cryocooler. The 4-6 GHz IF outputs are passed first to IF processor modules and then to a digital FFT spectrometer. The IF processor filters, amplifies, and downconverts the 5 GHz IF to baseband. Bias voltages for each mixer's SIS device, electromagnet, and LNA are provided by 8-channel bias cards mounted in a half-height rackmount chassis adjacent to the cryostat. All voltages in the cryostat are monitored by the bias cards' macrocontrollers; isolation and noise reduction for returning signals is provided by a preamplifier between the bias cards and the cryostat. The instrument is remotely controlled via TCP socket servers over ethernet.

An overview of the instrument and its APEX interfaces is shown in in Figure 1.1.

2 MECHANICAL INTERFACE

2.1 CRYOSTAT AND OPTICAL FRAME

Supercam will install to the APEX standard mounting ring (the invar ring) at the top of the Cassegrain Cabin (C-cabin). While a floor support is shown in current drawings, it does not provide significant structural support. The baseline development plan leaves the **LABOCA M3 mirror in place and undisturbed**; a protective table will be installed over the mirror to help support the cryostat during installation and can support the instrument support electronics during operation. The baseline plan also permits **manual operation of the A/B/C cabin swing arm assembly** at zenith only and under physical supervision, as at least one Supercam mechanical support must be removed to allow the arm to swing into position. Utilization of the A-cabin will be explicitly supported in November, and B-cabin operation can be supported beyond that timescale if requirements are requested well in advance.

Design Principles

The Supercam mechanical support system is comprised of four assemblies:

1. An octopod open structure using fixed supports, extending from the APEX invar mounting ring to a smaller-diameter Secondary Mounting Ring that directly supports the instrument. This Secondary Mounting Ring decouples the location of dewar supports from mounting points available on the APEX invar ring, as the two are not naturally coincident.
2. A substantial U-shaped support structure that holds the cryostat in place using four main supports that allow operation of the APEX A/C cabin optical swing arm assembly. These supports provide distributed support to the Supercam secondary ring and crucial rigidity at all zenith angles. One support can be removed for installation of the instrument and for operation of the APEX swing arm. The removable support will **only** be removed at the stow position and **only** for brief operation of the swing-arm.
3. An extruded aluminum subframe that directly attaches to the cryostat to provide mounts for all Supercam optical elements (sky beam reimaging lens, Local Oscillator (LO) imaging lenses, LO mount).
4. An M3 Protection Table to be initially installed to allow work on Supercam without impact to the LABOCA M3 mirror. It will also be used for mounting of the Supercam IF system and to provide staging support for the cryostat during its installation into the U-mount.

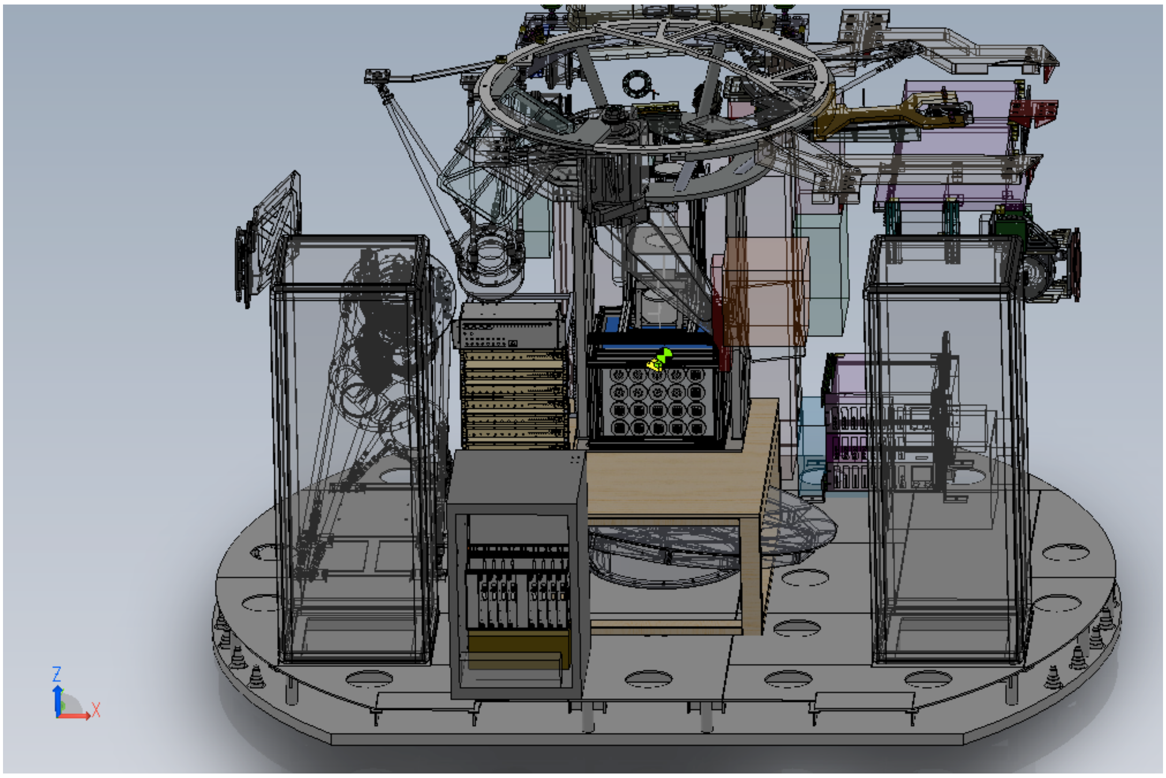

Figure 2.1: Diagram of Supercam installed into the APEX C-cabin. The cryostat is supported from above via the U-mount and Secondary Mounting Ring, and its supporting electronics are attached to the floor.

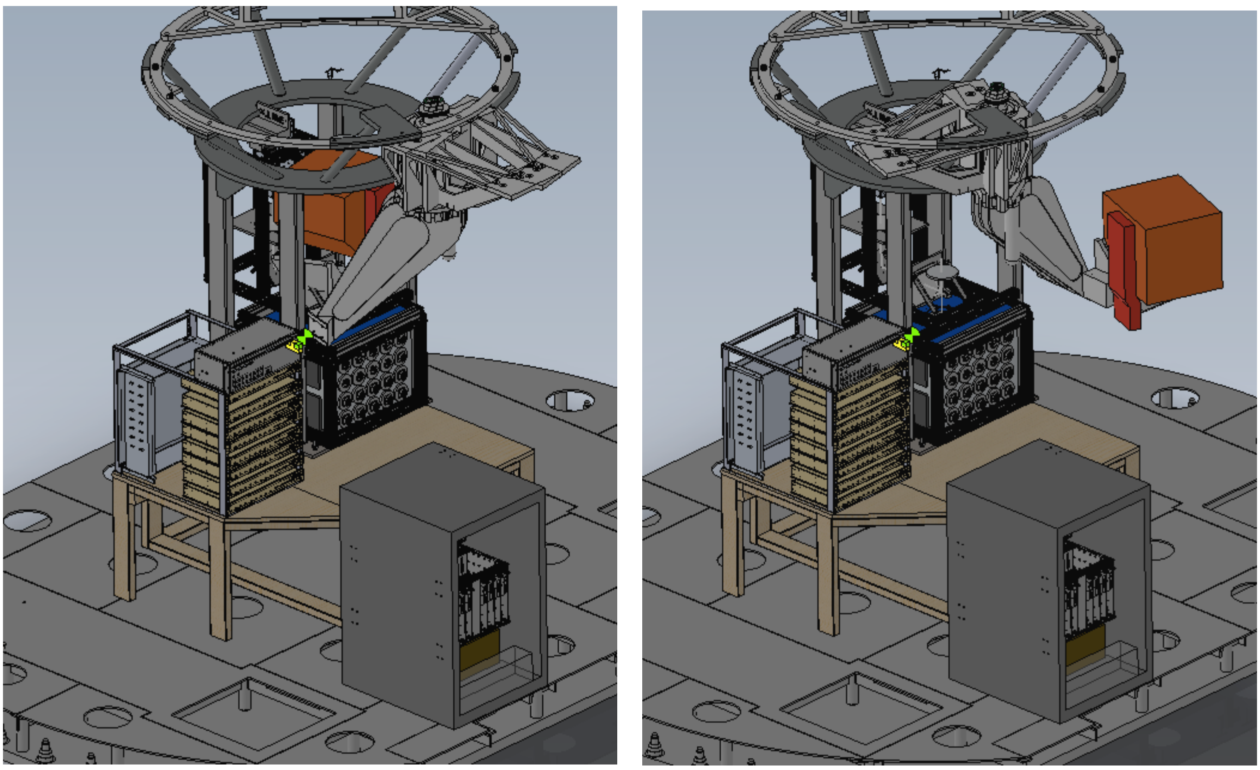

Figure 2.2: Cut-away of Supercam in the APEX C-cabin, showing the APEX swing arm in the A-cabin (left) and C-cabin (right) positions. A single vertical support is removed from the Supercam mount to allow the arm to be operated, then reinstalled once the swing arm is in place.

Design Loads, Limits, and Structural Analysis

FEA and fastener analysis was performed on the Supercam mechanical assembly to assess structural integrity. In response to **Action Item 009** from Michael Cantzler, "After review of antenna documentation and consultation of Vertex Duisburg, the design limits shall be defined by the estimated worst case accelerations of an earthquake scenario. The corresponding values are given in the table below."

Direction	Acceleration (g)	Safety Factor	Design Limit (g)
Vertical	1.80	2.0	3.60
Horizontal	1.15	2.0	2.30

Table 2.1: Defined load limits per AI0009

Because the allowable bending of the structure is most stringently defined by the optical tolerancing, it very naturally provides a very high degree of safety in overall integrity. The FEA analysis begins at the invar ring, assuming that it is fixed, and determines the stresses and deflections of the Supercam structure from gravity at two elevation angles; zenith and horizon. The worst-case deflections are naturally present when pointed at the horizon (Figure 2.4). The deflections and structural safety factors assuming A500, A36 structural steel for the entire assembly and are shown in Table 2.2

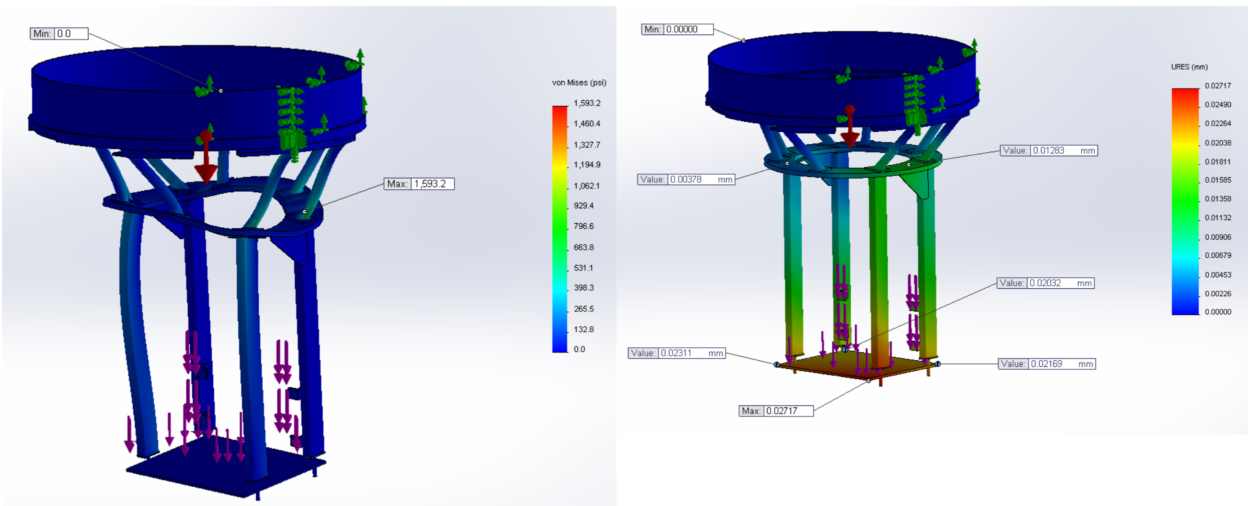

Figure 2.3: Finite Element Analysis (FEA) of the Supercam mechanical mounting structure when pointed at zenith. (left) von Mises stress plot shows that the highest stress is at the octopod tubes attached to the Secondary Support Ring. (right) Maximum displacement of the structure is less than 0.1 mm. Safety factors exceed 20 everywhere.

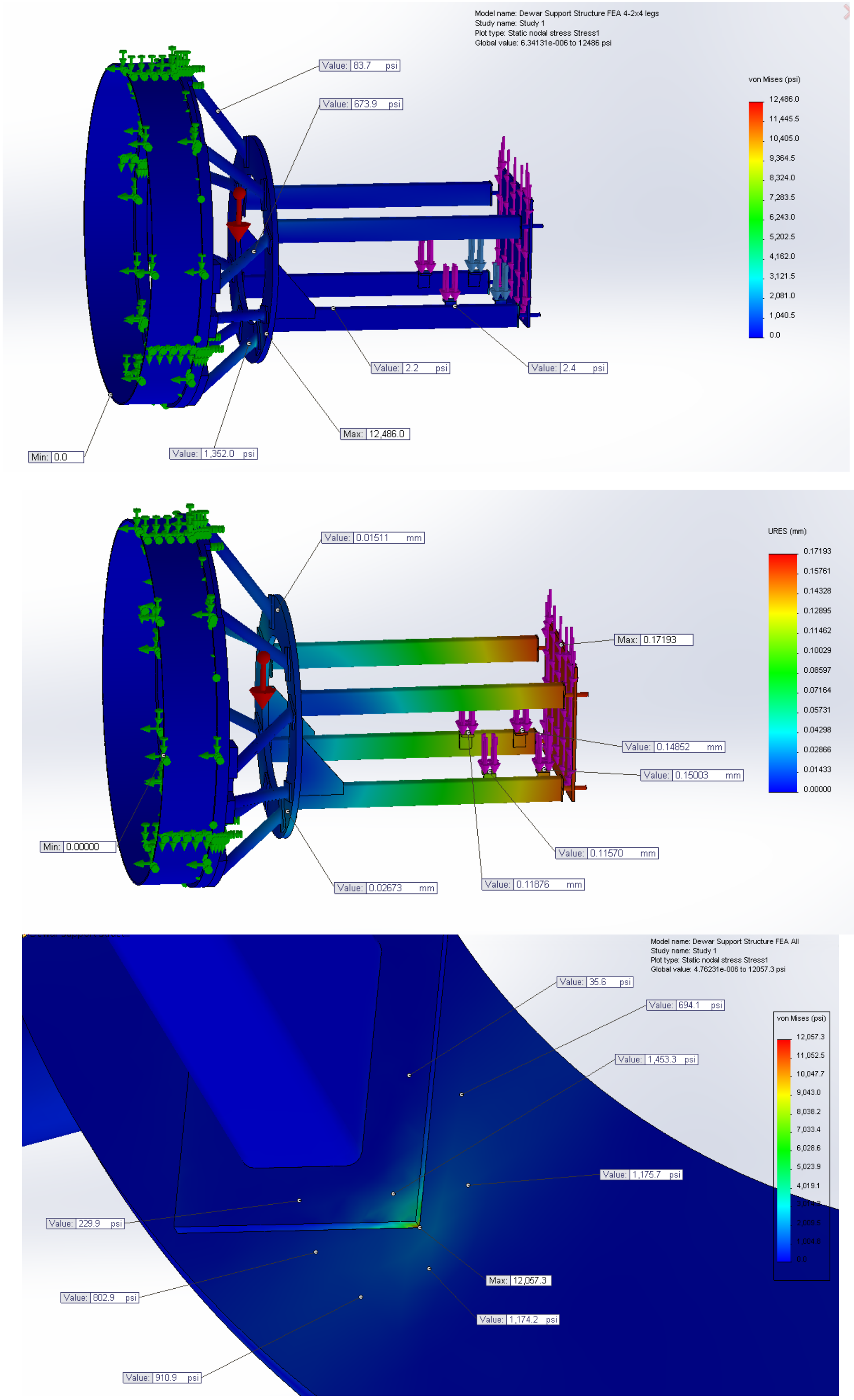

Figure 2.4: Finite Element Analysis (FEA) of the Supercam mechanical mounting structure, pointed at horizon. (top): von Mises stress plot shows that the highest stress is at the octopod tubes attached to the Secondary Support Ring. (middle): Maximum displacement of the structure is less than 0.1 mm. Safety factors exceed 20 everywhere. Maximum displacement of the structure is 0.2 mm. Safety factors for both structures exceed 20 in most regions. (bottom): Zoom-in on the highest stress point in the model; the edge of an octopod plate. The point stress can be eliminated by placing a radius at the corner of the plate, bringing the stresses to 3 kpsi and bringing the safety factor above 5.

The main structural limitation of the Supercam mechanical assembly is not the main structure itself, which is clearly designed to the much more stringent optical tolerances. **Rather, it is the thread strength of the fasteners which is the limiting factor.**

The cryostat is supported with 4 x 3/4”-16 bolts to the four vertical cryostat supports, with L-brackets and ¼-20 bolts providing additional support at the top of the cryostat. The vertical members are attached with a T-interface to the Secondary Support Ring using 6 x 3/8” bolts each (24 total). The 8 octopod supports mount with 4 x 3/8” bolts to the Secondary Support Ring and to the Invar Ring with 13 x M12 bolts.

Maximum Deflection	Maximum stress	Safety Factor
0.1 mm at zenith 0.2 mm at horizon	Up to 1.6 kpsi Up to 5 kpsi horizon*	>20 zenith >6 horizon

*Table 2.2: Summary of load analysis of main structural members. * See Figure 2.4 for details.*

Bolt set	Thread strength	Max Load	Safety Margin
Lower Cryostat 4 x 3/4”	20000 lb ea	160 lb ea	100
Upper Cryostat 16x3/8”	3600 lb ea	50 lb ea	75
Lower Ring 32x3/8”	3600 lb ea	25 lb ea	150
Upper Ring 13xM12	7200 lb ea	75 lb ea	100

Table 2.3: Fastener analysis assuming ***uniform*** *load distribution at ZENITH.*

Bolt set	Thread stress limit	Max stress	Safety Margin
Lower Cryostat 4 x 3/4”	30 kpsi	2 kpsi	15
Upper Cryostat 24x3/8”	30 kpsi	3 kpsi	10
Lower Ring 32x3/8”	30 kpsi	8 kpsi no clamps 4 kpsi clamped	3.75 7.5
Upper Ring 13xM12	30 kpsi	10 kpsi no clamps 5 kpsi clamped	3 6

Table 2.4: Fastener analysis assuming ***asymmetric*** *load distribution at HORIZON. These loadings are based on the direct moment arm calculation and upon the FEA stresses at specific points in the structure. To improve safety margin at the invar ring, clamp fixtures will be added to the invar ring, between the M12 bolts, to reduce the tension load and eliminate any possibility of thread stripping or shearing.*

A summary of the fastener analysis is shown in Table 2.2 and 2.3 for zenith & horizon pointing. Grade 5 imperial and grade 9.8 metric bolts are assumed for analysis, though we intend to use grade 8 and grade 10.9 where possible. The thread strength conservatively assumes the yield strength as the starting point, not the ultimate tensile strength.

2.2 COMPRESSORS AND HELIUM LINES

Two Gifford-McMahon cryocoolers are used to provide cooling stages at 50K, 15K and 4K. The first, a CTI-350 cold head, is driven by a CTI-8200 helium compressor located at a distance up to 20m away. Two 0.5" diameter helium lines with 0.5" self-sealing Aeroquip fittings are used to provide supply and return gas to the cryocooler head. The second, a Sumitomo Heavy Industries (SHI) RDK-415D, is driven by a CNA-61C helium compressor, which is itself split into an indoor electronics unit and an outdoor compressor & fan unit. Each module has 10 meters of 1" diameter helium transfer line with 0.5" Aeroquip fittings, combining to 20 meters. Both compressors are air-cooled and require no additional interfaces for cooling. Based on the low atmospheric pressure at APEX (~525 mbar), care must be taken that the compressor outdoor unit not be subjected to ambient air temperatures above 20C for operation. This implies a sun shade. The footprints of the compressor modules are shown in Table 2.5 below. We anticipate that all compressor modules can be installed on the instrument platform near the other APEX heat exchangers.

The ARTEMIS helium lines extending through the cable wrap from the compressor loft to the C-cabin use 3/4" (-12 series) couplings. Supercam uses 1/2" couplings (-8 series). We will make 4 adapters to allow mating to the ARTEMIS lines for the CTI compressor: a stub with 1/2" female (5400-S5-8) coupling brazed on one side and a 3/4" male (5400-S2-12) coupling brazed on the other. Helium line arrangement to be deployed is shown in Figure 2.5 below.

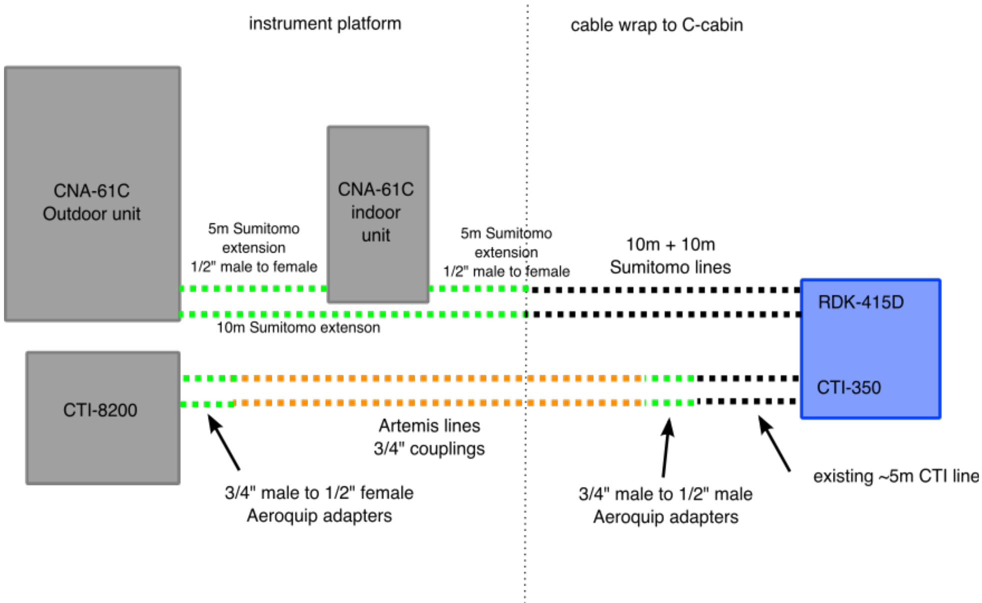

Figure 2.5: Helium line arrangement to be baselined for Supercam's APEX integration. Portions in green must be purchased by the Supercam team; the orange portion represents the Artemis lines.

Compressor Unit	Dimensions (cm)	Weight (kg)	Power	Environment
CNA-61C "indoor"	63 x 27 x 57	45	208V 3Φ @40A 8.0 kW / 50 Hz 9.2 kW / 60 Hz	5C to 35C
CNA-61C "outdoor"	91 x 103 x 39	115	From indoor unit	-30C to 45C
CTI-8200	51 x 43 x 57	70	230V 1Φ @10A 2.1 kW rms	0C to 40C

Table 2.5: Supercam helium compressor specifications

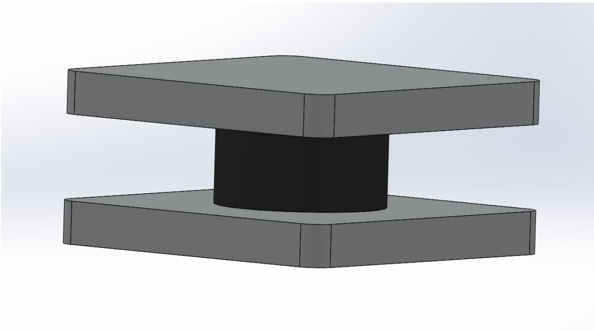

Figure 2.6: Conceptual diagram of an isolation mount for Supercam's compressors. Sandwiched between two aluminum plates is a soft rubber plug with 1/4-20 threaded center. Ratchet-type hooks will tie into the grating floor on the instrument platform.

Facility UHP helium should be available to charge compressors and helium lines. The static pressure for the CTI-8200 is 1.7 MPa (250 psi) and the CNA-61C is 1.65 MPa (245 psi).

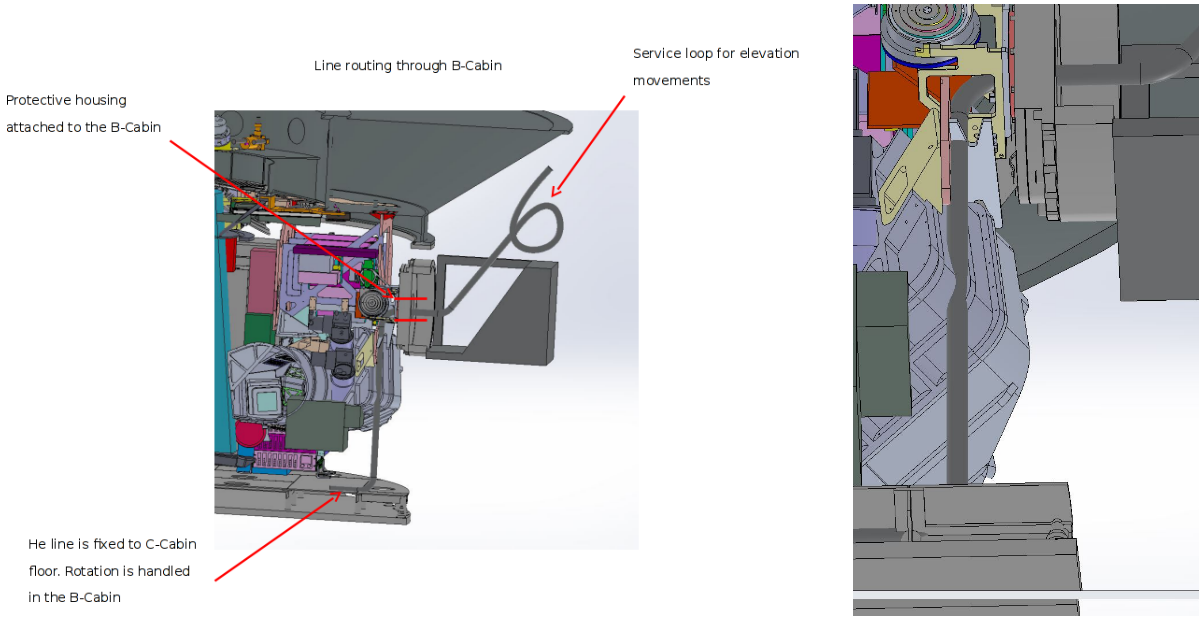

Figure 2.7: Diagram showing the C-cabin tie-downs and routing pattern of Supercam's Sumitomo helium lines. The right hand drawing shows the clearance of the helium lines through the MKIDS instrument area. Constraining the helium lines in the B-cabin remains a work in progress and a detailed model of the B-cabin installation is required.

2.3 SUPPORT ELECTRONICS RACK

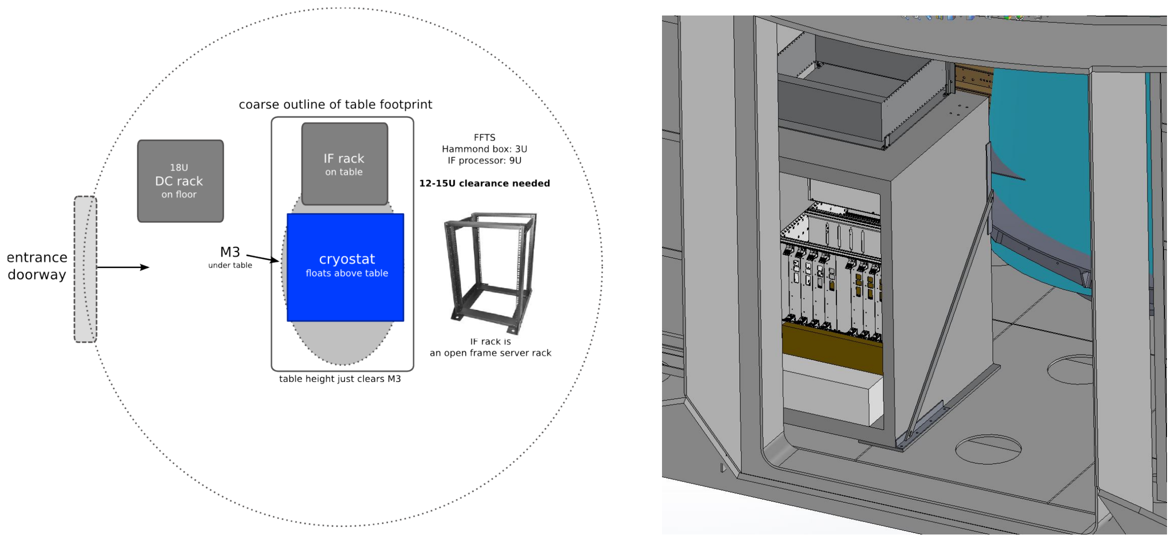

Figure 2.8: (Left): Overhead diagram of Supercam electronics installation options atop or adjacent to the M3 protection table. (Right): Conceptual structural support for electronics rack when horizon pointing (full triangular brace and correct dimensioning is underway).

All of the electronics needed to operate Supercam are to be installed in the C-cabin in close proximity to the cryostat. The M3 Protection Table will house the IF and FFTS system in open-frame server racks on the ARTEMIS side of the cryostat (Figure 2.5-left). The DC electronics will be mounted in the current 18U half-height rack and mount the LO distribution box, FFTS and IF processor on the table.

Because of its significant weight, the support electronics rack needs additional anchoring for horizontal-pointing. This support comes in the form of triangular metal braces that attach to the floor (Figure 2.5-right). Weights and dimensions of the three modules are shown below in Table 2.3.

Electronics Module	Dimensions (cm)	Weight
Support electronics rack	50 x 60 x 100	130 kg
IF processor	45 x 45 x 60	40 kg
FFT spectrometer	50 x 40 x 15	10 kg

Table 2.6: Specifications for the three electronics modules to be installed in the C-cabin

2.4 TOTAL INSTALLED WEIGHT INTO C-CABIN

Module	Weight (kg)
Cryostat + U-mount + Optics Subsystem	420
Support Electronics Modules	180
TOTAL	**600**

Table 2.7: Total weight installed into C-cabin.

3 OPTICAL INTERFACES

3.1 OPERATION OF SWING ARM FOR A-CABIN AND B-CABIN

During poorer summer weather at APEX, it may be necessary to switch to the 230 GHz receiver (SHFI's APEX-1) in the A-cabin. We have baselined a mechanical structure that can support operation of the APEX optical swing-arm assembly with the temporary removal of one structural member of the Supercam mount. **Automatic operation of the swing arm must be disabled**; it must only be done at stow and under direct, manual control. The nominal procedure is expected to be:

1. Stow telescope and remove one (A-cabin) or both (B-cabin) removable Supercam vertical truss supports. Use of the swing arm also requires removal of the Supercam LO beamsplitter and sky lens mounts and should only be done by Supercam personnel. B-cabin operation is not being supported for the Novermber/December 2014 run but can be discussed for a hypothetical second run if it materializes.
2. Remove beamsplitter mount and upper Supercam lens.
3. Move swing arm into position.
4. Reinstall Supercam vertical support and unstow telescope for operation.

Figure 2.2 illustrates the setup for A-cabin and C-cabin modes and Figure 3.1 shows the A-cabin mirror in position from the top.

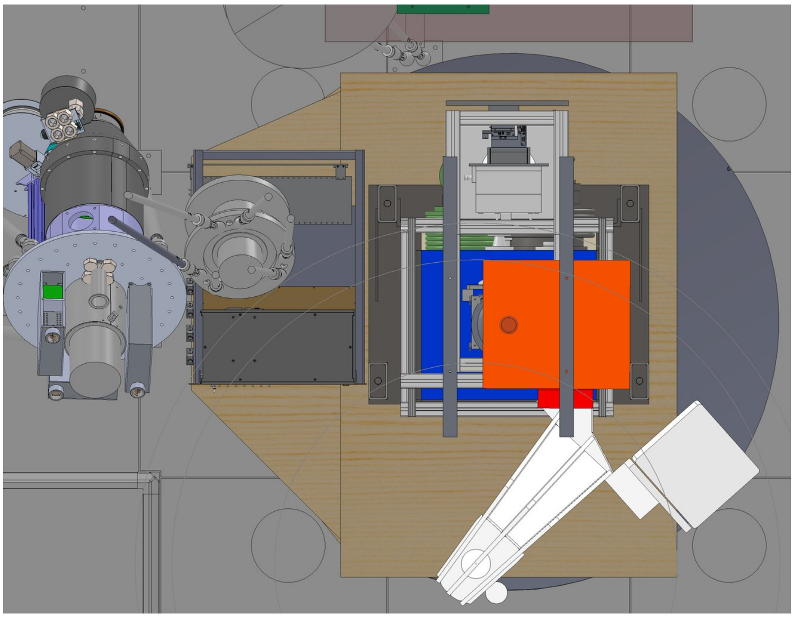

Figure 3.1: Illustration of the A-cabin swing arm in position, surrounded by the 4 vertical Supercam cryostat supports.

3.2 TWO-POSITION CALIBRATION LOAD

A rotary stepper motor actuator will be used to insert an aluminum disk lined with multiple layers of eccosorb AN-72 into the beam for calibration-wheel calibration of the temperature scale. Calibrations will be performed at regular intervals, typically every few minutes depending on the variability of the atmosphere. The actuator will flip between two fixed positions and the absolute position of the disk will be verified through the use of an internal encoder, indexer position, and registration of the disk by magnetic Hall-effect sensors at the clockwise and counter-clockwise limits. The (blackbody) temperature of the load will be continuously monitored for calibration.

3.3 COLD CALIBRATIONS

At the HHT, manual cold calibrations using a two-layer ~20x20 cm paddle of LN_2-soaked eccosorb AN-72 are performed whenever the receiver is re-tuned or otherwise about 2-3 times daily. At APEX, it is expected that Supercam will spend nearly all of its time at the supported ^{12}CO 3-2 frequency (345.795 GHz). Other frequencies will be tested in the lab by request. Currently the ^{13}CO J=3-2 line at 330 GHz is the only other known requirement for December 2014. **As it may involve a change in hardware and requires cold-calibration, switching spectral lines can only be done when personnel are on-site.**

To facilitate manual cold calibrations, the facilitator will need to bring a laptop computer into the cabin with a **cold-load software application** running. The Cold Load application will listen to APECS for signals to perform a Hot/Cold/Sky calibration and will advise the facilitator to insert the cold load into position, prompt when the load is in position, and advise when the load should be removed.

3.4 SKY BEAM OPTICAL RELAY

The f/8 beam directly arriving from the APEX secondary will be relayed to the Supercam focal plane by two anti-reflection coated lenses. Because the cryostat was lowered to allow use of the swing arm, the lower lens can no longer be used as a replacement for the cryostat window. It now resides atop the beamsplitter mount. UHMW polyethylene will be used as the lens material and the AR coating will be an 8-mil thick sheet of Zitex G108 (45% pore volume) with thin LDPE film to be heated as the 'glue' layer. The master reference for coating HDPE with Zitex is Hargrave & Savini, 2010, Proc SPIE, 7741 (Cardiff group). http://loke.as.arizona.edu/~ckulesa/binaries/supercam/optics/Hargrave_AR_Coat_HDPE.pdf The combination of absorptive and reflective losses is not expected to exceed 8% in either lens and while slightly lossier than a reflective system, will provide the very simplest opto-mechanical interface to the APEX telescope.

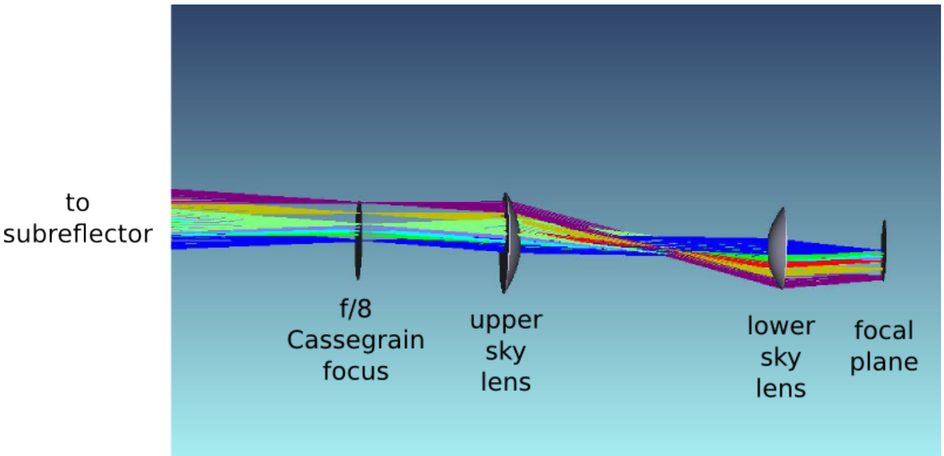

Figure 3.2: Zemax rendering of Supercam optical relay from f/8 Cassegrain focus to f/5 focal plane.

4 ELECTRICAL INTERFACES

4.1 COMPRESSORS & TRANSFORMERS

The electrical requirements for the CTI and SHI GM cryocooler compressor units are shown in Table 2.1; a total of 50A at 208 VAC, 50/60 Hz, 3-phase and about 15A at 230V 1-phase. The currently-adopted plug types are shown in Table 4.1. The CTI can be operated from the single phase 230VAC 50 Hz with the appropriate switches set inside the compressor. The Supercam team will identify an isolated 15 kVA transformer needed to supply Supercam's SHI compressor with 50 Hz 208V 3-phase power. The transformer should be installed in advance of the 22 November start of installation if possible. If shipped from North America, the following isolation transformer may be selected:

`http://www.temcoindustrialpower.com/products/Transformers_-_General/T46078.html`

Figure 4.1: Isolation transformer selected for Supercam's Sumitomo compressor if shipped from North America.

An isolation transformer is specified for safety: to ensure that a failure in either winding does not transfer to the other, or that an overvoltage condition in the primary does not auto-transform to an overvoltage in the secondary.

Attribute	Specification
Phase	3 (primary Delta, secondary Wye)
KVA	15
Windings	Copper
Temperature rise	115C or less
Mechanical	Steel enclosure, 86 kg total 40x60x55 cm

Table 4.1: Isolation transformer specifications

Compressor	Plug type and diagram	Power rating
CTI-8200	NEMA twist lock L21-20 	20A, 3Φ (Y or Δ), 208 VAC Note: wired for North American split-phase; 3rd leg is unwired inside compressor!
SHI CNA-61C	IEC 309 3 pole+N+G = 5 pin 	60A, 3Φ Y, 208 VAC

Table 4.2: Compressor plug types currently used in Supercam

4.2 SUPPORT ELECTRONICS

The three electronics support modules shown in Table 2.2 nominally operate from single phase 115V AC power. **We will adapt all support electronics to use 1 phase, 50 Hz 230V AC.** Naturally, some of these components are already dual-voltage capable. In summer 2014, we will make as many components “230VAC-native” as possible. It is expected that we will combine all such 230VAC-native components (still using North American plugs) onto a single power strip which can be mated to the normal European AC power receptacle with a straightforward adapter. The remaining (few) items at 115 VAC will operate from small power transformers to be installed in or near the Support Electronics Module.

4.3 POWER FILTERING AND UPS

Power conditioning and protection for the Supercam instrument will be provided by a 1500 VA Eaton 9130 UPS (Figure 4.2), which has a standard rackmount 2U footprint and weighs 20 kg. It has IEC-320-C14 plugs for the AC input and IEC-320-C13 receptacles for the outputs. At a 1 kW load, the standard run time is anticipated to be 7 minutes; adequate to safely shut down the system (1 minute or less). The AC power distribution interface diagram is shown in Figure 4.3 and puts all critical items behind the operation of the UPS. These items are also under direct power control of an ethernet-controlled 8-port AC power distribution box which allows independent subsystems to be turned on and off remotely. This will allow the system to be powered down in a controlled fashion in the event of power loss. It further allows the system to be brought up remotely in a controlled fashion. The Supercam UPS will be programmed to power up after a power loss only once the batteries are recharged or under manual intervention.

Figure 4.2: (top) UPS system selected for Supercam electronics is a 2U rackmount system with 230VAC capability and a remote, managed interface. ***Only the top 2U unit will be used****; the bottom module in the figure is an add-on battery module for extended runtime. (bottom) The back face shows the connectors needed to interface with the APEX power system. Schuko to IEC cable adapters are baselined.*

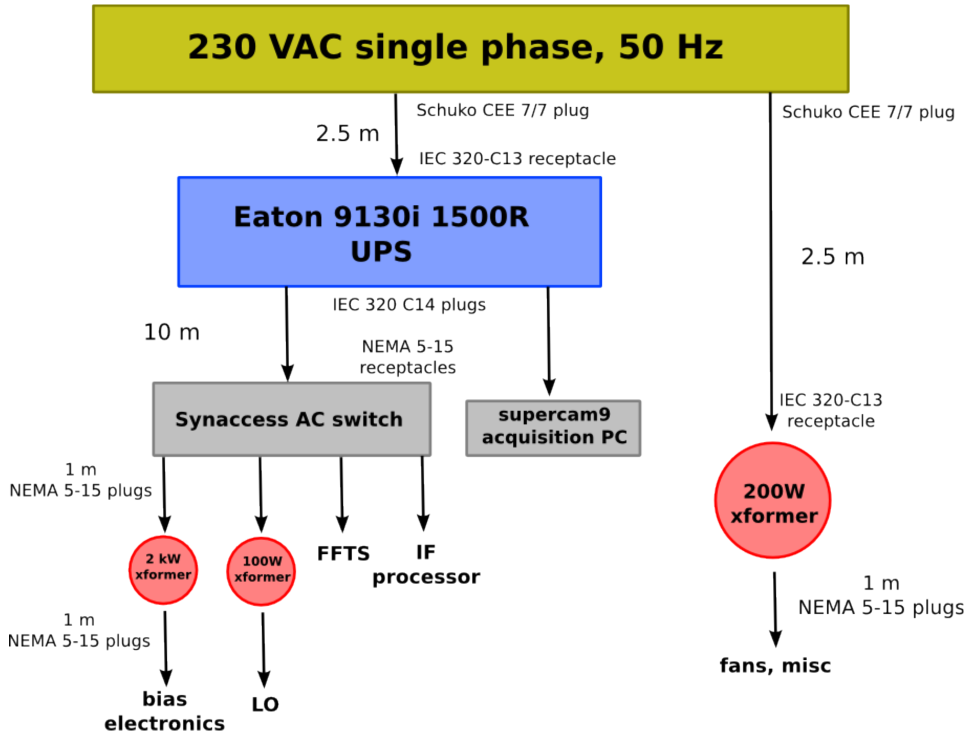

Figure 4.3: Block diagram of power distribution system for Supercam.

4.4 TOTAL POWER CONSUMPTION

Table 4.2 summarizes the expected breakdown of power consumption after the transformation of as many components as possible to 230 VAC power. The listed "peak" power consumption represents the inrush current, applicable for << 100 ms, if all devices are switched on at the same time. This value is useful for defining the (fuse) rating(s) for Supercam's AC circuit(s).

Subsystem	1 phase, 230 VAC, 50 Hz Power Requirements	3 phase, 208 VAC, 50 Hz Power Requirements
SHI CNA-61C (4K)	-	8.2 kW avg (11 kW peak)
CTI – 8200 (15K)	2.1 kW avg (2.8 kW peak)	
Support electronics #1 (230 VAC "native")	500W avg (700W peak)	-
Support electronics #2 (Transform to 115 VAC)	900W avg (1500W peak)	-
TOTAL	**3.5 kW (5.0 kW peak)**	**8.2 kW (11 kW peak)**

Table 4.3: Overall breakdown of Supercam's power consumption, including transformer losses.

5 RF INTERFACES

5.1 10 MHZ REFERENCE

The Supercam LO system and the downconverter module for the 64-channel IF processor both require a 10 MHz reference source, to be provided by the facility's GPS station clock. The power level required is 6-13 dBm. 7.5 dBm is the current measurement of the power level available. The Supercam team will bring a low frequency amplifier as backup.

5.2 SYNTHESIZERS

As shown in Figure 5.1, the Supercam LO system operates fully independently of the supporting telescope. We will continue this mode of operation at APEX. For successful operation, the Supercam Command and Control system needs access to the sky frequency computed by APECS. The sky frequency should include the Doppler correction for the antenna velocity and the observer's catalog V_{LSR}.

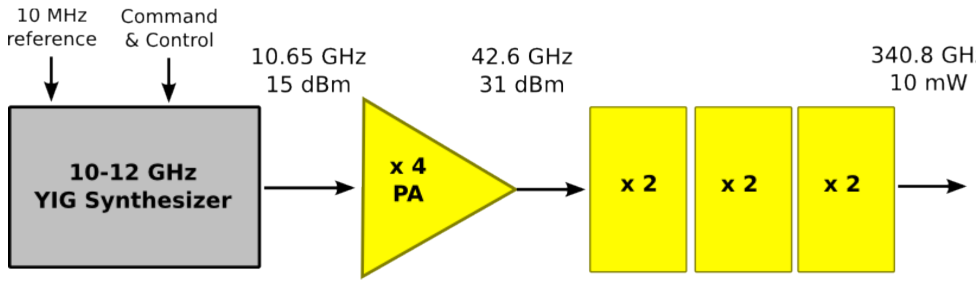

Figure 5.1: Block diagram of Supercam LO subsystem.

5.3 IF OUTPUTS AND THE "SUPERCAM FIDUCIAL PIXEL"

Supercam performs its own IF processing independent of APEX. The IF chain is comprised of a series of 8-channel IF Processor modules which amplify and filter the 64 IFs from the cryostat, downconverting from 4-6 GHz to the baseband signal (0-500 MHz, -10 dBm) required at the input of a 16 GHz wide digital FFT spectrometer (FFTS). 64 output IFs are power-combined into 32 FFTS inputs, yielding 256 MHz of bandwidth per Supercam "pixel" in 1024 channels. In reality, the edges of the spectra are trimmed because of overlap in the power-combined region (typically ~900 channels over ~240 MHz of bandwidth).

While IF independence is important for Supercam, it increases the effort needed to perform basic commissioning and observing. To this end, it is advantageous to split one pixel from Supercam to provide a "facility IF" that can be used for basic pointing and focusing operations. In essence, this so-called *fiducial pixel* presents a standard single pixel interface so that Supercam looks like a "normal" receiver to the facility.

A diagram of the "fiducial pixel" IF that the Supercam team will make available to APEX is shown in Figure 5.2. We will supply the broadest IF possible but degradation above 7.5 GHz is likely. The output power can be as high as -35 dBm and can be manually attenuated to any required level. We notionally assume -50 dBm in a 4-6 GHz bandpass as a default, with an option to run filterless or with a broader filter.

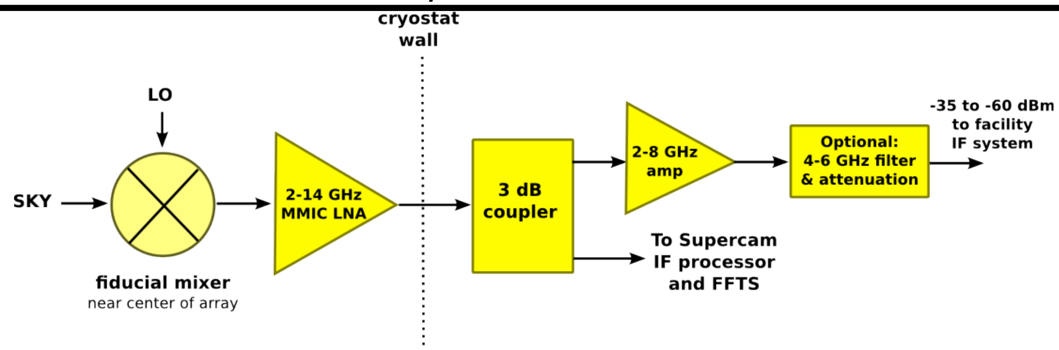

Figure 5.2: Block diagram of Supercam's generic single-pixel (a.k.a. 'fiducial') interface to the APEX facility IF system.

6 TIMING INTERFACES

6.1 SYNCHRONIZATION AND BLANKING SIGNALS

For beam-switched observations, external synchronization and blanking signals are needed. The SYNC signal defines the phase for the beam-switched integration (secondary nutation left or right), and the BLANKING signal is used to mask out the transition time. The Supercam FFTS requires a minimum 40 msec blanking time; 50 msec is preferred. We understand that the delayed blanking signals from APEX are to be used for this specification. We ask to not nutate the subreflector faster than 2 Hz; 1 Hz is ideal. These signals are brought into the Supercam FFTS over BNC-terminated coax cables from the facility D-sub connector.

Q The pinout specification and cable length are required.

6.2 NTP TIME REFERENCE

The Supercam data acquisition PC needs to have access to an NTP time server to serve as a time reference. **Q** What is the IP address or name of the nearest time server?

7 SOFTWARE INTERFACES

7.1 INSTRUMENT COMMAND AND CONTROL

7.1.1 Low Level Instrument Control

The overall software layout for Supercam as anticipated for APEX is diagrammed in Figure 7.1. The Supercam instrument hardware is controlled by a series of TCP socket servers operating from embedded ARM macrocontrollers (supercam1-8), and the Data Acquisition computer (supercam9) in the Support Electronics Rack. These hardware servers are:

- *biasServer*: runs on all 8 Supercam macrocontrollers and controls the bias electronics cards that supply SIS, electromagnet, and LNA bias voltages to the cryostat. BiasServer also can monitor any of the sensed voltages in the cryostat. Supercam8 also is wired to handle the *synthesizer* function that sets the sky frequency for the LO.
- *blankServer*: runs on supercam1 and provides the 'integrate' TTL signal to the Omnisys FFT spectrometer that is used for OTF mapping. This signal is locally generated by *blankServer* or is switched to an external TTL "blanking" input from the secondary (for beam-switched observations), and logically inverted as needed.

- *cryoMon*: runs on supercam8 and provides an interface to the Lakeshore 208 temperature monitor that reads the DT470 silicon diodes inside the cryostat.

Basic communication with these servers can be done interactively from the command line via **`telnet`** or **`netcat`** to a particular server, interactively by GUI, or non-interactively via higher level scripts or programs. Supercam is to be operated through a series of single-purpose scripts which can be invoked through a master GUI. Engineering level GUIs for single-pixel adjustments will be provided, and monitoring of the instrument through the master GUI or a remote web page is the expected mode of operation at APEX.

However, all observing sequences operate through higher level 'glue logic' interfaces that monitor the state of the telescope and observing, and keep Supercam's operation in sync. This logic is held within *SuperComm*, the recipient of observing messages from the HHT. Using an orchestral analogy, *SuperComm* acts as the central conductor who keeps the various socket servers playing on-time and in-tune. Its sidekick, *Monitor*, harvests information from the various socket servers to maintain knowledge of the current state of the instrument.

In its software implementation for the HHT, Supercam is passive to the underlying telescope control system; it only receives messages and never sends commands. It only sends unsolicited messages to the log system when it is having difficulties and wants to notify the cognizant observer or telescope operator. We anticipate the same interface at APEX.

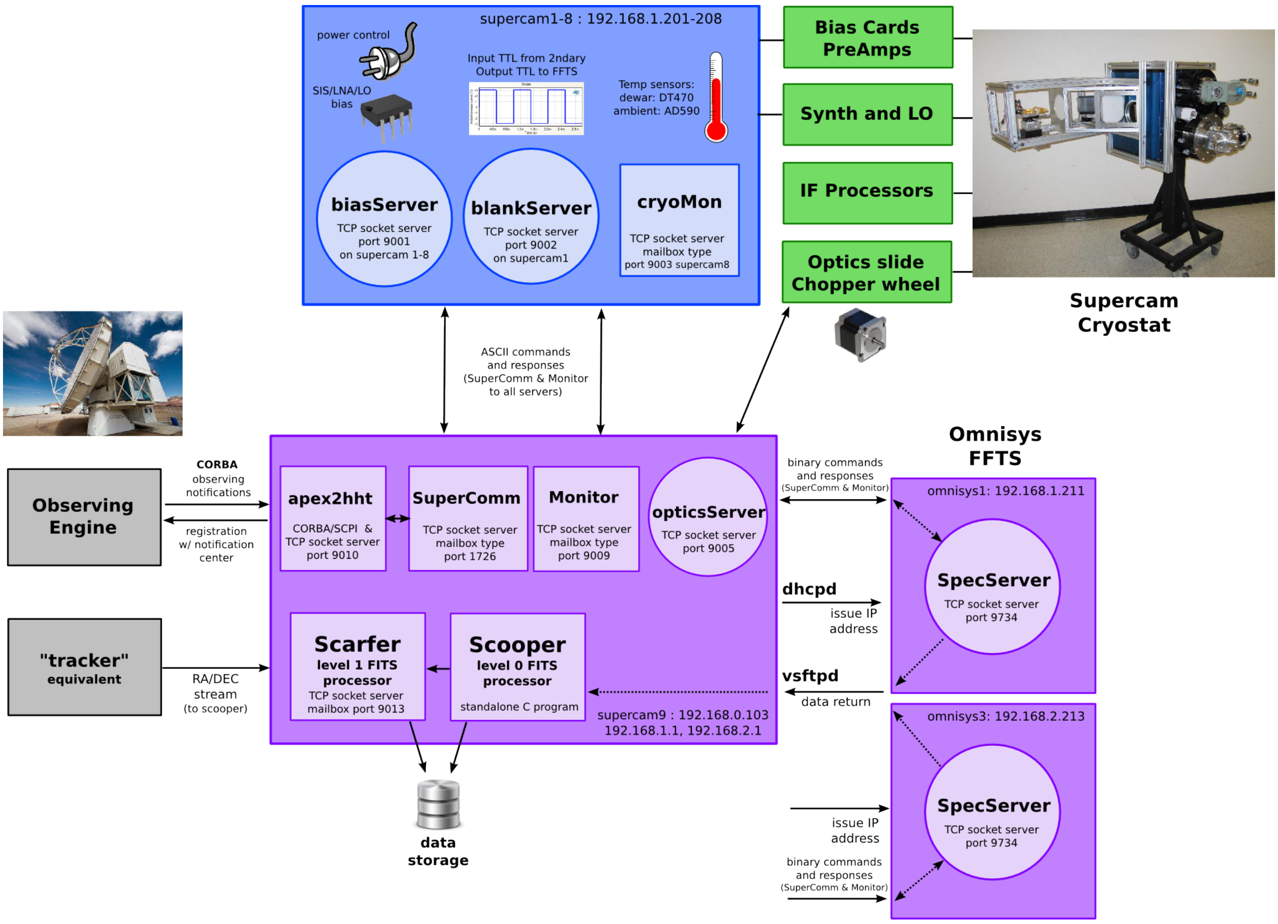

Figure 7.1: Block diagram of Supercam's command and control system, from hardware to APECS interface.

7.1.2 Supercam's Command and Control Interface to APECS

Strategy

While the current HHT interface defined in *SuperComm* is well tested, it does not match the formalized distributed object (DO) model used at APEX, as canonized in the current APEX Control System (APECS), through DOs defined by IDLs, communicating through CORBA at the high level and SCPI at the hardware level.

We will augment *SuperComm* with a python-based SCPI-to-socket messaging layer with an HHT-like output messaging interface. In Figure 7.1, this module is shown as *apex2hht*. Here, we leave *SuperComm* mostly intact and only add a SCPI layer to scan for APEX messages involving Supercam, transform them to their HHT equivalents, and rebroadcast them via socket server messages to *SuperComm*.

Messages Needed By Supercam

When an observation is requested, Supercam needs the following kinds of notifications to stay synchronized with APEX. We will seek 1:1 analogs of these messages to be obtained from APECS. Table 7.1 indicates where these items can be found.

1. A message indicating that an **observation has been requested**. At this time, the ability to fill an internal structure with information about the observation is needed from APECS: observing mode, object and line name, sequence number, catalog coordinates, catalog offsets, antenna EL and AZ, catalog & antenna velocity, rest and sky frequencies, sideband, UT date/time, LST, temperature, pressure, humidity, subreflector focus, Tcal, pwv, atmospheric temperature and opacity in signal/image sidebands.
2. A message indicating the **start of a scan**. For all modes except OTF, one of the following:

   `Integrate for <x> seconds on {SIG | REF | Sky | Vane | Cold Load}`

   For OTF, we look for two messages: **`Prepare for OTF raster of length <x> seconds`**, followed by a **`Start`**.
3. **Ending the scan** requires either a successful "complete" message or an "abort".
4. Before and during observations, other messages that impact Supercam might be "Antenna On/Off Target" or "Antenna in +BEAM (or -BEAM) position".
5. For OTF mapping, Supercam needs a way to receive a stream of **antenna telemetry** of RA and DEC.

Implementation

While Table 7.1 shows where the needed scan information can be harvested, the highest challenge is figuring out how to get this information to Supercam in time to synchronize observations and inform the Supercam pipeline, which wants this information in advance. Dirk Muders has kindly provided a Virtual Machine for APECS that will allow the Supercam team to characterize the system and test the integration of the Command and Control software. We are experimenting with observing sequences and beginning to integrate the system.

Furthermore, the core of the *apex2hht* module will be a short script that Dirk has written for us (*monitorSupercamScans.py*), which listens to the Observing Engine from *observer3* and reacts to events pertaining to Supercam and the Supercam Backend (which shows up as SCBE in APECS). It harvests messages about the scan preparation phase including scan details such as mode, type, geometry, wobbler, source, offset, and command. Per subscan there is a message when it starts and finishes. The start messages optionally include the wobbler phase description if wobbling is enabled. This provides essential information for the Supercam pipeline, which wants this information prior to starting the observation.

The FITS headers can then be populated with remaining information from the obslog and syslog files (if necessary) and the top level FITS files as appropriate (Table 7.1). These can be accumulated by, or in parallel with, the level 1 processor (*scarfer*).

Obslog	Syslog	Top level FITS
Source name, coords, vel	Subscan #	MJD timestanp
Antenna az, el, focus	Integration time	LONGOFF, LATOFF
Line name and freq (to MHz)	Antenna offset	PHASE (1 or 2)
Source offsets	Scan Designation ON, REF, SKY, HOT, COLD	PARANGLE (deg)
OFF (ref) position	Source velocity & frame	
Scan number, # subscans	Earth velocity & frame	
Scan time	Sky frequency LSB & USB	
Obs mode / Scan type	Scan number	
Ambient temp, pressure, pwv	Scan type (MAP, CAL ...)	
Observing command w/parms	Scan mode (OTF, raster...)	
	Last CAL Tsys, Trec, Tcal...	
	Most recent MBFITS subscan	

Table 7.1: List of scan information available from APECS and where it can be found.

7.2 SUPPORTED OBSERVING MODES

Based on the science proposals submitted to APEX, we are aware of supporting two main observing modes: On the Fly (OTF) mapping and Position-Switching (PS). These modes will be fully supported in the Supercam data pipeline and command/control system. For commissioning and calibration, it is useful to support beam-switched observations using the nodding secondary. Provided that the secondary can be programmed to cycle at a sufficiently slow rate (1-2 Hz, creating a 2-4 Hz spectrometer cadence) with an adequate BLANKING time (see Section 6.1), beam-switched observations should be fully supported by the instrument control system and the data pipeline.

7.3 DATA FLOW AND ARCHIVING

7.3.1 Fiducial Single Pixel Interface

Supercam can provide a single pixel IF output centered at 5 GHz and at -30 to -60 dBm to a supported facility IF processor and backend. In this manner, one of Supercam's pixels can follow the expected data flow for an APEX receiver, through *apexOnlineFitsWriter* and *apexOnlineCalibrator* and *apexCalibDisplayServer*. These data products will flow through the standard APEX portals, from *display2* at the summit to Sequitor and then daily through the *esodata* archiving tool at the ESO data archive in Santiago and then on to ESO/Garching, with both MBFITS and CLASS data outputs. This basic data flow is shown in Figure 7.2 and is independent of the specific handling of the 64-beam Supercam FFTS data described in the following Section (7.3.2).

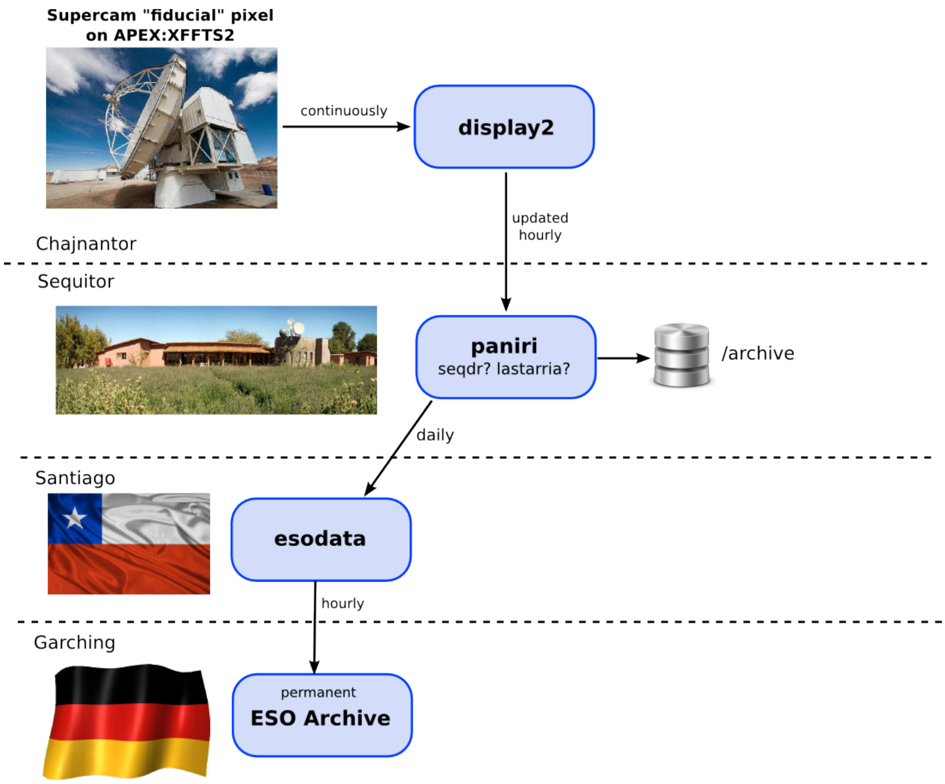

Figure 7.2: Data flow for Supercam's fiducial pixel, routed through the APEX facility IF system to a facility spectrometer (XFFTS2 or AFFTS). These data follow the standard flow for APEX and would provide quick-look data for one of Supercam's IFs.

7.3.2 Supercam FFTS data

Supercam's 64-beam spectral data are acquired independently of APEX systems and are automatically processed through a two-stage pipeline that takes the data to flux-calibrated and velocity-calibrated spectra. The data processing levels are defined as:

- Level 0: Raw spectrometer bandpasses (stateless binary files).
- Level 0.5: Raw bandpasses with header information, written as SDFITS.
- Level 1: Calibrated spectra, in (S-R)/R format, optionally baselined, in SDFITS.
- Level 2: Baseline-subtracted, regridded spectral line FITS cubes.

- Level 3: Science products (catalogs of objects, etc.).

Supercam automatically generates Level 0.5 and Level 1 data products through its two-stage pipeline. The Level 0 pipeline is called *scooper* and the Level 1 pipeline is called *scarfer* (see Figure 7.1). These are not normally run by the user interactively except during the initial phases of commissioning. In contrast, the level 2 pipeline is not run automatically but rather run interactively by the observer offline. Two Level 2 pipeline options will be available; one using *CLASS*, and another using a Supercam-specific rework of ATNF's *Gridzilla* package. These will be the supported options for science PIs using the standard Supercam pipeline.

What will be provided at APEX?

By default, the standard Supercam pipeline through Level 1 data is fully operational and can already be used (with appropriate APECS notifications and headers, Section 7.1.2) to feed the data archive at Sequitor with Supercam SDFITS data ready to baseline and regrid into Level 2 maps. This strategy is also compatible with the limited manpower on the Supercam team that would be needed to implement a new data system.

However, this approach comes with a disadvantage: it is foreign to the standard APEX data interface and archiving system. It comes with different reduction software requirements and different data formats, and is unlikely to match the expectations of seasoned APEX science PIs. The Supercam team does not have the resources to re-engineer a new data acquisition system based on MBFITS, when the current system works very well with (simpler) SDFITS.

However, a compromise may serve some portions of the APEX audience better: **a parallel datastream** (Figure 7.3). Here, Supercam's Level 0 processor (*scooper*) will also provide a raw binary datastream comprised of 64 x 900 channel IFs directly to *apexOnlineFitsWriter*. For the configuration of the Supercam Distributed Objects (DOs) in the ACS Configuration Data Base (CDB), hosts and ports for both commands and science data have been defined. The backend data stream format that *scooper* provides will follow the format defined in APEX-MPI-ICD-0005.

Figure 7.3 shows the expected implementation of the parallel data stream, and shows the archive flow analogous to Figure 7.2. The uncompressed data rate for OTF mapping at a 3 Hz cadence in dual-stream mode is 12 Mbit/s and could represent the *peak* rate. The compression level for level 0 data is expected to be 2:1 with *gzip* or greater using *xz* compression.

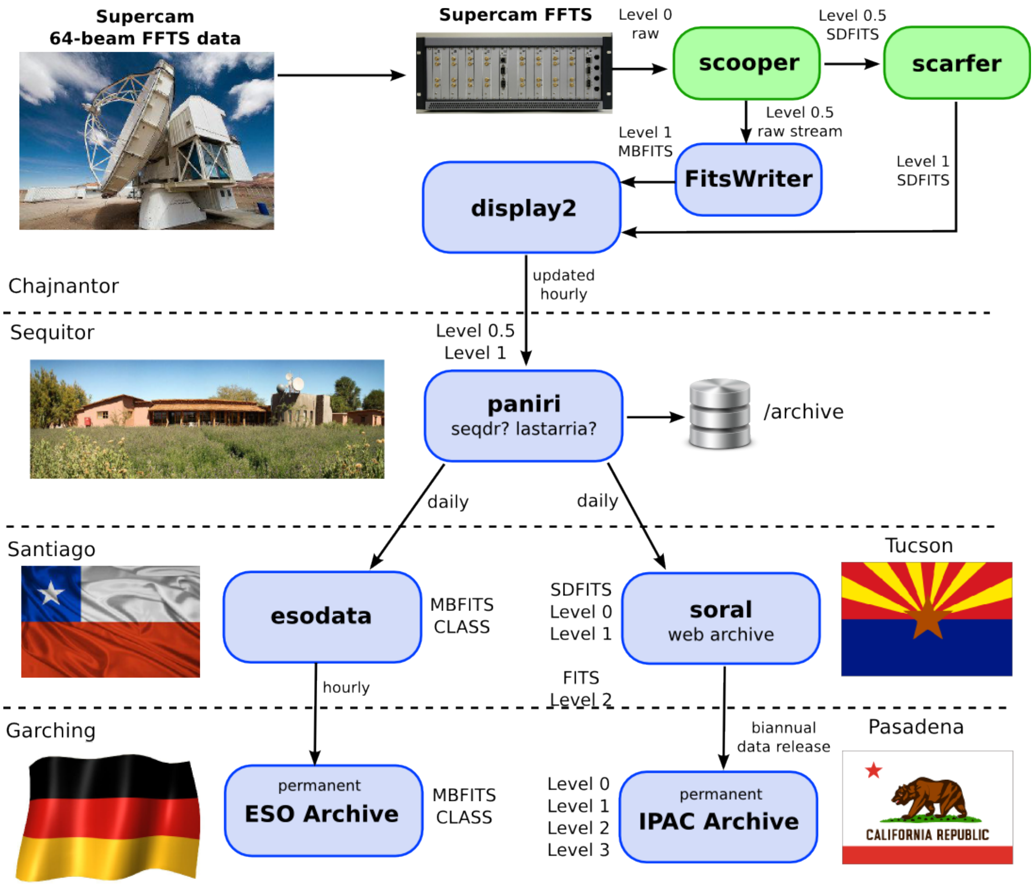

Figure 7.3: Dual-channel data flow for Supercam's 64-beam FFTS data. APEX-standard MBFITS and CLASS files will pass to ESO through the Archive, while the standard Supercam pipeline data in SDFITS format will likely stop at Sequitor and be archived with the final survey products at Arizona and IPAC.

7.4 NETWORK INTERFACES

Supercam's network structure is 'hidden' behind a 16-port 10/100 Mbit ethernet switch, which presents internal 192.168.1.xxx and 192.168.2.xxx subnets for instrument use. Only supercam9, the master data acquisition computer, requires a static IP address from the APEX network. Several IP addresses are required by the installation and commissioning team for personal laptops via ethernet and/or 802.11. However, dynamic allocation from a pool of addresses (e.g. DHCP) is adequate as these machines do not need to have static or stable addresses.

8 PERSONNEL INTERFACES

It is important to establish the general roles and responsibilities and overall structure of the work effort. In particular, here we would like to identify how the observing run is to be performed, by whom, in order to assess the requirements for the deploying team.

Installation and commissioning is a fairly straightforward work effort that necessarily leans heavily on the Supercam Instrument team. The overarching question is how observations will be undertaken and how the Supercam and APEX teams will be involved in planning them, scheduling them, carrying them out, and supporting them to publication.

Based on discussions, Supercam will be considered a PI instrument by the APEX facility. However, at the level of planning and performing the science observations, the Chilean, Swedish and ESO time will be each carried out in a **Service mode.** This reduces the need for several observers from the Supercam team to be present once commissioning ends, however, it is important for 1-2 members of the Supercam team to be available to process the data in real time and work with the ESO and OSO observers to verify that good data are being taken and that the target goals of the observations are being achieved. Furthermore, to best prepare for the run, it is suggested that ESO/OSO/Chilean PIs and observers work with Supercam team members to examine the awarded proposals, write up a general guideline for using Supercam at APEX (submitting catalogs, observing modes, updates on performance, etc.), and optionally contact PIs to solicit and answer any program-specific questions.

Once the instrument is commissioned and observing appears to be proceeding smoothly, then perhaps only one or two Supercam personnel need to be at the summit or at Sequitor. The role of these individuals would be to specifically support Supercam, follow the data taking and processing very closely, and manage any issues that might arise.

8.1 APEX STAFF

Responsible for the overall management of the run, and helping coordinate the Instrument team and observer PIs to allow the run to be efficiently scheduled and executed. The APEX Station Manager has the final say in all matters involving the APEX facility, will make all final decisions on the implementation and perform risk assessments for the continued safety and operation of the facility. APEX will provide documentation of existing hardware and software systems so that the Supercam instrument team can implement a working interface plan in advance of shipment. APEX is responsible for the processing and archiving of data written outside of the supported Supercam pipeline, such as to *apexOnlineFitsWriter*.

8.2 SUPERCAM INSTRUMENT TEAM

Provides the Supercam instrument and is responsible primarily for its installation and commissioning at APEX. The laboratory team will prepare the instrument to the specifications of this ICD and prepare the deployment team with its full operation and be available for remote and online support. The laboratory team will help provide guidance for observer PIs in planning observations. The deployment team will unpack and test the instrument to the greatest extent possible in the telescope laboratory at APEX before installation into the C-cabin. This staging effort will occur outside of the APEX telescope well prior to the start of November run, so that installation downtime may be as short as possible. The Supercam team is responsible for the instrument-standard Supercam pipeline, its data products, and archiving.

A draft schedule of the Supercam deployment team is shown below in Figure 8.1.

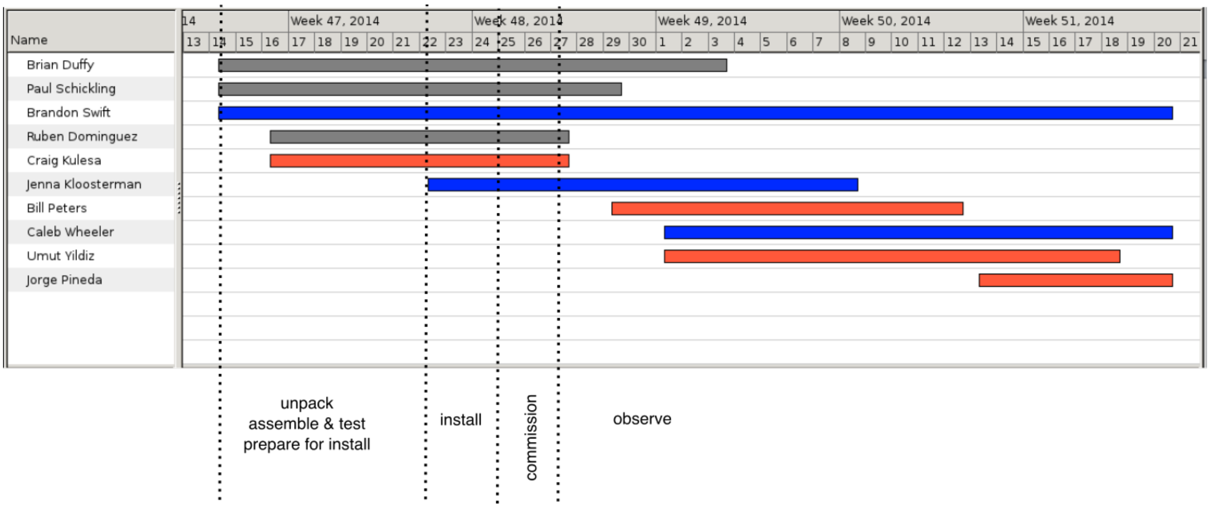

Figure 8.1: Supercam deployments, color-coded by speciality. Gray = mechanical and installation, Blue = instrument hardware, Red = instrument software and data systems.

8.3 OBSERVING RUN PRINCIPAL INVESTIGATORS

Responsible for the detailed planning and documentation of the awarded observing time. PIs will work with APEX staff and the Supercam instrument team in assuring that the observations planned are compatible with the facility and instrument capabilities. Any instrumental deviations need to be coordinated with the instrument team with the greatest possible advanced notice (e.g. tuning to a line other than CO J=3-2).

9 MASTER TABLE OF INTERFACE CONTROLS

Interface Type	Interface From…	Interface To…	Description	Other Information
Mechanical				
Dewar Mount	*Invar Ring*	*Supercam*	*Supercam mechanical mount*	*M12 bolts and clamps*
Rack Mount	*Floor*	*Electronics Cabinet*	*Floor Mount*	*M12 bolts and reinforcing frame*
Compressor Mount	*Instrument platform*	*Compressors*	*Vibration isolation mounts*	
Optical				
Optical relay	*APEX f/8 focus*	*Supercam f/5 focus*	*2 refractive lens relay*	*Removed for A-cabin ops*
Electrical				
AC power 1	*Instrument rack*	*Supercam UPS*	*230VAC 50 Hz Schuko to IEC*	*Supercam electronics*
AC power 2	*C-cabin*	*120VAC inverter*	*120VAC to fans and incidentals*	
Subreflector	*C-cabin DB15*	*Supercam FFTS*	*7 meter DB15M to coax*	*Delayed SYNC and BLANK*
C&C Software				
apex2hht	*APECS Supercam events*	*SuperComm*	*Python script running on observer3. Listens for Supercam events and communicates messages to Supercomm*	
MBFITS reader	*1st level MBFITS files*	*Level 1 processor for supercam*	*Read list of antenna positions for interpolation*	*For supercam pipeline*
Data Flow				
Data stream	*Supercam FFTS (SCBE)*	*FitsWriter*	*TCP stream of Supercam FFTS data*	*For APEX pipeline*
Network				
ethernet	*APEX*	*Supercam switch*	*Cat5 or cat6 with RJ45 termination*	*Single static IP address to supports supercam's internal network on 192.168.1.x and 192.168.2.x*

Appendix A: Approval

Signature: ______________________ Date: __________

Print Name: ______________________

Title: ______________________

Role: ______________________

Signature: ______________________ Date: __________

Print Name: ______________________

Title: ______________________

Role: ______________________

Signature: ______________________ Date: __________

Print Name: ______________________

Title: ______________________

Role: ______________________

APPENDIX B: REFERENCES

The following table summarizes the documents referenced in this document.

Document Name and Version	Description	Location
Supercam-Implementation *V1.5, 12 September 2014*	*Complete description of the Supercam integration effort for APEX.*	*http://loke.as.arizona.edu/~ckulesa/binaries/supercam/integration/APEX/*
APEX-MPI-MAN-0011 *V3.0, 21 July 2014*	*APECS User Manual*	*online*
APEX-MPI-ICD-0005 *V1.0, 29 March 2006*	*APEX SCPI socket command syntax and backend data stream format*	*online*
APEX-MPI-ICD-0004 *V1.9, 3 April 2007*	*APEX Instruments Generic CORBA IDL Interfaces*	*online*
APEX-MPI-ICD-0003 *V0.5, 6 September 2002*	*APEX Standard Hardware Interfaces*	*online*
APEX-MPI-DSD-0012 *V1.0, 10 January 2006*	*APEX Heterodyne Tertiary Optics*	*online*
APEX-MPI-ICD-0001 *V1.1, 1 October 2004*	*APEX Nasmyth A Cabin*	*online*
APEX-MPI-ICD-0002 *V1.63, 5 August 2011*	*MBFITS Raw Data Format*	*online*

APPENDIX C: KEY TERMS

The following table provides definitions for terms relevant to this document.

Term	Definition
C&C	*Command and Control*
QA	*Quality Assurance*
UHMW	*Ultra high molecular weight*
APECS	*APEX Control System*
FFTS	*Fast Fourier Transform Spectrometer*
CORBA	*Common Object Request Broker Architecture*
IDL	*Interface Description Language*
CDB	*Configuration Data Base*
SCPI	*Standard Commands for Programmable Instrumentation*
NTP	*Network Time Protocol*