Smithsonian Astrophysical Observatory

wSMA Upgrade

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Advisory Committee, July 2018

wSMA Upgrade Program

- Program has three major components
  - **New receiver system**, with new cryostat and receiver inserts
  - **IF/LO transport system upgrades** to accommodate 4 wide bandwidth IFs for dual pol, dual receiver operation, and future upgrades
  - **Add additional correlator capacity** on top of expanded 4-16 GHz SWARM to handle more IF from new receivers

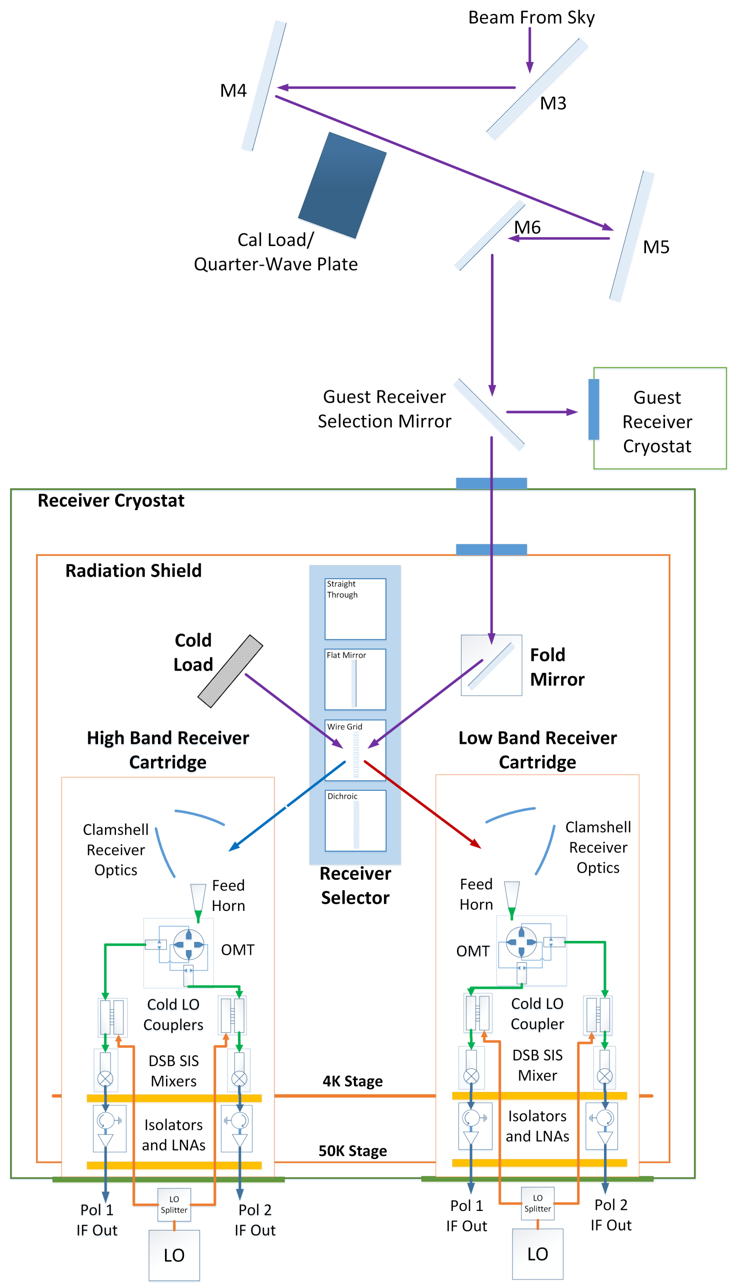
- Each element required for full capacity, but can be developed and deployed somewhat independently

- First two components deliver advantages before next is completed – e.g.
  - New receiver system replaces existing end-of-life cryogenics, will have lower system temperature, better polarization properties and better co-alignment of beams on sky
  - New IF/LO transport will move all signals to one of the three fibers to each pad, offering greater redundancy, and using new COTS components.
    - Also separates MRG signals to make YIG tuning simpler

wSMA Receiver System: Overview

- Dual Band Receiver System
  - Low Band (LO 210 – 270 GHz)
  - High Band (LO 280 – 360 GHz)
- Even Wider IF Bandwidth: target of 4 – 20 GHz, with future extension to lower IF
- New cryostat with two receiver cartridges (similar style to ALMA)
  - Low maintenance pulse-tube cryocooler
  - Cooled receiver selection optics and cold LO injection
- Dual polarization operation with waveguide Orthomode Transducer attached directly to SIS Mixer for improved sensitivity and enhanced polarimetry
- Simultaneous dual-band observation mode through the use of either a wire grid polarizer, dichroic plate or time domain band switching
- YIG or VCO-based Local Oscillator to simplify tuning
- Double-side-band mixer initially for lower cost and continuation of technology
- Better logistics for polarimetry using a single Wideband Quarter Wave Plate (210 – 360 GHz)
- Possibility of guest/PI instrumentation

- New receiver has two dual pol receiver cartridges
- Receivers selected by four position rotating selector wheel
- Straight through, mirror, grid, dichroic options



wSMA Receiver Selector

Selection	Lo Band Rx	Hi Band Rx
Thru	Cold Load	Dual Pol
Grid	Pol. #1	Pol. #2
Dichroic	Dual Pol	Dual Pol
Mirror	Dual Pol	Cold Load

- Smaller cryostat allows space for possible “Guest Receiver”
- Selector mirrors between M6 and cryostat.

Guest (PI) Receiver Selector

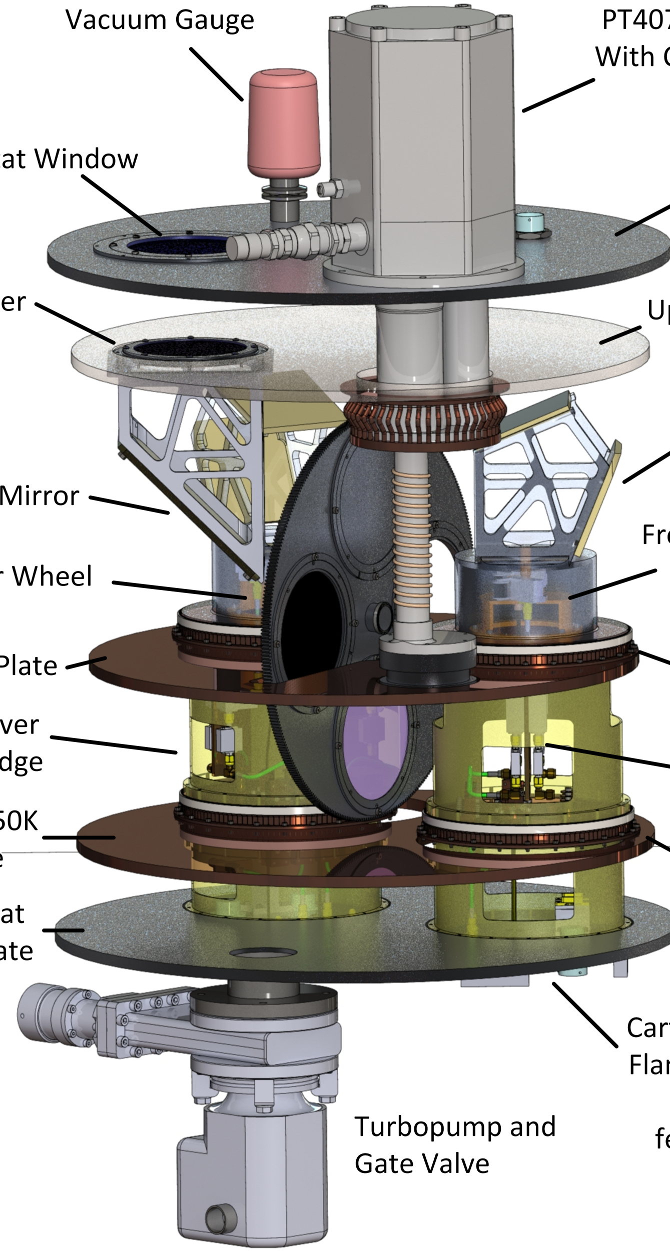
Selection	SMA Main Rx	Guest (PI) Rx
Thru	Inactive	Dual Pol
Grid	Single Pol	Single Pol
Mirror	Dual Pol	Inactive

Observation Modes

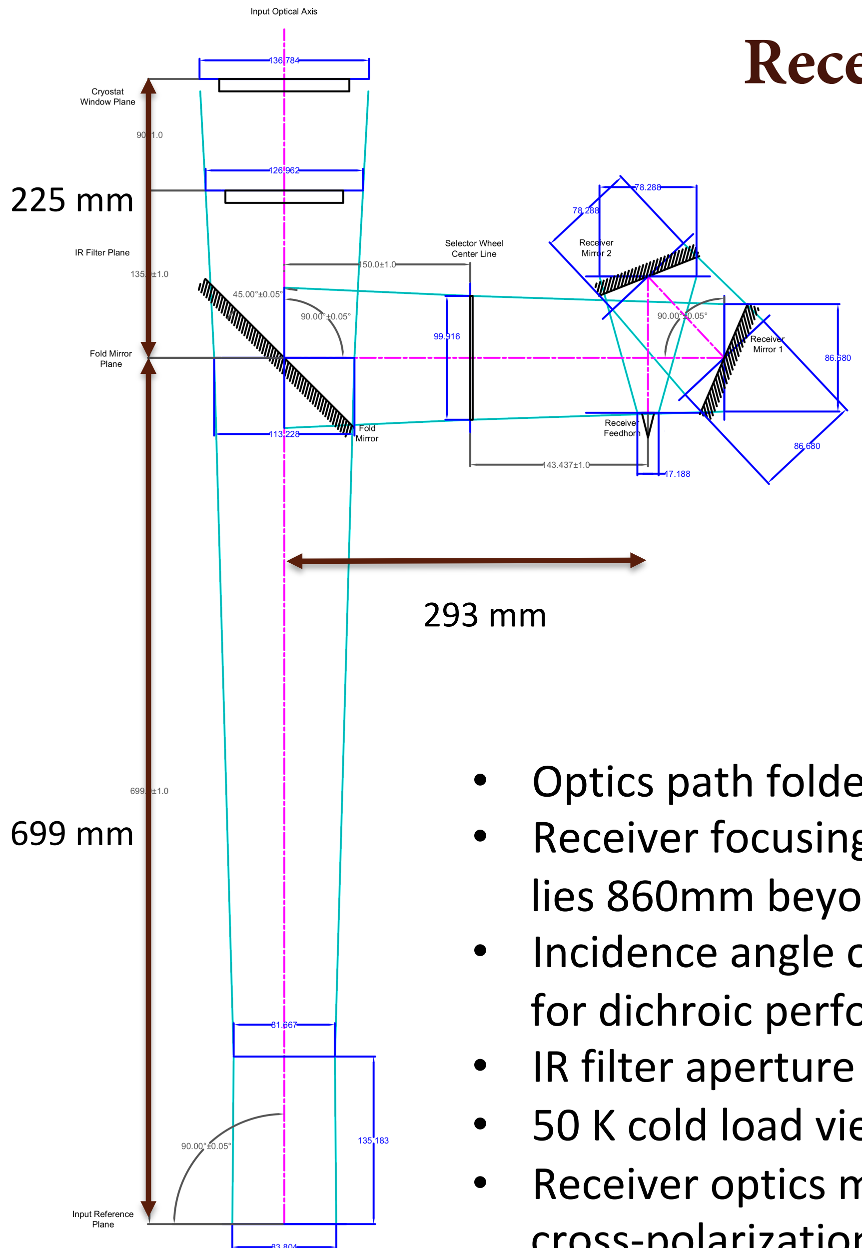
- Dual Pol Low Band (LO 210 – 270 GHz), IFBW 2 x 16 GHz DSB
- Dual Pol High Band (LO 280 – 360 GHz), IFBW 2 x 16 GHz DSB
- Dual Band observation can be accommodated by the use of either a wire grid (polarization combiner), a dichroic plate (frequency diplexing) or time domain band switching
  - **Wire Grid**: one polarization (mixer) from each band is active. System sensitivity per band is 70% that of the dual pol mode.
  - **Dichroic Plate**: all 4 mixers will be operational, opening up the possibility of dual band polarimetry with the help of a wideband Quarter Wave Plate. Some sacrifice of sensitivity per band is expected and sky frequencies will be limited.
  - **Time Domain Switching**: Switching between low and high band receivers over minutes time scale. For example 70% at 345 GHz + 30% at 230 GHz, to achieve matched sensitivity in good weather.

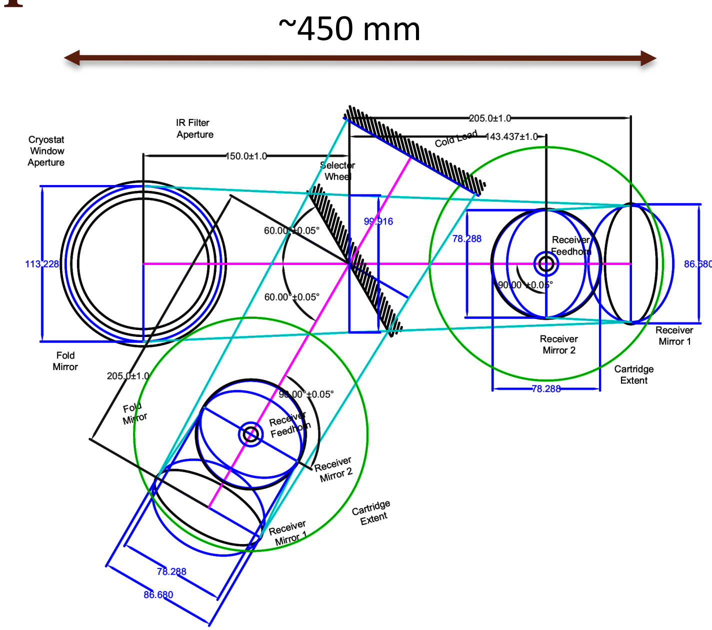
wSMA Receiver

- Diameter of cryostat: about half of current one. Height is similar
- Two temperature stages – 50K for radiation shield and selection optics and 4K for receivers
- Cooled receiver selection optics replaces Optics Cage – Cryostat top plate is higher
- Selector wheel mounted on radiation shield top plate
- Single cryostat window and IR filter
- Two receiver inserts, each housing a dual pol receiver
- Use automatic thermal links similar to ALMA
- No manual connections to cartridges inside cryostat



Receiver Optics



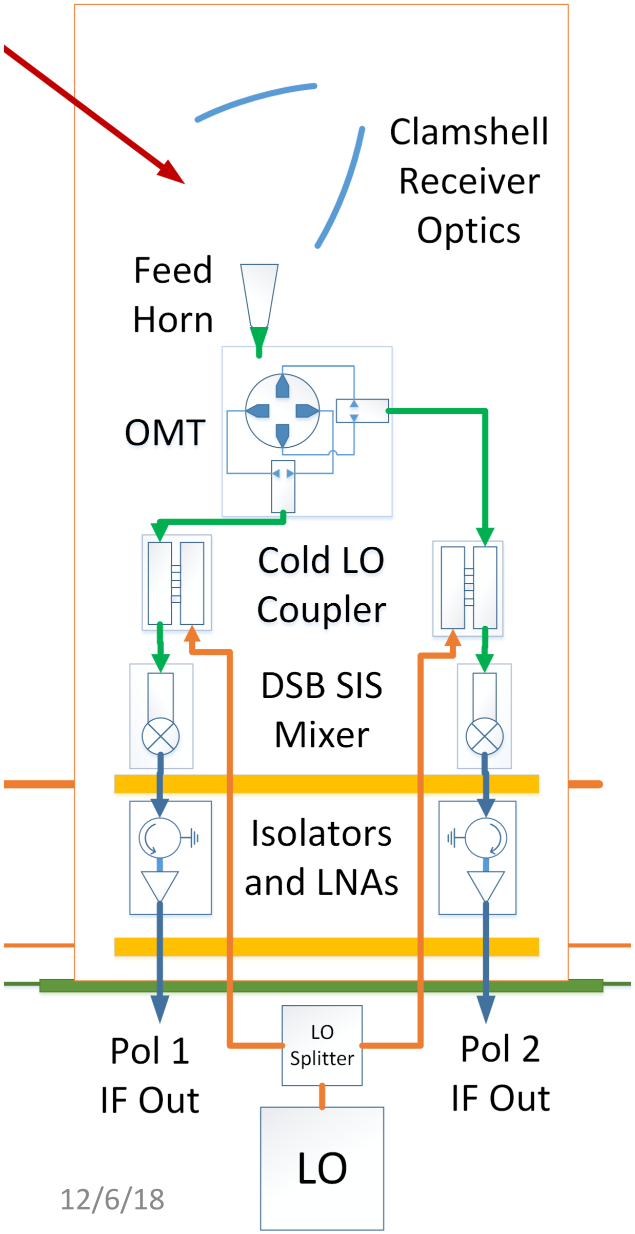


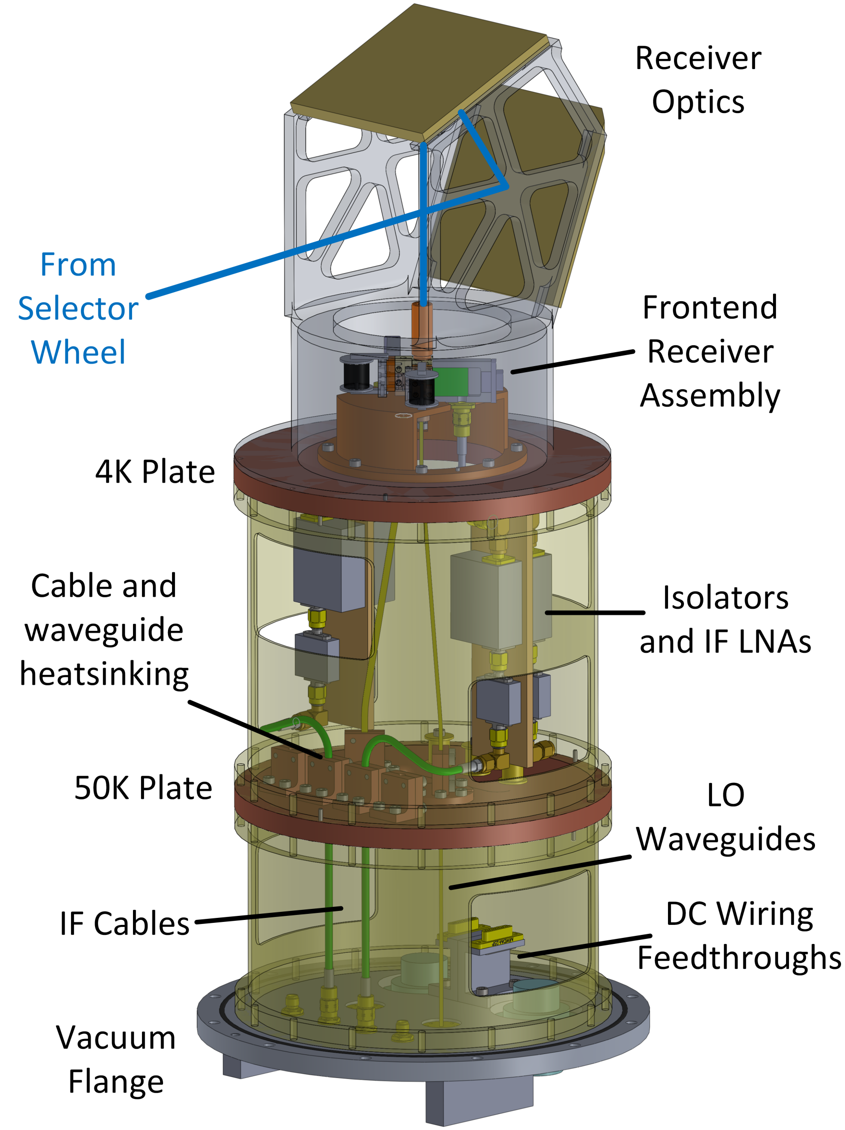
- Optics path folded to “use up” path length
- Receiver focusing optics places image of primary aperture that lies 860mm beyond reference plane onto feed horn aperture
- Incidence angle on selector wheel kept as low as space allows for dichroic performance reasons
- IR filter aperture acts as cold stop at 50 K
- 50 K cold load viewed by receiver not on sky
- Receiver optics meets Mizuguchi-Dragone condition to minimize cross-polarization

Cryostat Development

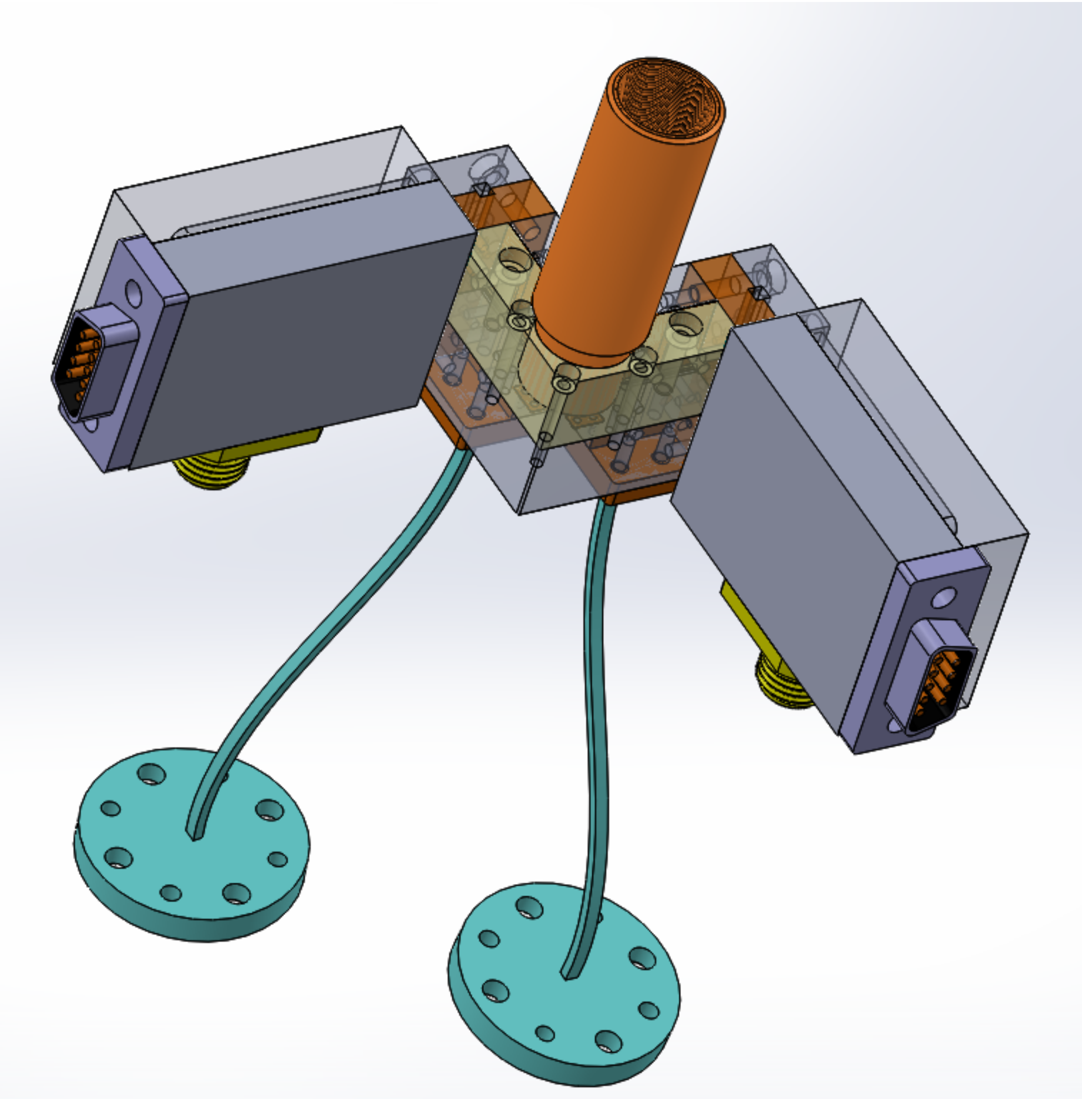
- Contract has been placed with High Precision Devices Inc. (Boulder, CO) for the design and build of two prototype cryostats – June 24th, 2018
- Cryostat concept design supplied by SAO as part of RFP package
- Contract is structured as multiphase Design and Build contract:
  - Initial contract deliverables – July 2019
    - Documented ready-to-build design (licensed for reuse)
    - 2 prototype cryostats and supporting spares and test hardware
    - 4 blank receiver cartridges
  - Additional Build options in HPD Offer:
    - 6, 8 or 10 production cryostats (with small modifications identified in testing prototypes)
    - 14, 16 or 18 blank receiver cartridges
    - First production cryostat delivered 6 months after exercising option, 3 months between cryostat deliveries
    - Option to be exercised within 6 months of close of initial contract
- Need a total of 10 cryostats: 8 antennas and 2 spare/lab test cryostats for Cambridge

Low Band Receiver Cartridge

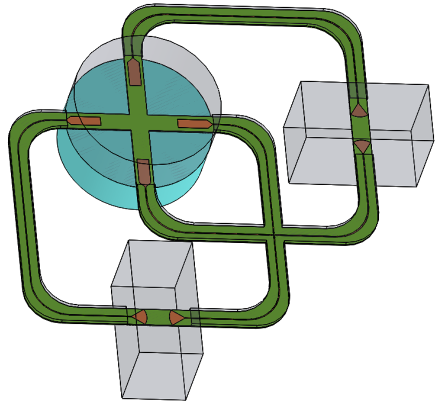


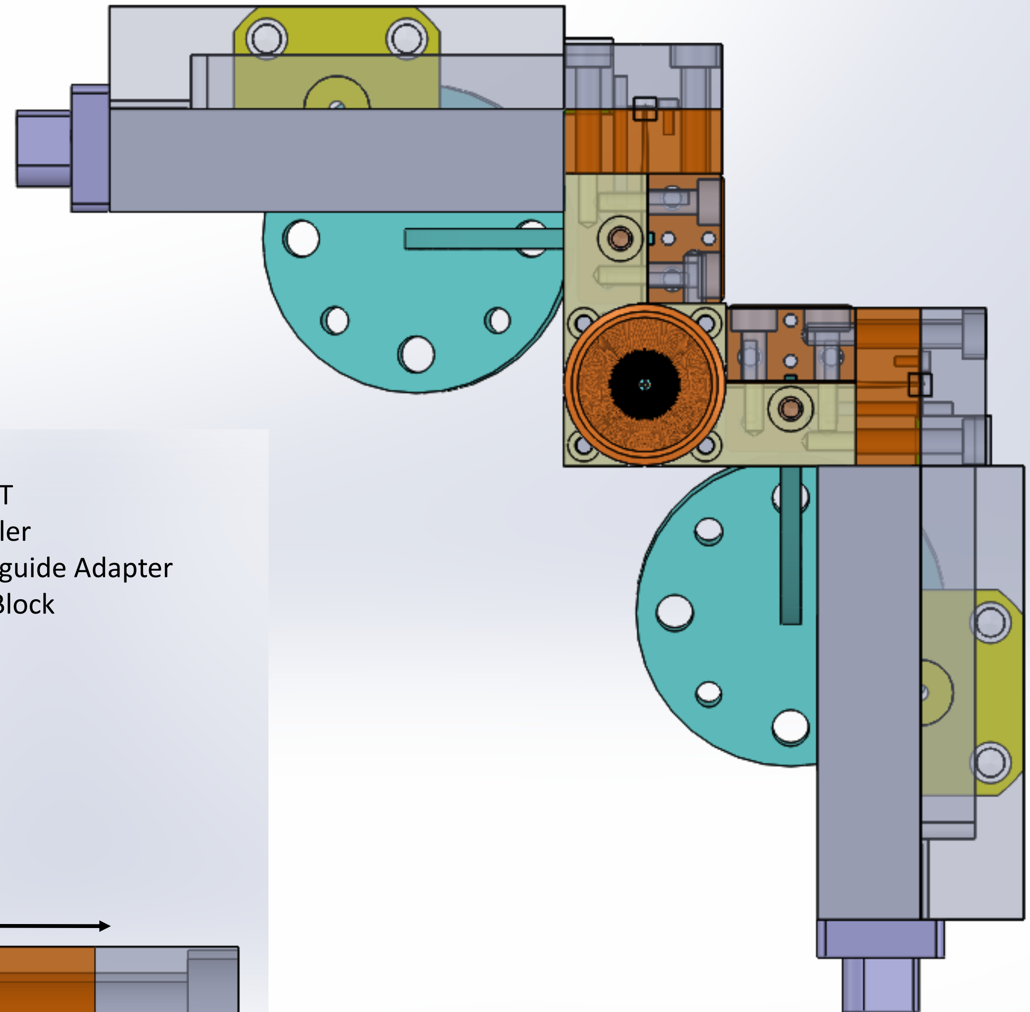


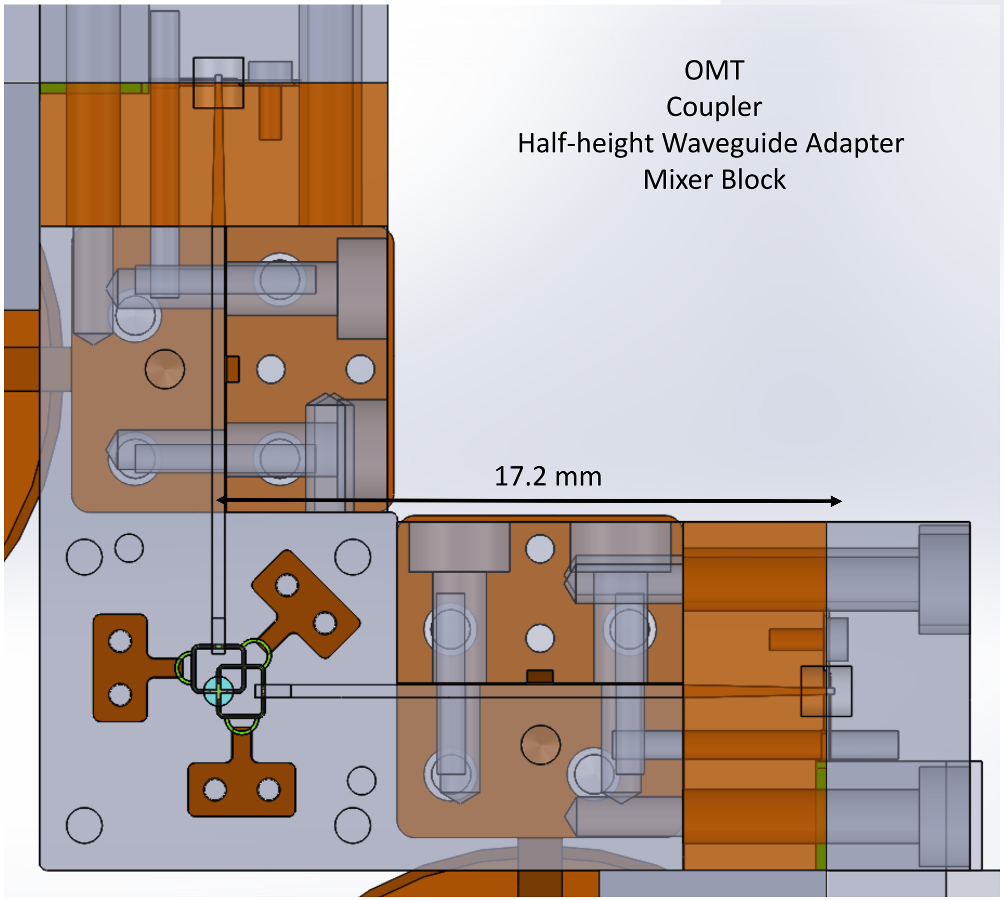
Frontend Receiver Module



- New feed horn designed to match new optics
- Planar OMT module
- Cold LO waveguide injection in cross-guide coupler
- Mixer block design adapted from existing SMA design
    - Future IF diplexer to allow access to low IF
- Each SIS mixer is permanently shunted by a 50-Ω inside mixer block.
- Four wire bias system using a modified version of existing bias circuitry.
- Will try to use permanent magnet for Low Band Receiver.







Design of Mixer Block in Progress

Cryogenic Isolator and LNA

- SAO developed wideband edge-mode coupled isolator – see Lingzhen Zeng's poster
- Low Noise Factory commercial "6-20" GHz LNA

Local Oscillator Module

- Mounted on the bottom below each insert
- Baseline: YIG Oscillator. VCO-based unit under development
- One module for each insert but each of the 2 mixers (polarization) to have independent LO power control
- Baseline design: motorized waveguide attenuator. Light-controlled waveguide attenuator under testing (patent pending)
- Current PLL electronic module will stay, with Raspberry Pi controller

IF Processor (to replace current Bandwidth Doubler Assembly)

- One processor for each mixer (Total of 4).
- To include digital attenuator, power monitoring and equalizer.
- Remote gain setting envisioned (with Raspberry PI control?).
- Estimated input power from cryostat -40 to -45 dBm. Output power -10 dBm (?)
- Output goes to IF/LO Signal Transport system

Receiver Electronic Rack

- To replace existing cheeks mounted around cryostat
- Contains:
  – Analog Modules
  – SIS Bias Boards
  – Magnetic Field Controllers
  – HEMT amplifier Bias Modules
  – IF processor
  – Receiver selection wheel driver
- Place rack under or beside cryostat
- Analog Modules adapted from current SMA designs, with ability to operate all four mixers simultaneously
- Digital Modules: Raspberry PIs + DAC and ADC interface
- Each Raspberry PI to have its own IP and connected to ACC via ethernet

Antenna Modifications for New Receivers

- (in addition to IF/LO fiber upgrades)
- Remove old cryostat
- Install new cryostat support and cryostat alignment structure
- Rearrange electronics rack
- Install new compressor (smaller than current Daikin system)
- Cooling system modifications
- Install new vacuum pump system
- Install new receiver
- Align receiver to existing optics

- Will need to be done in hangar
- Will proceed one antenna at a time and combine with other maintenance

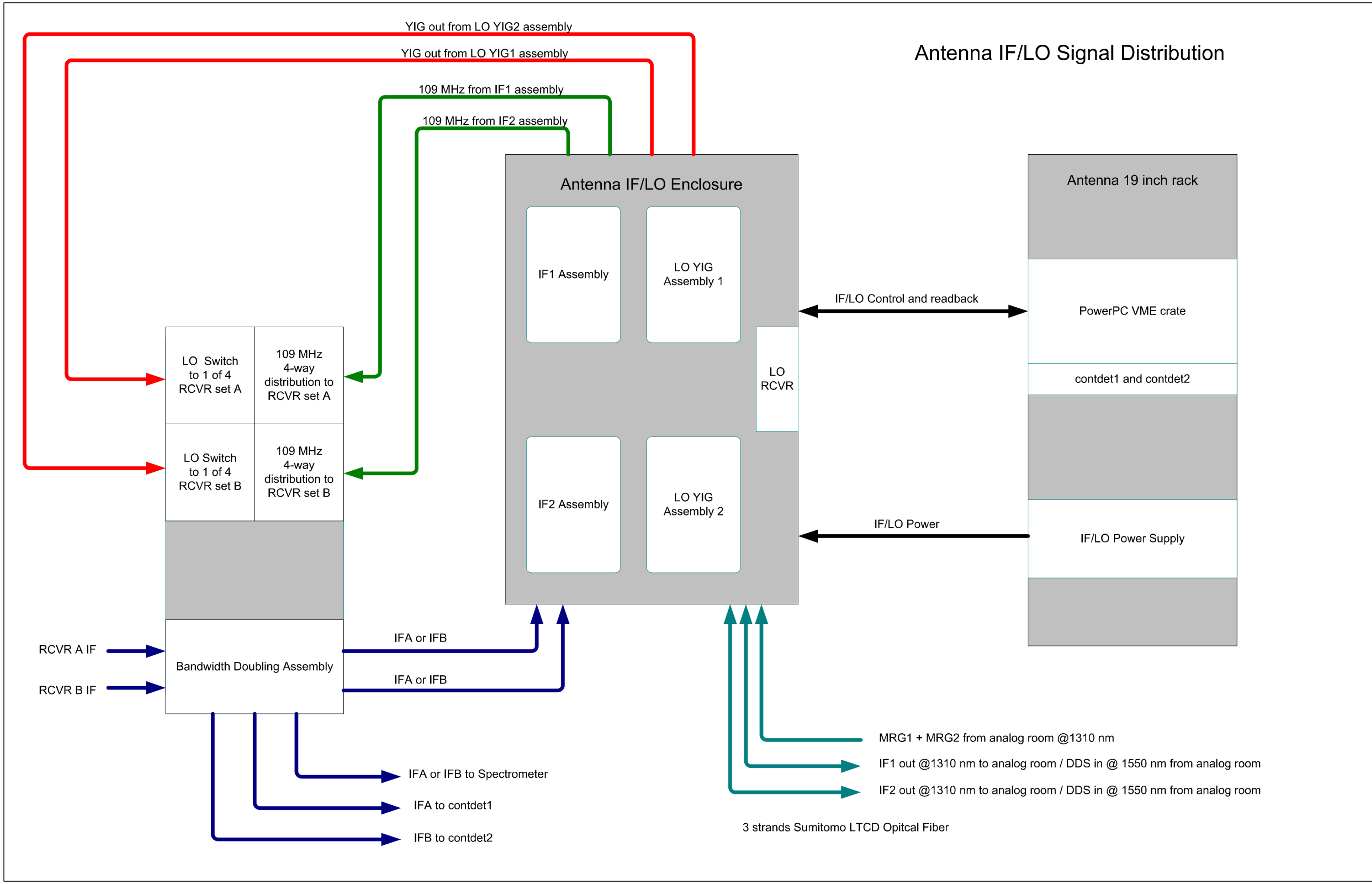
Receiver Control Software

- New controllers/hardware will be interfaced through Raspberry Pi on Ethernet
- Some existing controllers will stay, for example Optics Control board to control Cal Load/Waveplate Assembly
- Will move functionality from monolithic **TUNE6** code on ACC to smaller pieces of Python code on Raspberry Pis
- As we are building up the system, and adding functionality, we will use the **TUNE** utility to direct commands to the relevant processor
- Separate future program to replace antenna computers is required – keep this in mind as development for new receivers goes ahead
- Study group set up in Cambridge to work on this, led by Attila and Bob Wilson

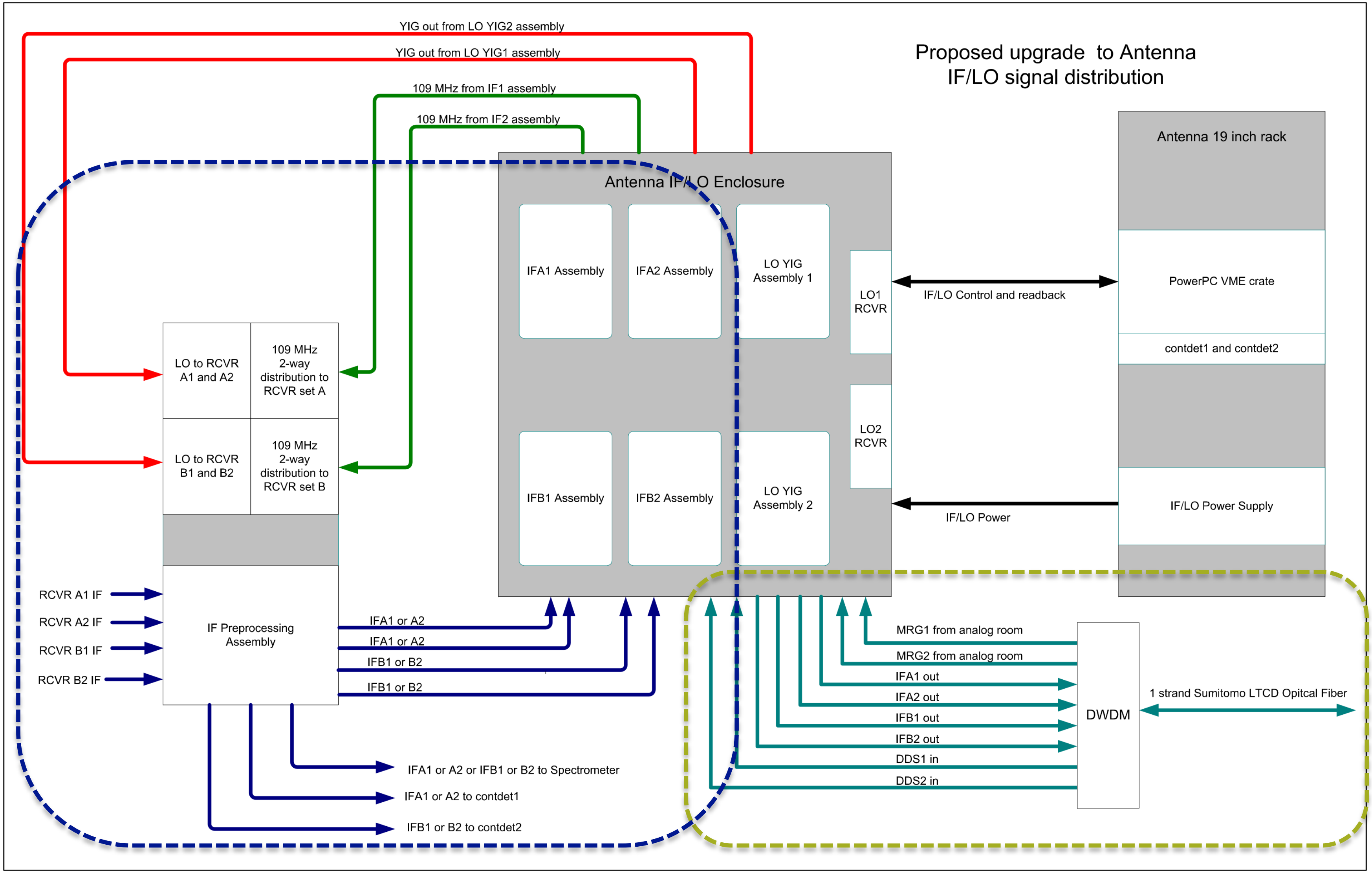
Upgrade to Fiber Optic System and IF/LO processing

- Current system will operate to 16 GHz IF with minor upgrades (late 2018)
- For full 20 GHz IF (late 2020):
  - Move IF signals from 1310 nm to 1550nm on current fibers to allow multiplexing multiple IF signals on single fiber with commercial DWDM equipment
  - Hardware needed:
    - 34 transmitters: 4x8 = 32 for IF + 2 for MRG.
    - 48 receivers: 4x8 = 32 for IF + 2x8 = 16 used to for MRG.
  - Propose to use the existing 12 GHz 1310 nm Ortel/Emcore receivers located in the 1DCVs as MRG receivers. Therefore, we need 32 Optilab receivers: 30 GHz BW @1550 nm.
  - 16 FiberSpan transmitters with DWDM channel spacing.
  - 16 DWDM modules. 8 for the antennas and 8 to demultiplex analog room. For example: 200 GHz 8-channel multiplexers 1546 – 1557 nm @ $490 each. 3 dB insertion loss max.

IF/LO Distribution



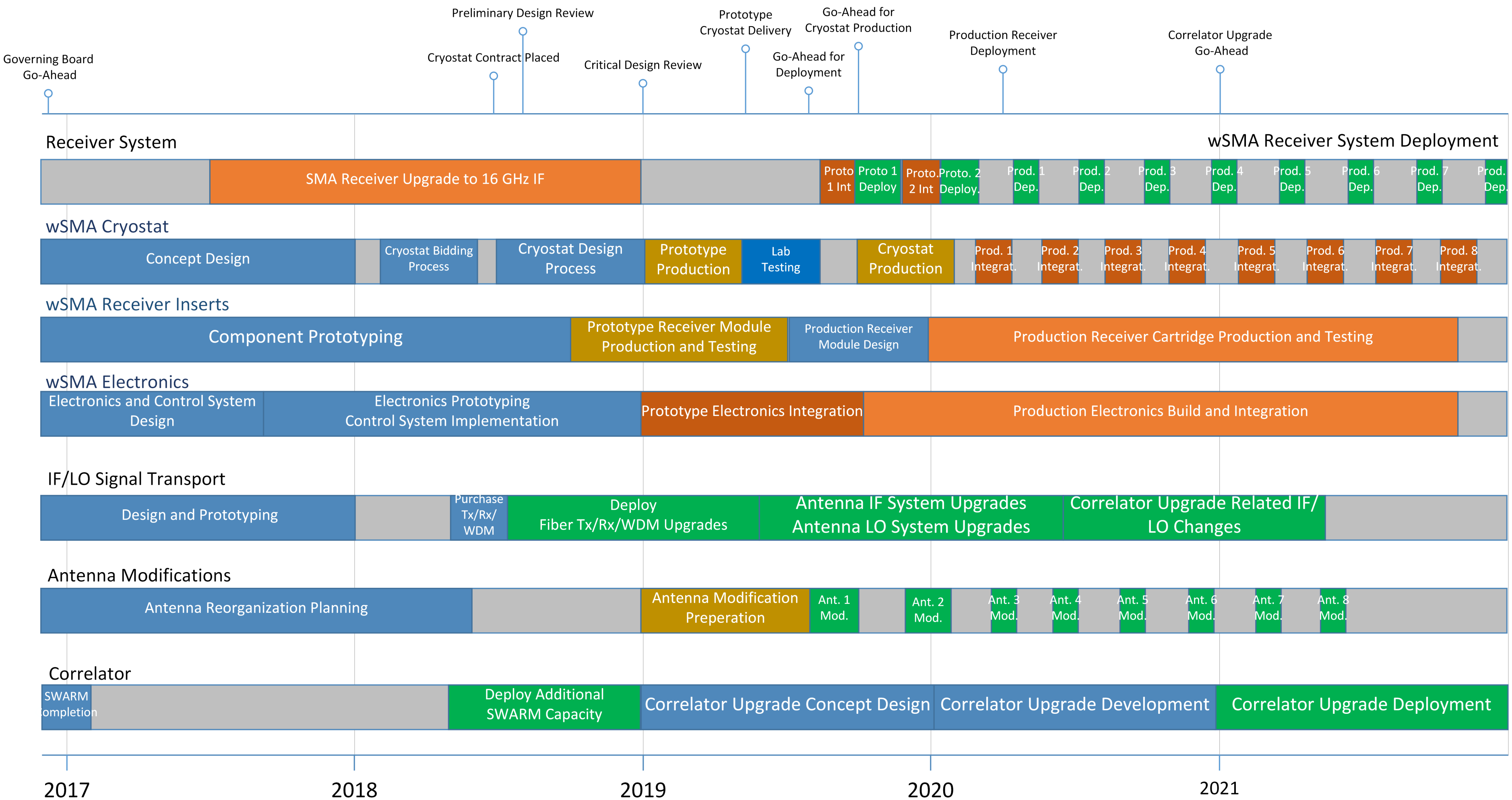
IF/LO Distribution



Correlator

- Correlator expansion to new 12 – 16 GHz IF band underway by adding two additional SWARM segments – will be ready this year
- Jonathon will discuss options next
  - Digitization in the Receiver Cabin is desirable
- Decision for 20 GHz expansion not required immediately

wSMA Timeline



Maintaining compatibility during upgrade

- During transition, SMA will not be able to observe at the very highest and lowest sky frequencies with all receivers
- Necessarily will remove those observation options from proposal system at some point – most likely when third antenna is upgraded
- LO tuning options will be limited to same frequency on each polarization in 230/240 (Low) bands and 300/380 (High) bands
  - Some thought is needed to get MRG references and Walshing correct
- Polarization observations should be able to continue as before, although only one Walsh cycle per antenna

The future beyond the wSMA

- Digitization in cabin enables sideband separating receivers:
  - Increased sensitivity, reduced confusion of spectral lines
  - Digital IF separation and calibration – approach being tested by other groups now – e.g. ALMA Band 9 2SB team
- Dual band observing with phase transfer

- Guest instrument space allows new science capabilities and technologies to be tested without affecting "core" SMA science operations
  - 3mm/2mm receivers
  - Sub-mm focal plane arrays for wide-field interferometry
  - Atomic carbon receiver for 492 GHz/809 GHz
  - Water vapor radiometry for phase correction

wSMA Timeline