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

<table>
<thead>
<tr>
<th>Selection</th>
<th>Lo Band Rx</th>
<th>Hi Band Rx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thru</td>
<td>Cold Load</td>
<td>Dual Pol</td>
</tr>
<tr>
<td>Grid</td>
<td>Pol. #1</td>
<td>Pol. #2</td>
</tr>
<tr>
<td>Dichroic</td>
<td>Dual Pol</td>
<td>Dual Pol</td>
</tr>
<tr>
<td>Mirror</td>
<td>Dual Pol</td>
<td>Cold Load</td>
</tr>
</tbody>
</table>

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

### Guest (PI) Receiver Selector

<table>
<thead>
<tr>
<th>Selection</th>
<th>SMA Main Rx</th>
<th>Guest (PI) Rx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thru</td>
<td>Inactive</td>
<td>Dual Pol</td>
</tr>
<tr>
<td>Grid</td>
<td>Single Pol</td>
<td>Single Pol</td>
</tr>
<tr>
<td>Mirror</td>
<td>Dual Pol</td>
<td>Inactive</td>
</tr>
</tbody>
</table>

**wSMA Upgrade - Advisory Committee**
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
• 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
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 Doublor 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 1550 nm 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

109 MHz from IF1 assembly
109 MHz from IF2 assembly
109 MHz from LO YIG 1 assembly
YIG out from LO YIG 2 assembly

Antenna IF/LO Enclosure

- IFA1 Assembly
- IFA2 Assembly
- LO YIG Assembly 1
- LO YIG Assembly 2
- LO1 RCVR
- LO2 RCVR

IF/LO Power
IF/LO Control and readback

Proposed upgrade to Antenna IF/LO signal distribution

Antenna 19 inch rack

PowerPC VME crate
contdet1 and contdet2

IF/LO Power Supply

1 strand Sumitomo LTCD Optical Fiber

DWDM

RCVR A1 IF
RCVR A2 IF
RCVR B1 IF
RCVR B2 IF

IF Preprocessing Assembly

- IFA1 or A2
- IFA1 or A2
- IFA1 or A2
- IFA1 or A2
- IFB1 or B2
- IFB1 or B2
- IFB1 or B2
- IFB1 or B2

- IFA1 or A2 or IFB1 or B2 to Spectrometer
- IFA1 or A2 to contdet1
- IFB1 or B2 to contdet2

LO to RCVR A1 and A2
LO to RCVR B1 and B2

109 MHz 2-way distribution to RCVR set A
109 MHz 2-way distribution to RCVR set B

12/6/18 wSMA Upgrade - Advisory Committee
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

wSMA Receiver System

- SMA Receiver Upgrade to 16 GHz IF
- Proto 1 int
- Proto 1 Deploy
- Proto 2 int

wSMA Cryostat

- Concept Design
- Cryostat Bidding Process
- Cryostat Design Process
- Proto Production
- Lab Testing
- Cryostat Production
- Prod 1 Integrate
- Prod 2 Integrate
- Prod 3 Integrate
- Prod 4 Integrate
- Prod 5 Integrate
- Prod 6 Integrate
- Prod 7 Integrate
- Prod 8 Integrate

wSMA Receiver Inserts

- Component Prototyping
- Prototype Receiver Module Production and Testing
- Prod Receiver Module Design
- Prod Receiver Cartridge Production and Testing

wSMA Electronics

- Electronics and Control System Design
- Electronics Prototyping
- Control System Implementation
- Prototype Electronics Integration
- Prod Electronics Build and Integration

IF/LO Signal Transport

- Design and Prototyping
- Purchase Tx/Rx WDM
- Deploy Fiber Tx/Rx WDM Upgrades
- Antenna IF System Upgrades
- Antenna IF System Upgrades
- Antenna LO System Upgrades
- Correlator Upgrade Related IF/LO Changes

Antenna Modifications

- Antenna Reorganization Planning
- Antenna Modification Preparation
- Ant 1 Mod
- Ant 2 Mod
- Ant 3 Mod
- Ant 4 Mod
- Ant 5 Mod
- Ant 6 Mod
- Ant 7 Mod
- Ant 8 Mod

Correlator

- Deploy Additional SWARM Capacity
- Correlator Upgrade Concept Design
- Correlator Upgrade Development
- Correlator Upgrade Deployment

2017 2018 2019 2020 2021
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

12/6/18
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