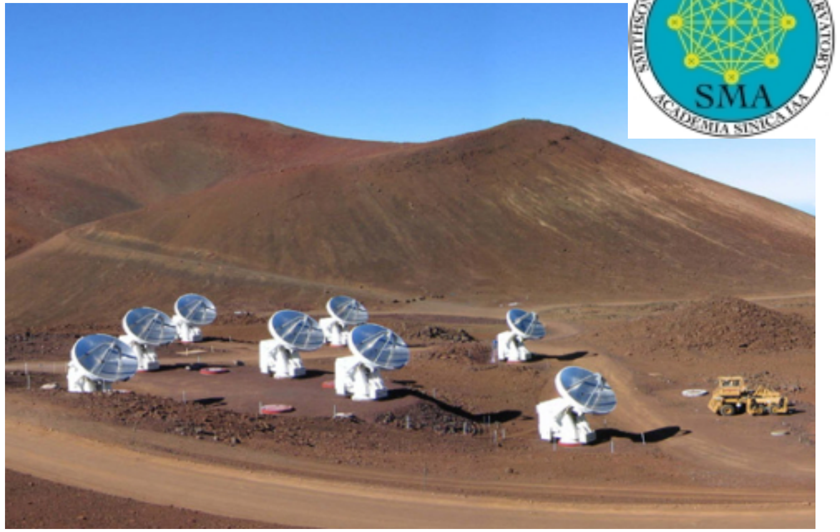


SMA Ongoing Wideband Upgrade

Upgrades leading to wSMA

How to further improve SMA sensitivity and throughput?

- **Add more antennas?**
- **Increase the size of antennas?**
- **Increase the instantaneous bandwidth of SMA**

  > Improve continuum sensitivity of SMA $\Delta T \sim 1/\sqrt{B}$

  > Catch more spectral lines with a single tuning

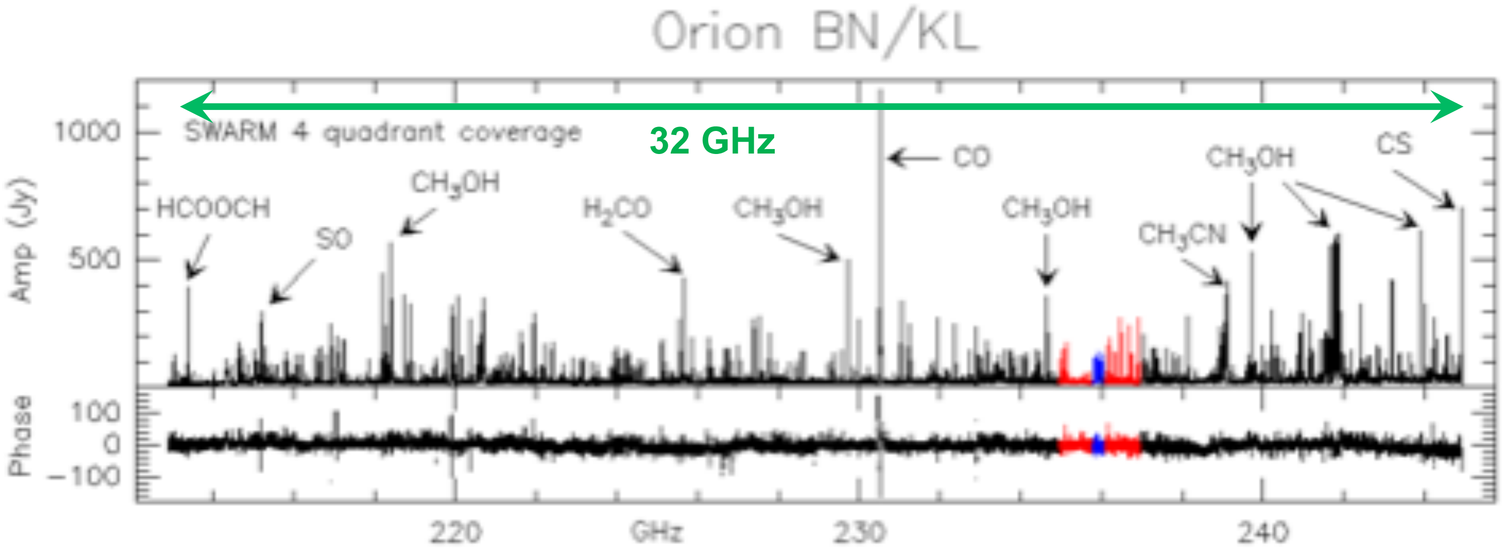
- **Improve receiver noise temperature**

  > Remove room temperature optics

- **Going to multi-pixel**

Frontier for Radio Astronomy: Quest for Wider Bandwidth

- SMA is performing nightly observation with 32 GHz wide on-sky bandwidth thanks to wideband SIS receivers and SWARM.
- SWARM = Q1, Q2, Q3 + Q4, each quadrant handles 2 GHz DSB x 2 Rx
- 4 fold increase in BW compared to 10 years ago. Equivalent to collecting and processing 4 times as many photons.
- Can we go further in increasing the bandwidth? YES



32 GHz wide spectrum produced by the SWARM correlator of the Submillimeter Array (SMA), using 2x8 GHz Double-side-band IF of the SMA receivers. SWARM is powered by state-of-the-art fast digital FPGA processors.

Upgrade Path of SMA

2018

Current Status of SMA
Dual DSB Rx
4 - 12 GHz IF
4Q SWARM
32 GHz On sky BW

2019

Interim Upgrade
Keep Cryostat
4 - 16 GHz IF
6Q SWARM
48 GHz On sky BW

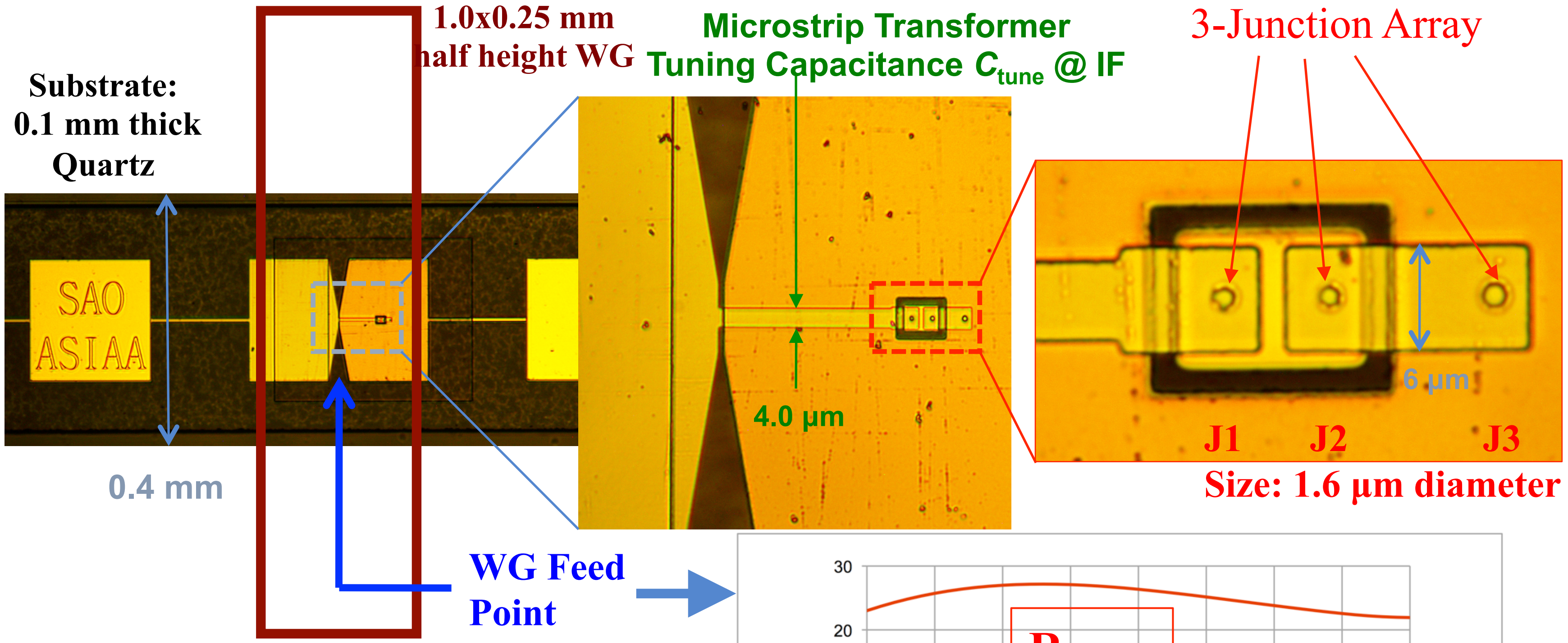
2021-
2022

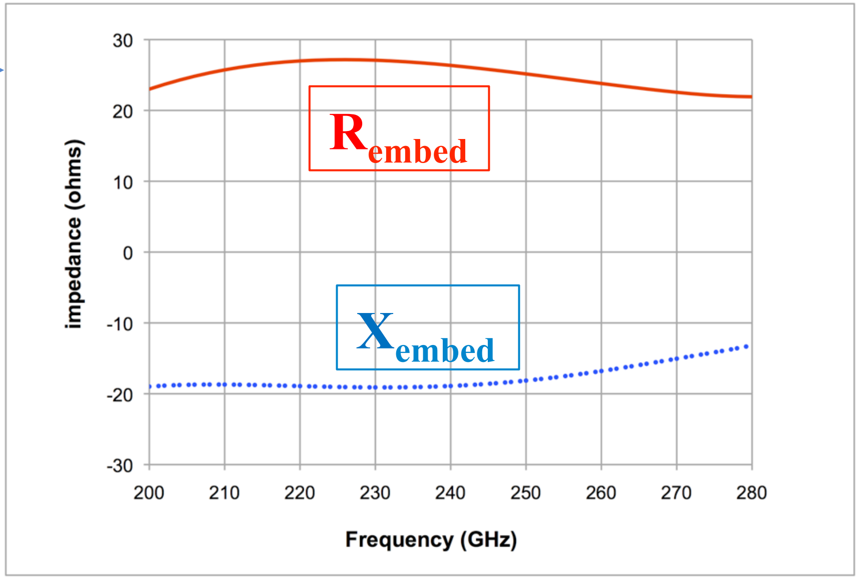
wSMA Goal
New Cryostat
4 - 20 GHz IF (min)
Next gen Correlator (?)
> 64 GHz On sky BW

Factors Limiting IF Bandwidth of SIS Mixers

- **High IF quantum effect (from Tucker Theory) phases in for IF > F_{LO}/10.**
- **Junction Capacitance --- Use small devices or series junction array.**
- **Output Saturation: Wider IF band leads to higher IF voltage swing across the junction. Max voltage swing is set by the width of photon step (LO frequency + # of junctions) -- -Reduce IF load impedance** (Tan 2014) **or use series junction array.**
- **SIS output match to Low Noise Amplifier (LNA)**
  1. **Direct interface** (Rice 2002).
  2. **Employ Impedance transformer** (Tan 2014) **.**
  3. **SIS device with High Current Density** (Kojima 2017)**.**
  4. **Employ a wideband isolator in front of LNA.**
- **RF/IF Grounding of SIS Mixer -- Need to ground as close to device as possible.**

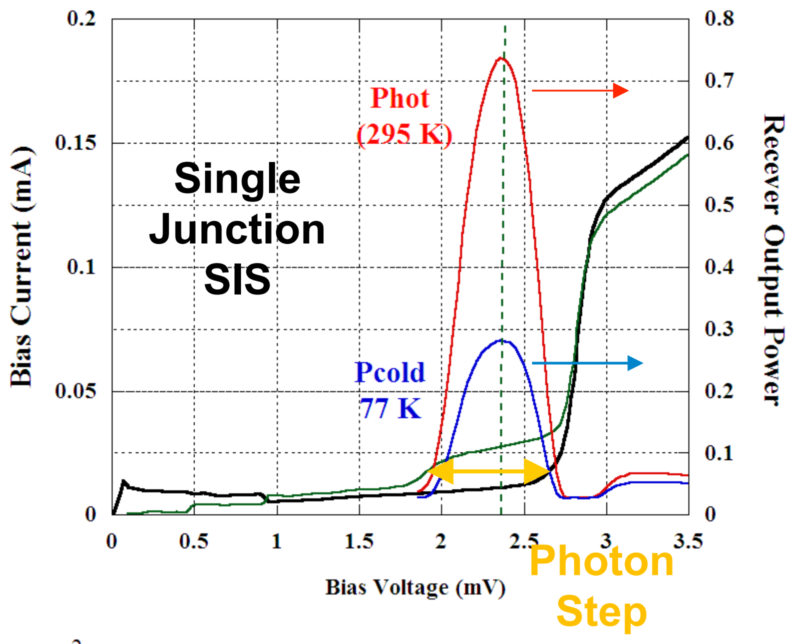
SIS Mixer for wSMA-240

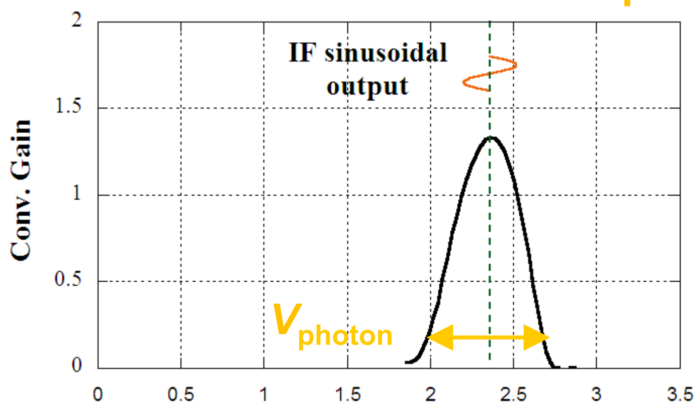




- $C_{array} = C_j / 3$
- $C_{mixer} = C_{array} + C_{tune} \sim 115$ fF.
- RC time constant of mixer gives
  $F_{3dB} > 25$ GHz.

Output Saturation in SIS Mixers





Power output of SIS mixer:

$$P_{out} = G_{conv} \times k_B T_{inp} B$$

$G_{conv} \sim 1$: Conversion gain of SIS
$T_{inp} \sim 300$ K : Input (Antenna) Temp.
$B \sim 20$ GHz : Effective IF Bandwidth
$P_{out} \sim 10^{-10}$ W (100 pW)

RMS IF Voltage swing V_{IF} :

$$P_{out} = (V_{IF})^2 / R_L$$

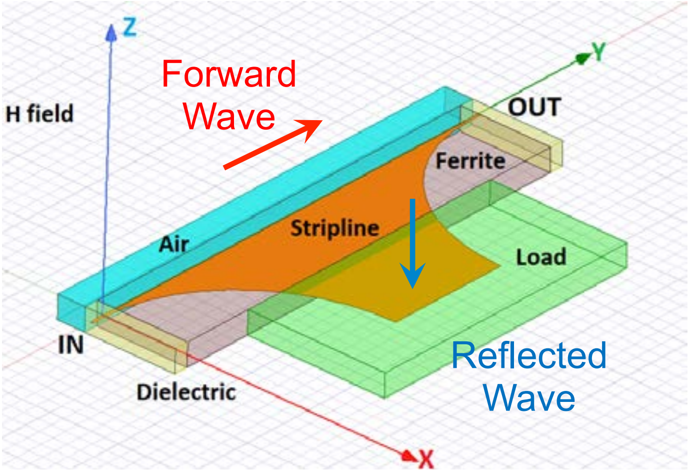
$R_L \sim 50\ \Omega$: Load resistance
$V_{IF} \sim 7\text{x}10^{-5}$ V (0.07 mV)

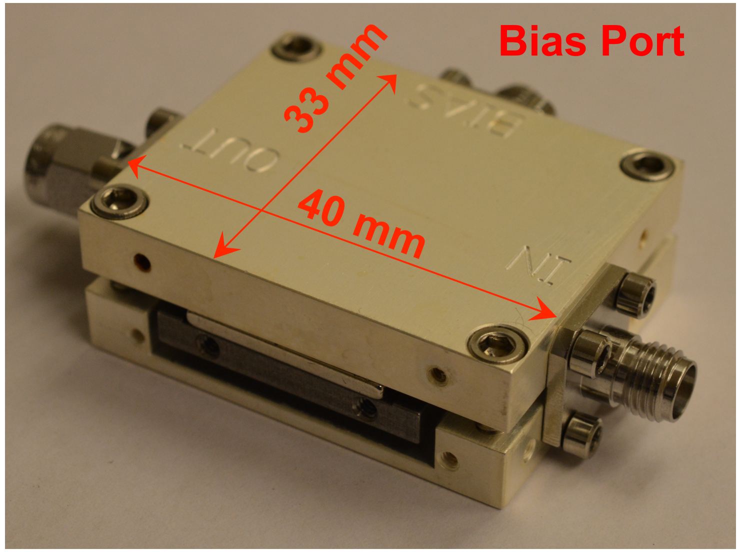
$$V_{photon} = N \times (hf_{LO} / e)$$
$$= N f_{LO}\ [\text{GHz}]/242 \text{ mV}$$

Use of 3-junction array increases the power handling capacity of the SIS mixer by a factor of 3.

Wideband Cryogenic Isolator Development at CfA

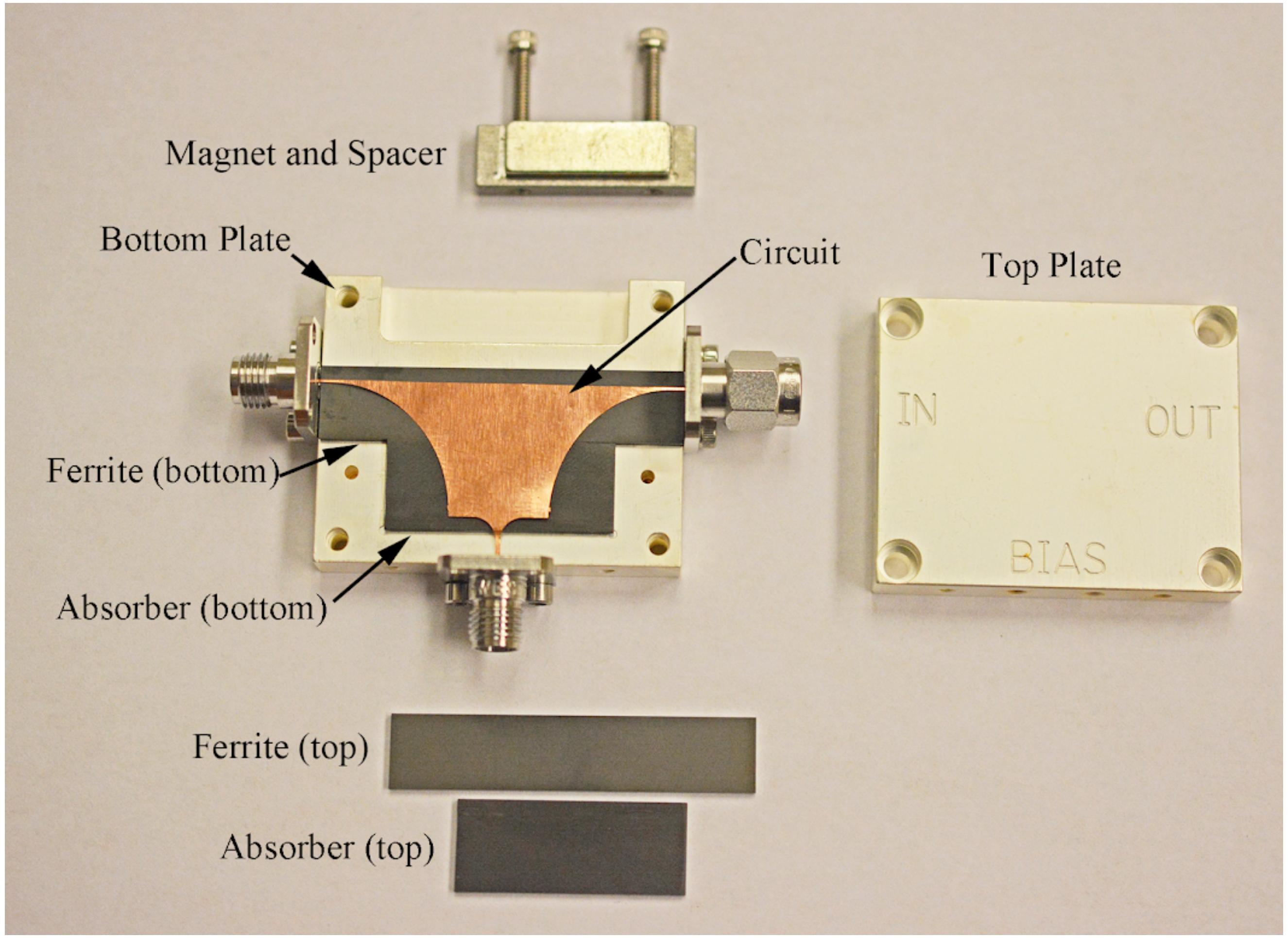
- Commercial cryogenic edge-mode isolator offers 3:1 BW operation.
- Quinstar 4-12 GHz isolator in use in many ALMA band.
- SMA uses a 4-14 GHz version from Quinstar
- We have developed a even wider band isolator





- Under DC magnetic field, RF current on ferrite stripline is displaced laterally, and becomes concentrated along the edge -- Edge-mode.
- By adding appropriate absorbing material, the reflected wave can be removed.

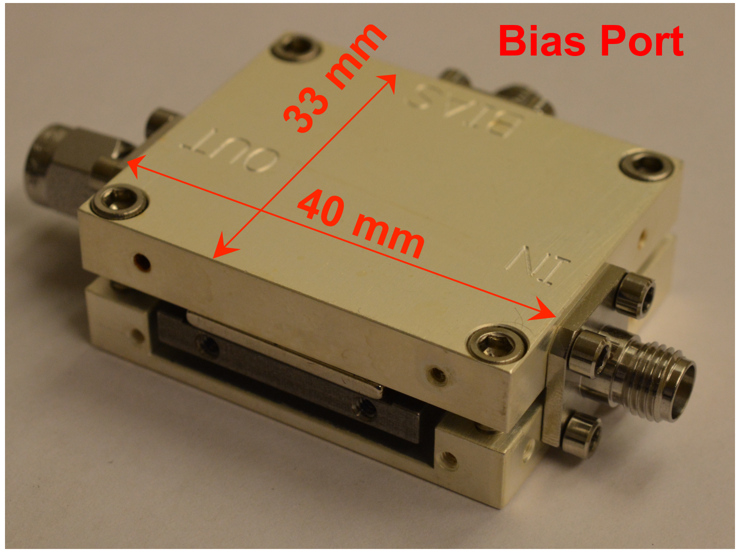
Assembly Photo of SMA Wideband Isolator

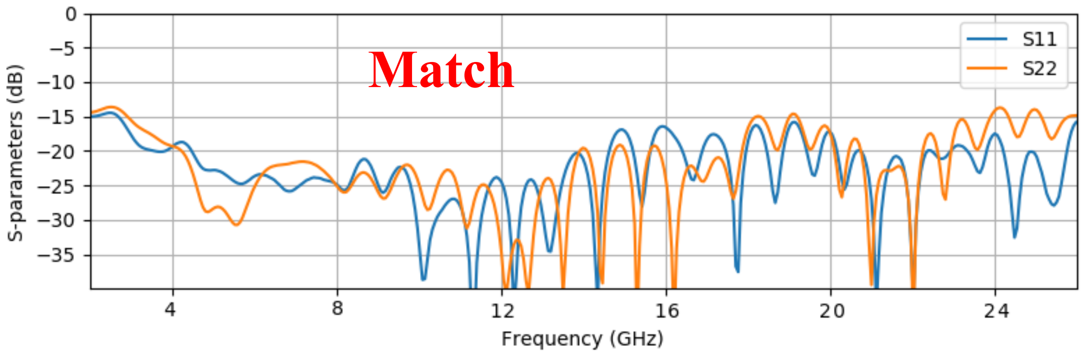


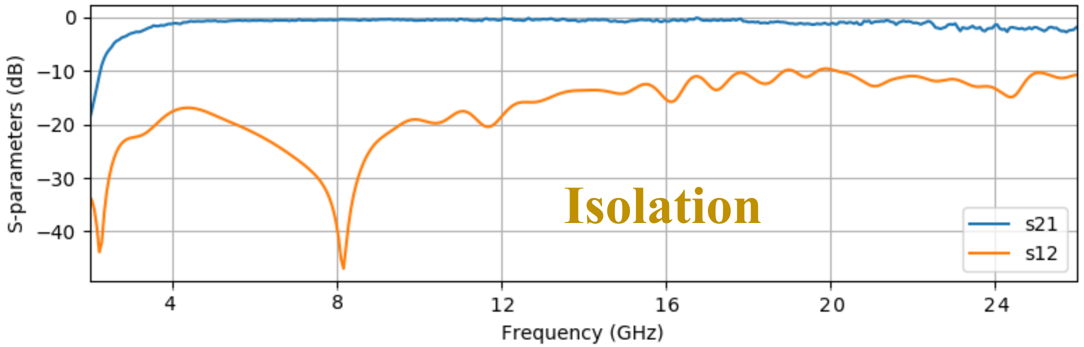
L. Zeng et al, "A low-loss edge-mode isolator with improved bandwidth for Cryogenic operation," IEEE Trans. Microwave Theory & Techniques, 2018. DOI: 10.1109/TMTT.2018.2799574

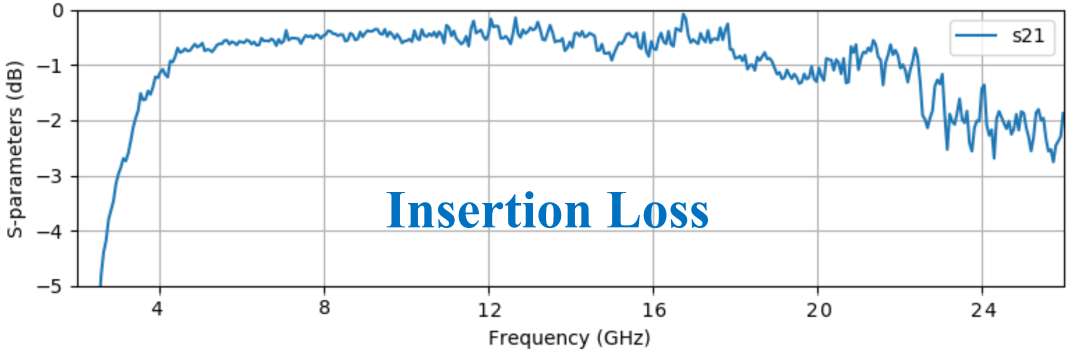
Performance of Wideband Isolator at 4 K

- **Insertion Loss <-1 dB for 4 - 17 GHz, rising to 1 - 1.5 dB for 17 - 22 GHz**
- **Isolation < -15 dB for 4 - 13 GHz, rising to 10 - 13 dB above 13 GHz**
- **Input & Output Match < -15 dB**



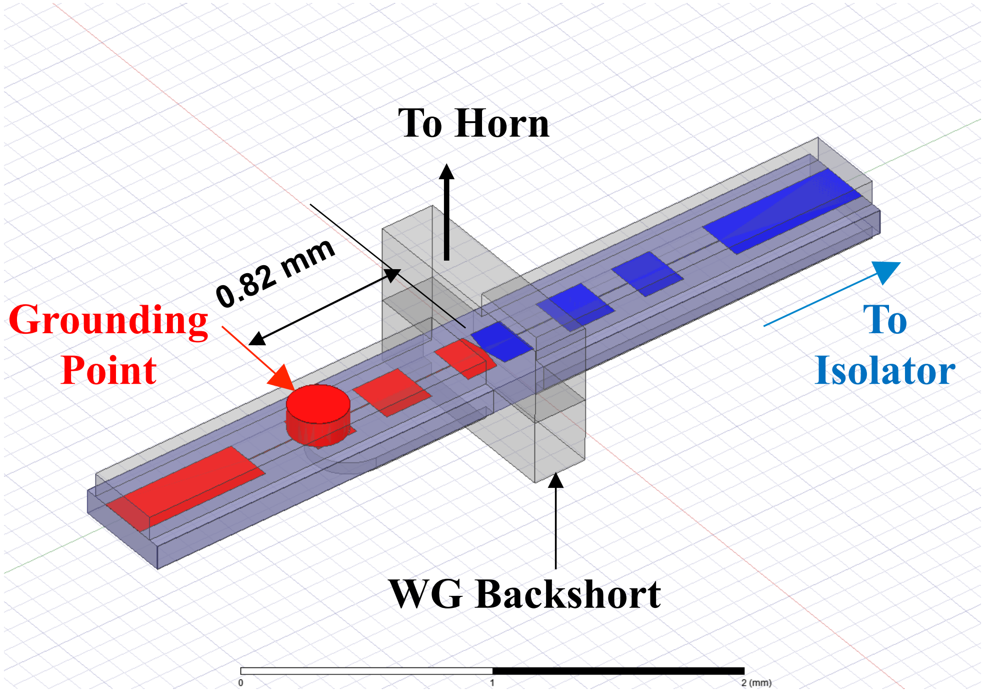


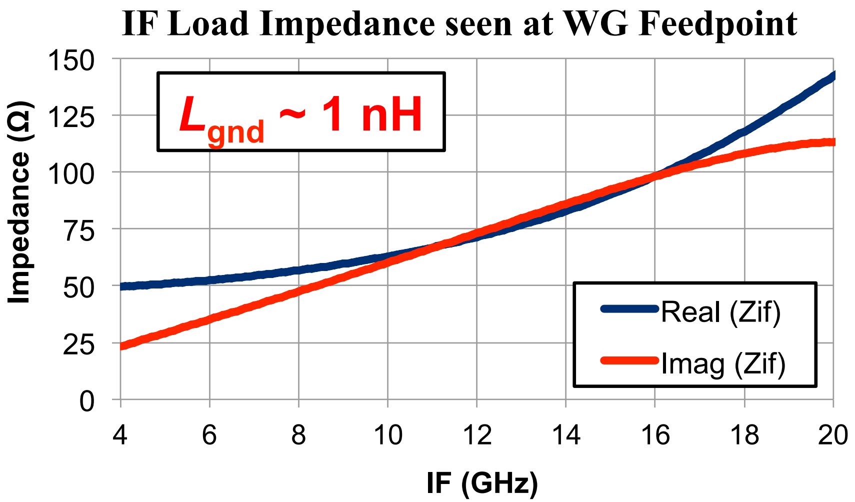


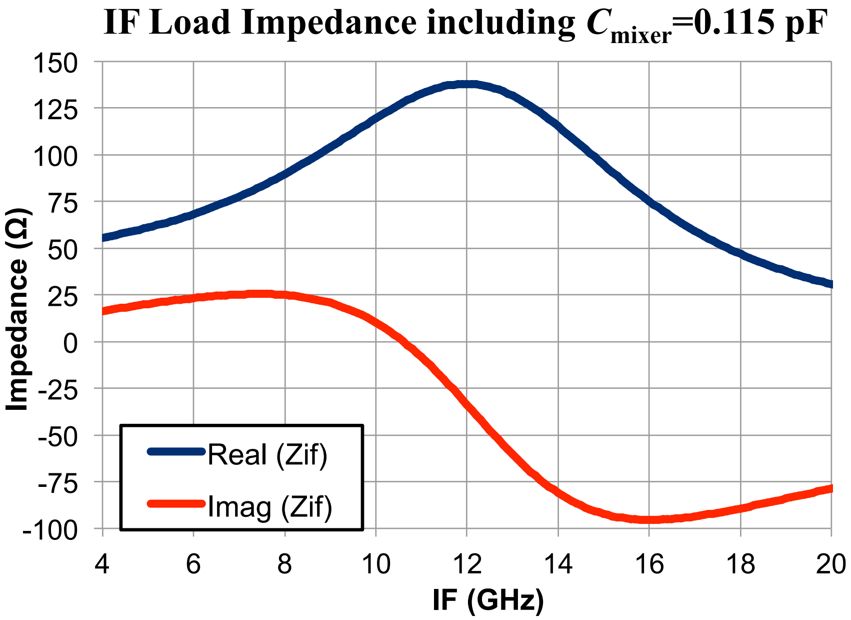


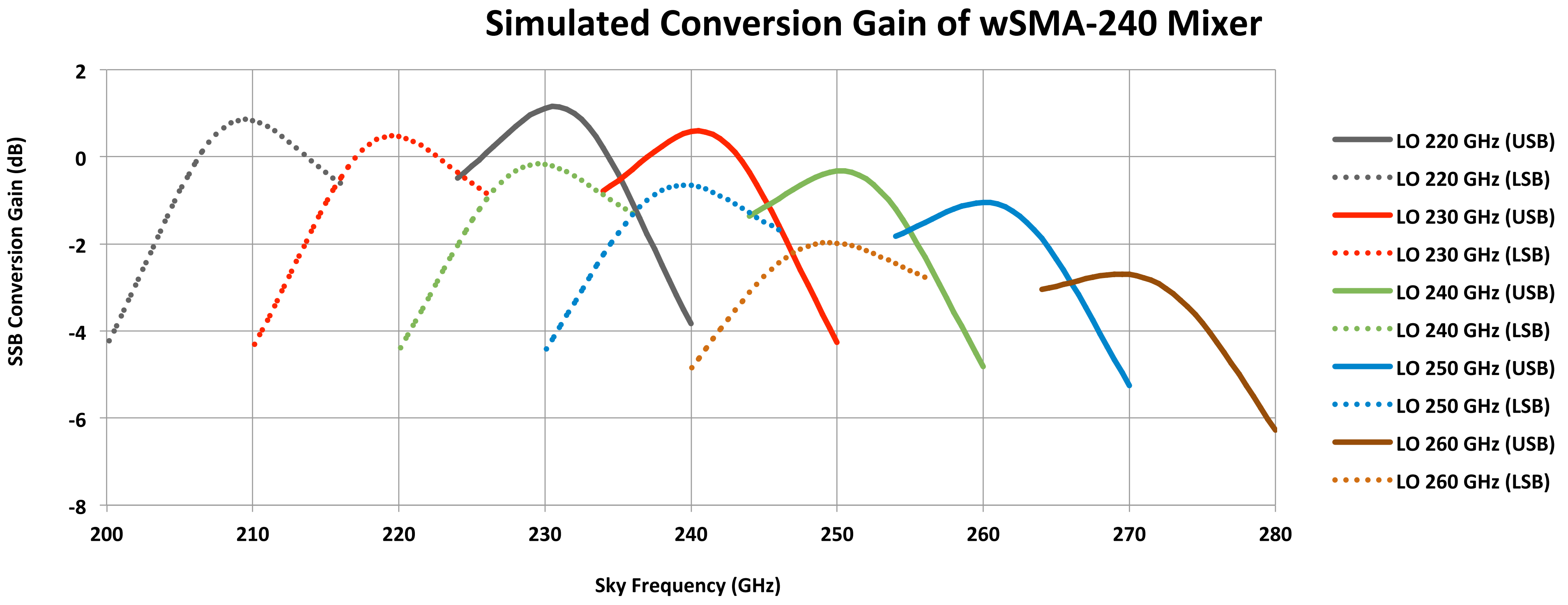
Grounding of Mixer Chip

- Grounding of mixer chip may introduce extra inductance (L_{gnd}) to the IF circuit.
- The extra load reactance may offset C_{mixer}, sum of junction & tuning circuit capacitances.
- Peak IF response of mixer occurs at resonance between L_{gnd} and C_{mixer}







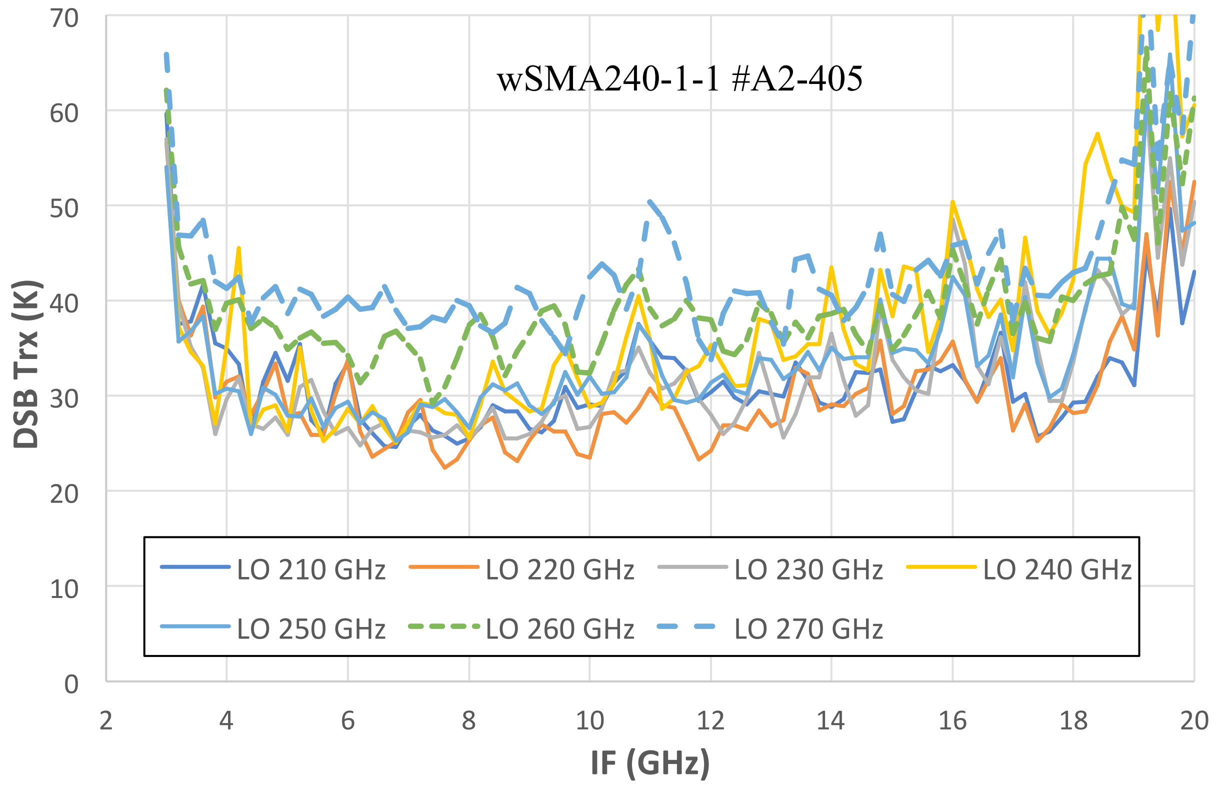


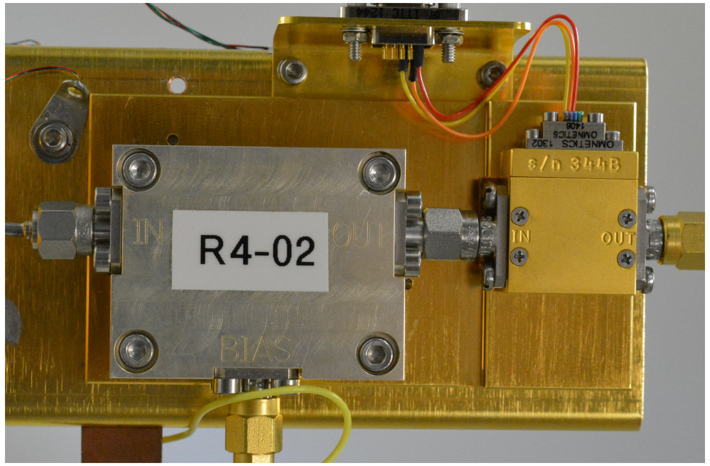
- **Peak IF response predicted at ~12 GHz**
- **Sideband ratio is within 1 dB, except at high LO**
- **DSB Conversion Gain is sum of USB & LSB Gain**
- **G_{SSB} = 0 dB translates into G_{DSB} = +3 dB**

Laboratory Results

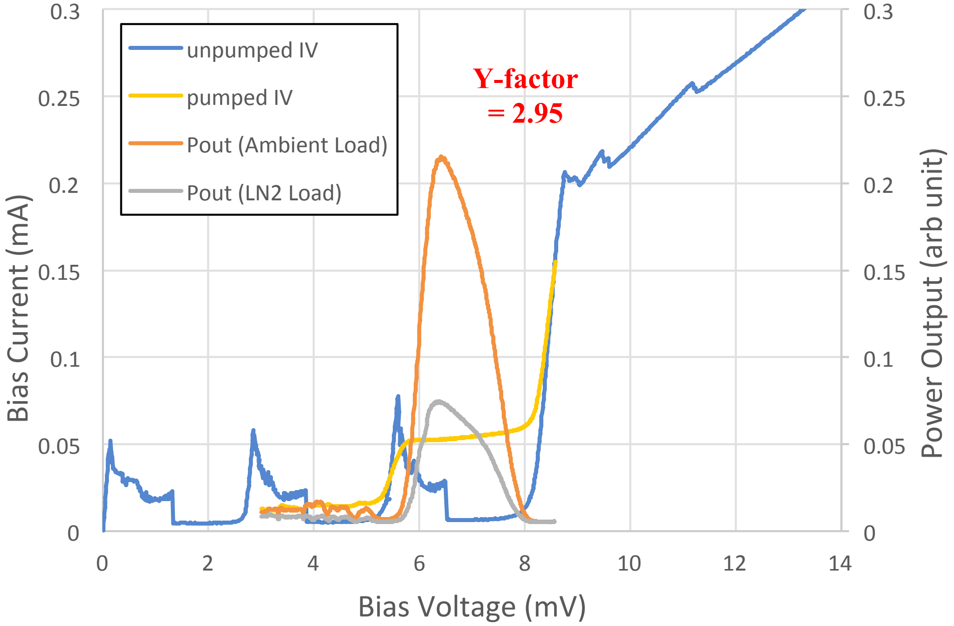
SMA Cryo + LNF 6 - 20 GHz LNA

Measured DSB Noise Temperature as a Function of IF



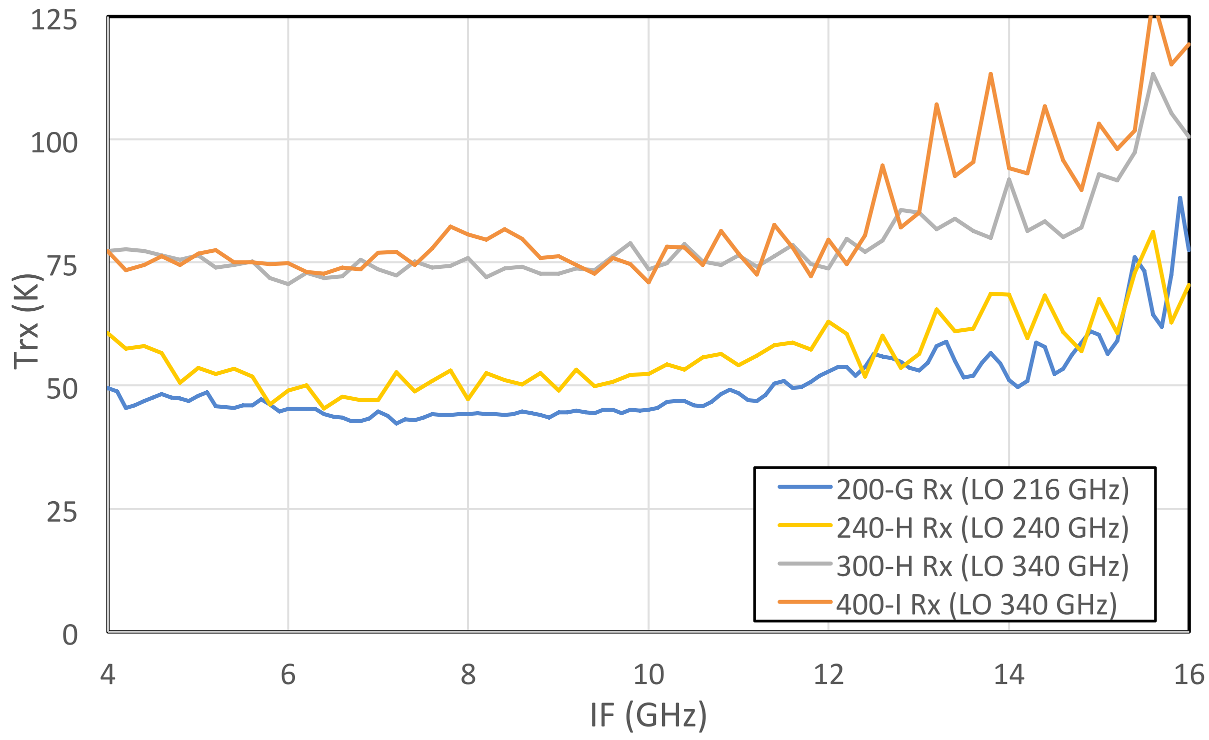


wSMA240-1-1 mixer: LO 230 GHz IF 18 GHz

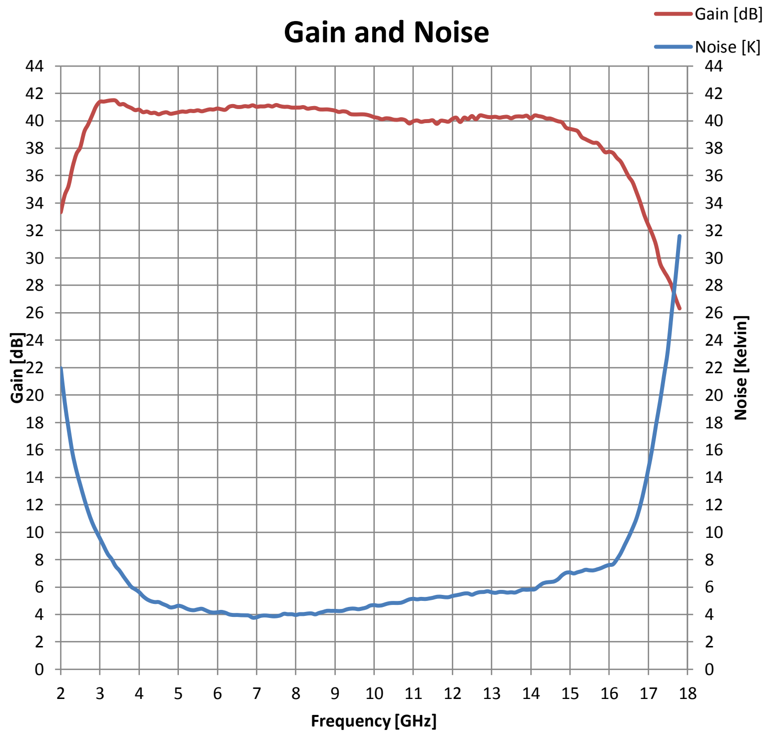


- **Ripples in Trx Vs IF is linked to the 15 cm long coaxial cable between isolator and SIS mixer.**

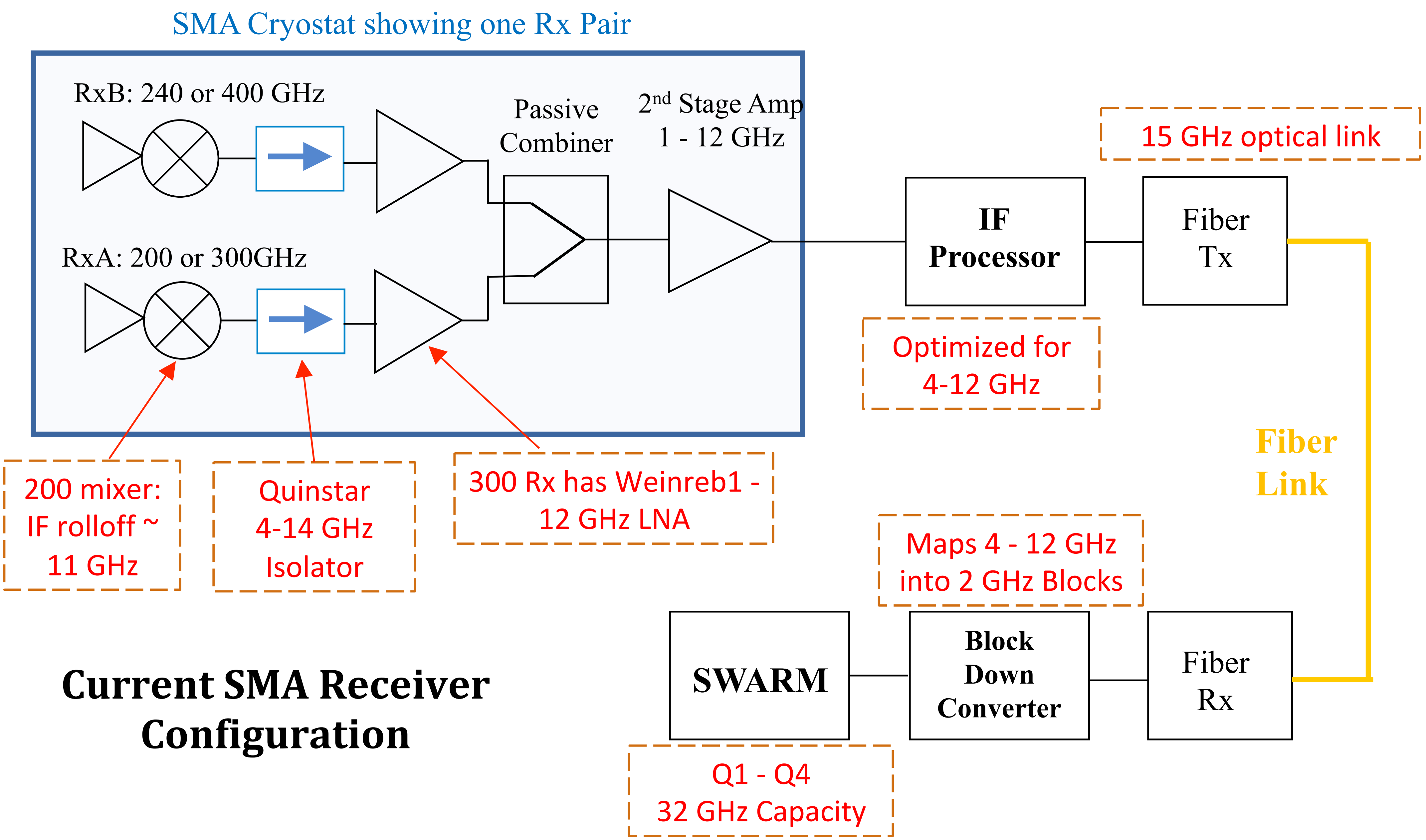
Performance of Receiver Inserts in Field



- **Quinstar 4 - 14 GHz Isolator**
- **LNF 4 - 16 GHz amplifier**



- **Trx data taken in lab but with full SMA optics**
- **Receiver noise @ 16 GHz IF is typically 40% higher than at 10 GHz.**
- **More noise ripples seen above 12 GHz IF due to poorer match.**



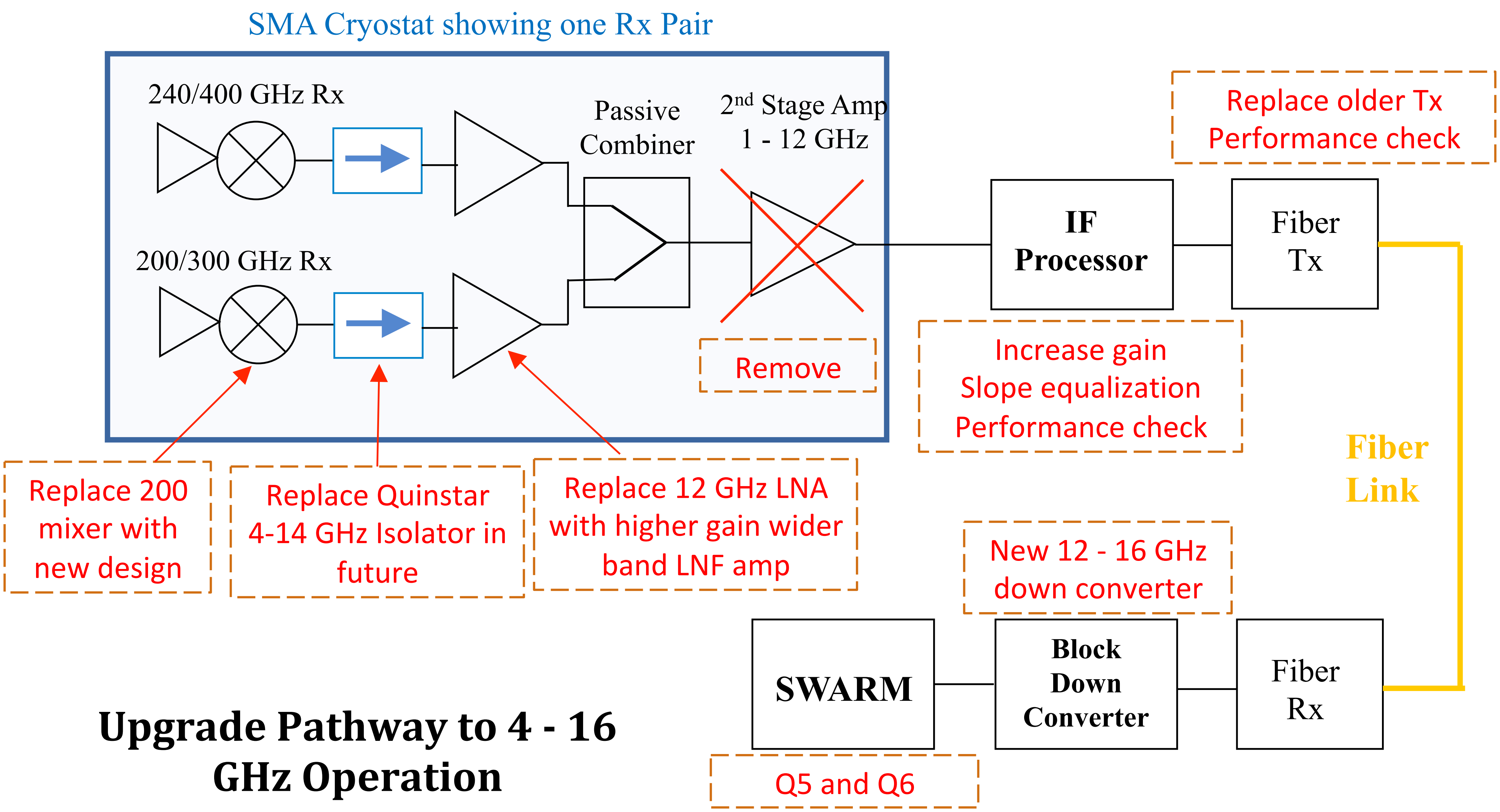
Current SMA Receiver Configuration

Implementation of wider IF design into SMA operations

- Replace existing SMA-200 mixers with new wSMA mixer chips.
- Use wider band LNA from LNF as first stage IF amplifier:
  LNC4_16B covers 4 - 16 GHz (used already in many SMA Rx)
  LNC6_20C covers <6 - 20 GHz (target LNA for future wSMA cryostat)
- Remove 2nd stage 12 GHz amplifier from inside cryostat.
- Introduce slope equalization in IF system.
- Replace old fiber transmitters.
- Add 12 - 16 GHz Block down-converter.
- Add SWARM Q5 and Q6 (Q5: 12-14 GHz; Q6: 14-16 GHz)

SMA will be operational with 4 - 16 GHz IF

Upgrade Pathway to 4 - 16 GHz Operation

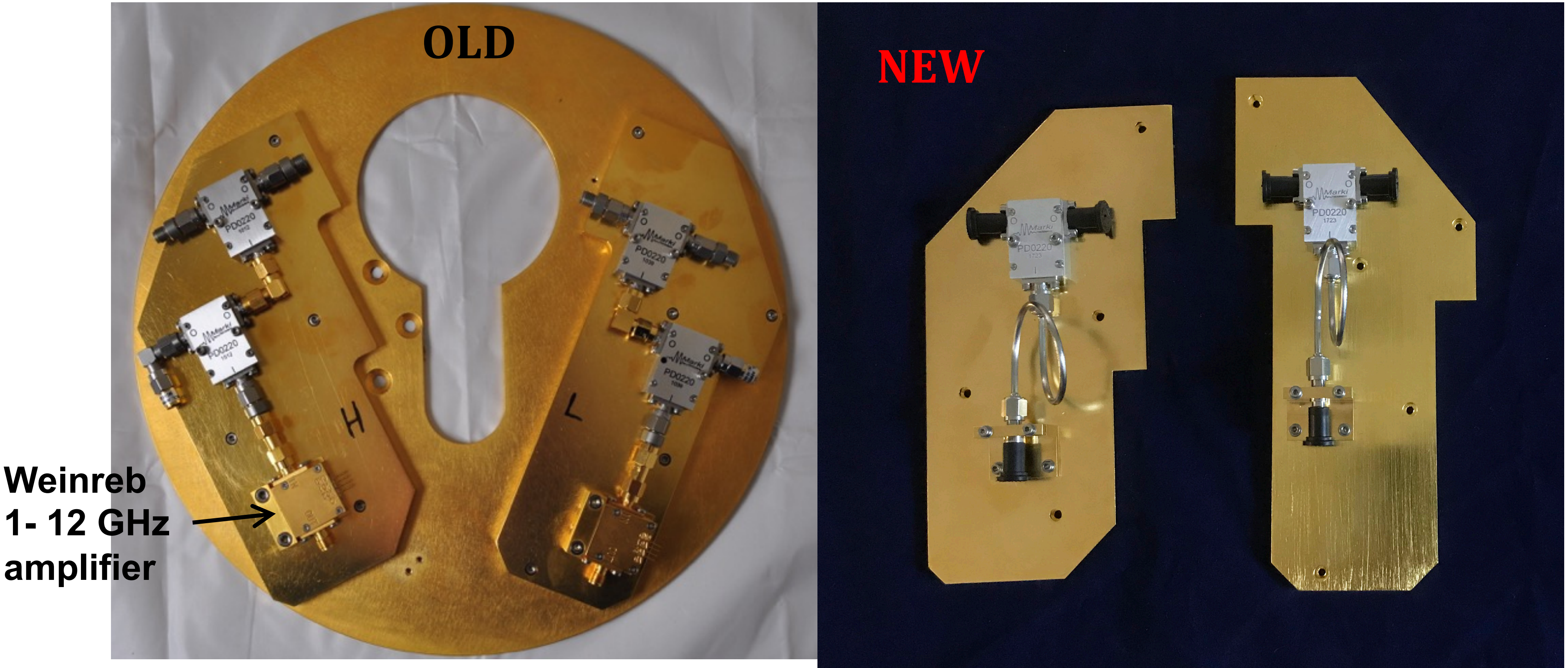


Removal of 2nd Stage Cryo amp (Limiting us to 12 GHz)

New LNA from LNF has higher gain (>35 dB). No need of 2nd stage cryogenic amp

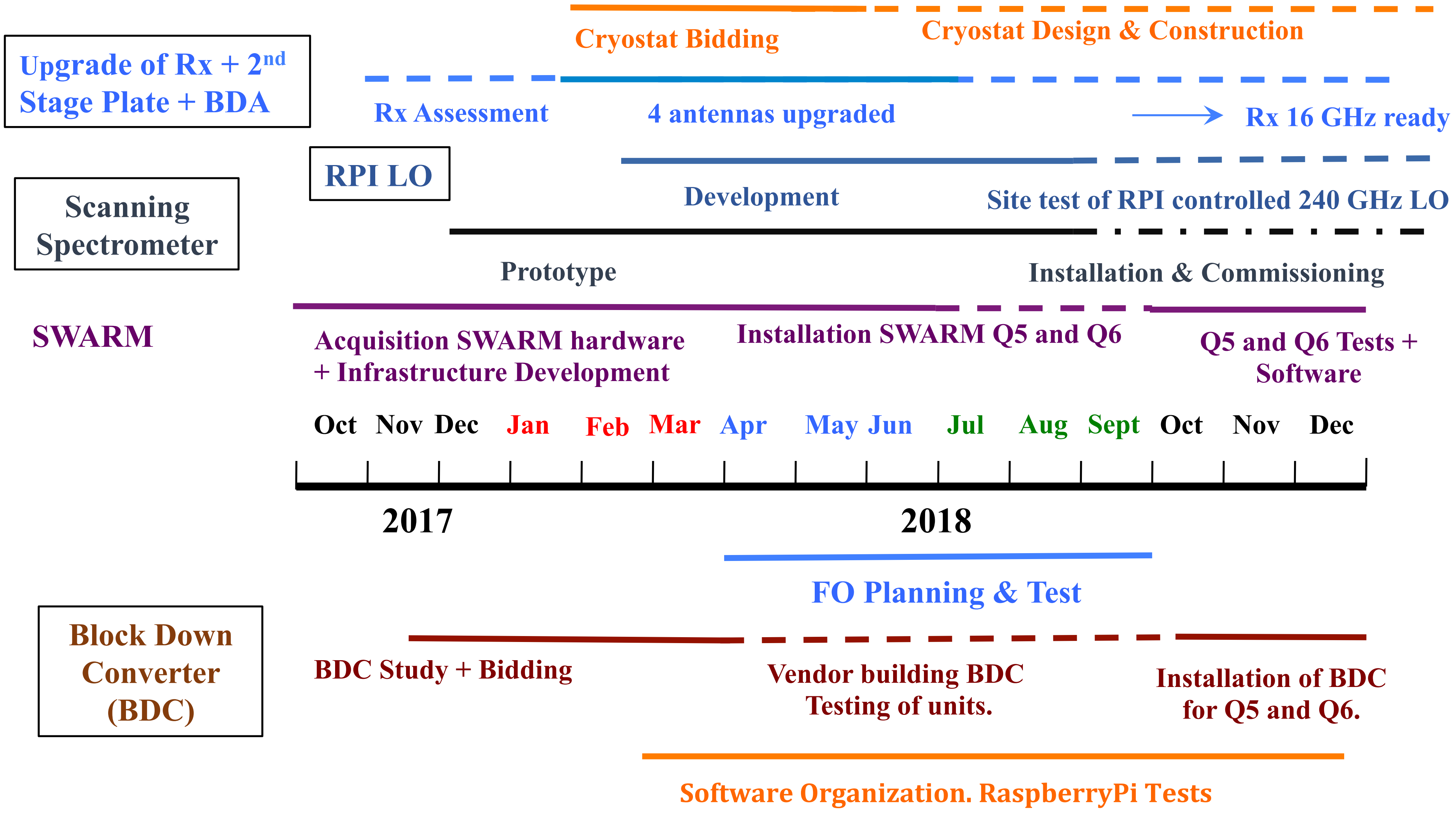
Two sets of New 2nd Stage plates have been prepared.

We plan to replace two cryostats each round. Outgoing plate and power splitters will be recycled.



Status of wSMA 16 GHz Upgrade (June 2018)

Antenna	2nd Stage Plate	200 Rx Upgrade	300 LNA Upgrade	IF Processor
1	X	X	X	X
2	X	X	ASIAA	X
3	X	X	ASIAA	X
4	Yes	Missing magnet	X	Yes
5	Yes	Yes	Yes	Yes
6	X	X	X	X
7	Yes	Yes	Yes	Yes
8	Yes	X	Yes	Yes

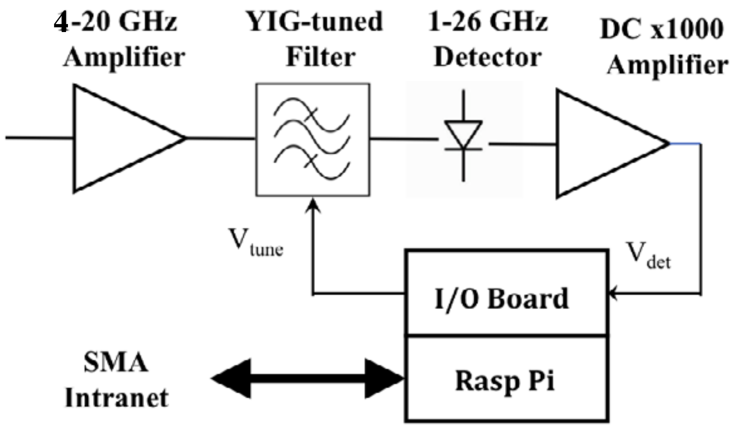


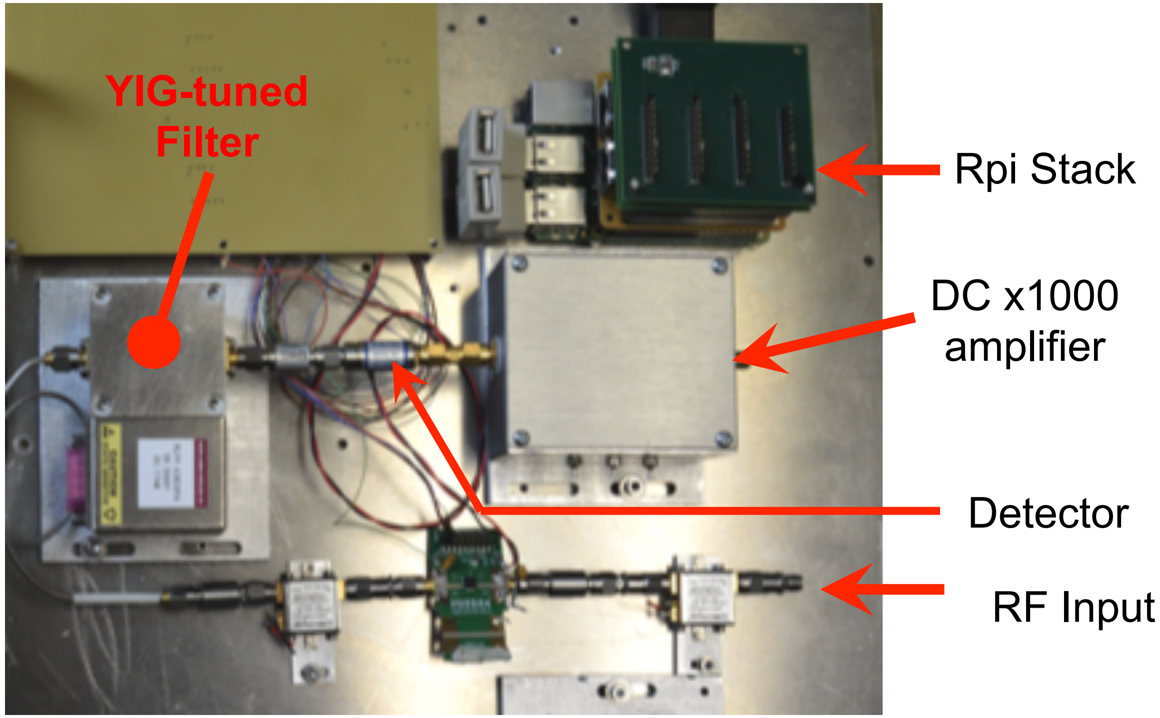
wSMA Planning for 2018 as of 06/29/2018

Technological Developments associated with wSMA

- Scanning Spectrometer
- Raspberry-Pi based Controllers
- Silicon based waveguide components

Scanning Spectrometer

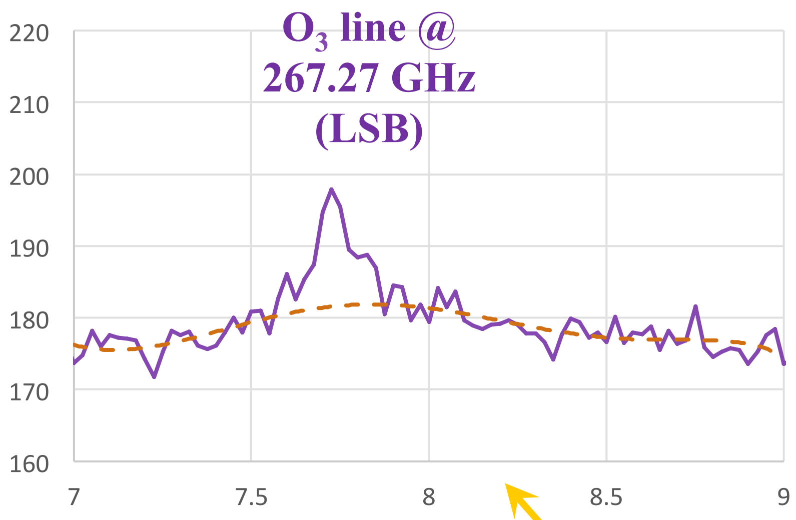




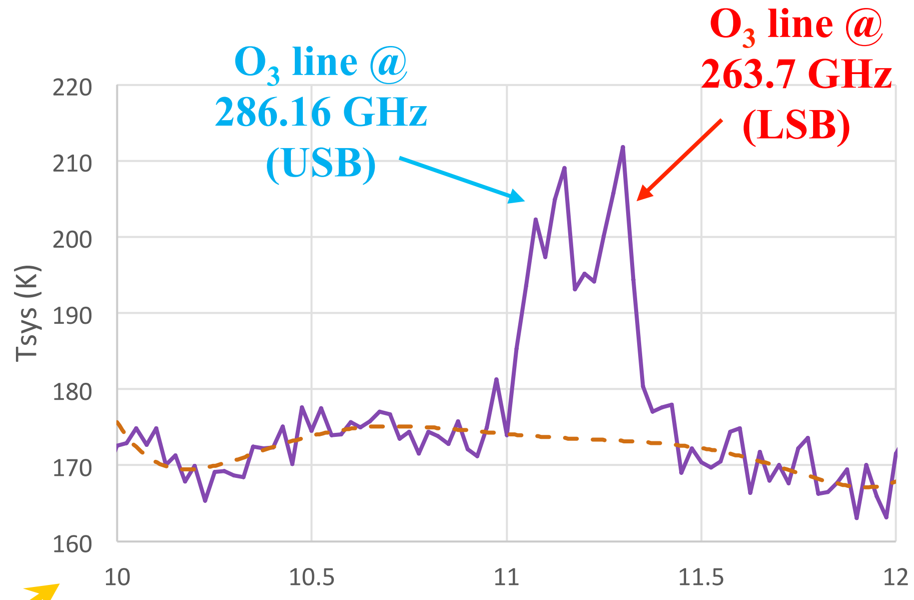
RF amplifier chain + Digital Attenuator

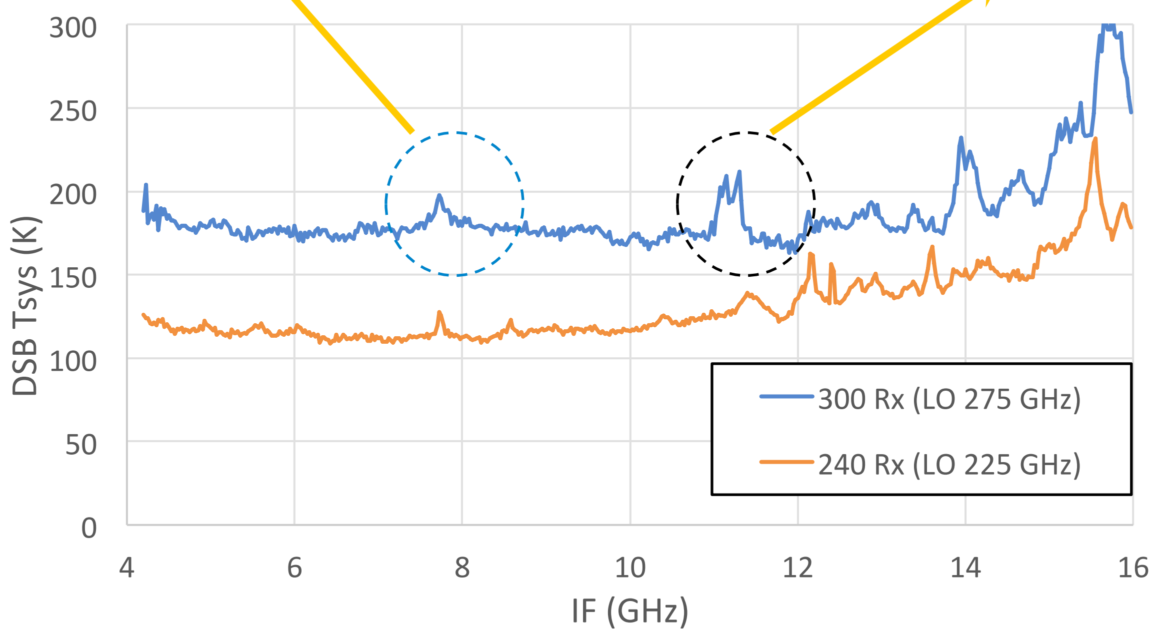
- **To provide Tsys measurement as a function of IF (currently a single value of Tsys is logged)**
- **Useful for system diagnosis**
- **Able to observe atmospheric ozone lines.**
- **Resolution of YIG filter: ~30 MHz**
- **Scan Time: ~0.5 s**

- Prototype installed in antenna 7.
- Awaiting reorganization of network to synchronize with other real time components.
- Two more units to be installed in fall



2018-07-06
Antenna 7
Elevation 67°





Tau225 ~ 0.150

Average of 8 scans

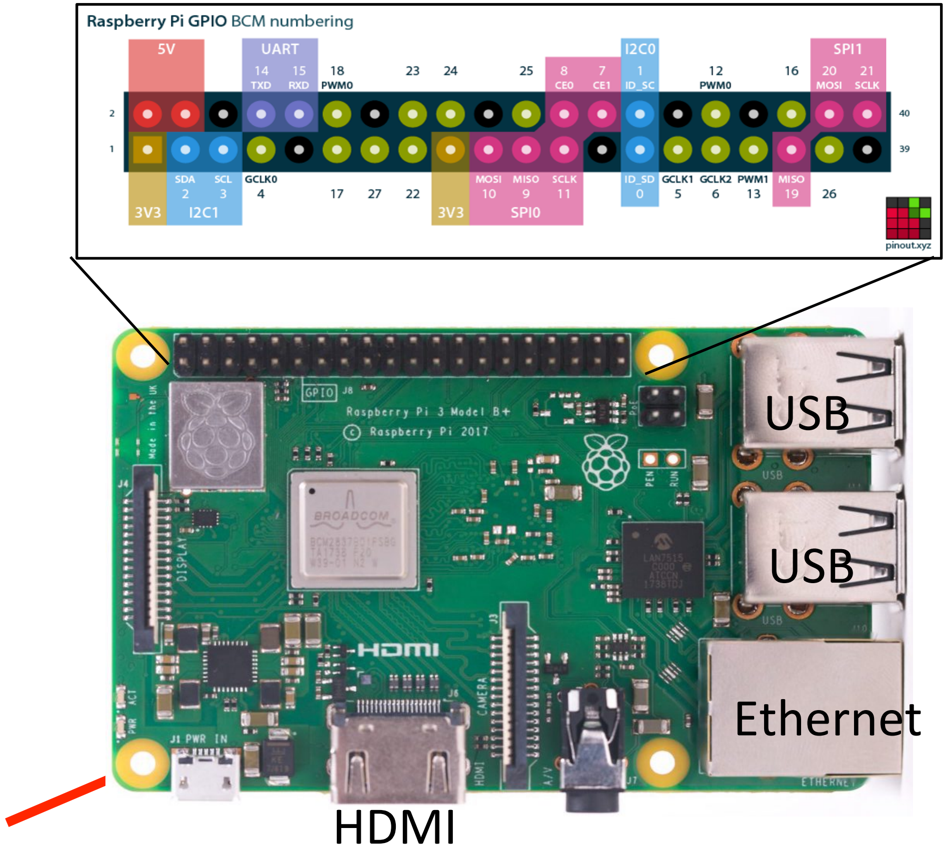
Integration time per channel
= 1.2 ms x 8 ~ 10 ms

Channel spacing 25 MHz

Expected baseline ΔT ~ 0.3 K

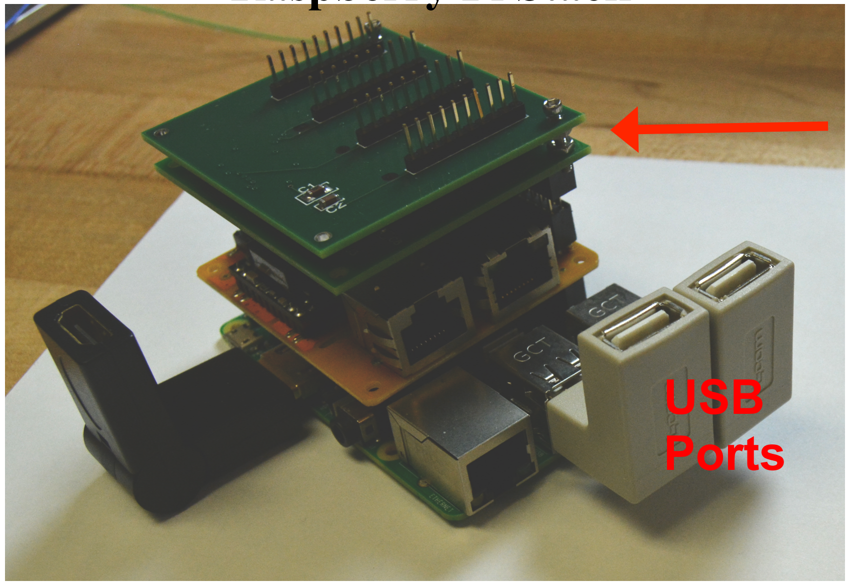
Observed ΔT ~ 1 - 2 K

Raspberry Pi-based Controllers



Raspberry Pi model 3b+ showing various connectors plus the top 40- pin GPIO connectors

Raspberry Pi Stack



Daughter & Grand-daughter Boards for IO

POE Board (Power on Ethernet)

- Low cost compact Linux computer allowing efficient analog & digital I/O interface thru add-on boards
- Very useful as distributed controllers, remotely accessible through its ethernet port.

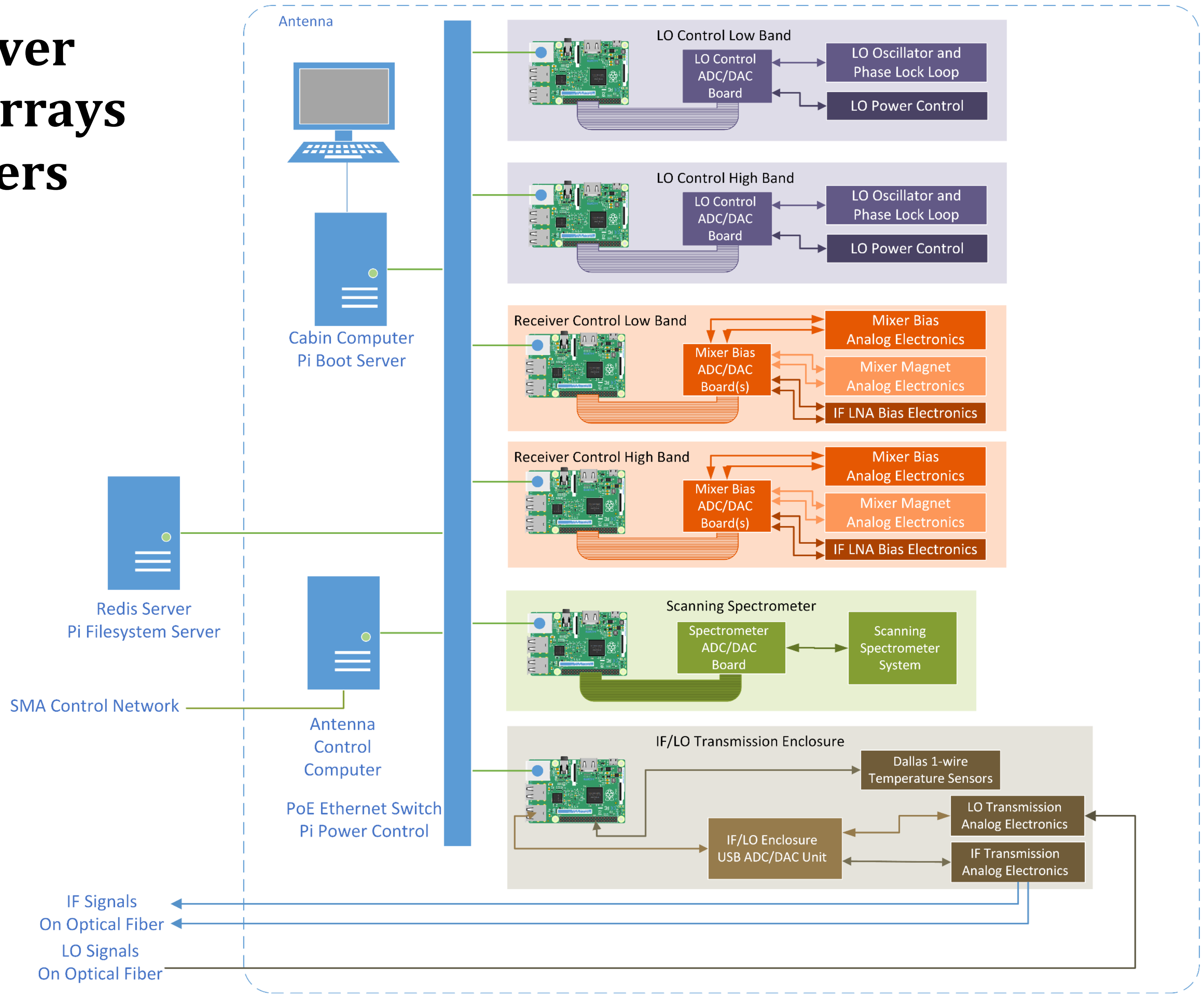
Testing RPi on Mauna Kea

- We power the RPi with a PoE (Power on Ethernet) board.
- PoE removes the necessity of an external power supply & UPS for the RPi and it allows remote power cycling through the PoE switch.
- Remote booting simplifies management since we could have as many as 8 RPi in each cabin.
- We have run batches of RPi (Pi Patches) on Mauna Kea for more than a year, with a cumulative up time of ~4 Pi year without failure.

Latest Pi Patch to be tested on Mauna Kea with the final hardware configuration.

Distributed wSMA Receiver Control system based on Arrays of RaspberryPI Controllers

- “RaspberryPIs in the wSMA” poster by Paul Grimes & Ram Rao
- Rao, Grimes, Leiker et al, “The Submillimeter Array needs some Raspberry Pis!!” in SMA Newsletter July 2018
- A RPi group led by Ram is laying down the ground work for future wSMA control system.



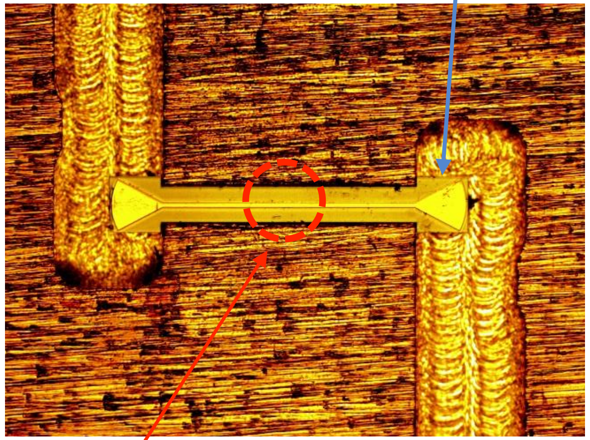
Development of Silicon Technology for wSMA

- High resistivity silicon has low losses up to THz frequency range.
- Processing of silicon micro-structures is a mature technology.
- Silicon chips with μm thickness can be manipulated easily.
- Joint development with ASIAA, using their nanofabrication capability.

Optically Controlled Waveguide Variable Attenuator

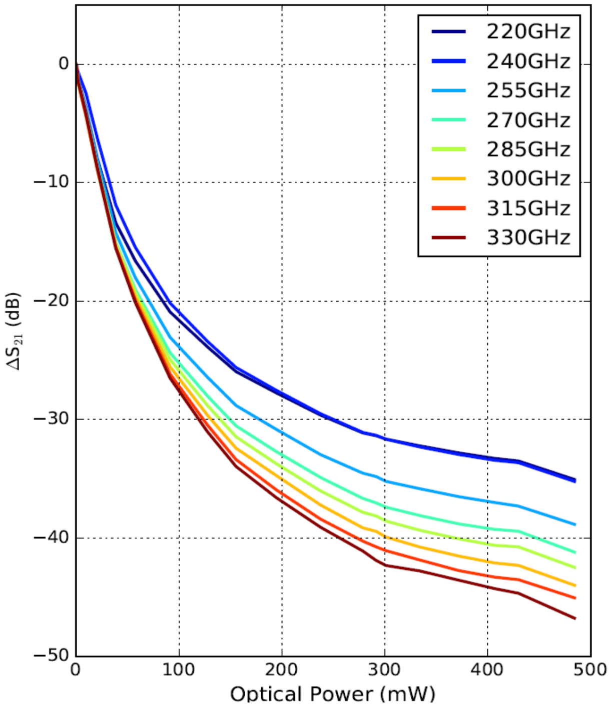
WR-3.4 Output

Silicon Chip
25 μm thick

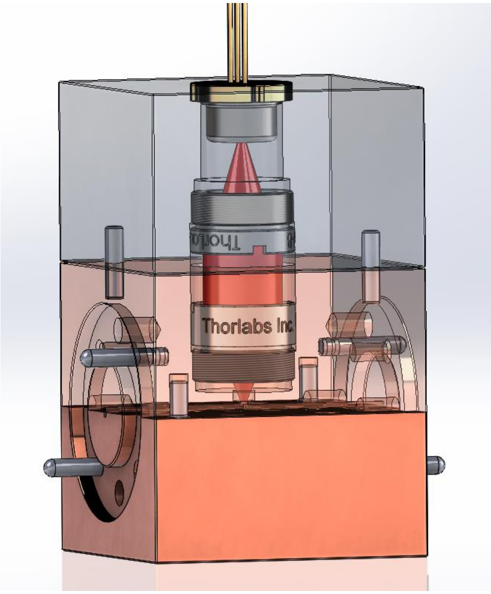


Laser Light
Illumination
λ ~ 850 nm

WR-3.4 Input
220-340 GHz

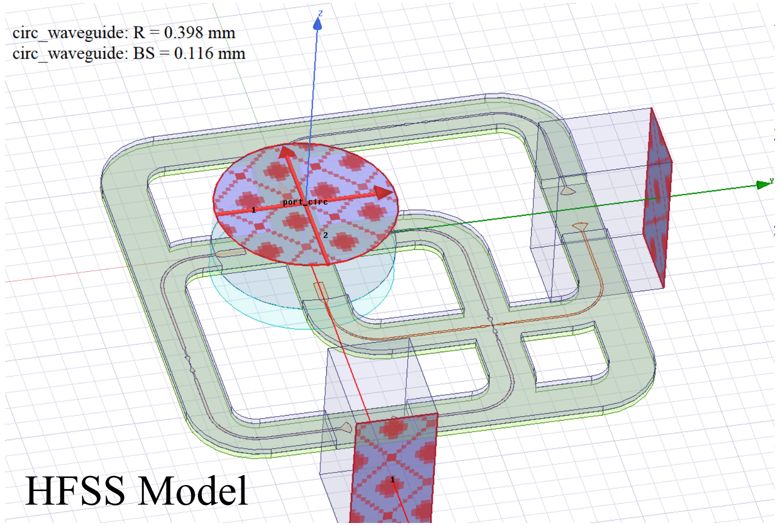


- Insertion Loss: 1 - 1.5 dB
- Response Time ~ 1 ms
- Laser DC power ~ 0.3 W for 100 mW optical power
- Will be used as in wSMA LO power control.

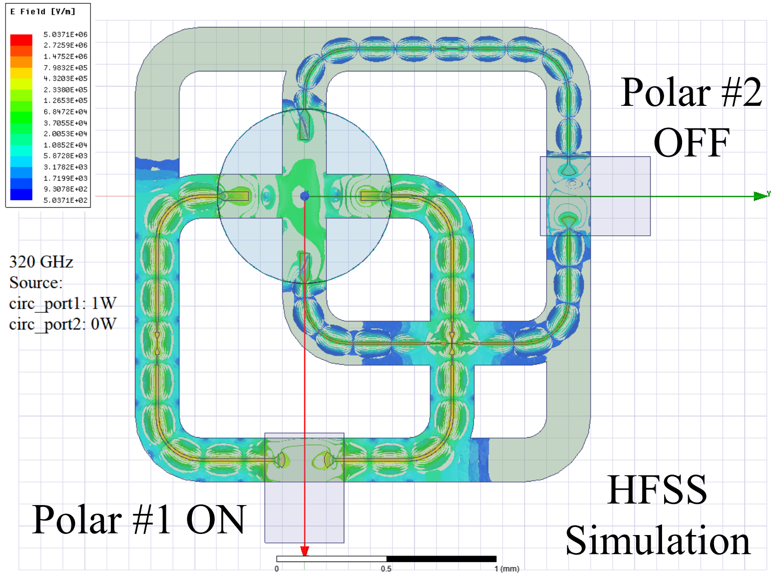


Orthomode Transducer (OMT) Based on Si Chip

- New wSMA Rx will use a waveguide OMT to separate the 2 polarizations
- Design tested in a 10 GHz scaled model
- 25 μm thick Si chip for 280-360 GHz
- Design with HFSS
- Isolation between polarizations > 25 dB
- Chips fabricated. Handle is easy
- Waiting for testing fixture.



HFSS Model



HFSS Simulation

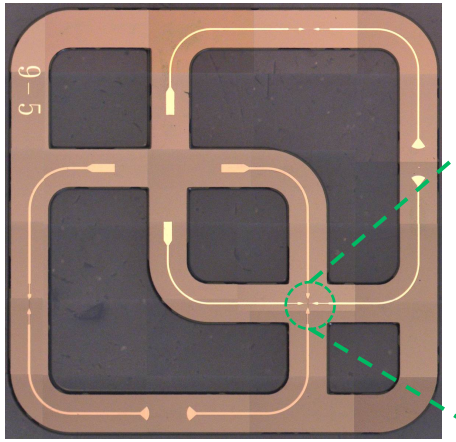
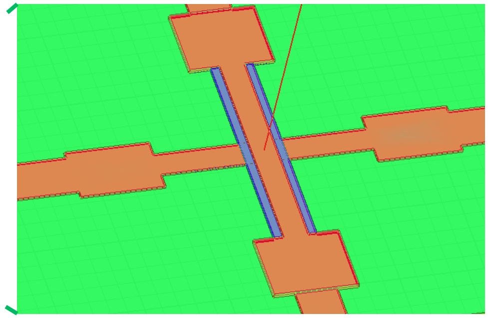


Photo of OMT Chip

Geometry of cross-over



Silicon Based LO Coupler

- **Level of coupling can be adjusted by changing chip**
- **Machining tolerances are more relaxed.**