Sponsored by NASA ESTO
Program: IRaST
Contract Number:

IRaST Update

ESTF2020

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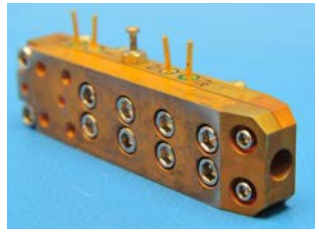
Outline

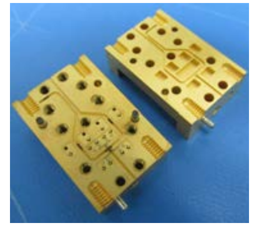
Integrated Receiver and Switching Technology (IRaST) Overview

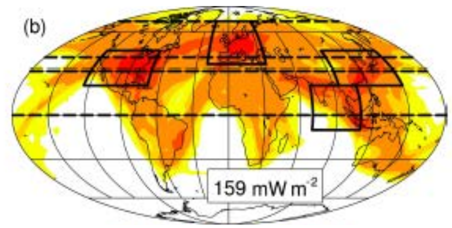
- Integrated Receiver: 424/448 GHz Receiver for optically thin contrail sensing
- Switching Technology: Submillimeter Wave Integrated Circuit Switch Update for 1/f noise reduction in direct detection receivers.
  - Benefits:
    - TWICE
    - SWIRP
    - SMICES

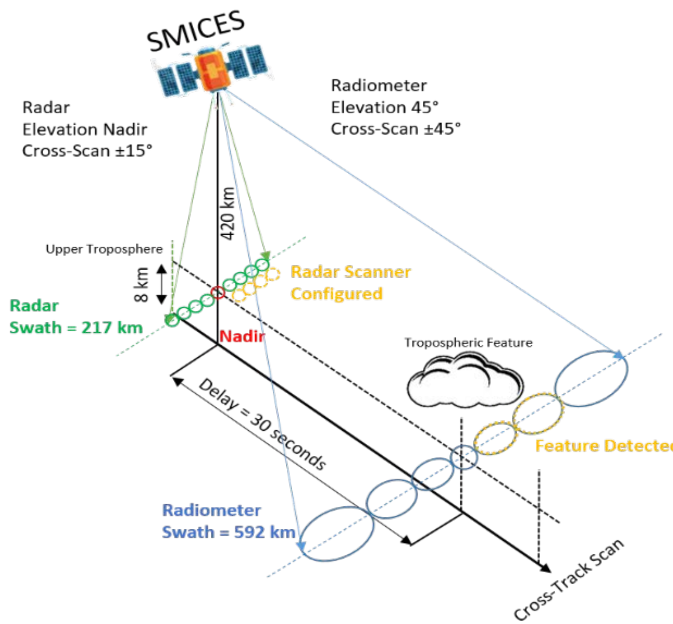
SMICES Introduction

- 239 GHz Radar
- Suite of passive radiometers
- Intelligent controller to activate radar for cloud profiling









IRaST Quad Chart (PI: Bill Deal/ NGC)

Objective

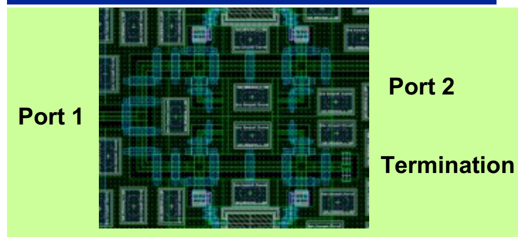
1a. Develop Integrated Switch technology to eliminate 1/f noise in submillimeter wave direct detection receivers through use of integrated Dicke switches.

1b. Develop different architectures of Dicke switches integrated with LNAs to trade 1/f noise improvement vs. sensitivity improvement

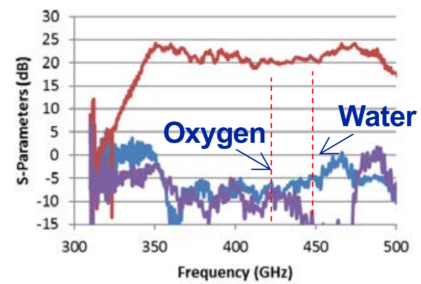
2a. Develop upper atmospheric receiver temperature and humidity sounder in single receiver at 424 GHz oxygen line and 448 GHz water vapor line.

2b. Minimize Size, Weight and Power (SWaP) using fully integrated receiver MMIC with I/Q mixer for low cost and performance.

670 GHz Dicke Switch



Integrated Dicke switch and LNAs will reduce 1/f noise with minimal noise impact



Integrated temperature and water vapor profiling receiver will allow upper atmospheric measurements

Approach:

Demonstrate two fundamental technology improvements for atmospheric science using shared 25 nm InP HEMT masksets for reduced costs:

1. Design first submillimeter wave Dicke switches monolithically integrated with LNAs
2. Validate impact by measuring NEDT with direct detection receivers already developed on TWICE
3. Design first single chip receiver with simultaneous oxygen and water vapor measurment
4. Validate with NEDT measurements
5. Combine on common maskset for reduced costs

CoIs: Pekka Kangaslahti, Boon Lim, JPL
Kevin Leong, NGC

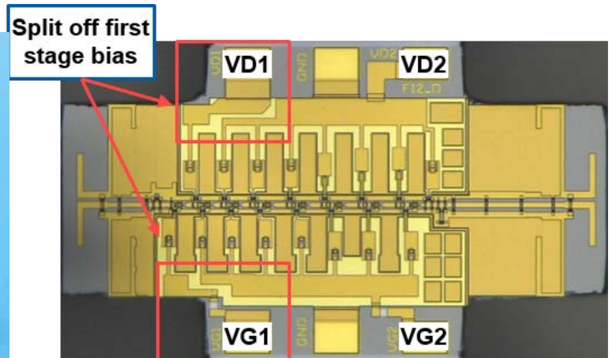
Key Milestones

• Switch validation (1st Iter.)	Complete	
• Receiver validation (1st Iter.)	Was: 1/19	Now: 3/20
• Second Maskset completion	Was: 6/19	Now: 10/20
• Switch validation (2st Iter.)	Was: 12/19	Now: 12/20
• Receiver validation (2st Iter.)	Was: 1/20	Now: 1/21
• Radiometric Validation	Was: 1/20	Now: 3/20

$TRL_{in} = 2$ $TRL_{exit} = 4$

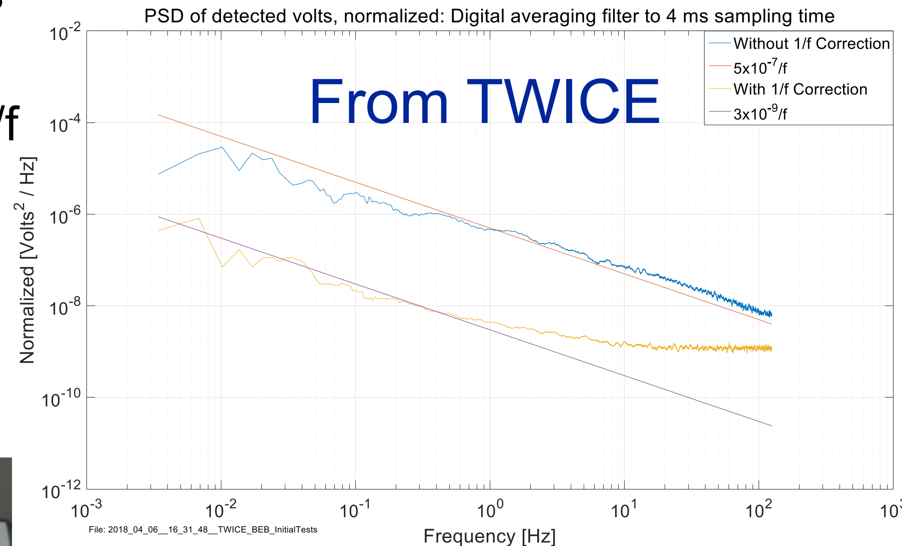
Switch Technology Objective and Approach

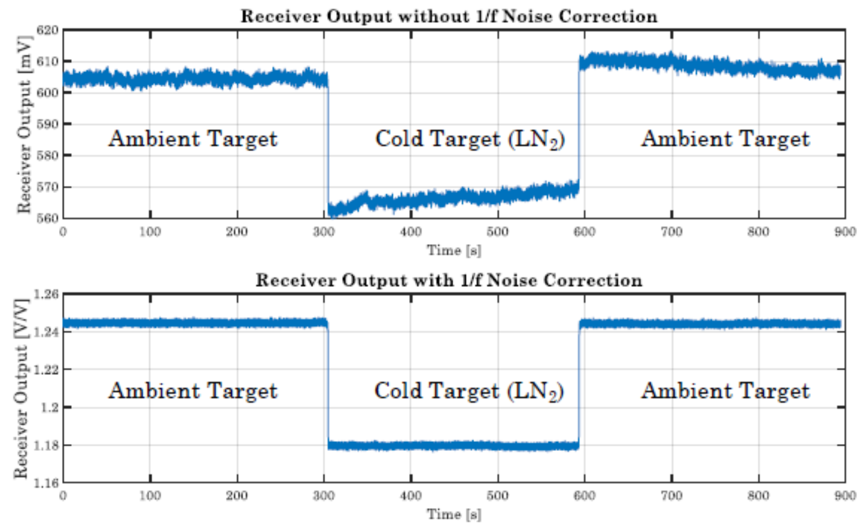
- Submillimeter Wave Direct Detection Receivers have excellent SWaP
- But, more prone to NEDT degradation due to 1/f noise
- Initial work on gain switching to lower NEDT performed on TWICE.
- IRaST is investigating other techniques



Sensitivity Results with 50 msec Integration Time

NEΔT Without Switching	NEΔT With Switching
4.75 K	0.88 K





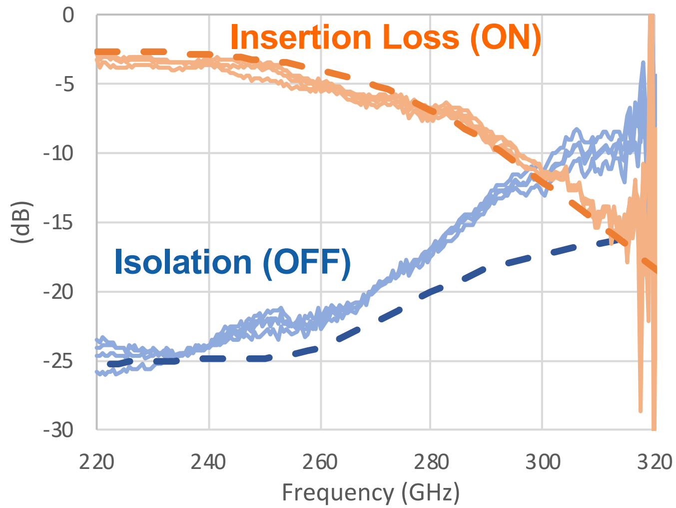
- M. Ogut, C. Cooke, W. Deal, P. Kangaslahti, A. Tanner, and S. C. Reising, “A Novel 1/f Noise Mitigation Technique Applied to 670 GHz Receiver,” *Submitted: IEEE Trans. On Terahertz Science and Technology.*

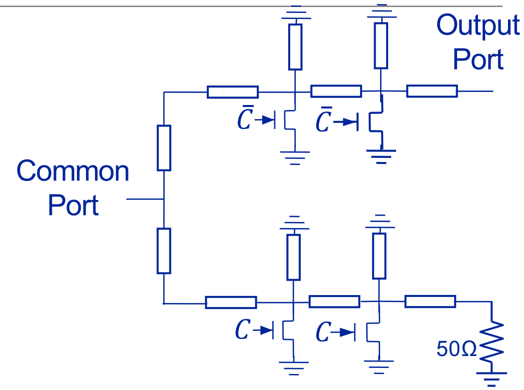
Single-Pull Double-Throw Switch Measurements

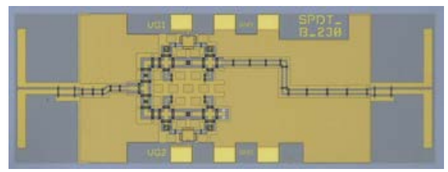
On-Wafer

- Developed test-cells for switches
- Good correspondence between measured and modeled
- Measured Performance:
  - 2.7 dB loss @ 230 GHz
  - 25 dB isolation @ 230 GHz

Thru Loss and Isolation: On-Wafer



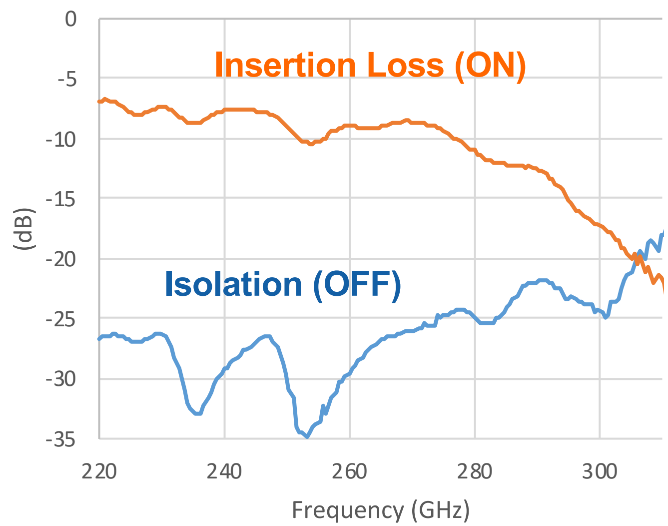




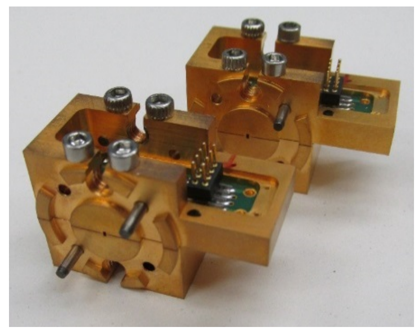
Packaged

- **Packaged using repurposed TWICE WR-4.3 housings**
- 7 dB loss in package @ 230 GHz
  - 1.2 dB loss per dipole
  - 1.8 dB loss CPW routing
  - 2.8 dB switch loss
- > 25 dB isolation

Thru Loss and Isolation: Packaged

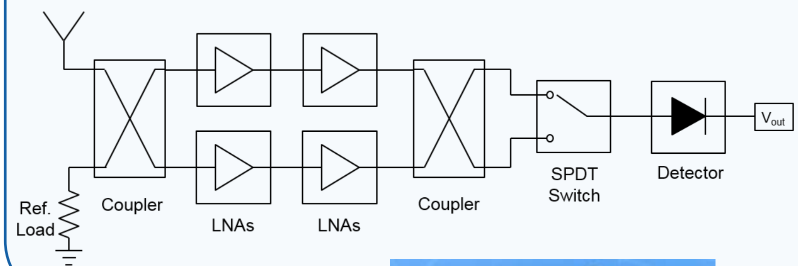


Repurposed WR-4.3 LNA Housings



Solid State Switches Demonstrated to 700 GHz

Switch Based 1/f Noise Improvement Techniques

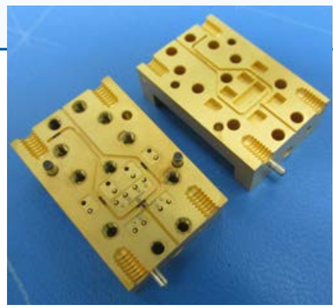


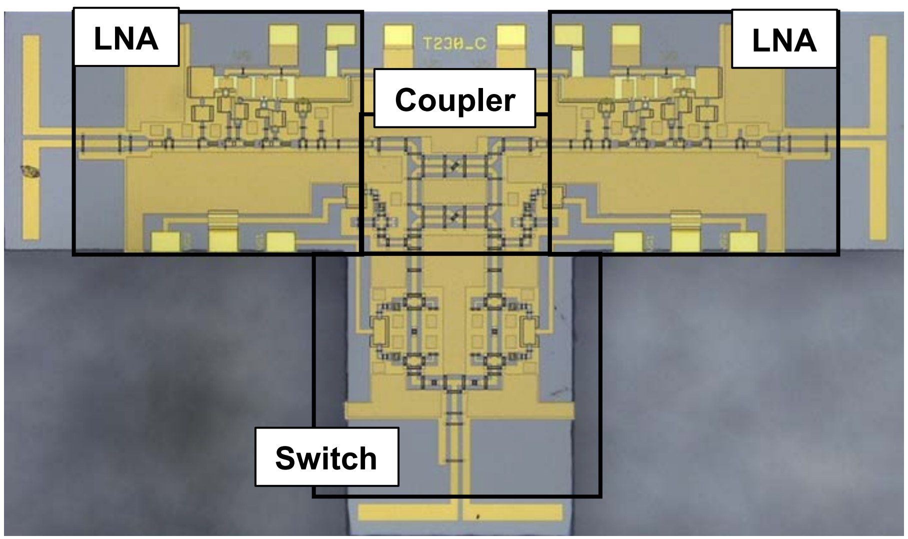
Benefit: Improved NEDT compared to Dicke

Status: Components validated, need to measure 1/f

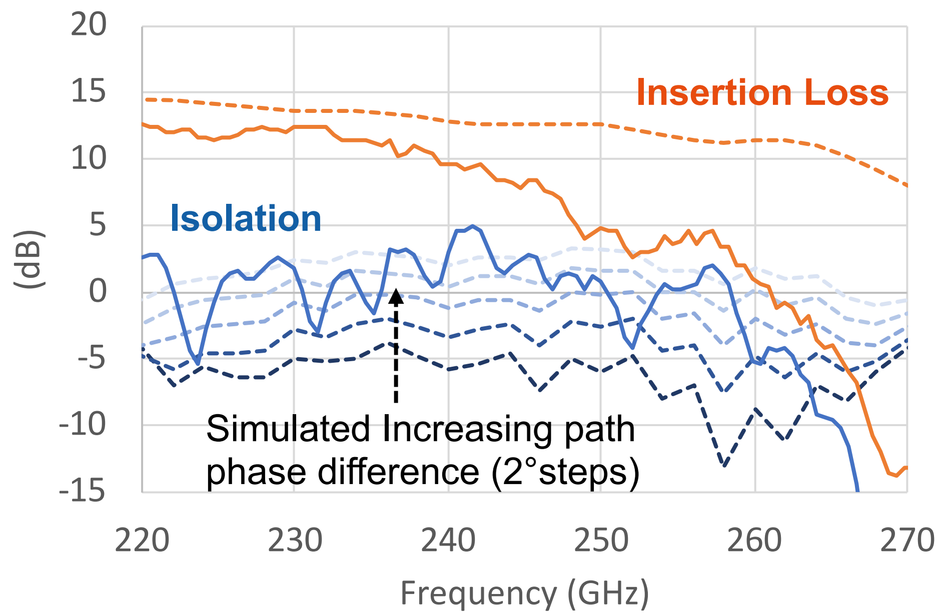
GOALS

- **Single housing with waveguide coupler (no detector)**
- **Evaluate receiver radiometric performance**
- **Test 1/f noise improvement, compare to Dicke switch**





Measured Response



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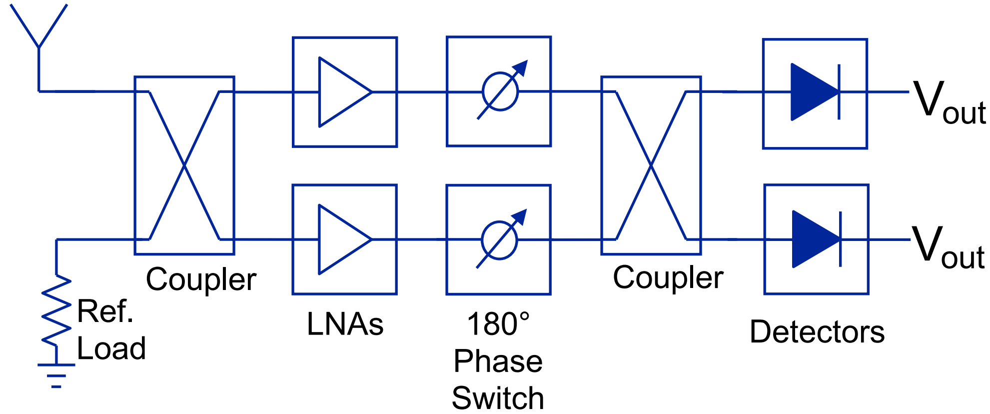
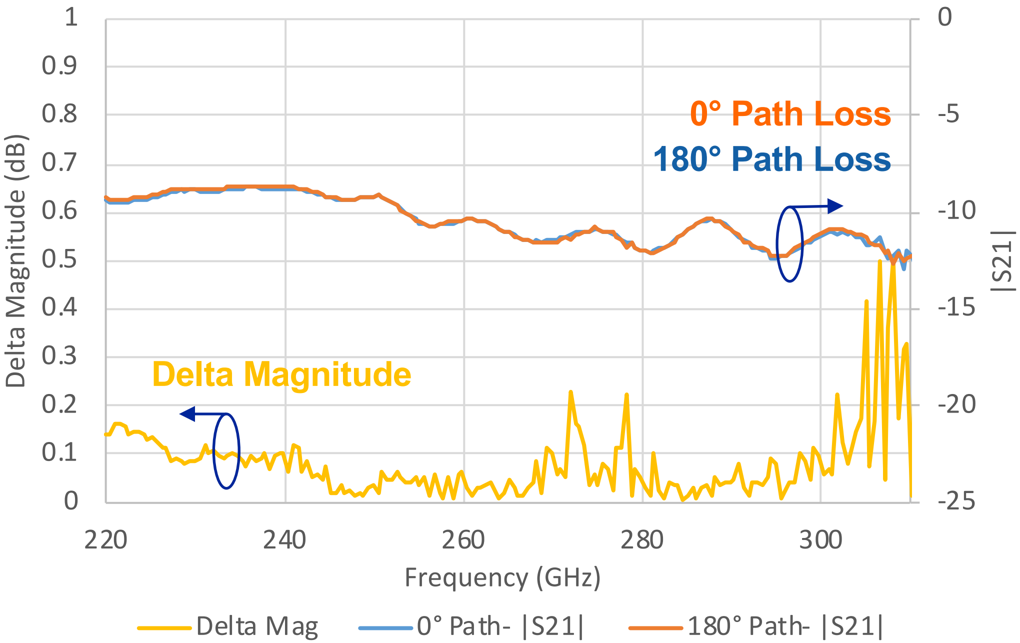
Pseudo-Correlator

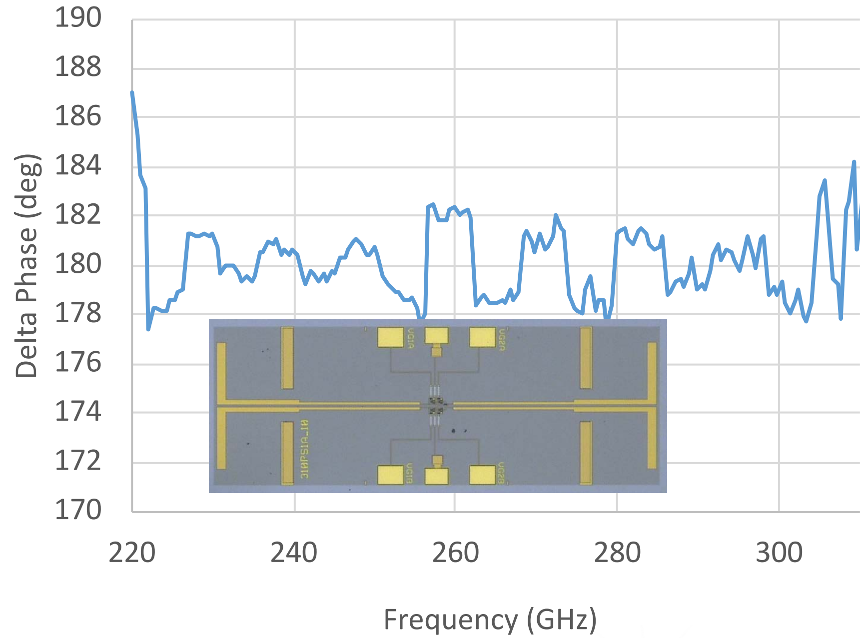
- Pseudo-correlator can reduce 1/f noise and eliminate sqrt(2) NEDT impact from switching
- Requires development of 180 degree phase switches
- Have demonstrated that to



Delta Insertion Loss Between 0° and 180° Paths

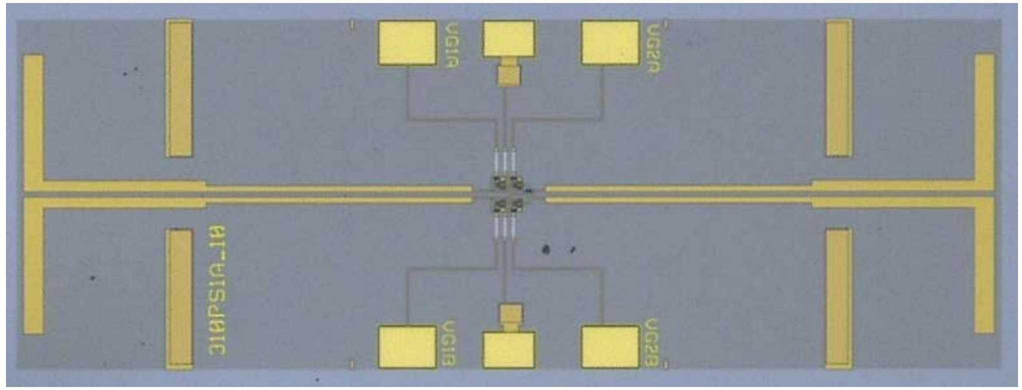


Phase Delta

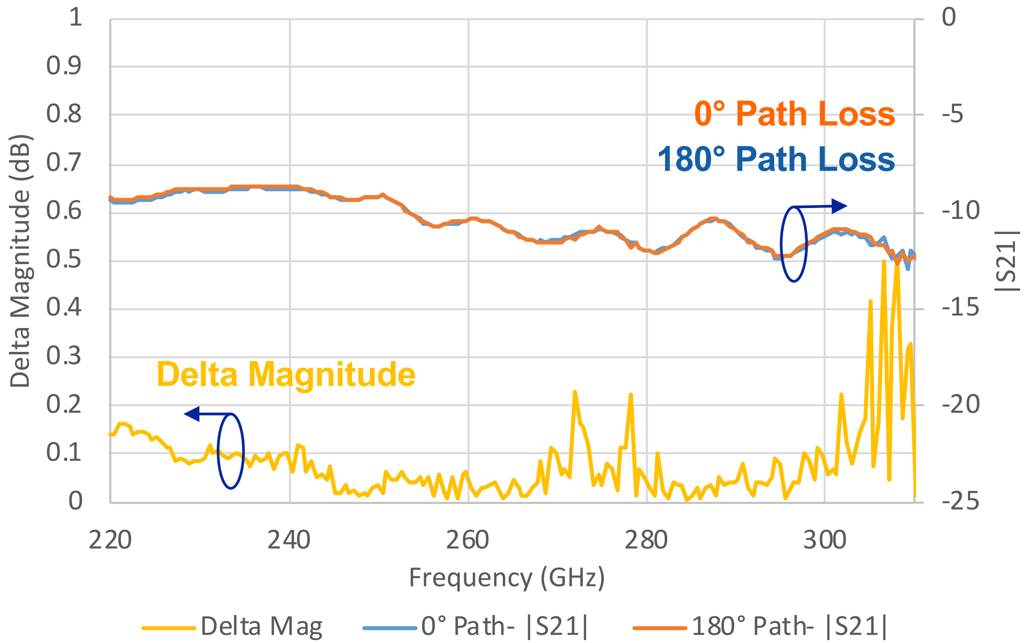


WR-4.3 Phase Switch- Packaged

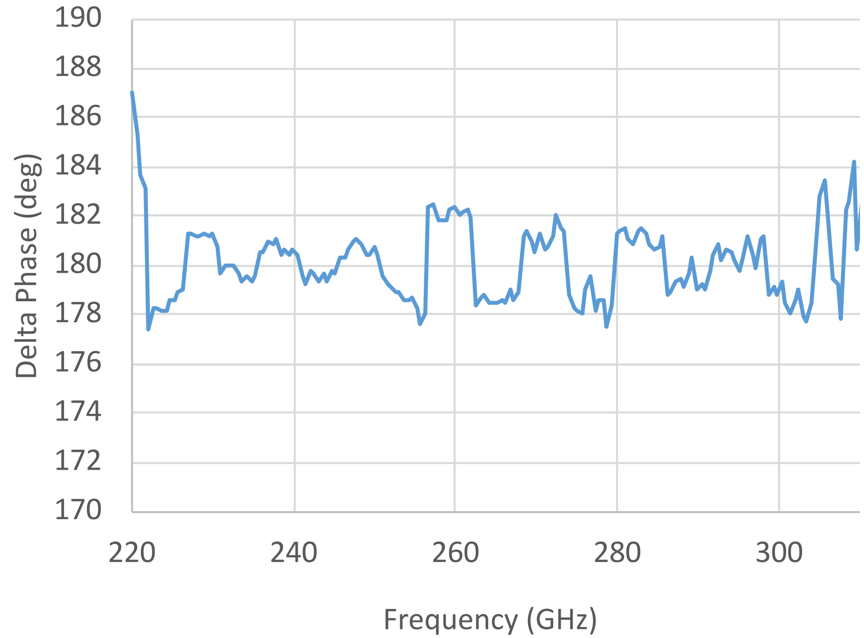
- 180 degree phase switch for use in the pseudo-correlator architecture
- **< 0.2 dB ΔMag** full WR-3 band
- **< +/-2° ΔPhase** from ideal 180°, full WR-3 band
- Switch losses = 4.0 dB, Package losses- 4.7 dB @ 230 GHz



Delta Insertion Loss Between 0° and 180° Paths



Phase Delta



Phase Switch will enable Pseudo-correlated Radiometers

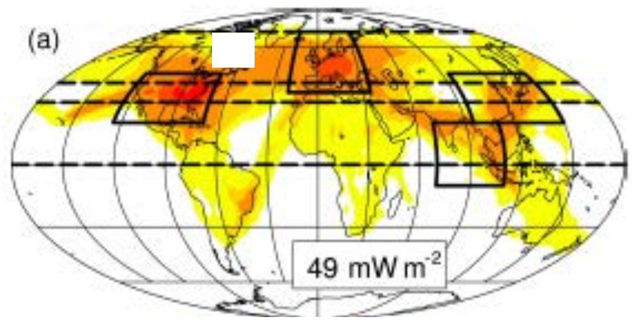
424/448 GHz Integrated Receiver Application

- **Air pressure** and **humidity** two driving forces behind the creation of airline contrails in the upper atmosphere
- **The IRaST 424/448 GHz receiver may be very well suited for sensing conditions for contrail formation**
- **We will discuss this more at the Annual PI review**
- Simultaneous observation of 424 GHz and 448 GHz channels
  - 424 GHz oxygen = measure of **temperature**
  - 448 GHz water vapor = measure of **humidity**

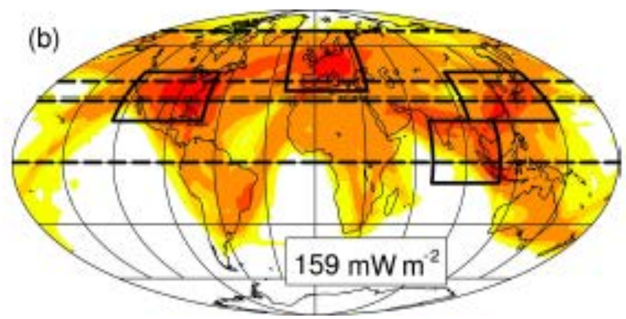
- Study released predicting the impacts of contrail formation on climate change
  - L. Bock, U. Burkhardt, "Contrail cirrus radiative forcing for future air traffic", *Atmospheric Chemistry and Physics*, vol. 19, pp. 8163-8174, Jun. 2019.

Increase in Radiative Forcing due to airline contrails
(from L. Bock, U. Burkhart, 2019)

Baseline (2006)

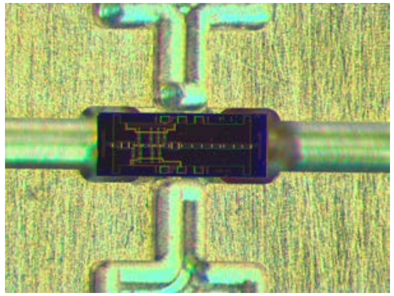


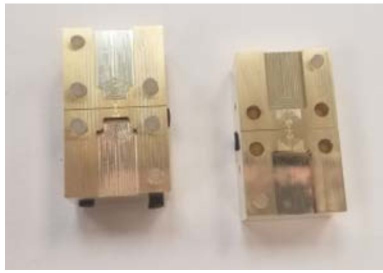
Increase by 2050



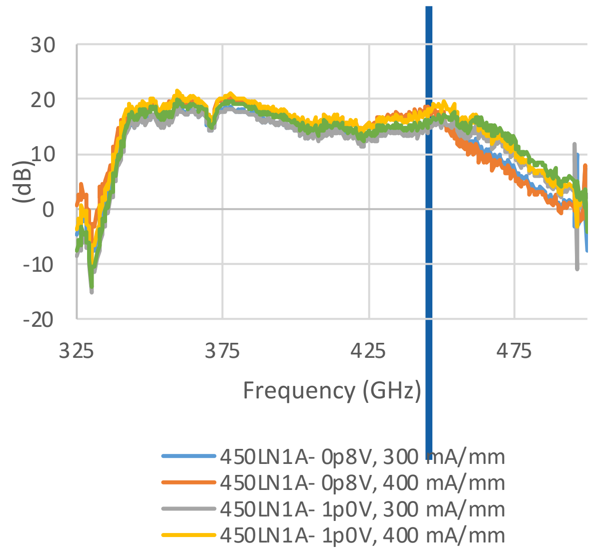
Integrated Receiver Technology Approach

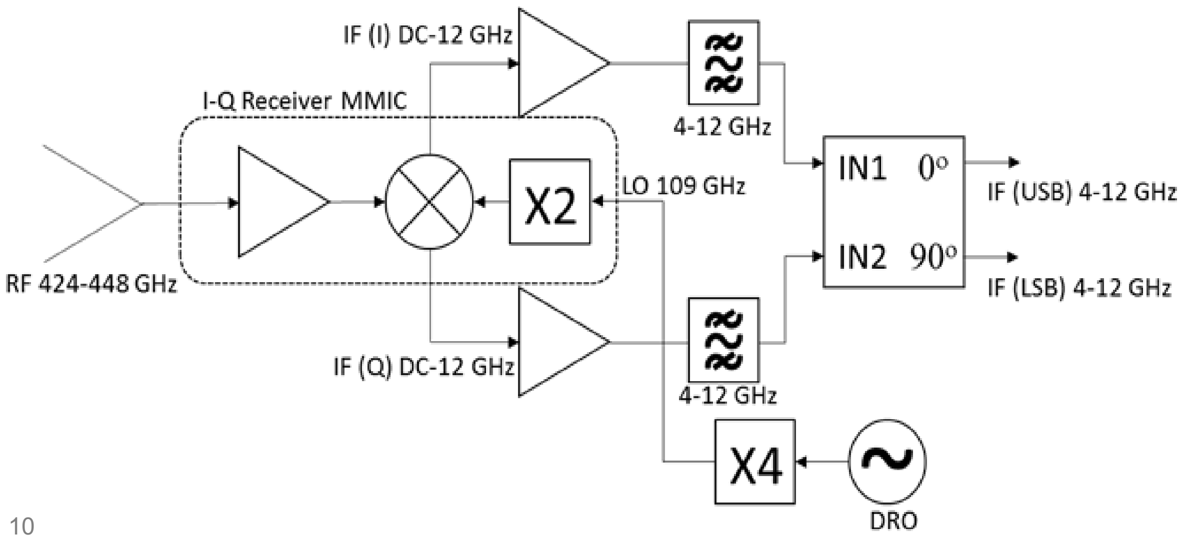
- 424 GHz (Oxygen) and 448 GHz (Water Vapor) will be measured in single aperture and receiver
- LNA's validated in packaging
- Waiting on block for other components (COVID-19)





Mixer LO Frequency: 436 GHz





448 GHz (water)

424 GHz (oxygen)

Smart Ice Cloud Sensing (SMICES)

PI: Bill Deal/ NGC

NORTHROP GRUMMAN

JPL

Objective

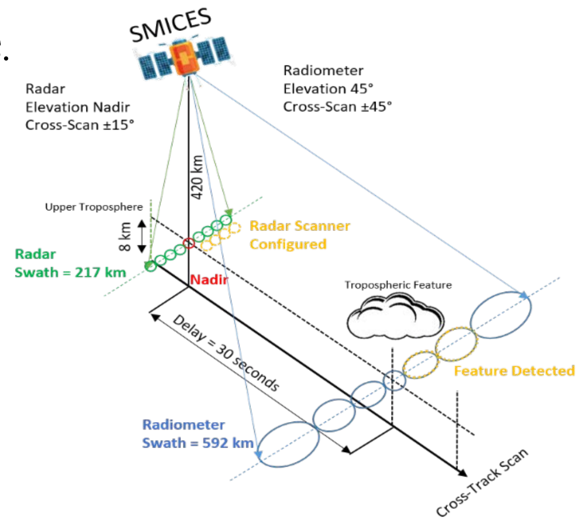
1. Develop intelligent control system for efficient data handling, power management and control of radar measurements.
2. First demonstration of cloud ice radar measurements at 233 GHz.
3. Active and Passive instrumentation in single instrument.
4. Increase maturity of TWICE receivers.
5. First NASA demonstration of 233 GHz TWT Technology useful for future transition to space based radar for cloud ice measurements.
6. Demonstrate PPM TWT at 233 GHz for improved Size, Weight and Power compared to fixed magnet TWT.

Passive and active simultaneous measurements.

Forward Looking Radiometers will identify tropospheric features.

Intelligent controller will efficiently control active and passive systems

233 GHz Radar will perform measurements of features



Approach:

Use intelligent control system to efficiently configure and coordinate active and passive measurements for cloud ice measurements:

1. Demonstrate intelligent controller.
2. Improve and mature 240, 310, 380 and 670 GHz receivers.
3. Demonstrate 233 GHz radar with 50 W PPM TWT.
4. Demonstrate quasi-optical duplexing for 233 GHz radar front-end.
5. Integrate system into airborne instrument and perform flight validation.

CoIs: Javier Bosch-Lluis, Pekka Kangaslahti, Jonathan Jiang, Erich Schlecht, Shannon Brown, Mehmet Ogut (JPL)
Ken Kreischer, John Tucek, Kevin Leong, Caitlyn Cooke (NGC)

Key Milestones

• MMIC Design Update	6/20
• MMIC Fab Complete	11/21
• Receiver/Transmitter Design Update	10/21
• Intelligent Controller Design	7/20
• Instrument Design	7/21
• Complete TWT	12/21
• Complete Radar Front-End	3/22
• SMICES Integration	6/22
• Aircraft Demonstration	9/22
• Final Report	12/22

$TRL_{in} = 3$ $TRL_{exit} = 5$

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