THE VALUE OF PERFORMANCE.

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Integrated Receiver and Switching Technology (IRaST) for Cloud Ice Measurements and Water Vapor Sounding

6/13/2019

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Outline

- Introduction
  - Background
  - Project goals
- 424 GHz and 448 GHz Integrated Receiver
  - Receiver Overview
  - 424-448 GHz chipset
- InP HEMT Switching Technology
  - Radiometric architecture trade study
  - Switching technology
  - Test component design
- Conclusion

Motivation:

- Ice clouds are a major source of uncertainty in climate models.

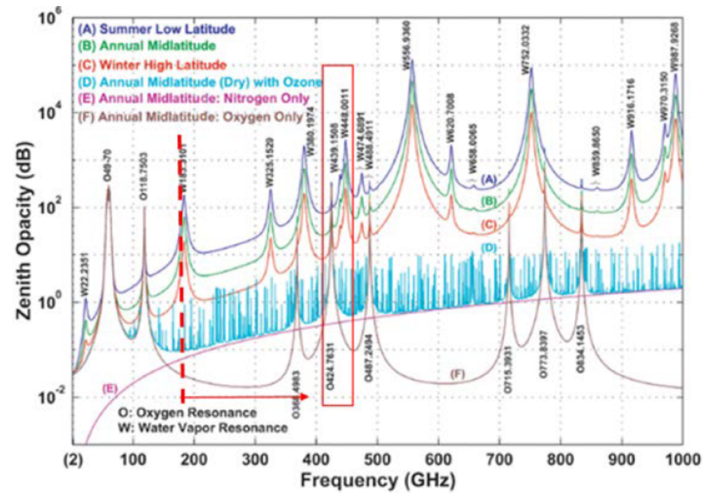
Measurement Objective:

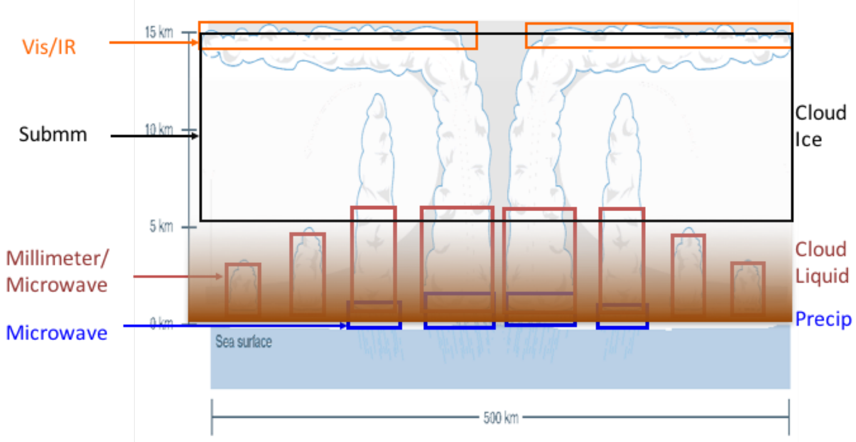
- Measure atmospheric water and oxygen content at heights of 4-16 km.
- Provide vertical profiles of upper atmosphere temperature, water vapor content, cloud ice particle microphysical properties.

OUR WORK:

- Improve the performance of submm-wave instrumentation from 118 GHz to far infrared.
- Reduce SWaP for compact low-cost instrument platforms such as CubeSats.

Microwave Absorption Spectrum





Integrated Receiver and Switch Technology (IRaST)

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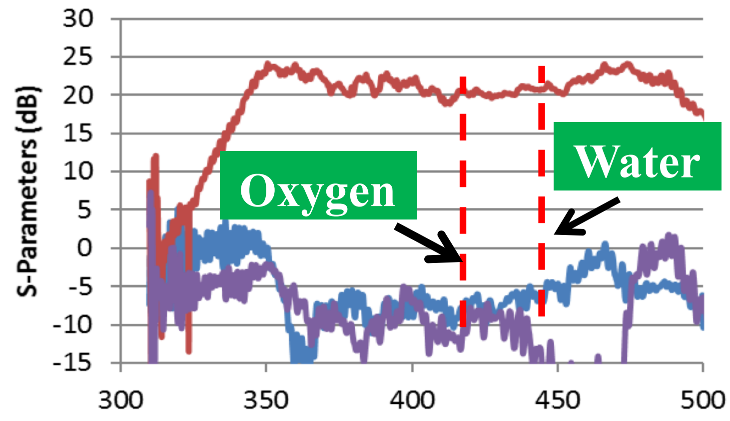
Task 1 (IR):

- Integrated 424 and 448 GHz receiver
- Atmospheric receiver temperature and humidity sounder in single receiver

JPL:

Pekka Kangaslahti (Co-I)

Boon Lim (Co-I)



400 GHz LNA S-Parameters

Task 2 (ST):

- Develop Integrated Switch technology to eliminate 1/f noise in submillimeter wave direct detection receivers

NGC:

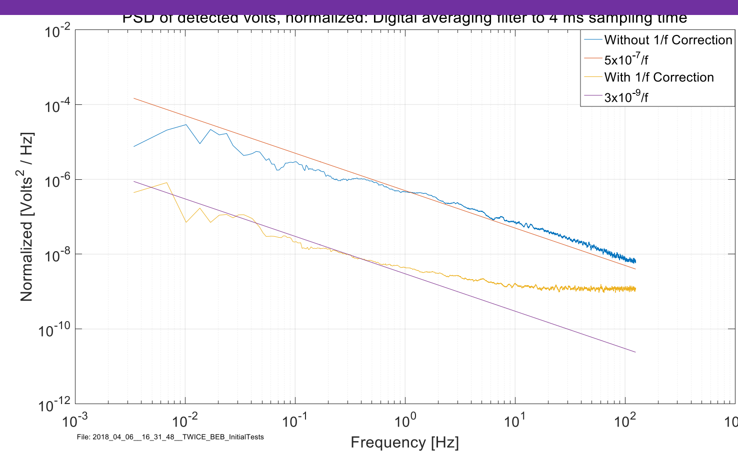
Bill Deal (PI)

Kevin Leong (Co-I)

Caitlyn Cooke

Aaron Swanson

Gerry Mei



Demonstrated 1/f Noise Improvement on TWICE Receiver

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Integrated Receiver Technology Approach

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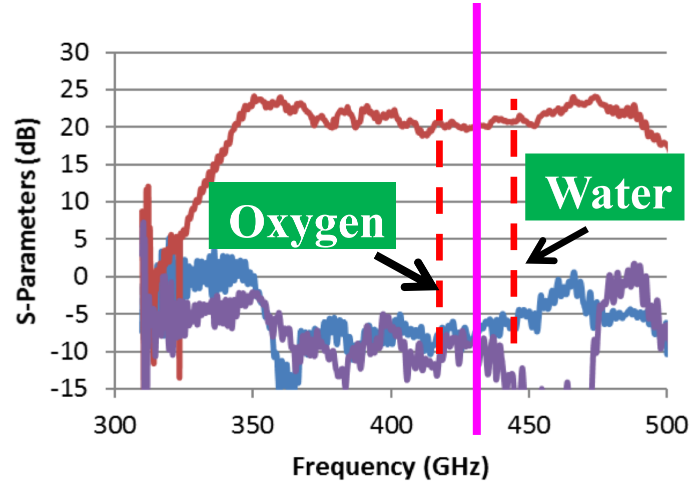
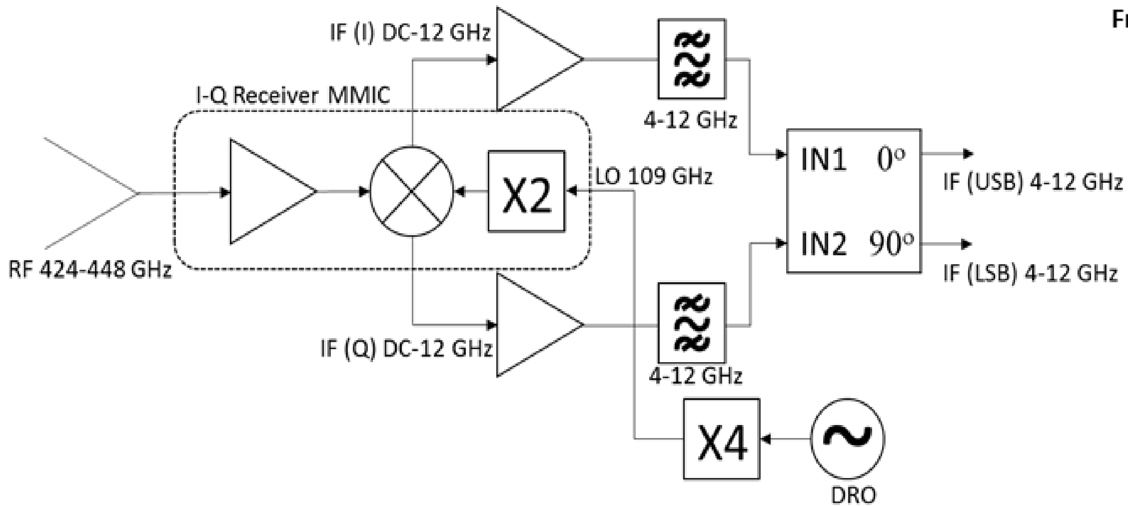
- 424 GHz (Oxygen) and 448 GHz (Water Vapor) will be measured in single aperture and receiver
- IQ Mixer demonstrated on ACT-5
- 424 GHz will be measured at 90 degree port
- 448 GHz will be measured at 0 degree port

Mixer LO Frequency: 436 GHz





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448 GHz Chipset

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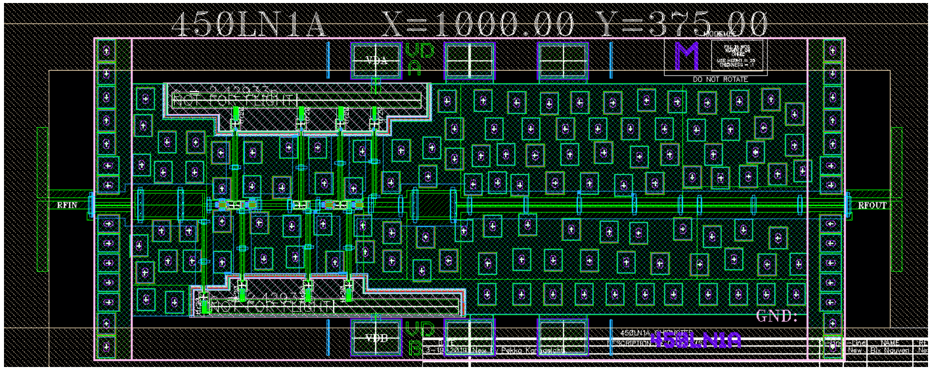
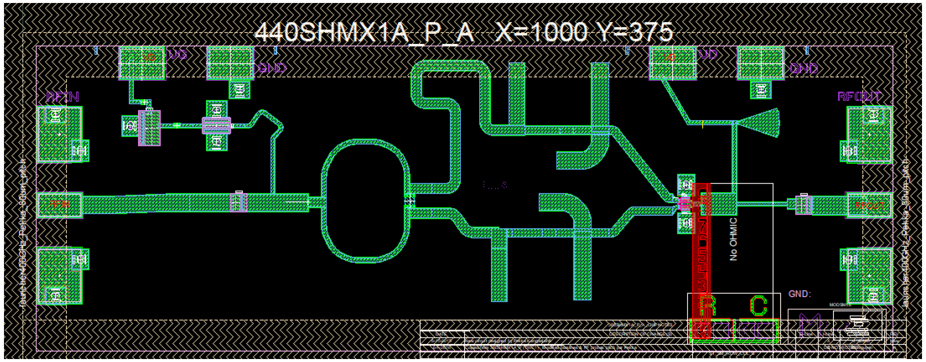
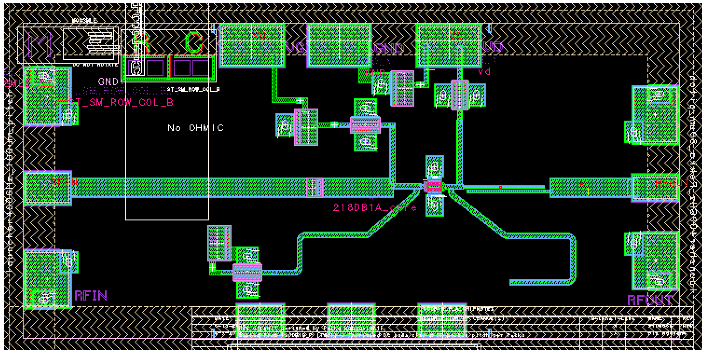
Low Noise Amplifier Specifications	
Bandwidth	420 – 450 GHz
Gain	16 dB minimum
Noise Figure	6 dB
Chip Dimensions	375 um x 1000 um



Second Harmonic Mixer Specifications	
Bandwidth	424 – 448 GHz
Conversion Gain	-17 dB
LO power	0 dBm
Output Waveguide	WR-2.2
Chip Dimensions	375 um x 1000 um



Frequency Doubler Specifications	
Bandwidth	208 – 226 GHz
Conversion Gain	-3 dB
Output power @218 GHz	0 dBm
Chip Width	375 um x 750 um



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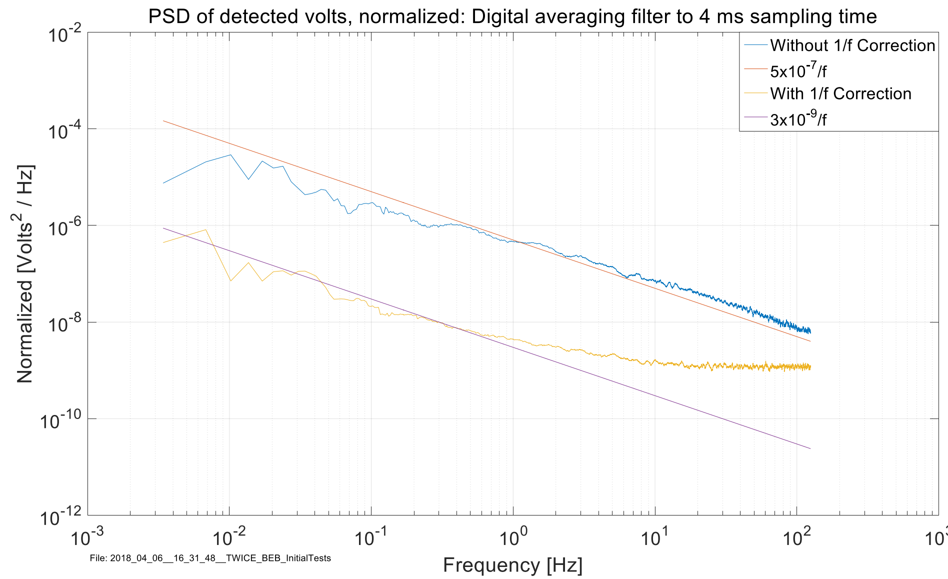
Switching Technology Objective

Develop and validate novel techniques for the mitigation of 1/f noise in submm-wave direct detection receivers.

Approach:

1. Design first submillimeter wave Dicke switches monolithically integrated with LNAs
2. Development radiometer architectures integrating switches and LNAs to trade 1/f noise improvement vs. sensitivity improvement.
3. Validate radiometric performance with NEDT measurements

TWICE 670: 1/f Noise Corrected Data



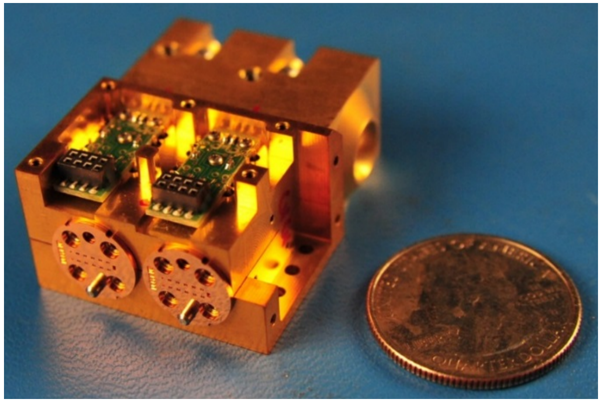
Noise figure — Gain fluctuations due to 1/f noise — Temperature fluctuations

$$\Delta T = T_{sys}\left[\frac{1}{B\tau} + \left(\frac{\Delta G(f)}{G}\right)^2 + \left(\frac{\Delta Tsys(f)}{T_{sys}}\right)^2\right]^{1/2}$$

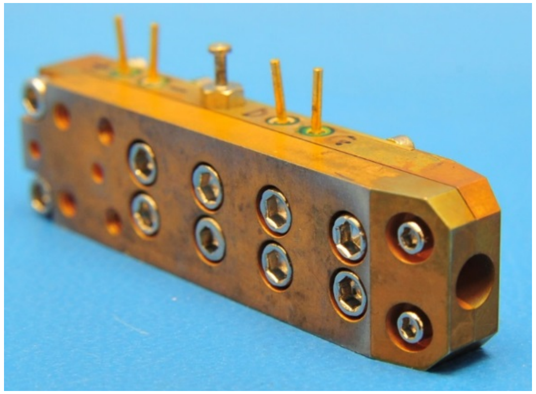
Benefits of Direct Detection Receivers

- Compact, less components
  - 220 GHz: 1.8 x 3.0 x 6.4 cm housing
  - 680 GHz: 0.8 x 1.3 x 4.8 cm housing
- Good Sensitivity with LNA
  - 220 GHz 5.1 dB front end noise figure
  - 680 GHz: 10.5 dB front end noise figure
- Low DC Power Consumption
  - 220 GHz: 250 mW (500 mW polarimetric)
  - 680 GHz: 210 mW (420 mW polarimetric)
- Compact, low power consumption makes them ideal for CubeSat applications, or large scale receiver arrays

SWIRP: 220 GHz Polarimeter

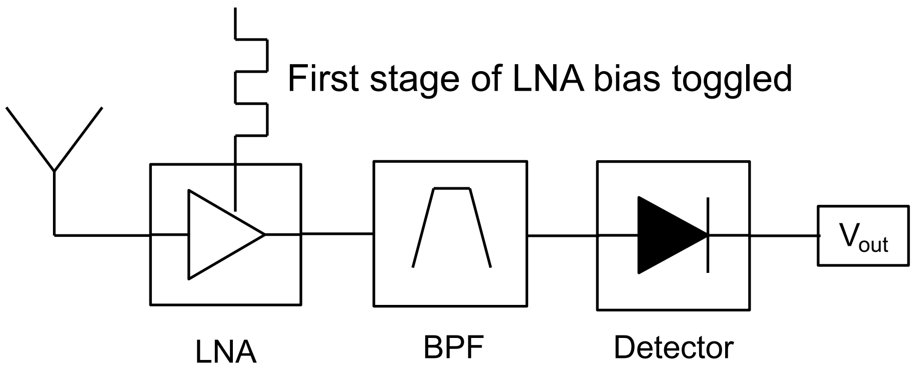


TWICE: 670 GHz Radiometer

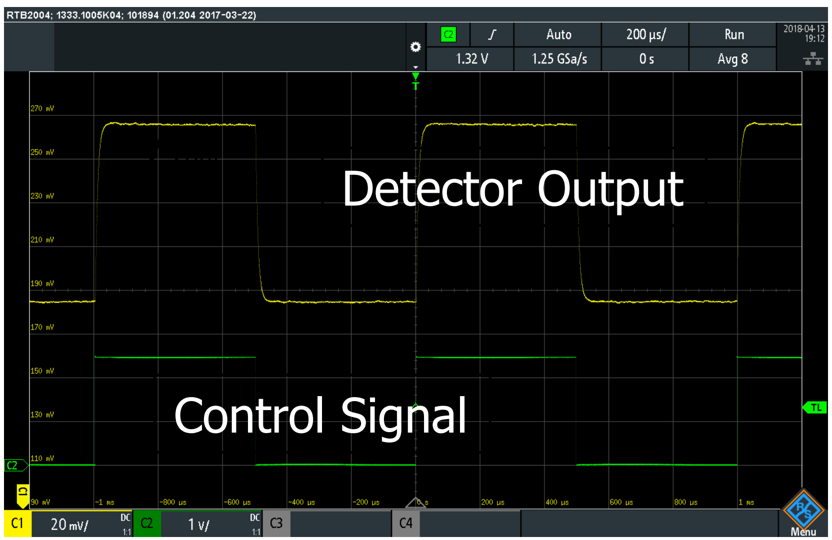


Modulated First Stage Bias

1. Switched LNA bias



- Achieving output voltage signal modulation through toggling first stage transistor in LNA chain
- Comparing on and off state output voltage, instead of to a reference load
- Only viable at frequencies where single stage transistor gain is low
- Proven on TWICE

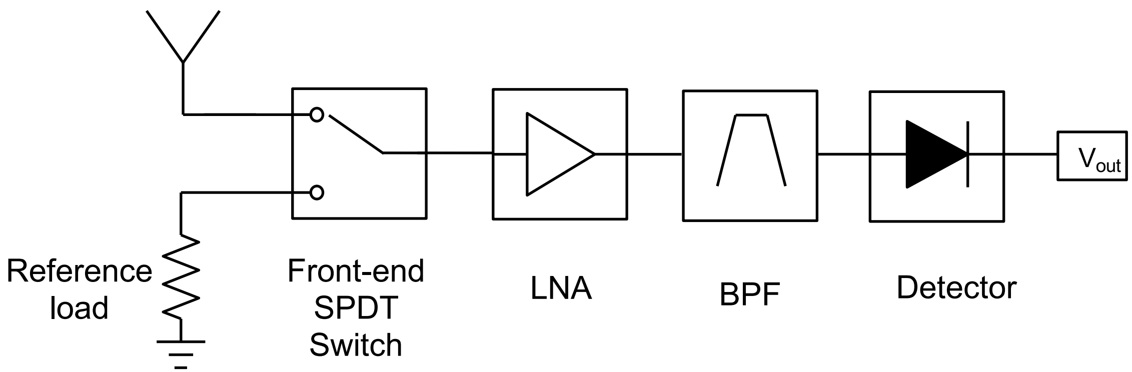


Pros:
- 1/f noise reduced
- Avoids noise figure degradation due to lack of front end switch or coupler losses
- No additional RF components, easily integrated into existing radiometer platforms

Cons:
- No reference load for gain calibration. (LNA impedance unknown when bias is toggled off)
- Additional 3 dB loss in receiver sensitivity due to switching

Dicke Switch Architecture

2. Front-end Dicke Switch



- SPDT switch in front to capture 1/f noise contributions from LNAs and detector
- Provides calibration via constant known reference load, close to antenna temperature
- Will account for noise in every component behind the reference load

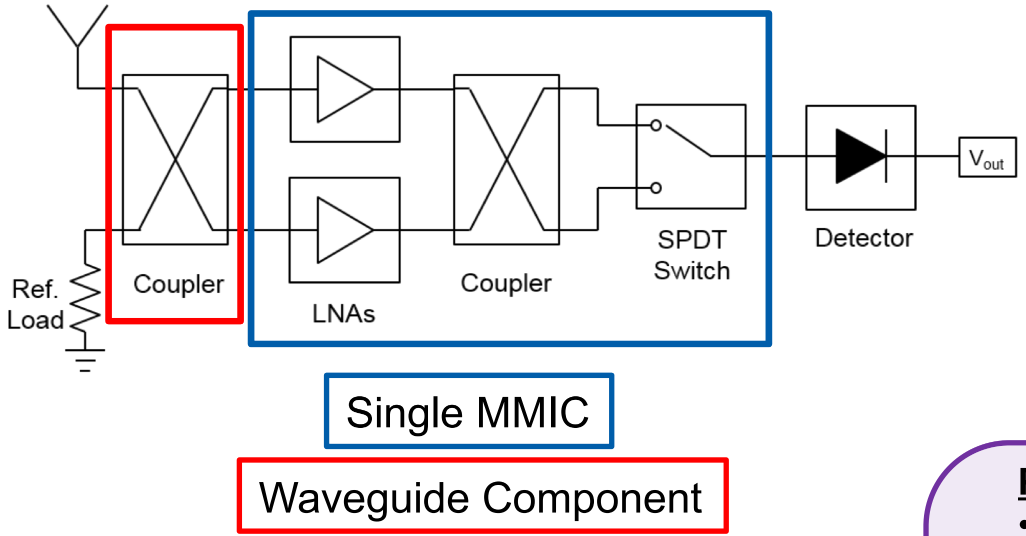
Switching configuration impact on noise figure

	180 GHz		230 GHz		670 GHz	
	Gain (dB)	NF (dB)	Gain (dB)	NF (dB)	Gain (dB)	NF (dB)
1. Baseline (Amp, Amp, Det)	36	4.0	34.8	4.9	28	10.2
2a. Dicke (Sw, Amp, Amp, Det)	31.8	8.3	29.7	10.0	20.5	17.7
2b. Dicke (Sw+Amp, Amp, Amp, Det)	51.8	6.5	49.7	7.4	42	14.3
2c. Dicke (Amp+Sw, Amp, Amp, Det)	51.8	4.1	49.7	4.9	42	10.4

Pros:
- Switching provides 1/f noise reduction
- Reference load provides gain calibration reference

Cons:
- Noise figure degradation due to front end switch losses
- Additional noise figure degradation due to interconnect losses before LNA

3. Pseudo-Dicke Switching



- Similar principle to Dicke switch architecture
- Switches between antenna and reference load
- Removes SPDT from front end for frequencies where switch loss will be high
- Coupler loss generally lower than switch loss (depending on frequency)

Pros:
- Switching provides 1/f noise reduction
- Reference load provides gain calibration reference
- Removes SPDT switch losses

Cons:
- Noise figure degradation due to front end coupler losses
- Additional noise figure degradation due to interconnect losses before LNA

Pseudo-Correlator Architecture

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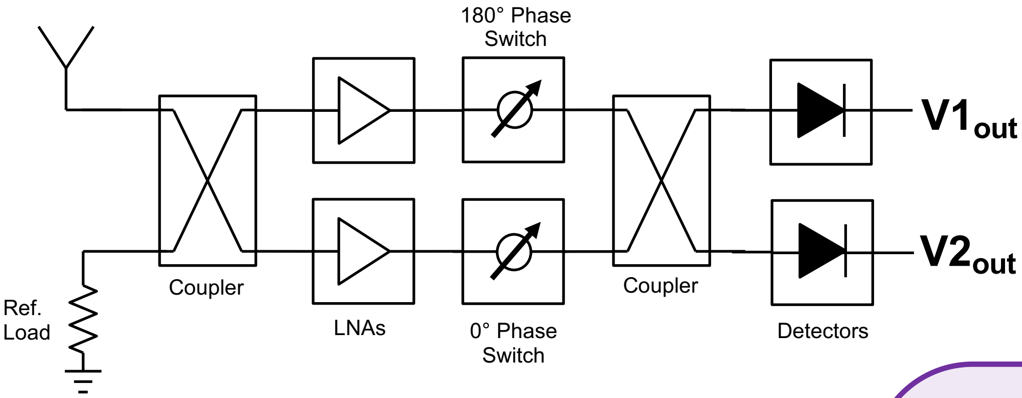
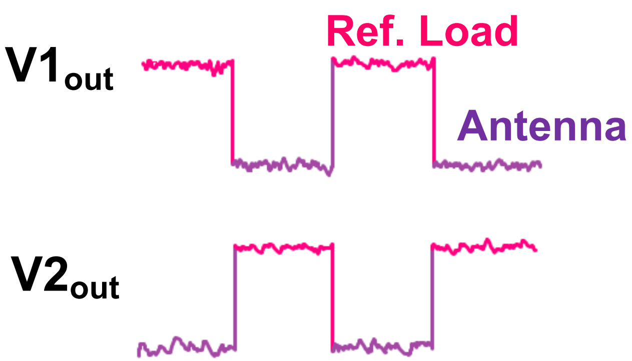
4. Pseudo-Correlated Radiometer



- Concept: two identical radiometers, one looking at reference load, one at incoming signal
- Two radiometer paths 180 degrees out of phase, so receiver always sees incoming signal
- Implemented by use of a 180 degree phase switch on one path



Two channel detector output

Pros:

- Switching provides 1/f noise reduction
- Reference load provides gain calibration reference
- No degradation in NEDT, since the receiver is always looking at the incoming signal

Cons:

- Inherent more complicated due to the need for two receivers
- Very important to have ideally equal performance from both receivers, otherwise will see a degradation in noise reduction

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Packaging Plan – WR4.3 band

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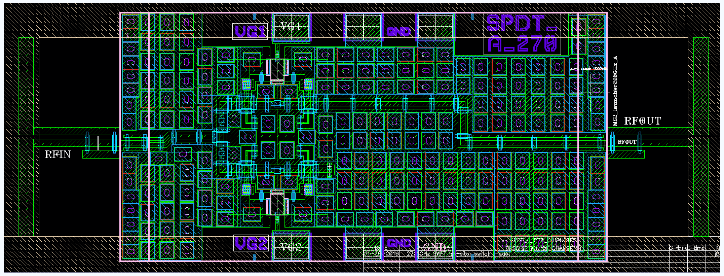
1. Dicke Switch Test Module

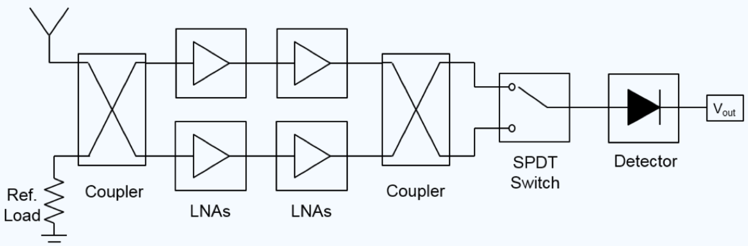


Standard Dicke switch architecture

GOALS

- Evaluate performance of SPDT switches
- Evaluate switch radiometric performance
- Baseline 1/f noise improvement due to switching

2. Pseudo-Dicke

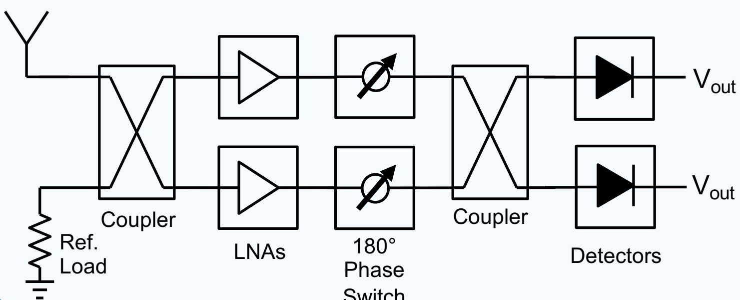


Removes front end Dicke switch losses

GOALS

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

3. Pseudo-correlator with Phase Switching



Eliminates front end Dicke switch losses AND 3dB sensitivity hit due to switching

GOALS

- Outputs to two separate detector channels
- Evaluate receiver radiometric performance
- Test 1/f noise improvement, compare to Dicke switch

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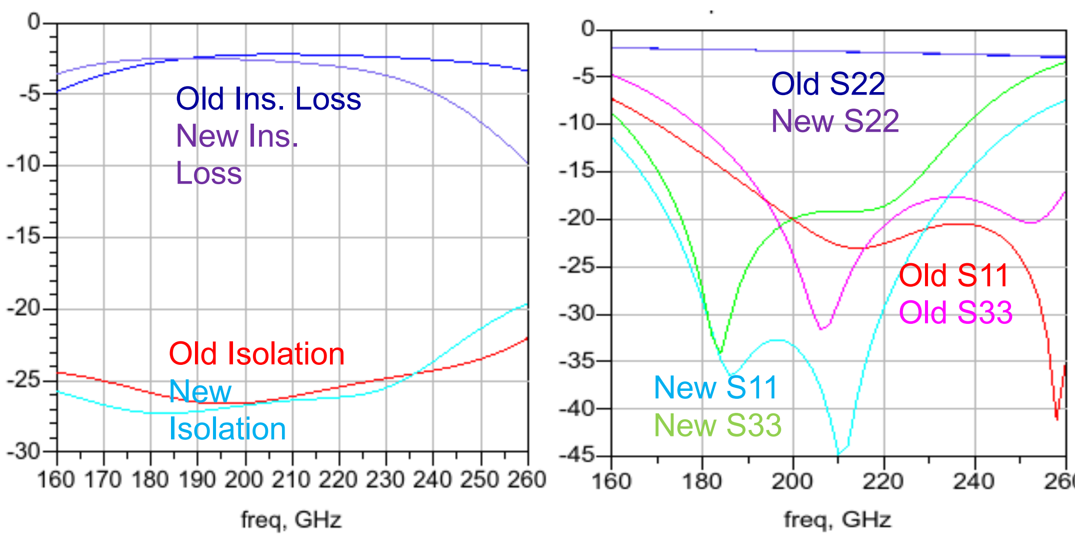
Switch Model

- **2-finger and 4-finger common source devices measured**
- **Intrinsic capacitances and resistances extracted as a function of bias**
- **Existing and new model will be used to validate switch model**
- **Common source and common gate devices will be designed for continued device modeling**

Intrinsic Parameter Effect on 230 GHz SPDT switch

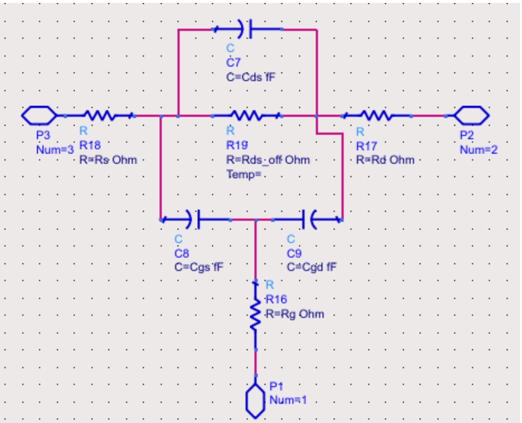


Extracted Intrinsic Switch Model Parameters

	New Model	Prior Model	% Change
Cgs_i off	3.7	19.3	-81%
Cgd_i off	4.7	3.9	22%
Cds_i off	10.4	5.8	80%
Rds_i off	30000[1]	30000	0%
Cgs_i on	16.2	25.0	-35%
Cgd_i on	12.2	5.0	144%
Cds_i on	10.4[2]	7.5	39%
Rds_i on	11	11	0%

1. Extractions for off-state Rds not clean, using old model
2. Extractions for on-state Cds not clean, assuming no change from off-state

Simulated HEMT Switch Model



Test Switch Structures

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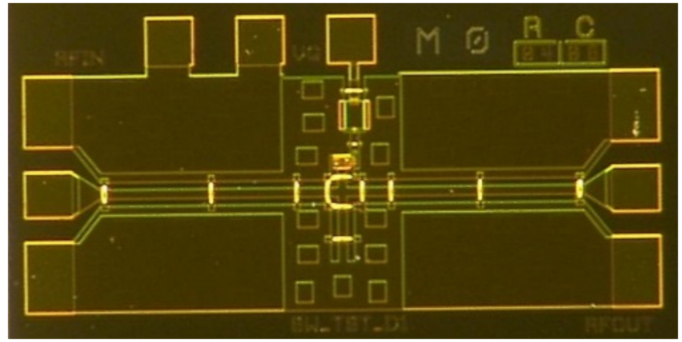
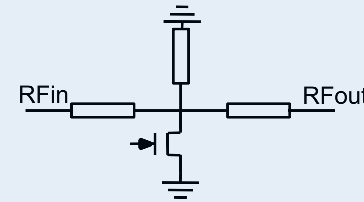
- **Compare measurements to simulated data for switch model validation**

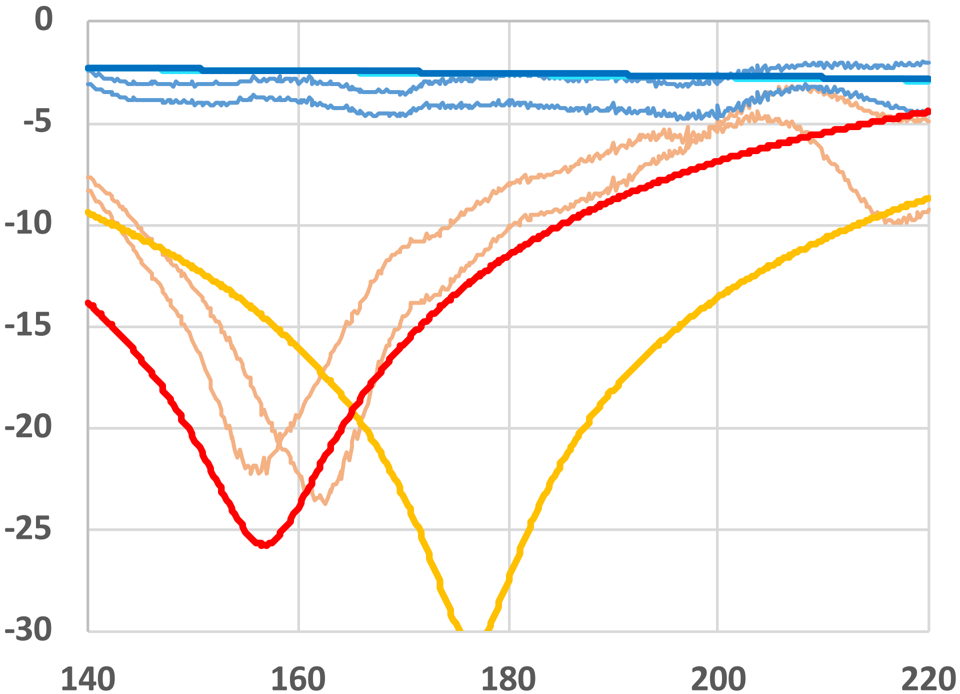
OFF-state	**ON-state**
Old Model	**Old Model**
New Model	**New Model**



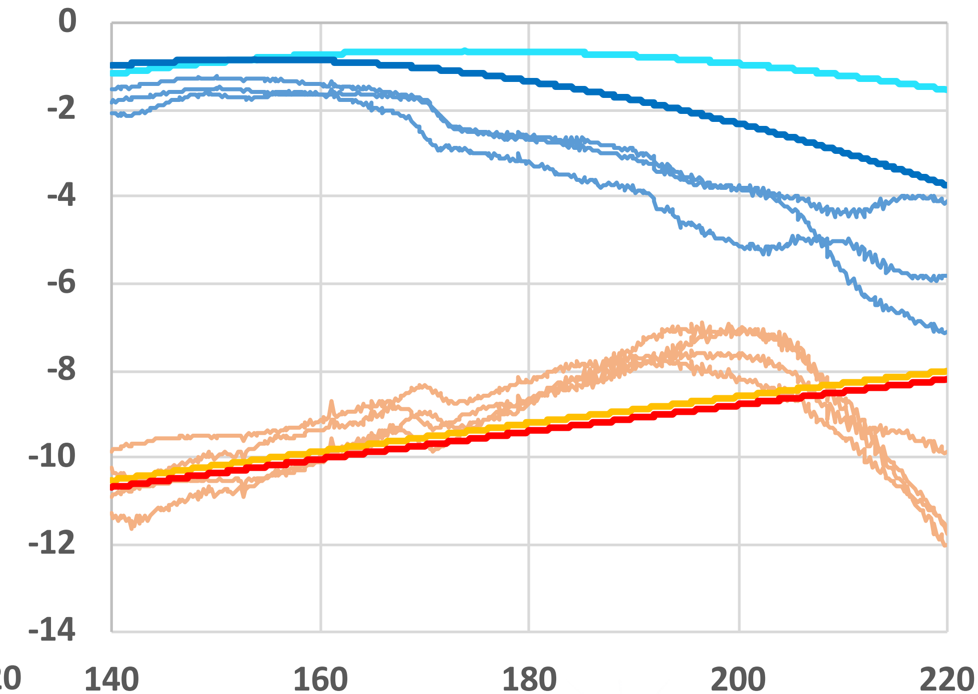
Single Shunt Transistor



Return Losses- Modeled vs. Measured



Insertion Loss & Isolation- Modeled vs. Measured



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SPDT Dicke Switch Simulations

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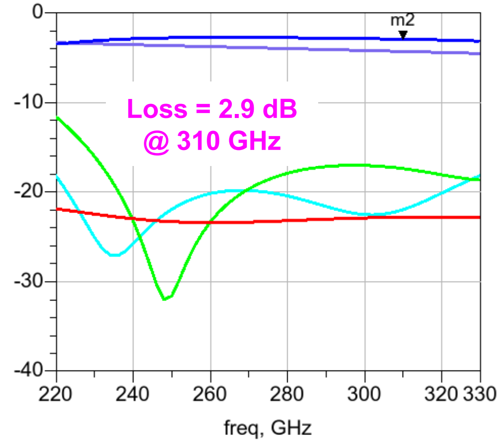
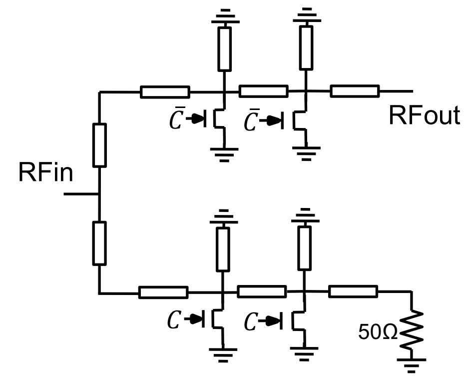
- SPDT switch designs for a range of bands
- Non-reflective switches designed for balanced amplifier module at 230 and 310 GHz
- One version on IRST1 for each the existing model and new model

WR-3

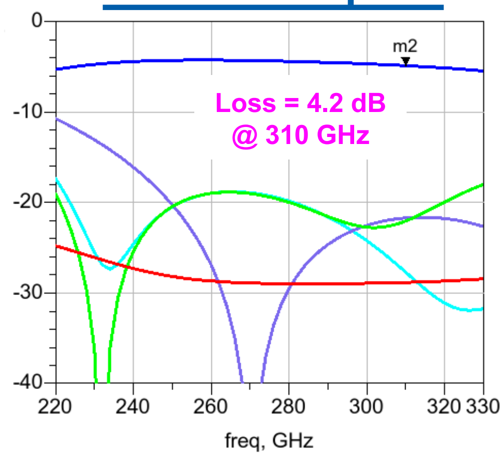


SPDT Switch

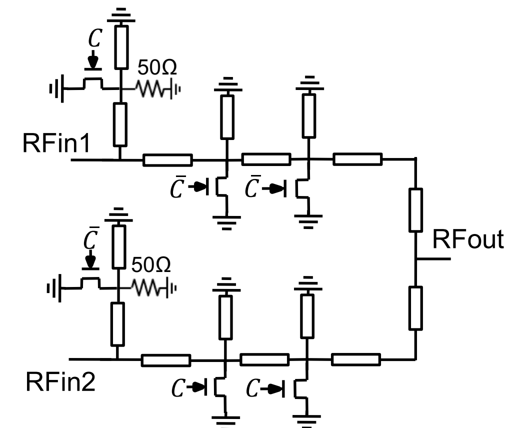


Band	Loss	Isolation
WR-5	2.2 dB @ 180 GHz	> 25 dB
WR-4	2.7 dB @ 230 GHz	> 24 dB
WR-4 absorb.	3.8 dB @ 310 GHz	> 25 dB
WR-3	2.9 dB @ 310 GHz	> 22 dB
WR-3 absorb.	4.2 dB @ 310 GHz	> 25 dB
WR-1.5	4.2 dB @ 670 GHz	> 15 dB

WR-3 Absorptive



Absorptive SPDT Switch



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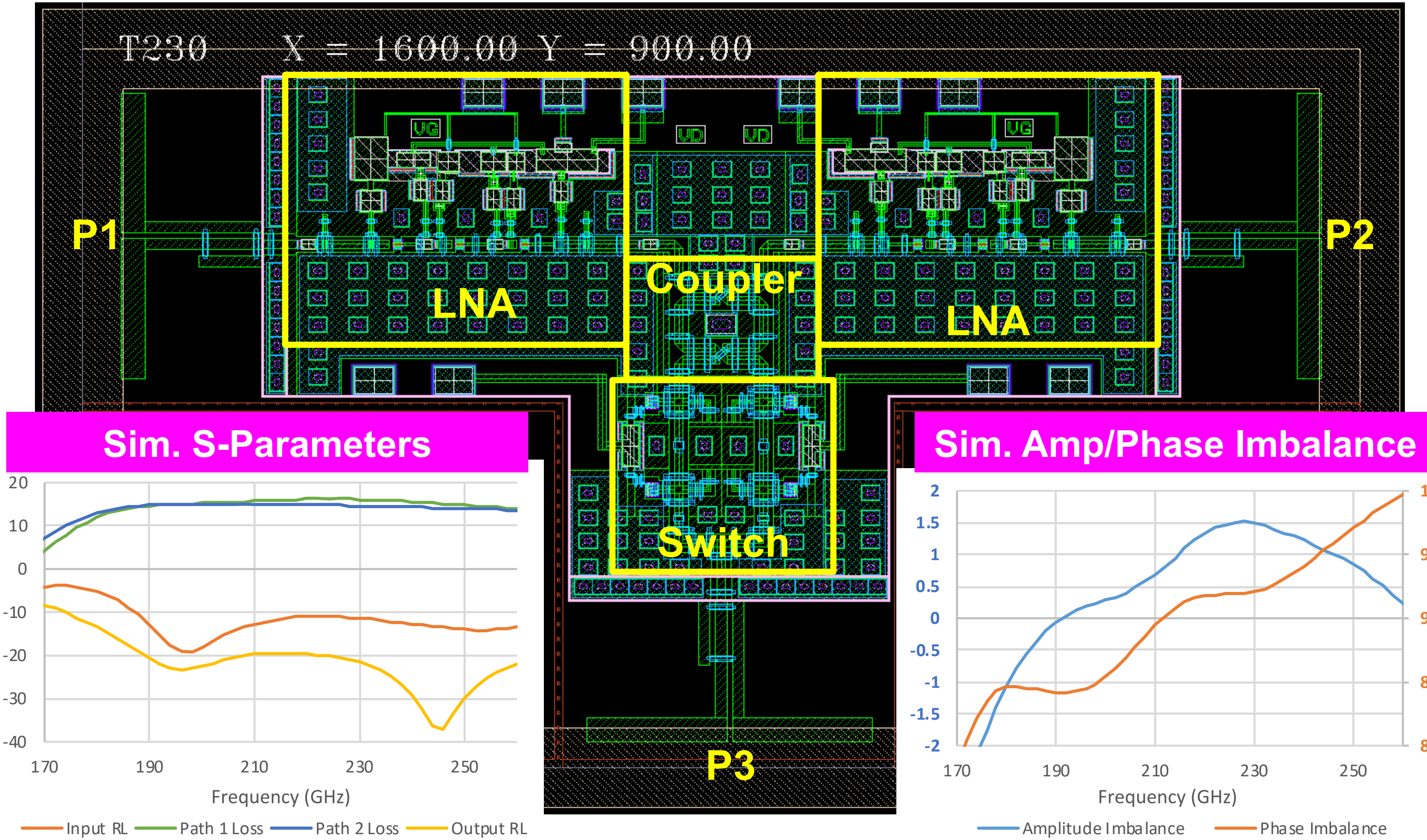
230 GHz Pseudo-Dicke "T-Chip"



230 GHz T-chip Packaging

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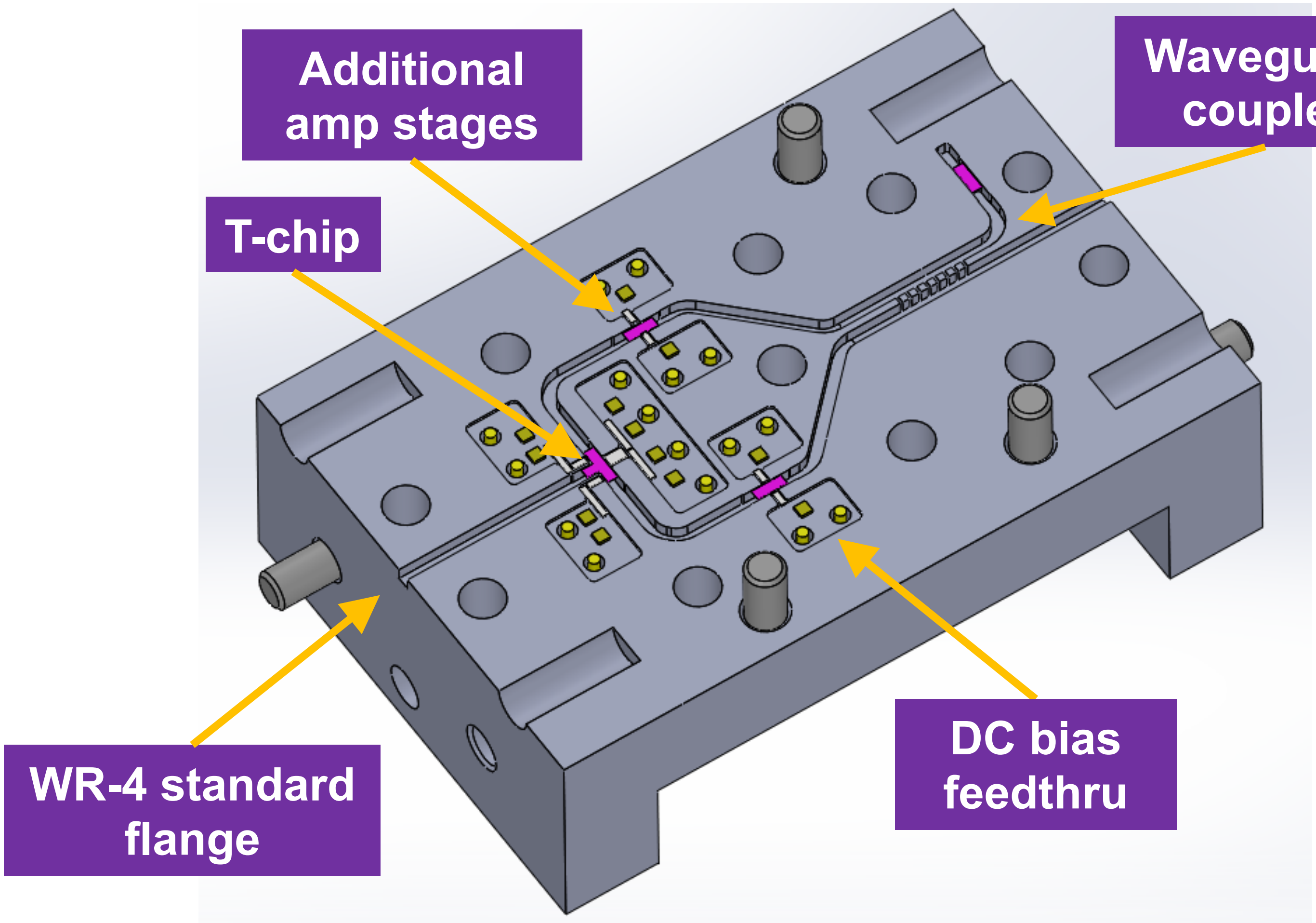
Pseudo-Dicke Housing

0.75" x 0.75" x 1.2"



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180° Phase Switch

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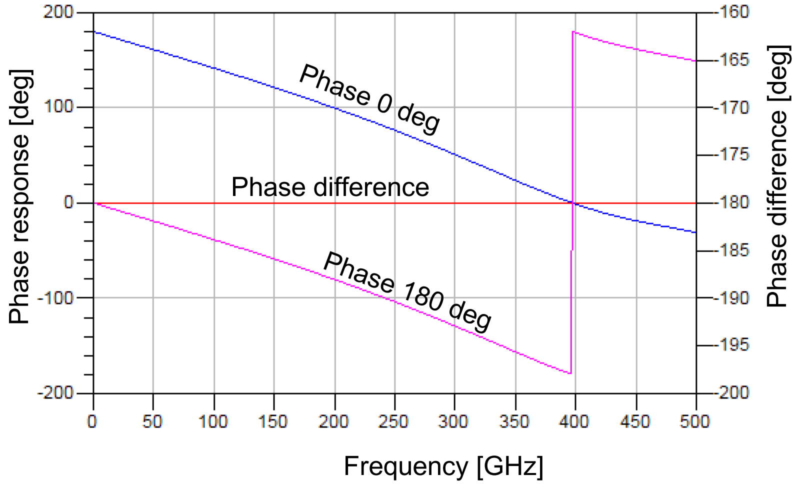
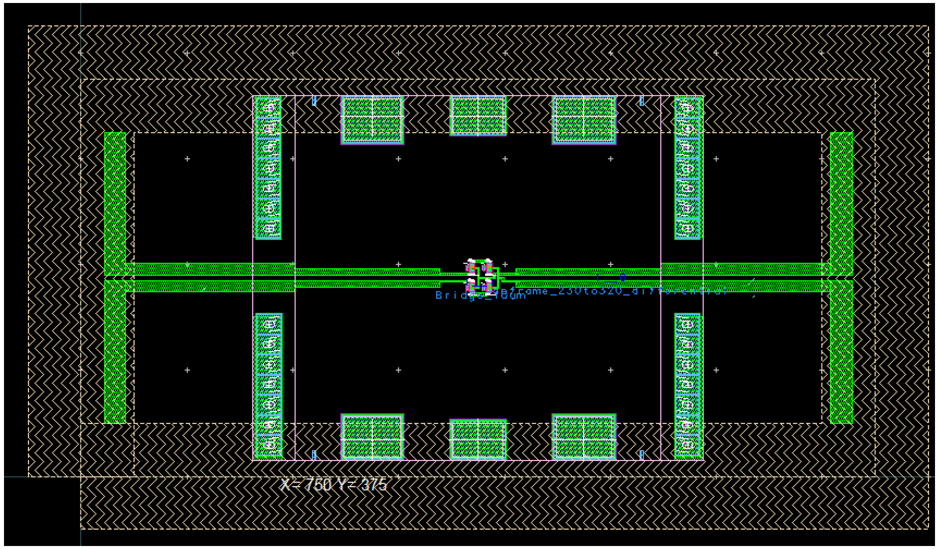
Simulated Specifications	
Bandwidth	230 – 320 GHz
Loss	3.5 dB
Phase error from 180°	+/- 1°
Amplitude difference	< 1dB
Chip Dim.	375 um
Chip Length	750 um

Simulated Performance (Ideal)



Layout



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Conclusion

- **IRaST is:**
  - Developing an Integrated 424 – 448 GHz receiver
  - Developing new 1/f noise reduction techniques for direct detection receivers
- **Project Status:**
  - 1st Mask layout completed
  - Wafers are in fabrication
  - Test blocks have been designed
  - Testing will begin August/September