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25 nm InP HEMT LNAs and Receiver Technology for the TWICE Instrument

6-15-2016

Presented by Bill Deal

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Northrop Grumman, Jet Propulsion Laboratory*

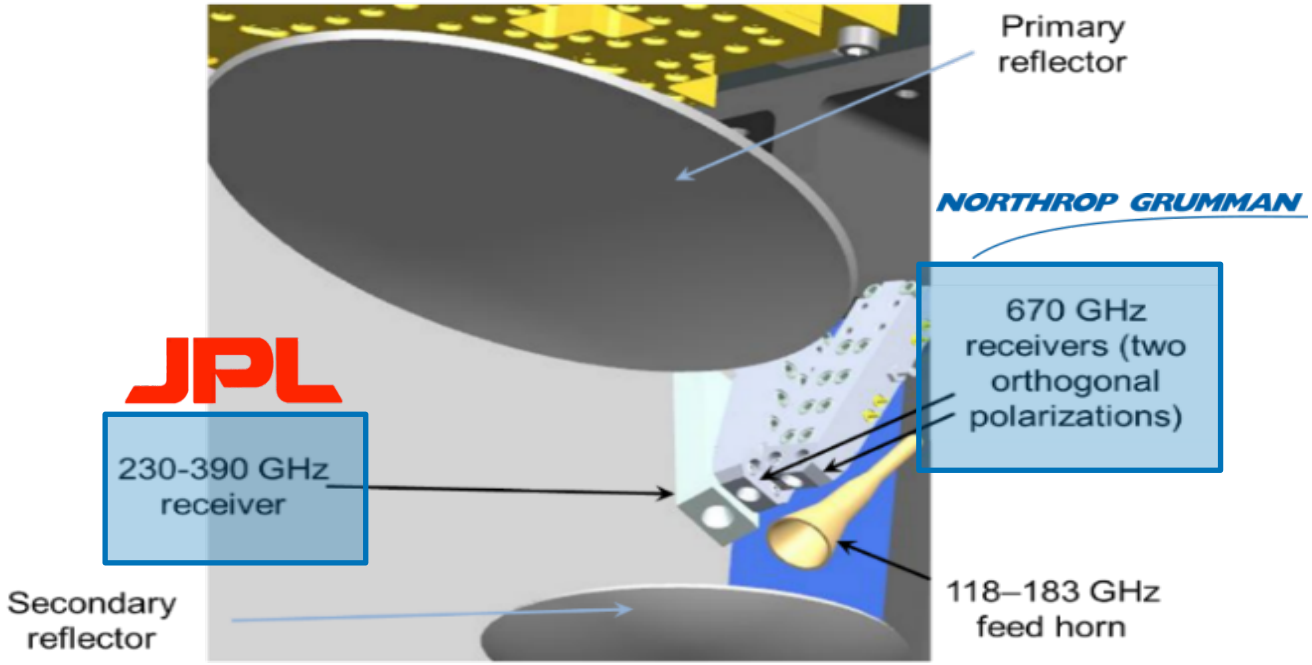
and Colorado State University**

Outline

- Outline
- Motivation
- 670 GHz Receiver Update
- 230-390 GHz Update
- Conclusion

TWICE Receiver Overview

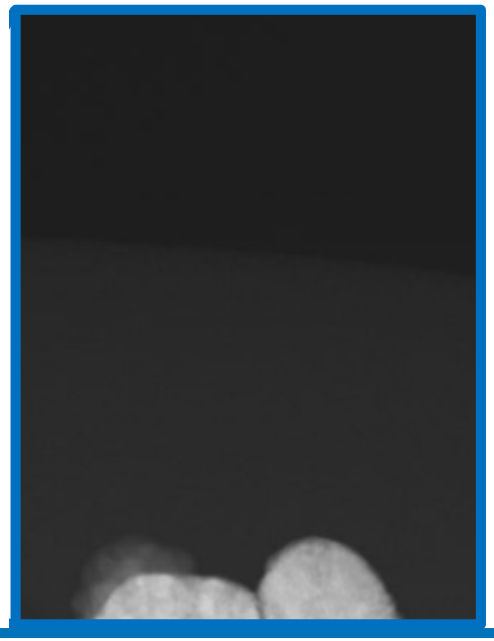
- Three millimeter/submillimeter wave receivers on instrument
- Two receivers implemented in recently available 25 nm InP HEMT
  - 660-680 GHz dual direct detection receivers (two orthogonal polarizations)
  - 230-390 GHz broadband receiver
- This talk provides an overview of progress of these two receivers

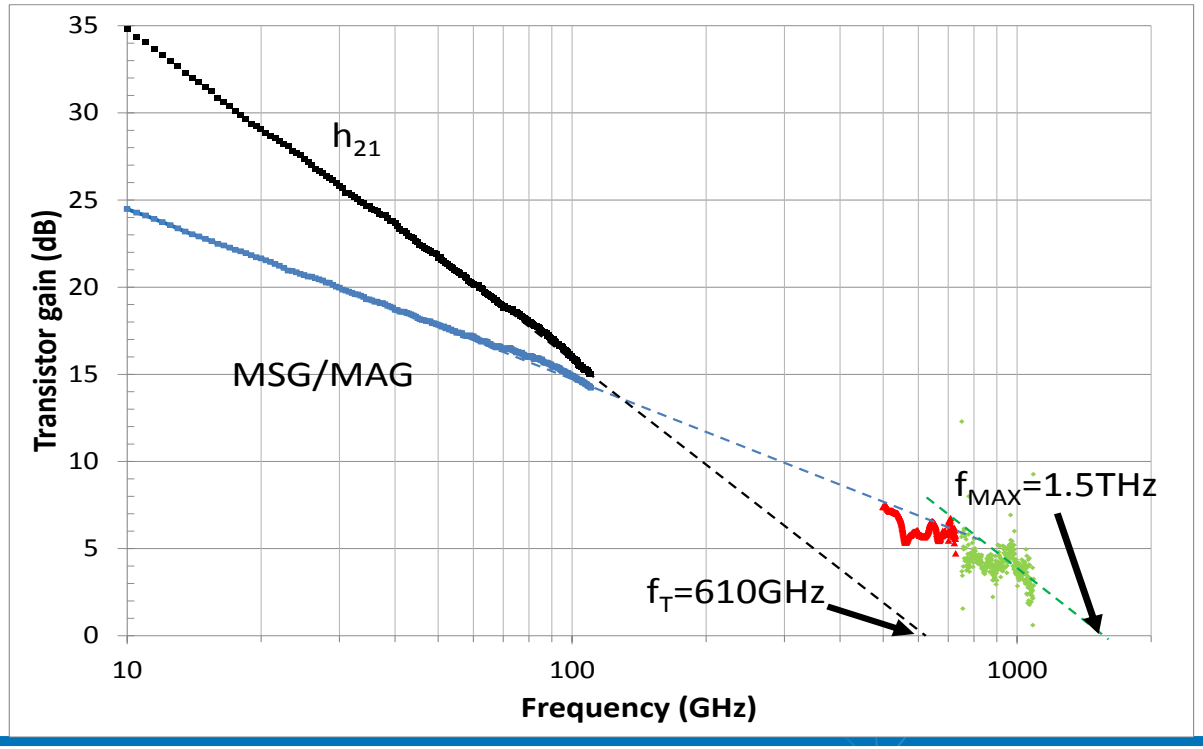


Motivation

Scaling enables significantly enhanced performance

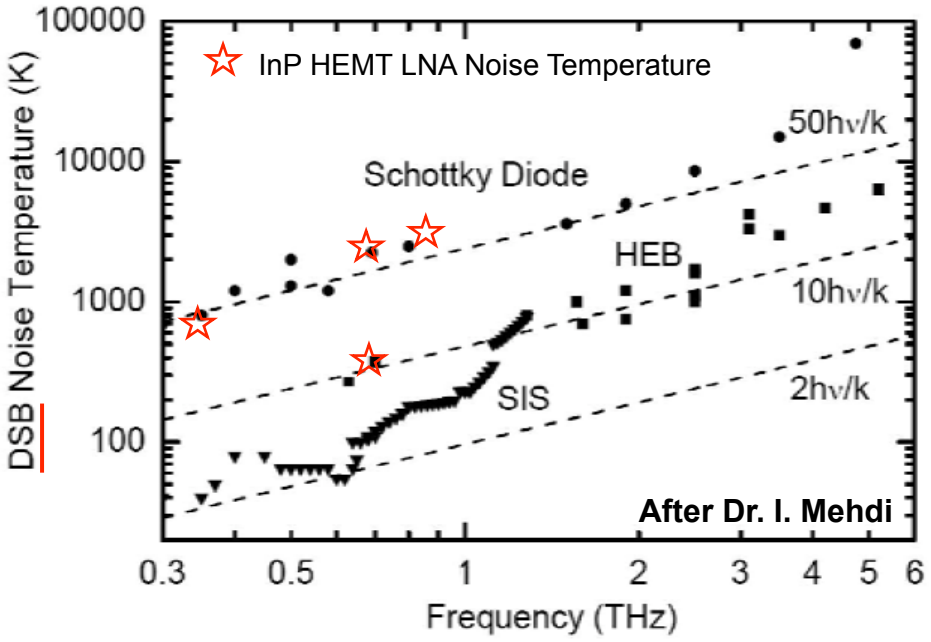
- 25 nm gatelength
- f_{max}: 1.5 THz
- f_T: 0.61 THz





Submillimeter LNA's

Mixer DSB Noise Performance



- **InP HEMT LNA sensitivity approaches that of DSB mixers.**
- **InP HEMT LNA is superior to that of mixers operated in SSB mode.**
- **This extends to cryogenic operation.**

670 GHz Comparison

	Ambient Temperature [K]	Noise Figure [dB]	Noise Temperature [K]
HEMT	270 25	9.6 3.8	2355 400
GaAs Schottky	270	9.4 DSB (12.4 SSB*)	2236 DSB (4750 SSB*)
HEB	Cryo	2.7 DSB (5.7 SSB*)	250 DSB (788 SSB*)
SIS	4	1.3 DSB (4.3 SSB*)	100 DSB (491 SSB*)

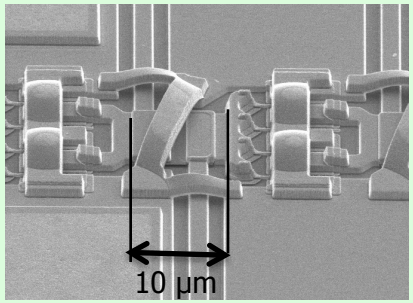
850 GHz Comparison

	Ambient Temperature [K]	Noise Figure [dB]	Noise Temperature [K]
HEMT	270	12	3361
GaAs Schottky	270	9.8 DSB (12.8 SSB*)	DSB 2500 (5236 SSB*)

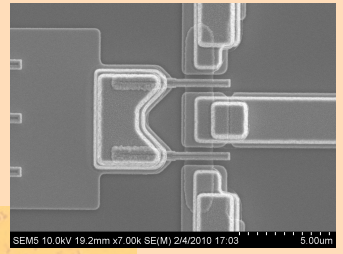
*Performance estimated from plot. SSB is calculated from DSB by adding 3 dB

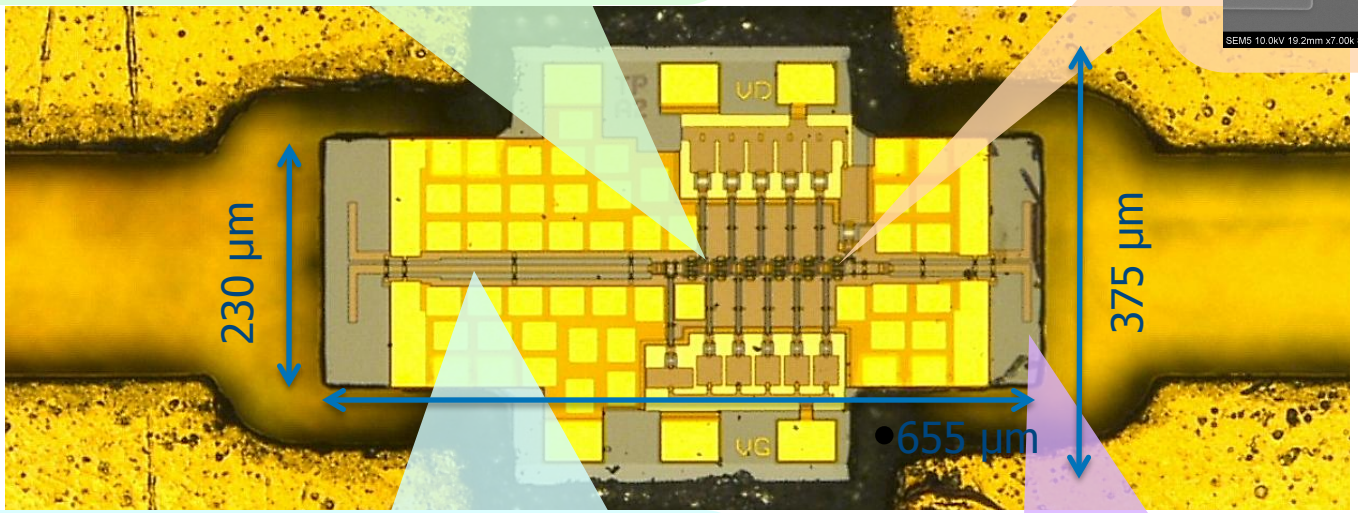
THz Monolithic Integrated Circuit (TMIC)

Passive TMIC Technology:
High compaction.
HEMT to HEMT spacing of 10 μm.

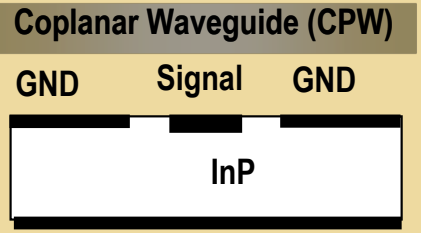


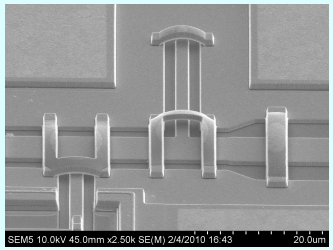
Transistor Technology:
25 nm InP HEMT



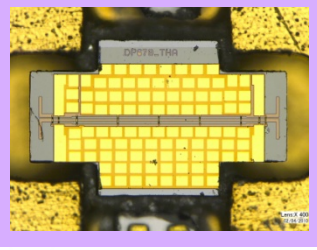


Coplanar Waveguide (CPW)





Integration Challenges:
Need wide chip for circuit, but narrow for transition
Cross-shaped chip



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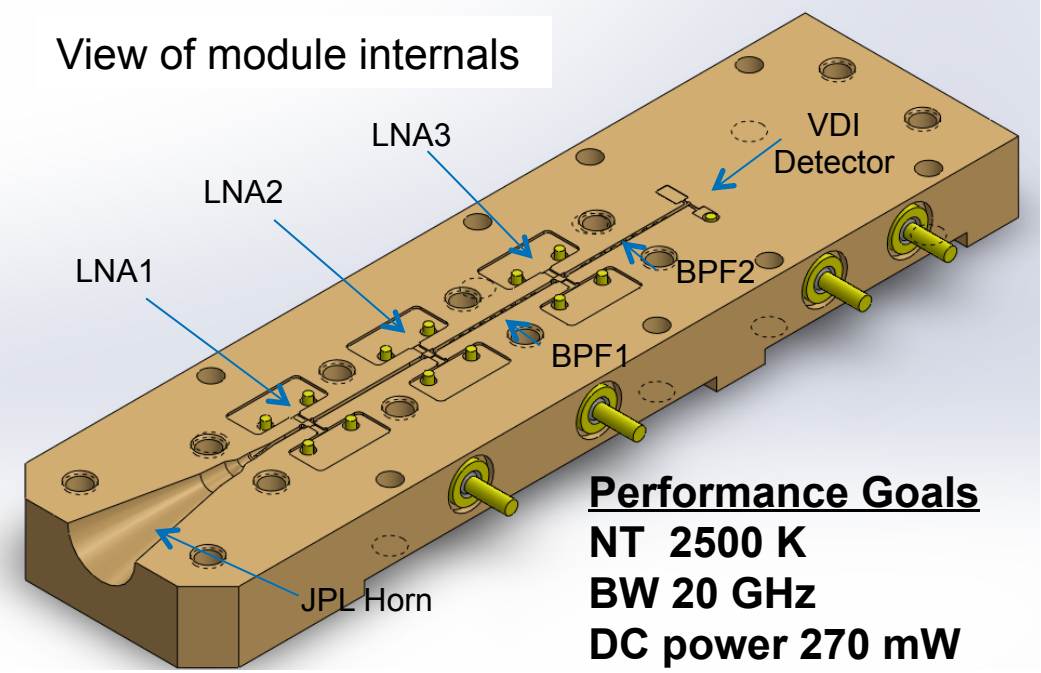
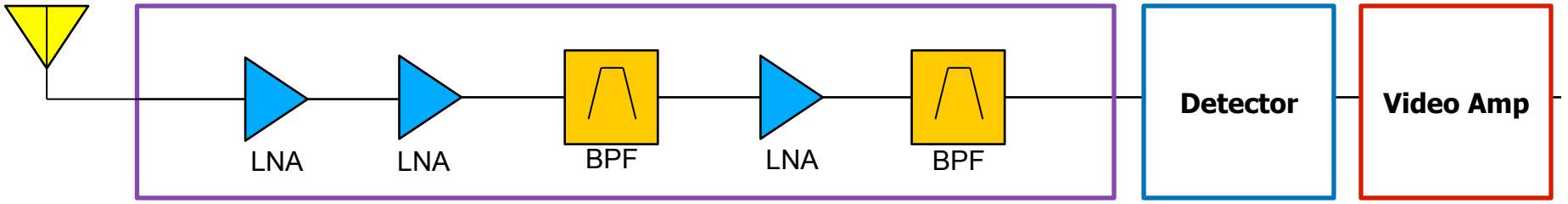
670 GHz Receiver Approach

- Final receiver is an integrated, single-block 670 GHz Receiver
- Module includes:
  - Feedhorn (JPL)
  - LNA MMICs
  - Bandpass filters
  - Zero Bias Detector (VDI)
  - Video Circuitry
- Each functional block has been prototyped and evaluated
- Components have been evaluated together to evaluate integrated performance



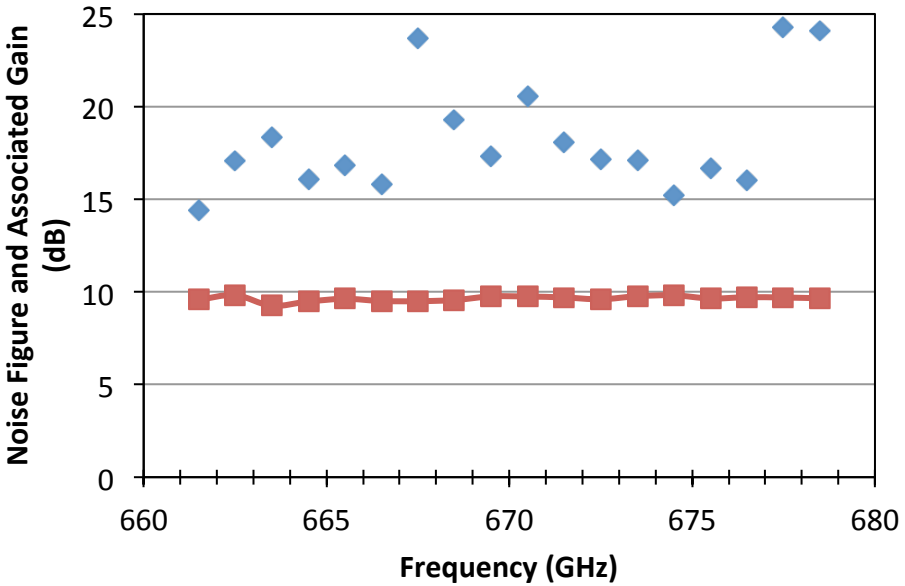
Performance Goals
NT 2500 K
BW 20 GHz
DC power 270 mW
13x50x8mm mm^3



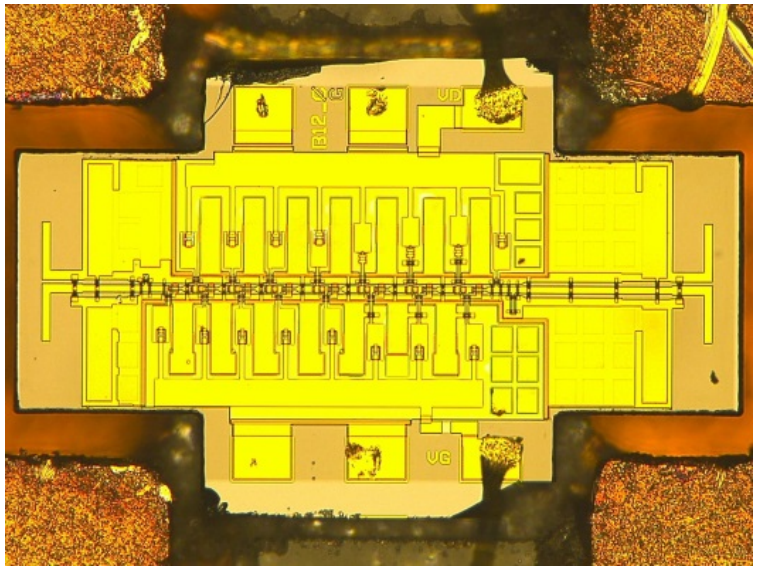
670 GHz LNA

- **670-GHz LNA:**
  - **8-stage, single-ended design**
  - **2-Finger 12 µm HEMTs**
  - **655 µm x 375 µm die size**

Packaged 670-GHz LNA Measured Gain and Noise Figure

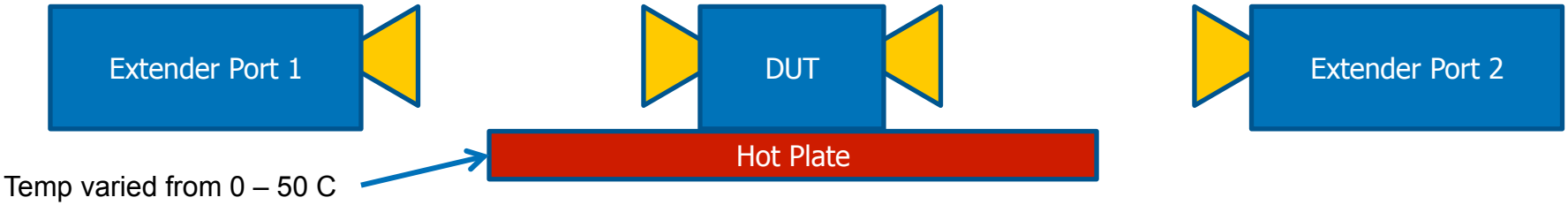


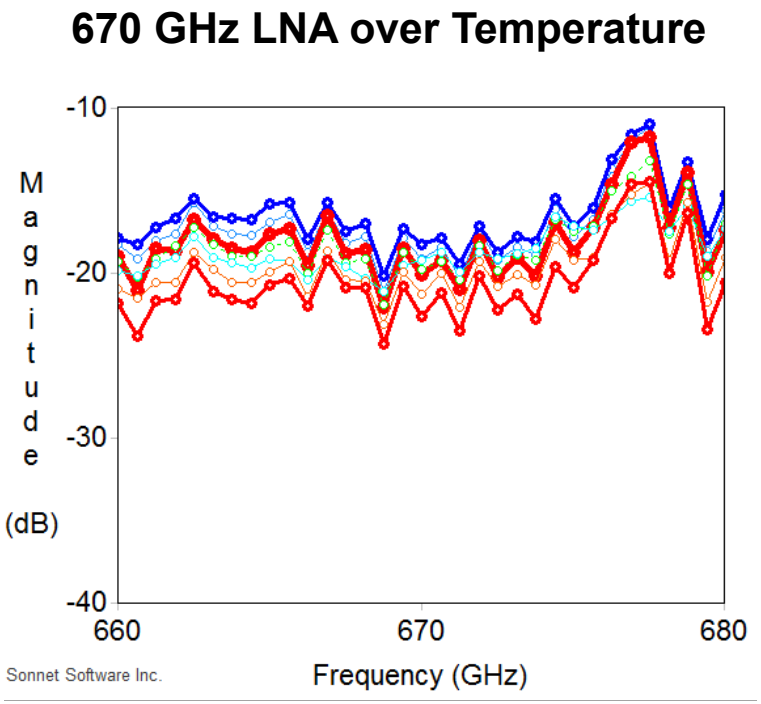
Packaged LNA TMIC

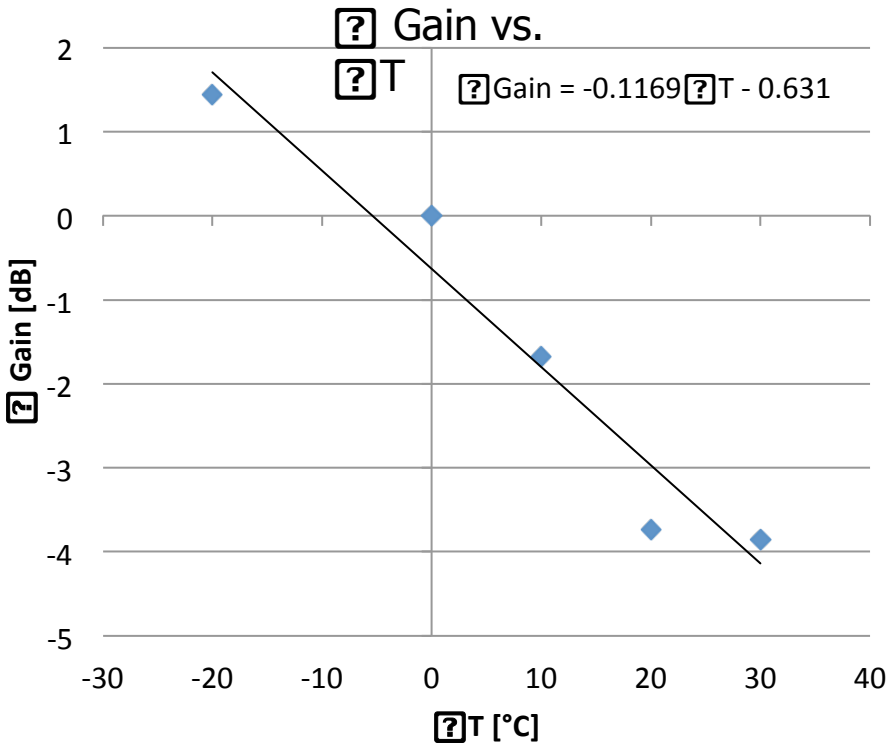


9.6 dB Measured Noise Figure (NT=2400K)

670 GHz LNA Gain vs. Temperature







~0.01 dB/C per Device Measured

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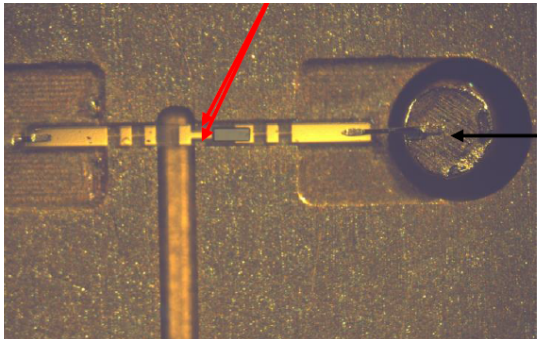
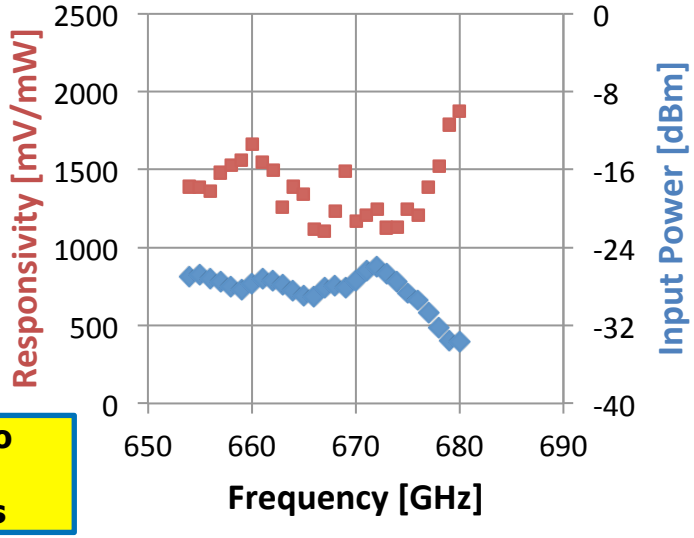
Detector Responsivity Measurements

VDI Detector
(Within Split-Block Waveguide)

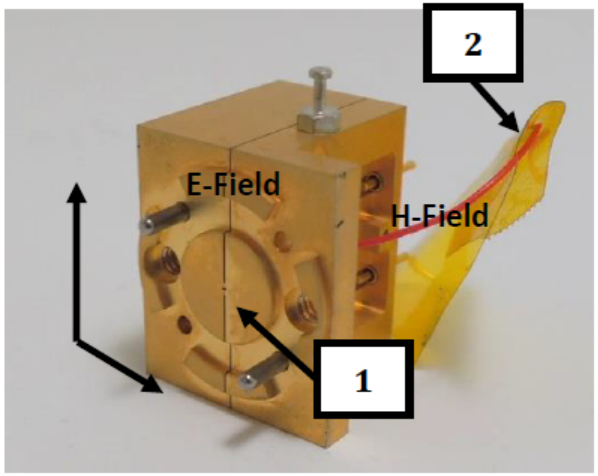


Detector Measured Responsivity vs. Frequency

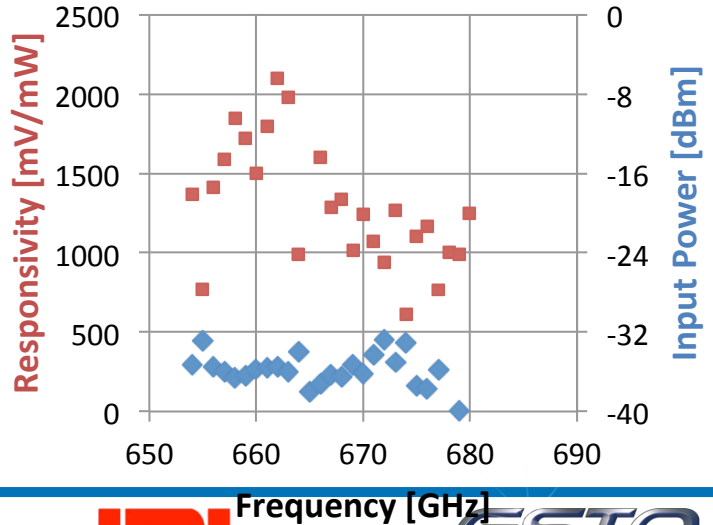


Measured with two different input power levels

Fabricated and tested Detector Prototyping Module



Detector Measured Responsivity vs. Frequency



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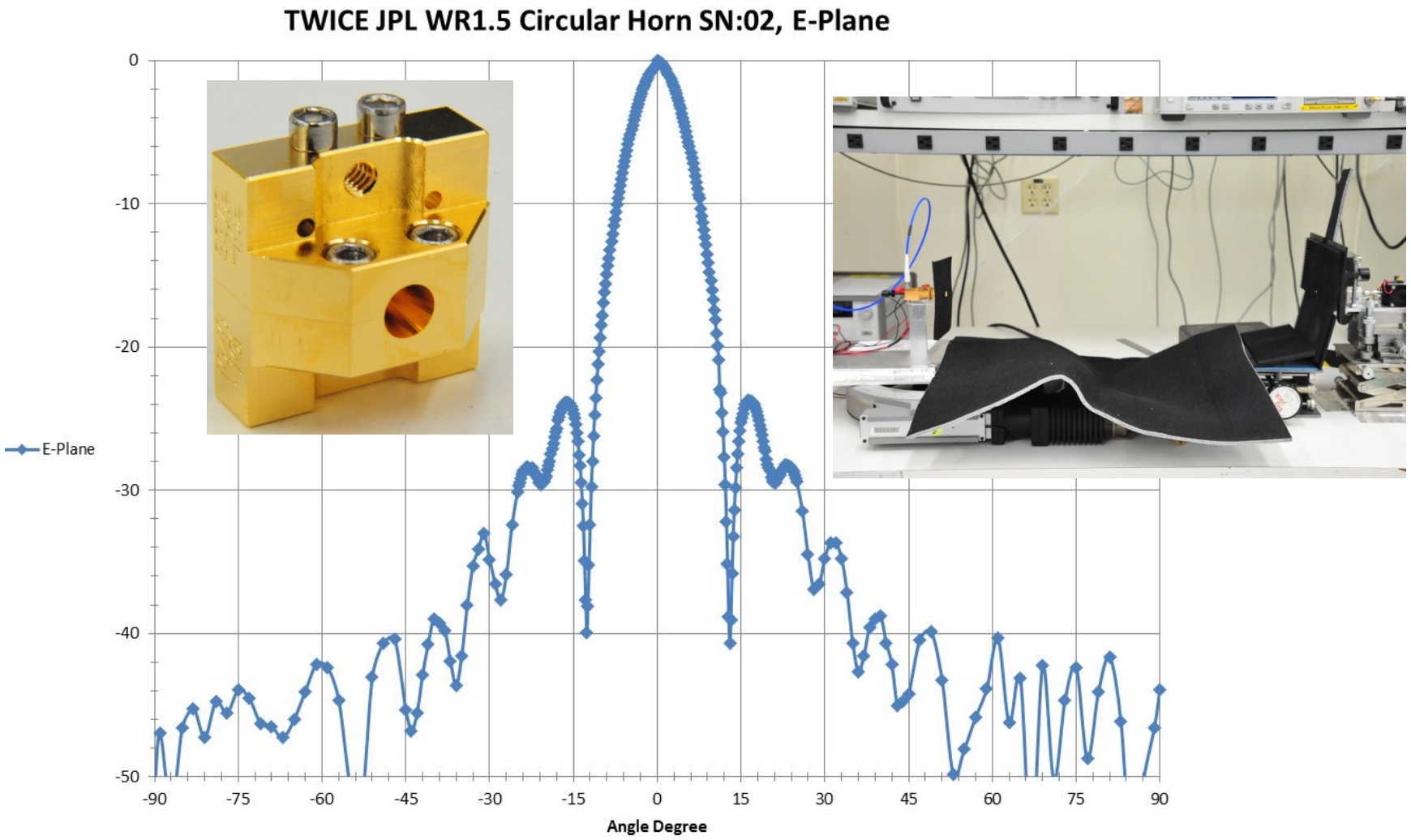
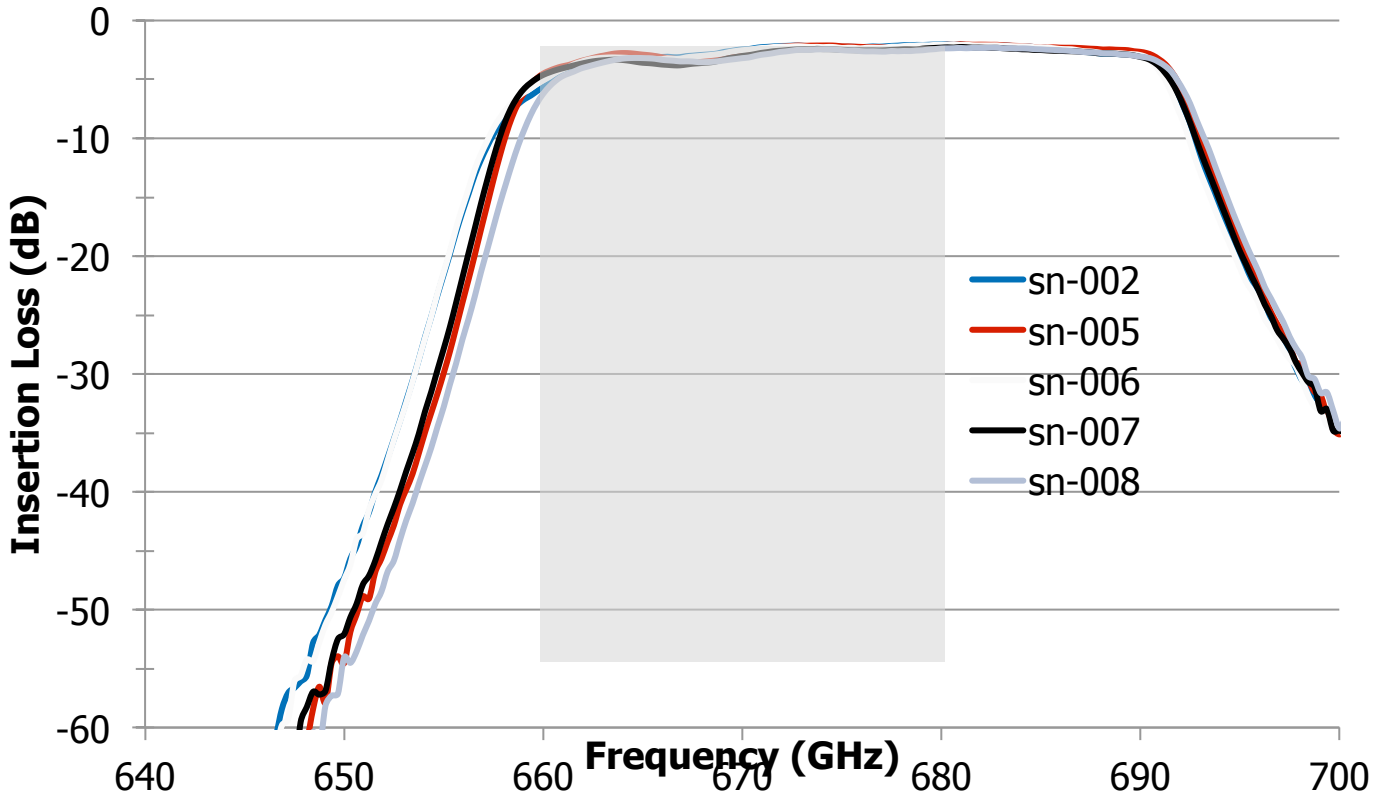
670 GHz Radiation Pattern

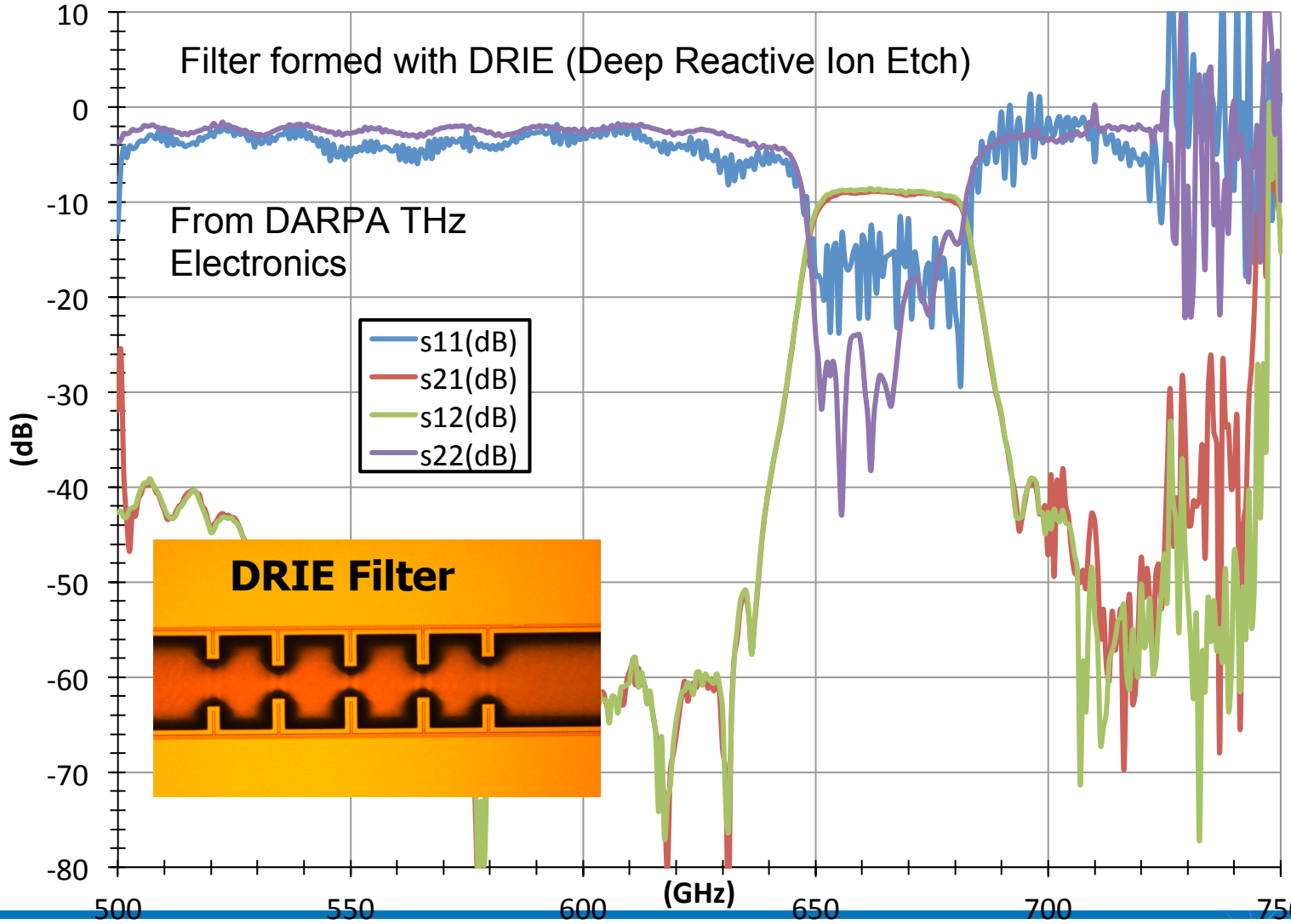


Bandpass filter

- CNC Machined Bandpass filter

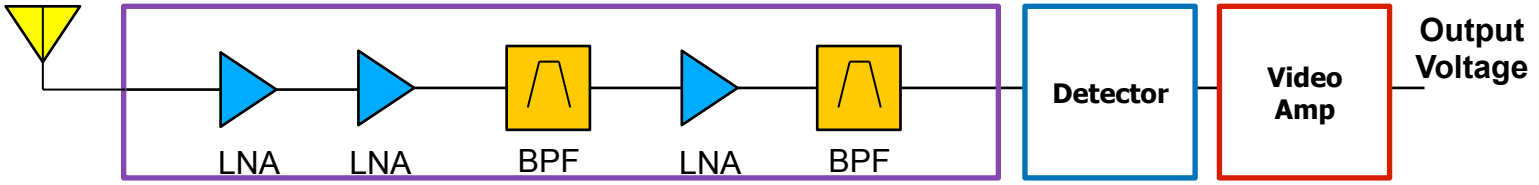


Other Filter Fabrication Techniques



670 GHz “Breadboard” Receiver Noise Temperature

660-680 GHz Receiver Block Diagram:

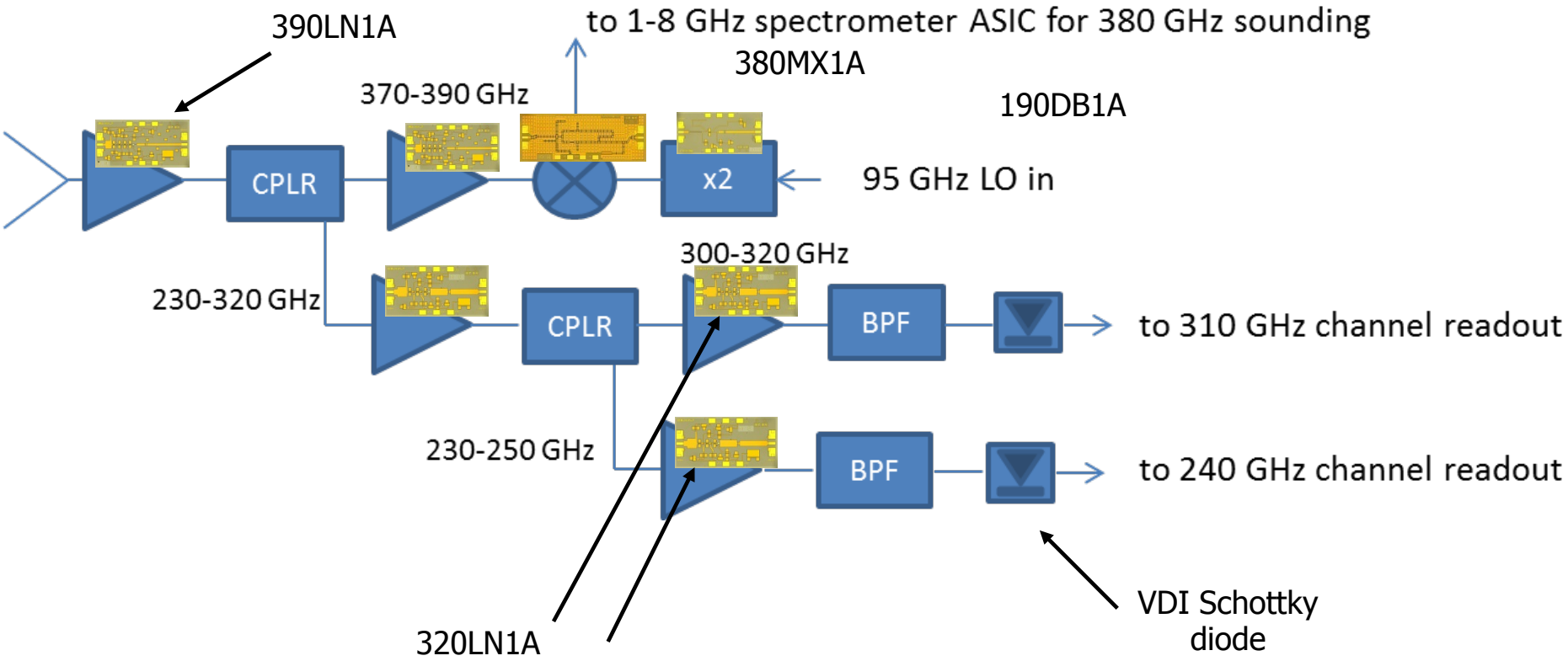


Room Temperature 670 GHz Receiver Noise Temperature Characterization

Cold Load Temperature [K]	Hot Load Temperature [K]	Hot Load Output Voltage [mV]	Cold Load Output Voltage [mV]	Calculated Noise Temperature [K]
178	290.65	61.05	59.19	3406.81

230-390 GHz Receiver

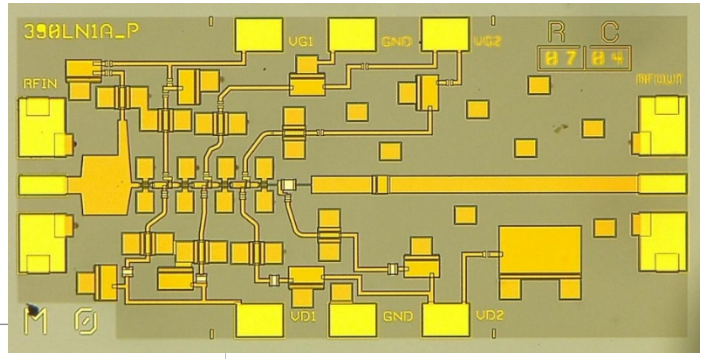
- A single feedhorn integrated in the module will cover the 240, 310 GHz direct detection bands and the 380 GHz sounder band
- On-wafer test results for a full chip set

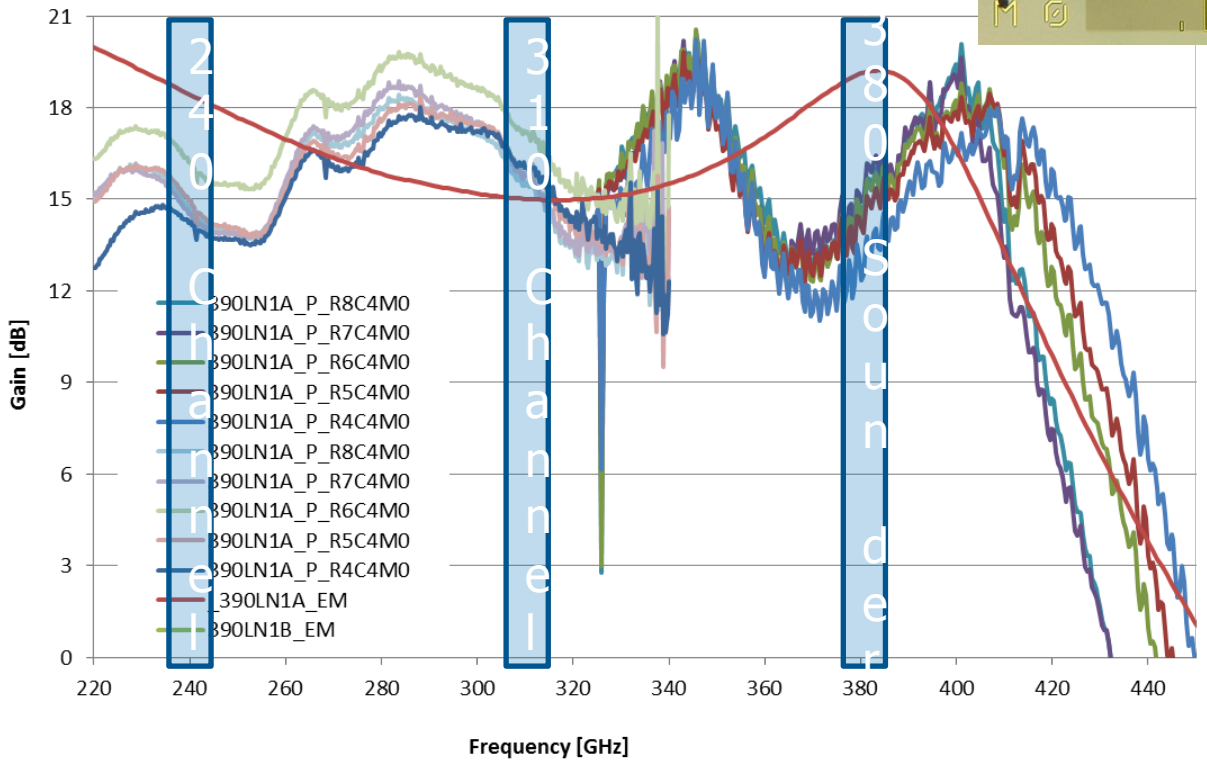


230-390 GHz Receiver

- 15-dB gain measured on-wafer
- Matches simulations
- Additional ripple from on-wafer calibration/ noise in measurement

Photograph of 230-390 GHz MMIC

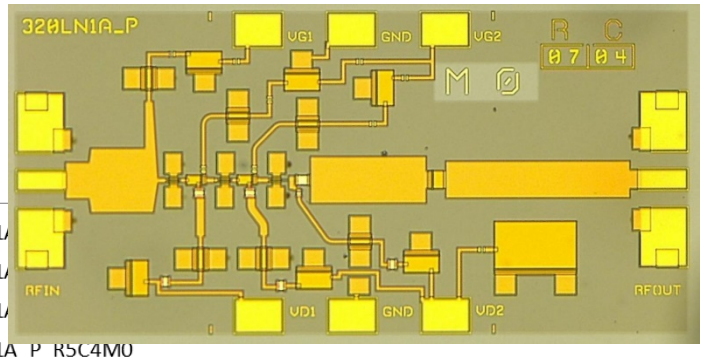


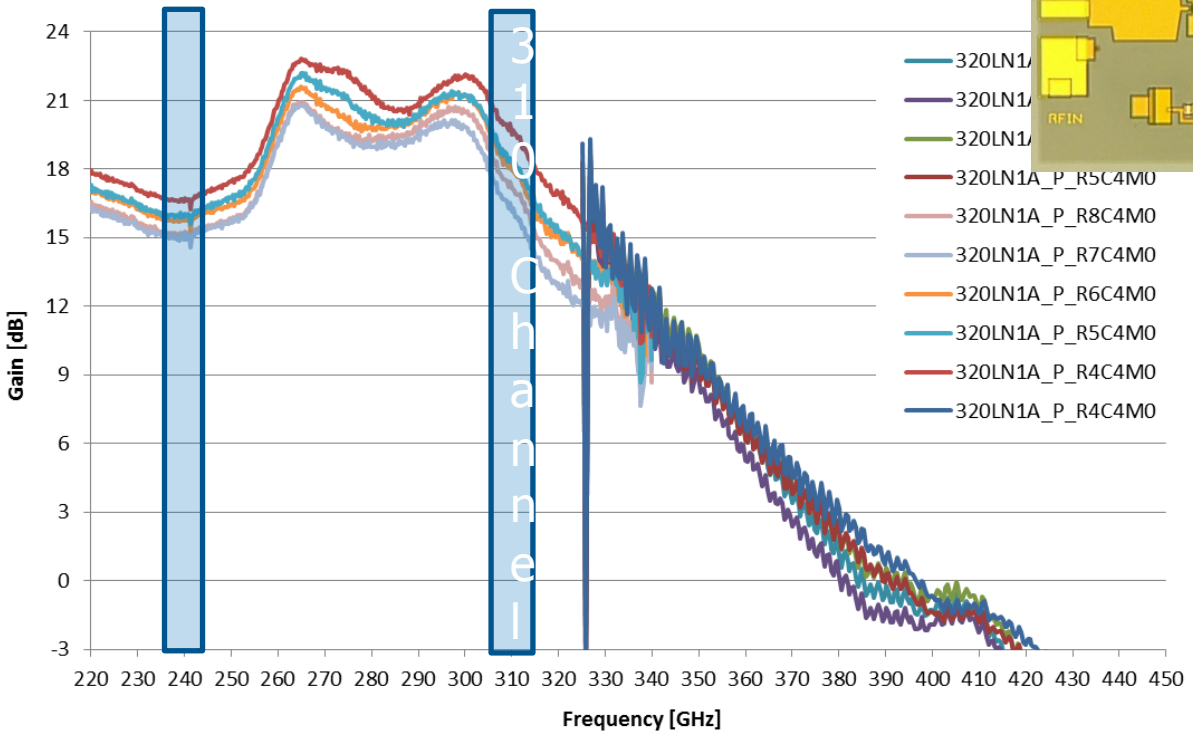


230-390 GHz Receiver

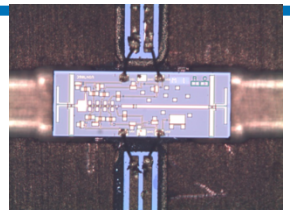
- 18-dB gain measured on-wafer
- Matches simulations

Photograph of 230-320 GHz MMIC

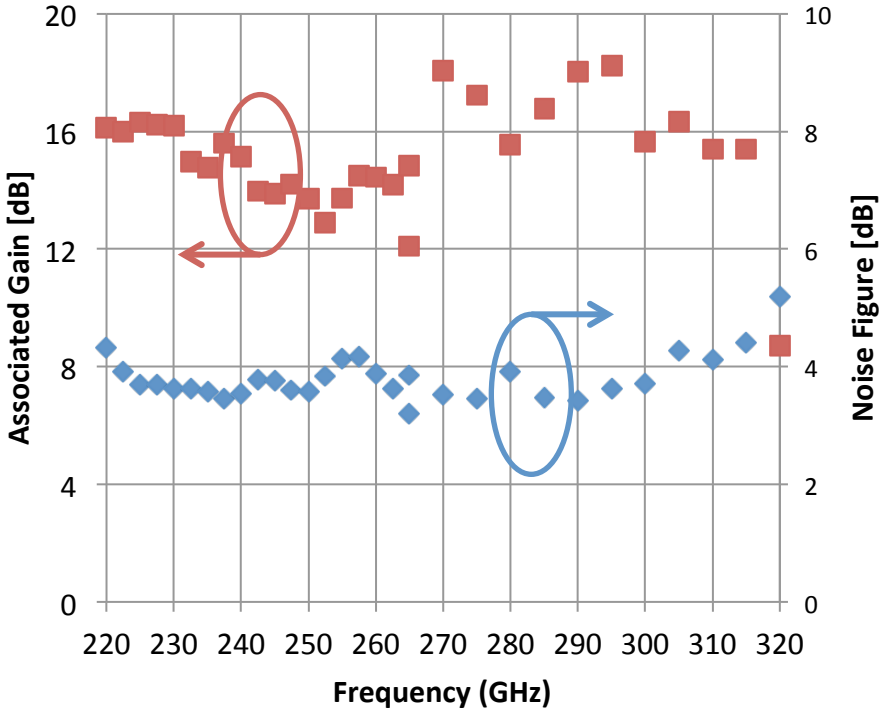




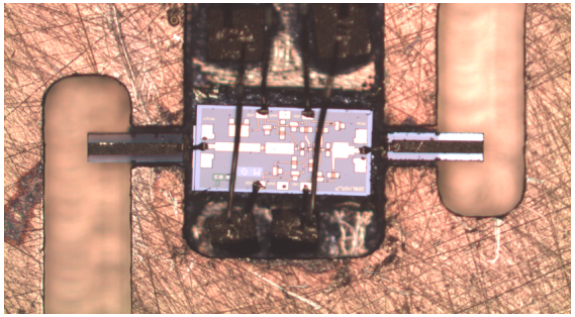
230-390 GHz Receiver: Packaging Approach

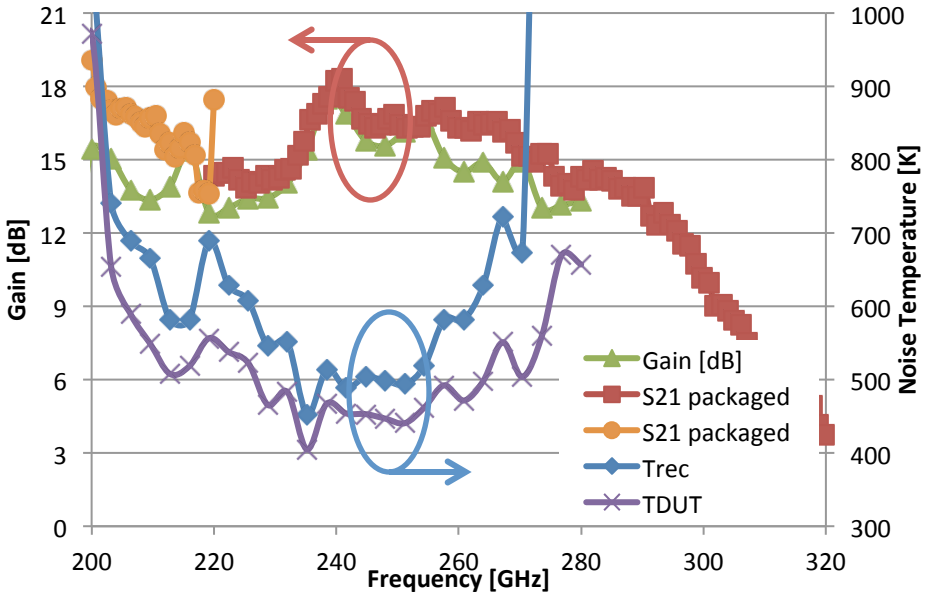


on chip transitions



wirebonded microstrip to WG transitions





3.8 dB Measured Noise Figure (NT 400K) @ 240 GHz

4.3 dB Measured Noise Figure (NT 500K) @ 310 GHz

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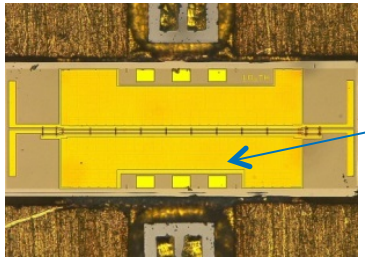
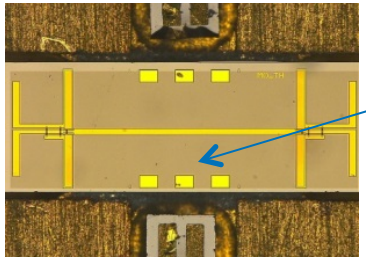
230-390 GHz Receiver

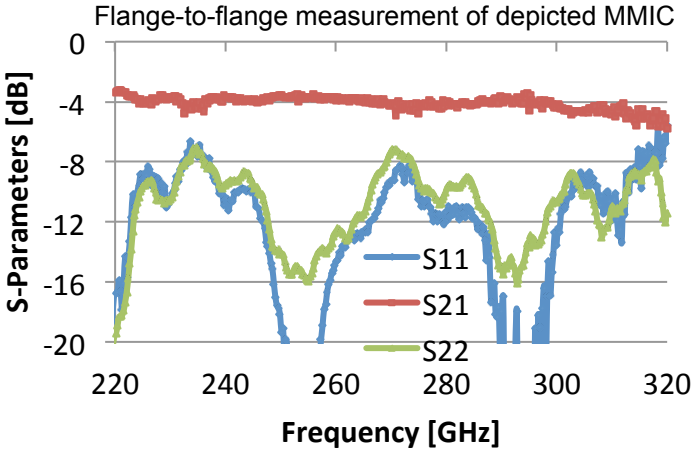
230-320 GHz Transition Loss Estimation

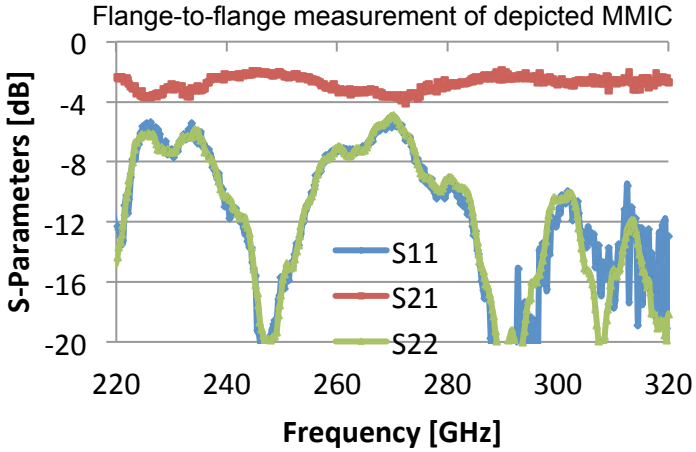


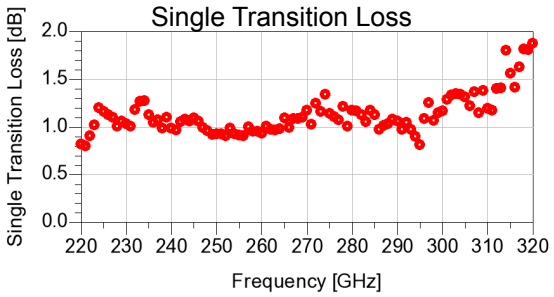
596 µm CPW Line
(Loss ~ 1.8 dB)

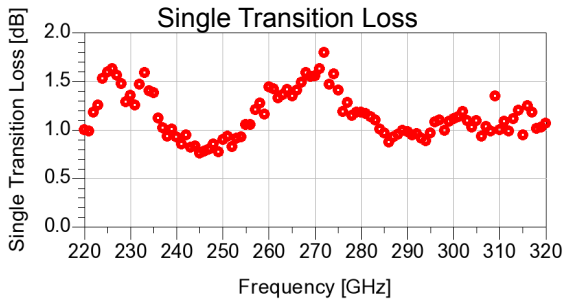


596 µm MS Line
(Loss ~ 0.5 dB)









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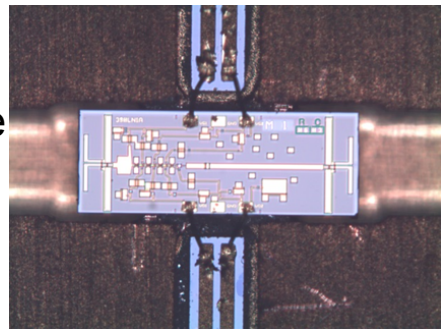
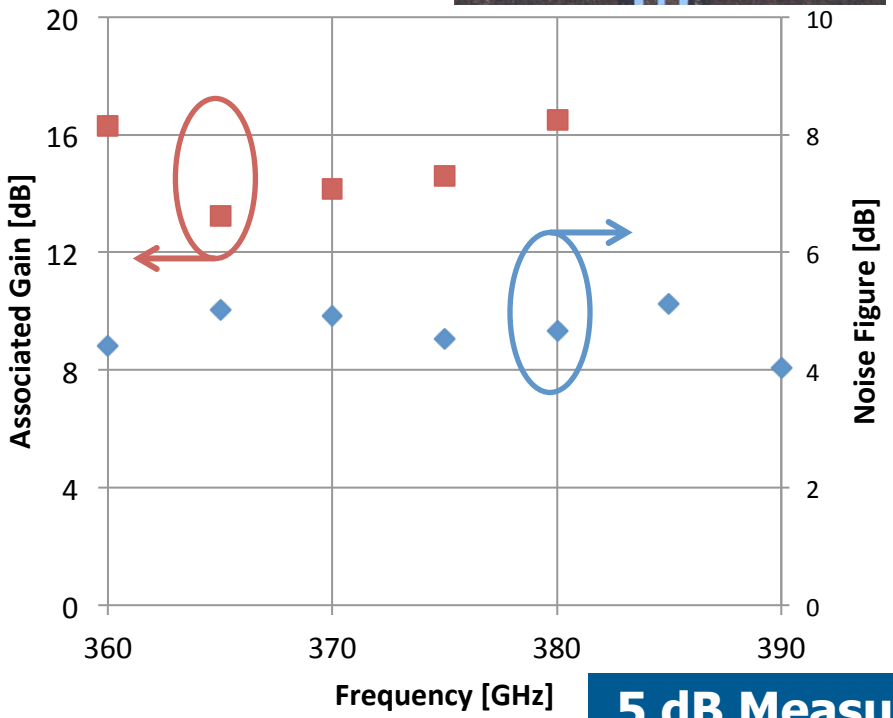
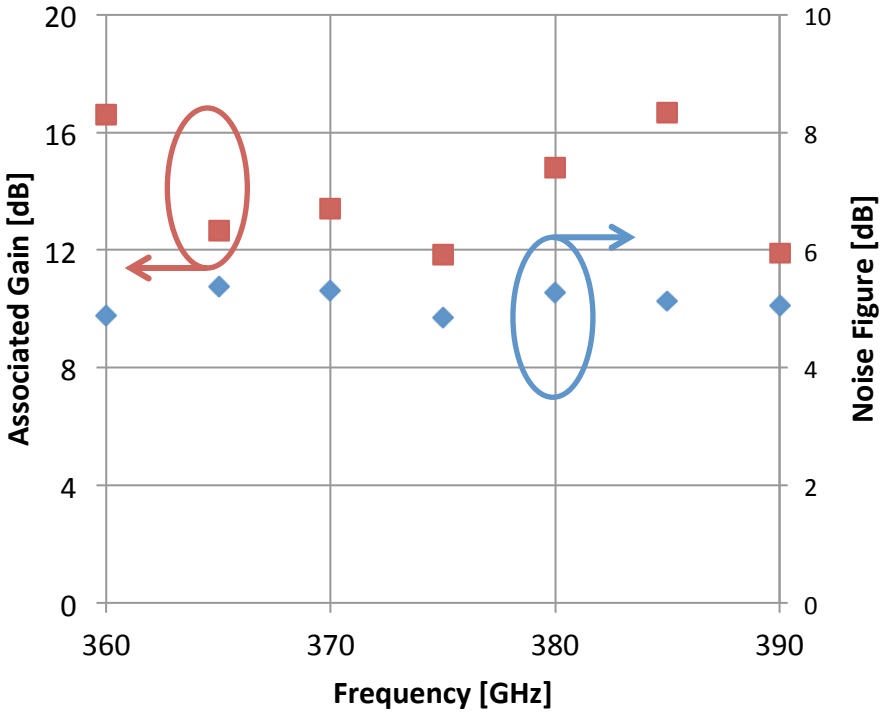
230-390 GHz Receiver

230–390 GHz LNA
With Integrated
narrowband waveguide
transitions





360–390 GHz LNA
Integrated waveguide
transitions



5 dB Measured Noise Figure (NT=650K) @ 380 GHz

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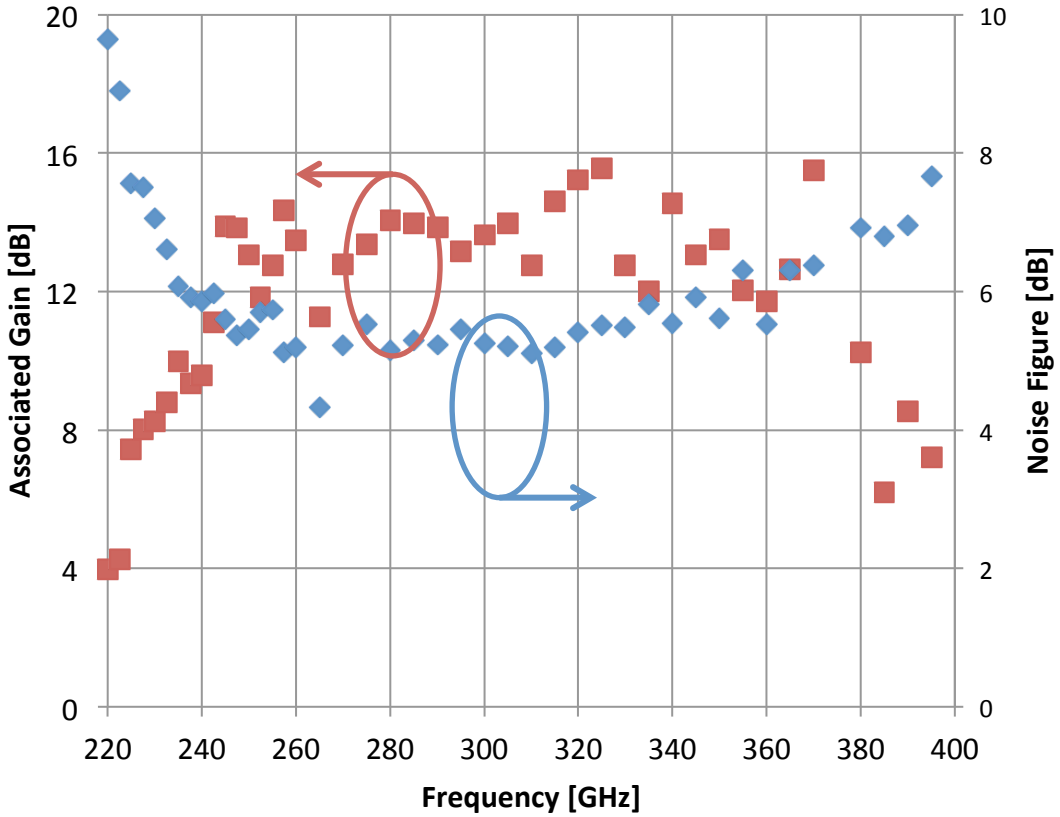
230-390 GHz Receiver

Currently:
230-390 GHz LNA with on-chip transition does not provide a significant advantage in receiver noise temperature compared to a diplexer followed by narrower band amplifiers



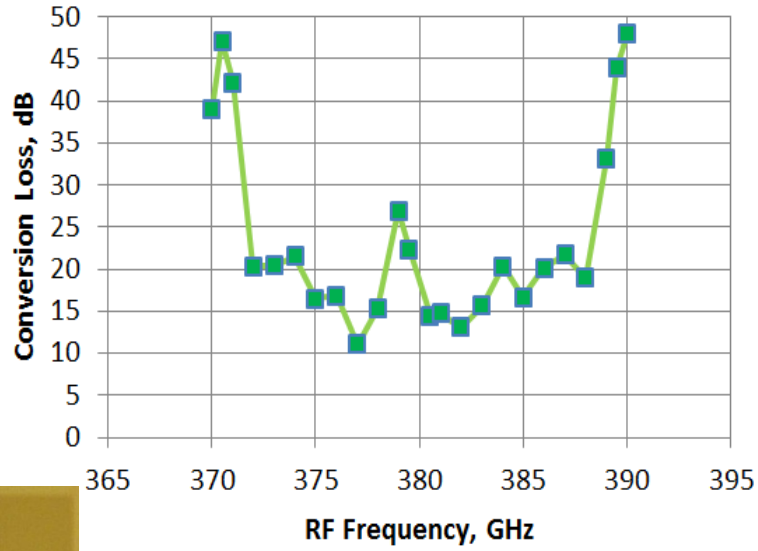
6 dB Measured Noise Figure (NT=900K) @ 240 GHz

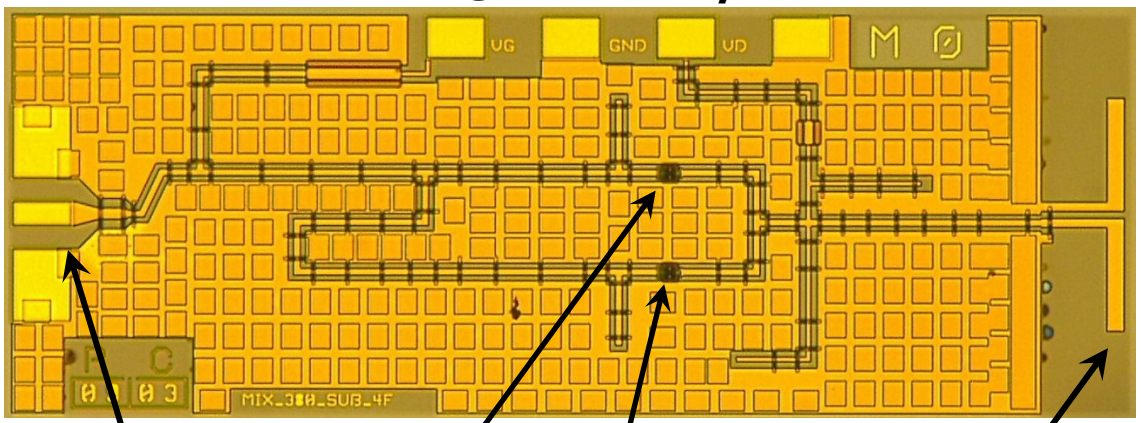
5.5 dB Measured Noise Figure (NT=650K) @ 310 GHz

7 dB Measured Noise Figure (NT=1200K) @ 380 GHz

230-390 GHz Receiver

380 GHz second harmonic mixer
- Broadband, 370 to 390 GHz
- Conversion loss ~ 15 dB for 6 dBm LO power
- Balanced design uses 2 transistors pumped 180° out of phase
- Chip size 375 X 1000 μ m^2

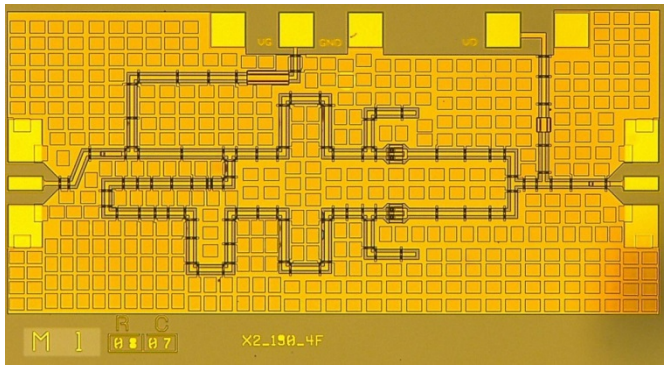


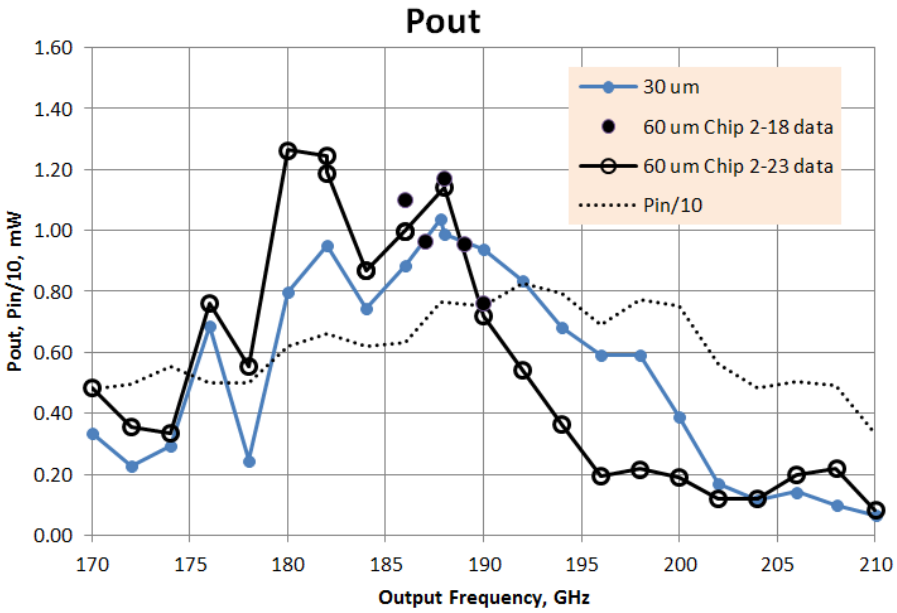


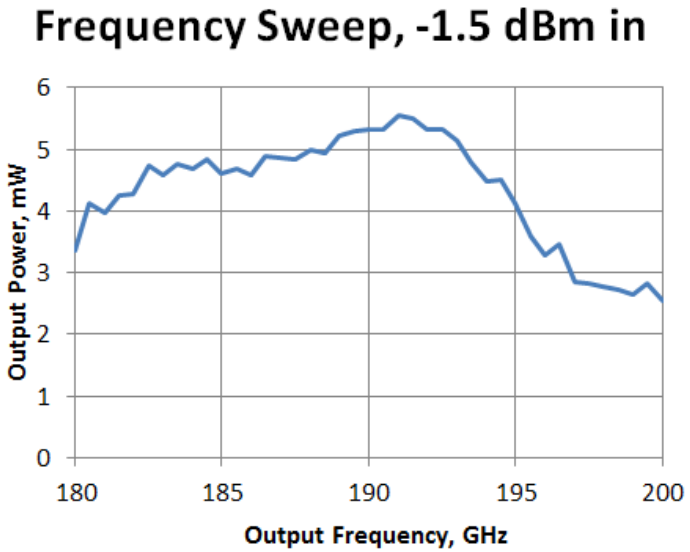
230-390 GHz Receiver

190 GHz frequency multipliers

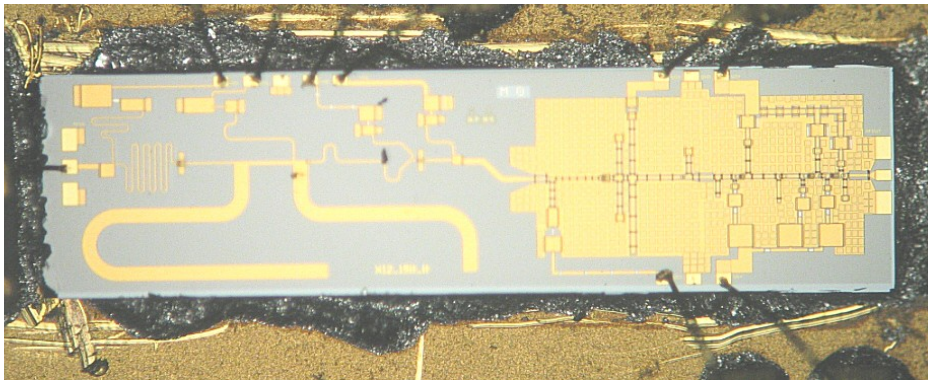
x2







x12



Conclusion

- Significant progress has been made in the new TWICE receivers
  - "Breadboard" demonstration of 670 GHz direct detect receiver complete
  - 230-390 GHz MMIC components demonstrated
- Currently completing 2nd MMIC design iteration
- Integrated Receiver housing on order
- Prototype will be assembled and tested by August


THE VALUE OF PERFORMANCE.
NORTHROP GRUMMAN