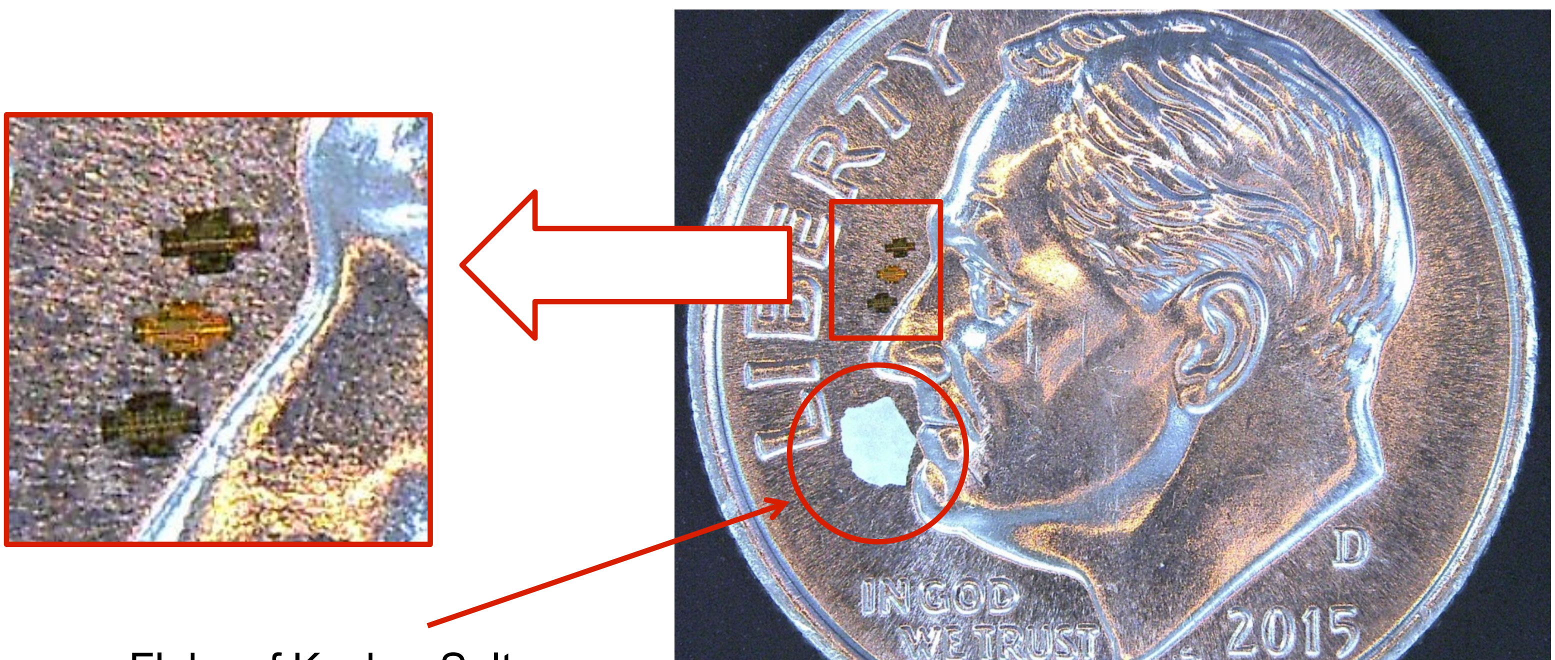
THz InP HEMT Technology for Sub-Millimeter Wave Atmospheric Sensing

6-23-2015

Bill Deal

Motivation

- Over the last 10 years, DARPA investment has pushed MMIC technology to ~1,000 GHz
- This new capability will directly benefit NASA Earth Science Missions

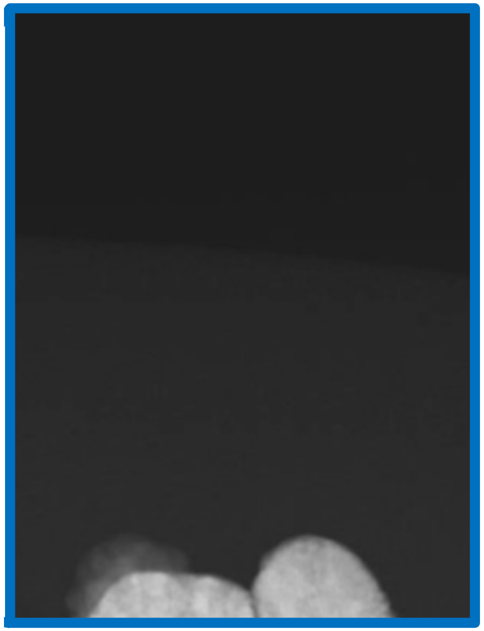


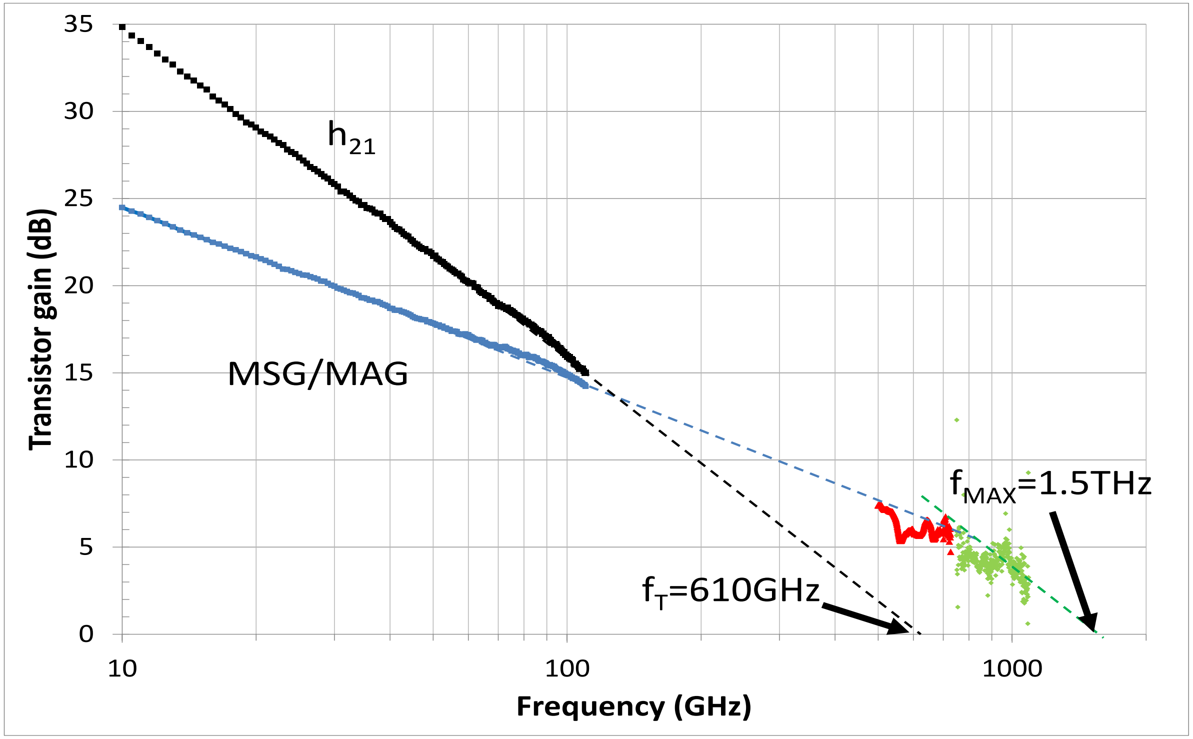
Flake of Kosher Salt

Motivation

Scaling enables significantly enhanced performance

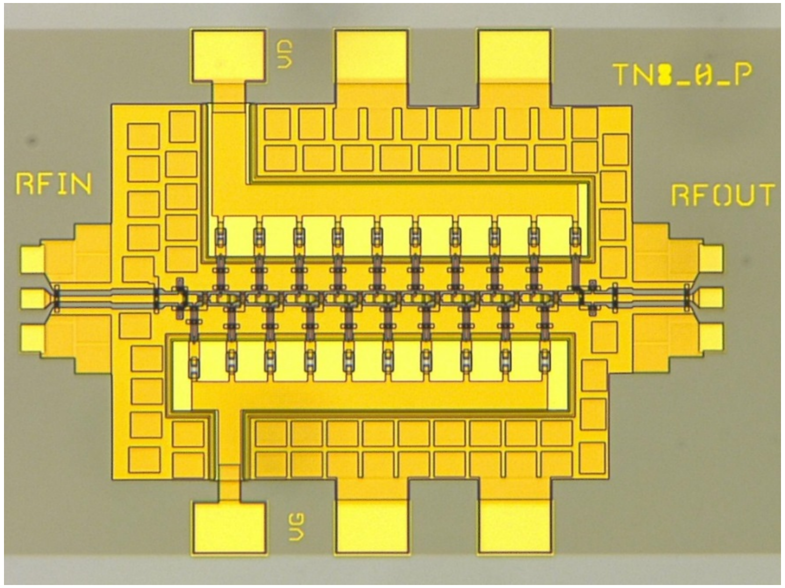
- 25 nm gatelength
- f_{max}: 1.5 THz
- f_T: 0.61 THz

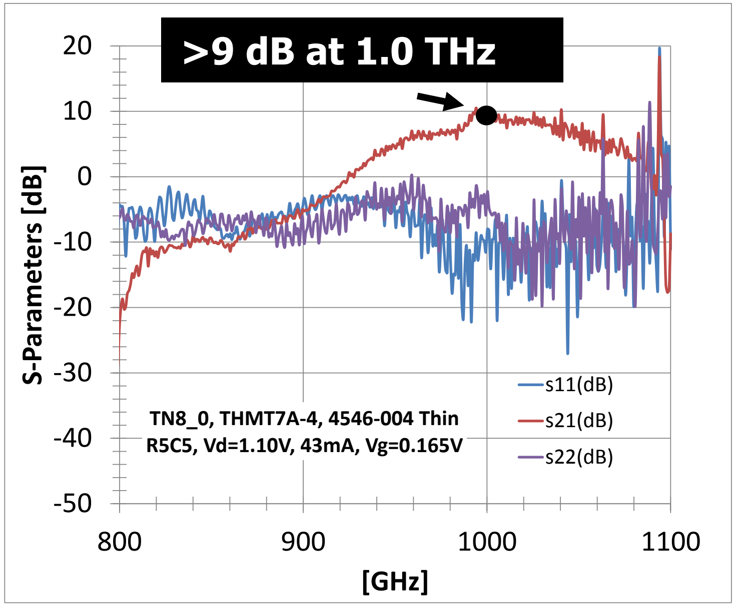


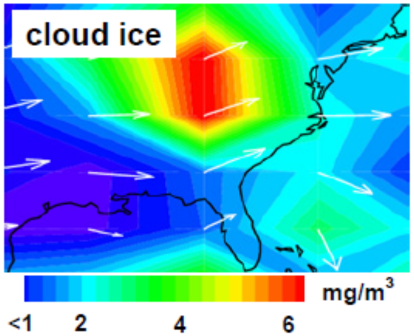


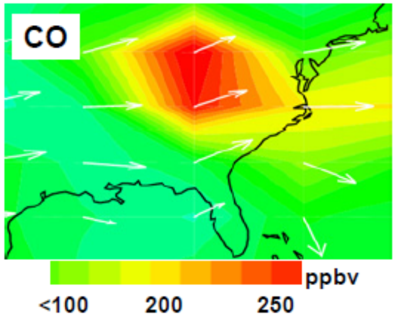
Motivation

- Amplifier Gain Demonstrated to 1 THz (1,000 GHz)
- Enables new generation of instruments for new science missions









Outline

- Motivation
- Outline
- Advantages of transistor based receivers at Sub-Millimeter Wave frequencies
- TMIC and “THz” InP HEMT Overview
- Technology Status
- Conclusion

Advantages of InP HEMT for Sub-Millimeter Wave Receivers

- Last decade has seen significant innovations in semiconductor technology

- SMMW Receivers can be implemented in GaAs Schottky, InP HBT and InP HEMT Technologies *at temperatures close to room temperature*

	GaAs Schottky	"THz" InP HBT	"THz" InP HEMT
Sensitivity	Good	Poor	Good Better if cooled!
DC Power	Poor	Good	Good
Size/Integration	Poor	Good	Good
Production Scalability	Moderate	Good	Good
Maturity	High	~TRL4-TRL5	~TRL4-TRL5

THz Monolithic Integrated Circuit (TMIC)

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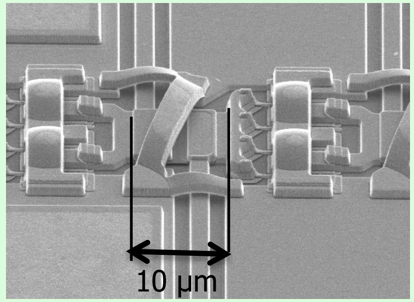
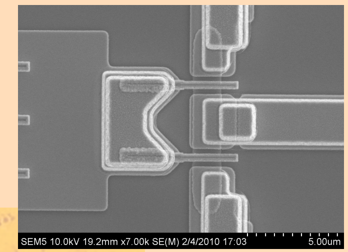
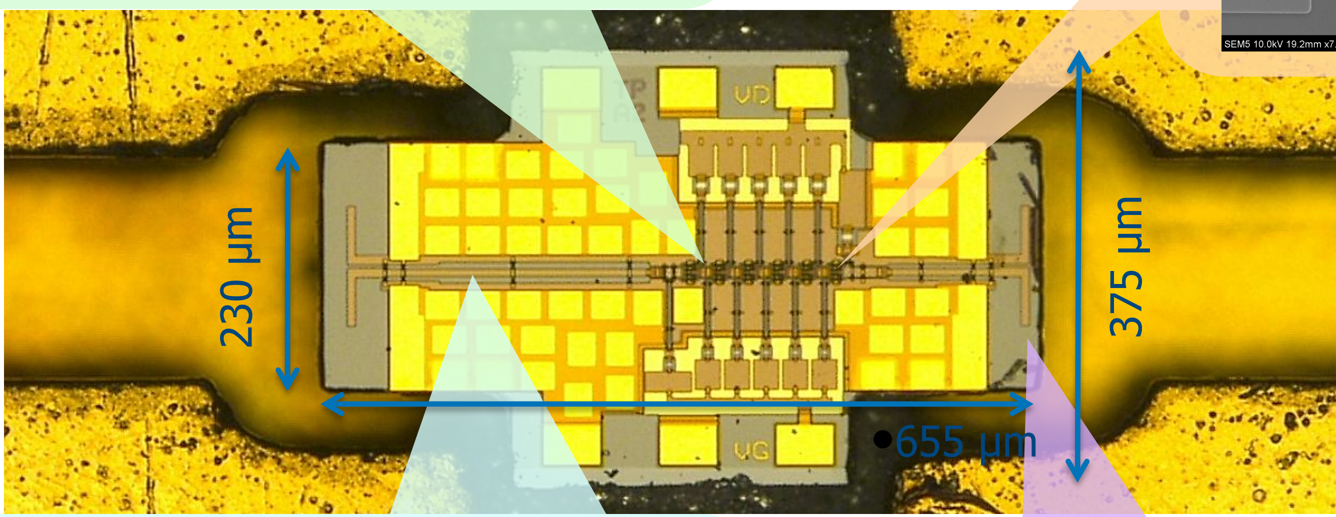
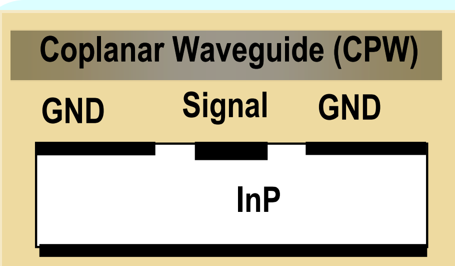
Passive TMIC Technology:
High compaction.
HEMT to HEMT spacing of 10 µm.

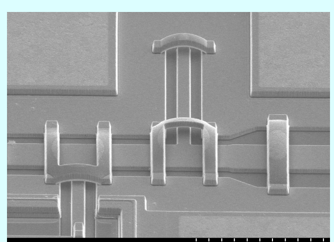


Transistor Technology:
25 nm InP HEMT

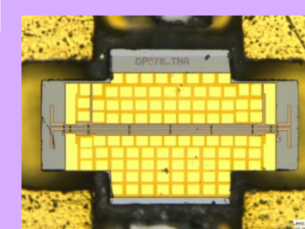








Integration Challenges:
Need wide chip for circuit, but narrow for transition
Cross-shaped chip



InP HEMT Technology

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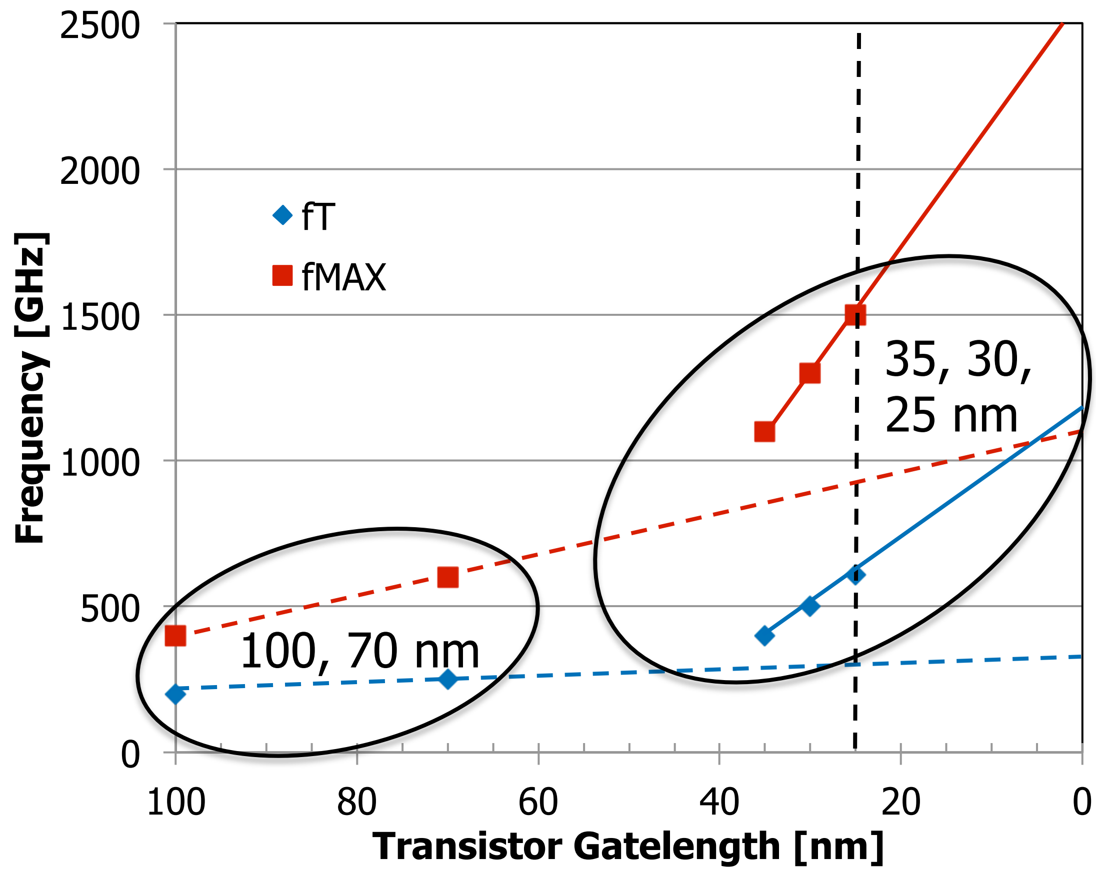
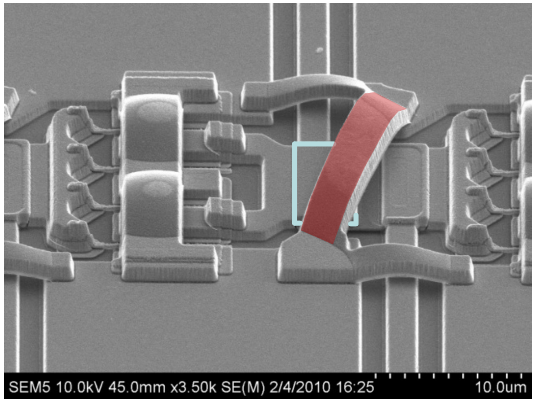
- Transistor speed improvements come from:
  - Gate scaling
  - Channel design
  - Device design
- Significant benefits come from channel and device design
- **Device continues to scale nicely**
- Upward f_{MAX} limit not yet reached.

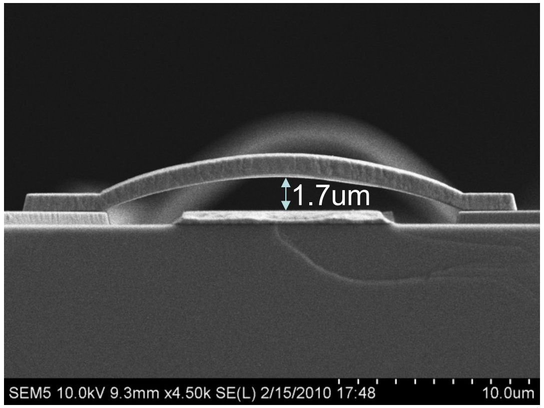


TMIC Frontside and Backside Scaling



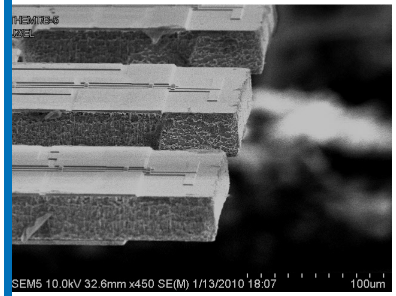
Frontside:

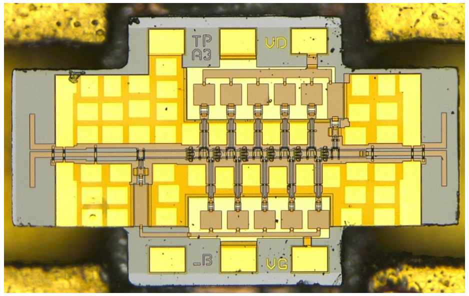
- TMICs realized in Grounded CoPlanar Waveguide
- Gaps/Widths to 1.5 um
- TFR20 and TFR100
- 100 pF/mm MIM capacitors
- "Compacted" transistor layouts reduce parasitics

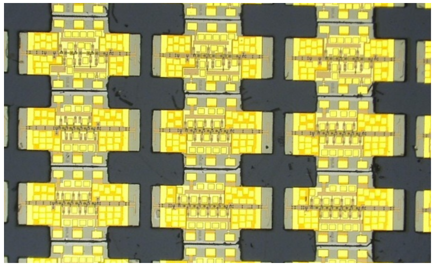


Backside:

- 18 um substrate thickness for 850 GHz circuits
- Small diameter substrate via with reduced pad
- RIE etch for substrate removal in areas of electromagnetic transition and partial singulation







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LNA Overview

- NGAS has developed low noise amplifiers operating to 850 GHz
- 1.0 THz LNA in development
- Limited data with new baseline (25 nm)
- PA’s have also been developed, not described in this presentation

Center Frequency	Technology	Minimum Demonstrated Noise Figure
183 GHz	35 nm IACC	4.2 dB
235 GHz	35 nm IACC	7.25 for receiver with window
180-280	30 nm IACC	5.5
340 GHz	30 nm IACC	7.5 dB
425 GHz	30 nm IACC	7.5 dB
670 GHz	• 30 nm IACC • 25 nm IACC	• 11.7 dB • 11 dB (in development)
850 GHz	25 nm IACC	• 11.5 dB
1030 GHz	20 nm IACC	TBD

183 GHz LNA

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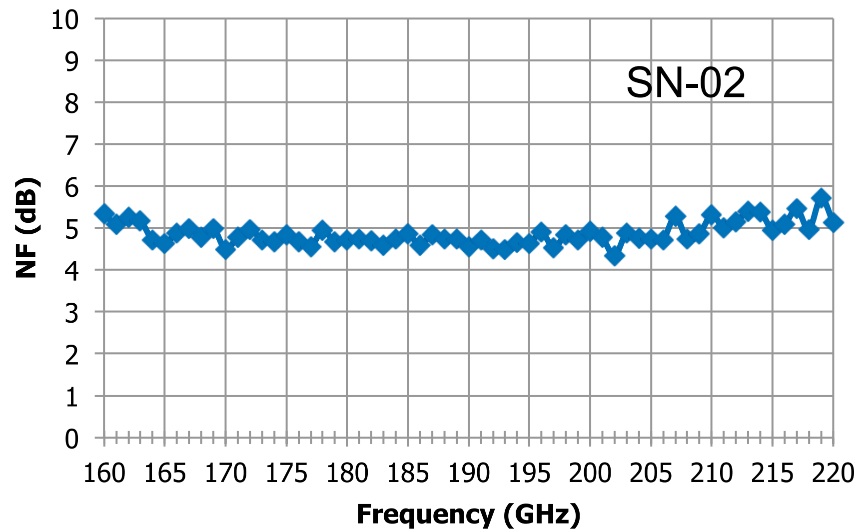
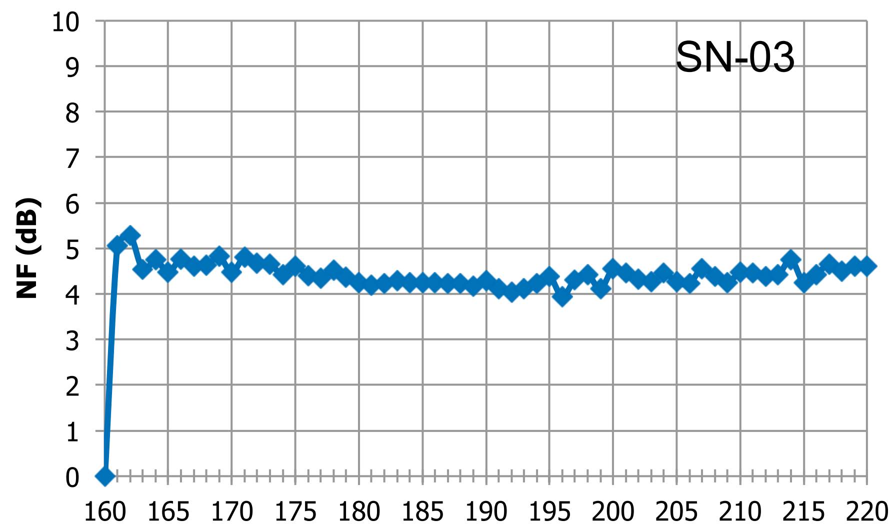
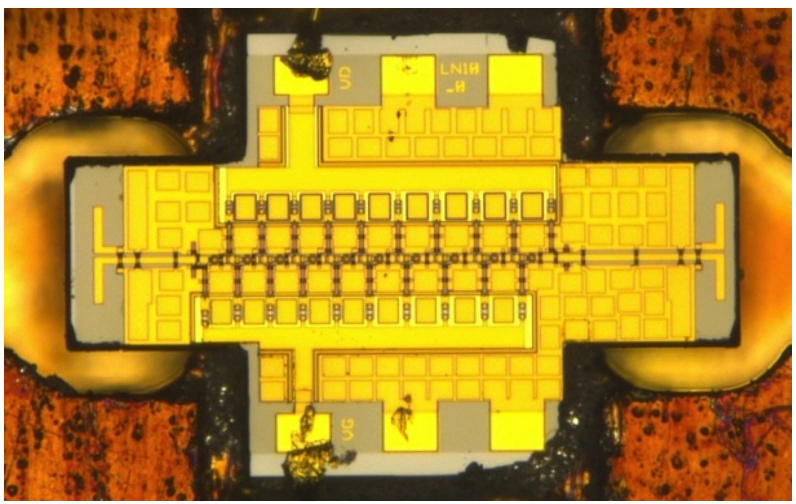
- **Packaged** Noise Figure Evaluation of 183 GHz LNA
- 35 nm process
- Bias Conditions: 0.9 V, 27 mA
- No results for 25 nm process (yet)

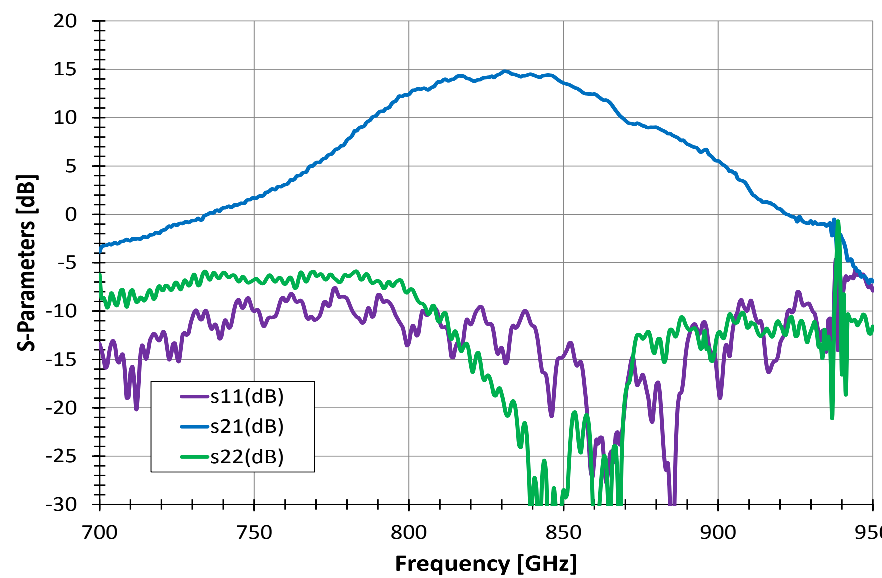




Packaged Results

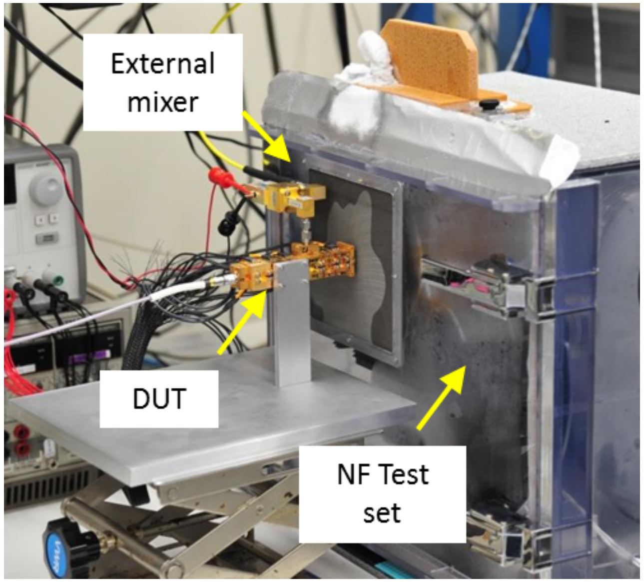
- 15 dB peak gain at 835 GHz
- 13 dB gain at 850 GHz

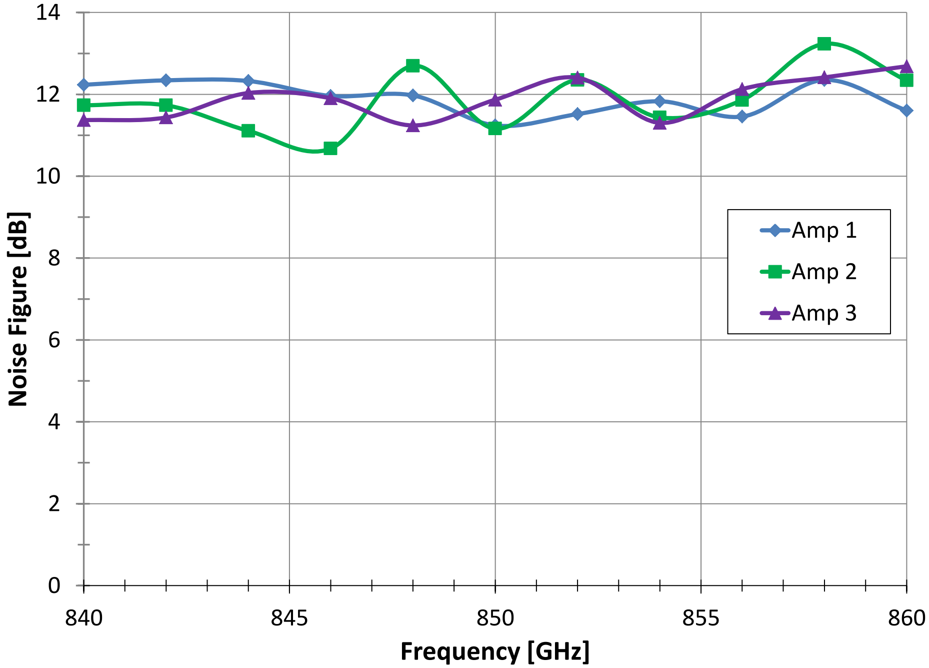




850 GHz Noise Figure

- Measured noise figure 11-12 dB
- Measured using hot/cold measurement setup





Progress towards 1 THz

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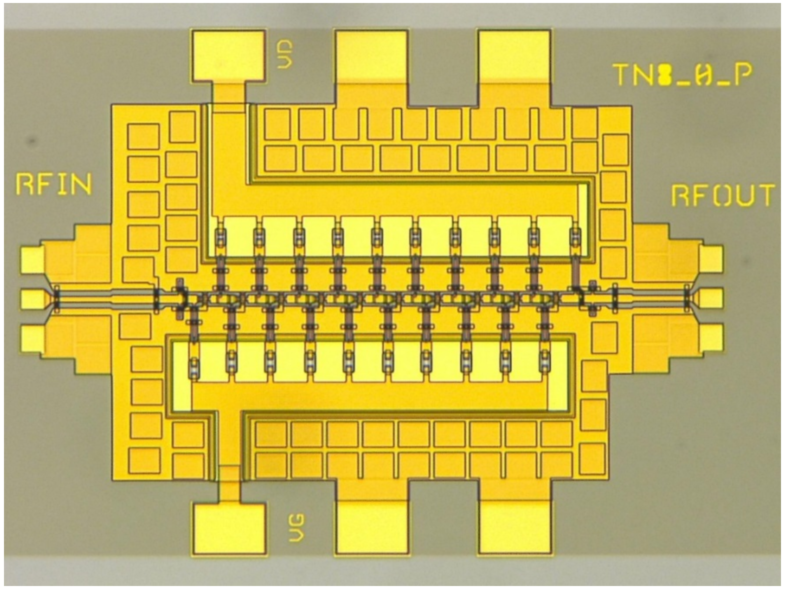
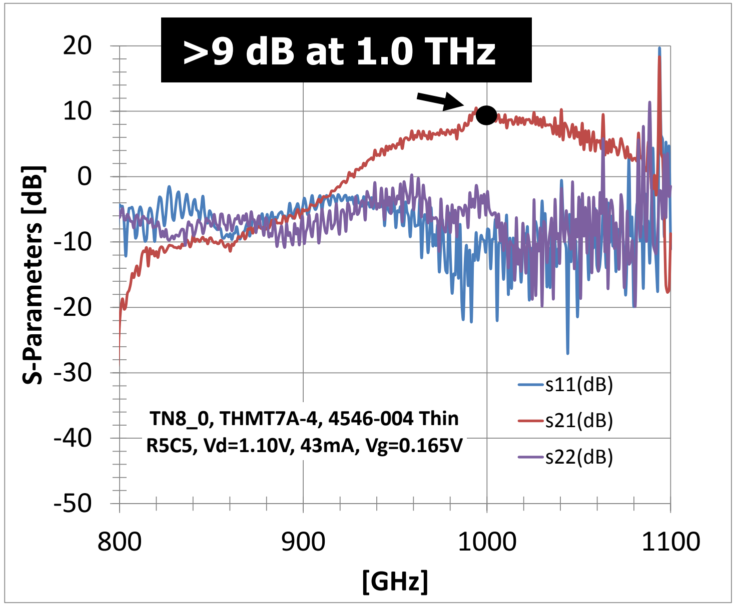
First demonstrated amplifier gain at 1 THz (1,000 GHz)





Receiver Overview

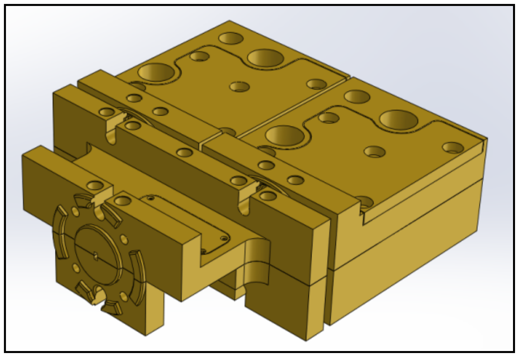
- Northrop Grumman was first organization to build transistor based Sub-Millimeter Wave receivers
- Initial receiver work has been for technology demonstration purposes
- Recent deliveries are to DoD contractors for field demonstrations
- New work is geared toward atmospheric sensing (TWICE and CAMLS)

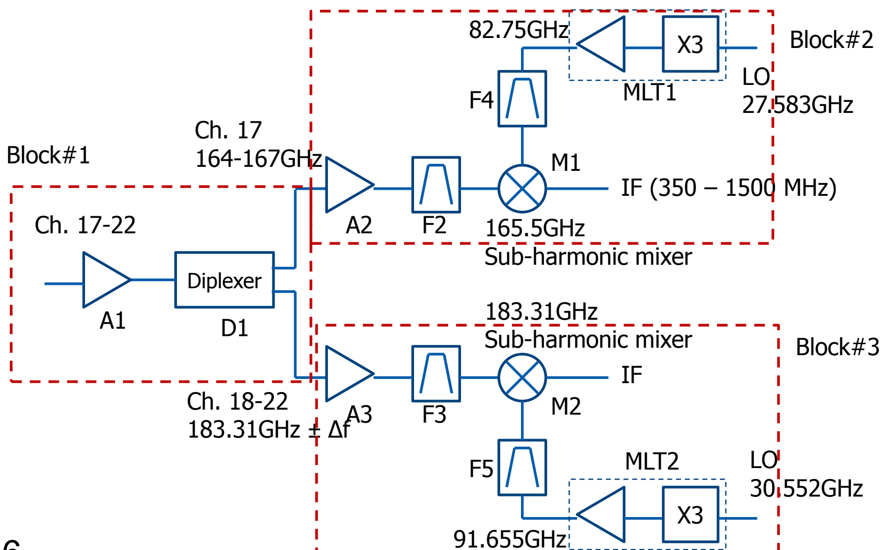
Center Frequency	Technology	Comment	Status
183 GHz	35 nm IACC	LNA front-end, diplexed dual mixers for bandwidth coverage	In test
235 GHz	35 nm IACC	ViSAR	21 Receivers delivered
670 GHz	• 30 nm IACC • 25 nm IACC	• First Demonstrated in 2010, Comm-Link • New development changes frequency plan and adds filtering	• Completed • Receiver update in progress
850 GHz	25 nm IACC	Comm-Link Demo	Demonstrated at DARPA MTO Exhibit
650 GHz	25 nm IACC	Dual-Channel Direct Detect, “TWICE”	In Development

Receiver Overview

183 GHz Receiver

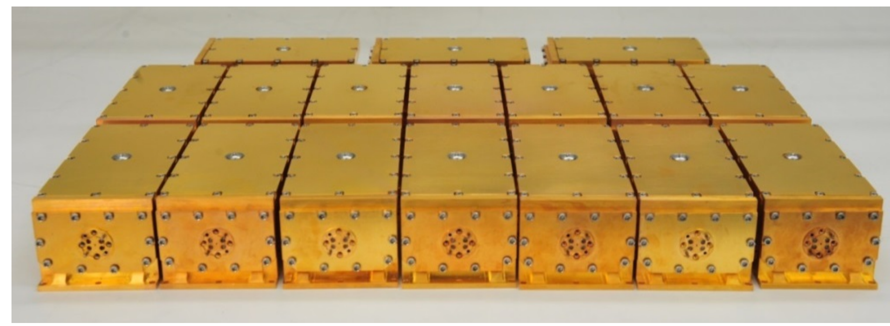
- IR&D
- Noise figure and Associated gain measured
- 1/f noise measurements pending

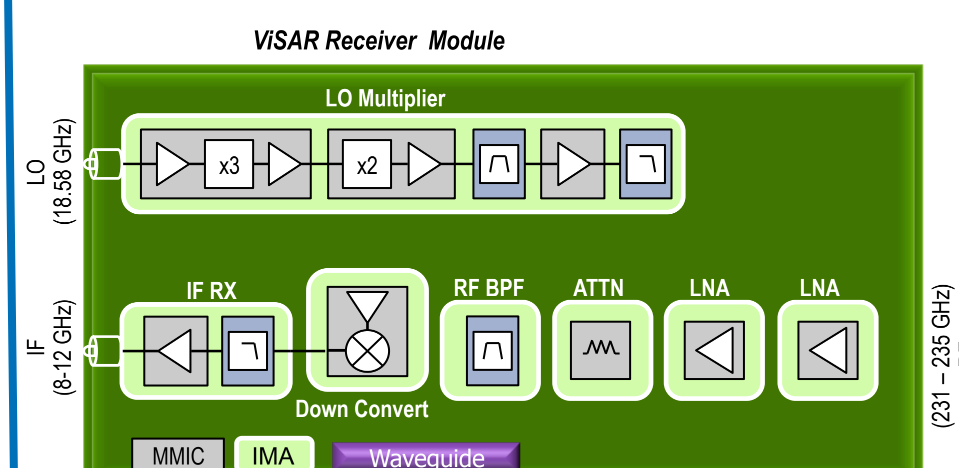




235 GHz Receiver

- ViSAR (DARPA STO)
- Airborne stand-off imaging demo
- Environmentally sealed
- 21 delivered

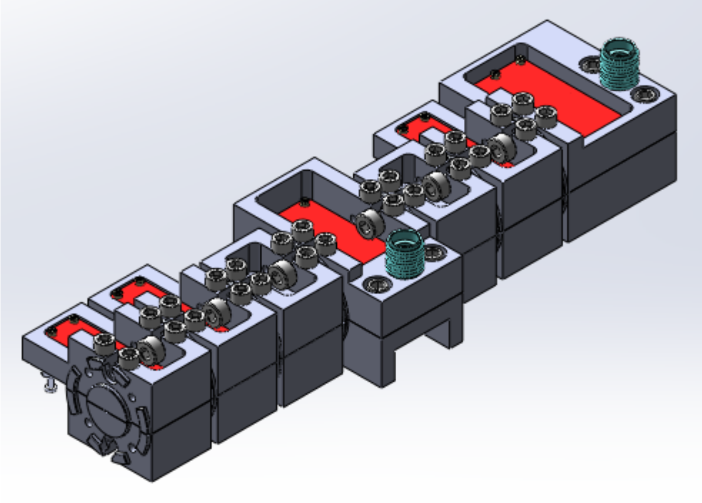


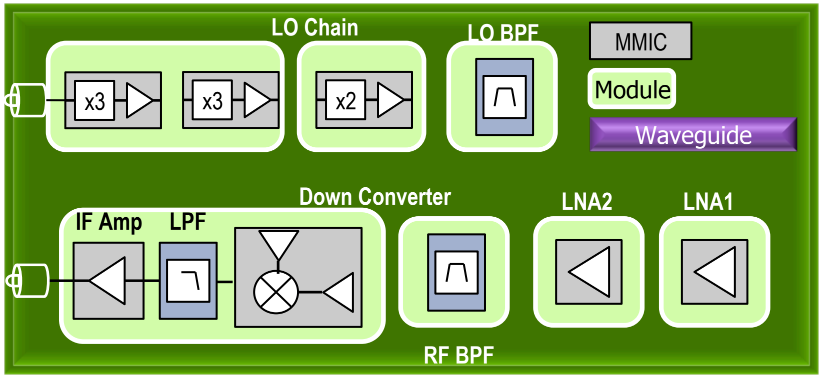


Receiver Overview

670 GHz Receiver (in development)

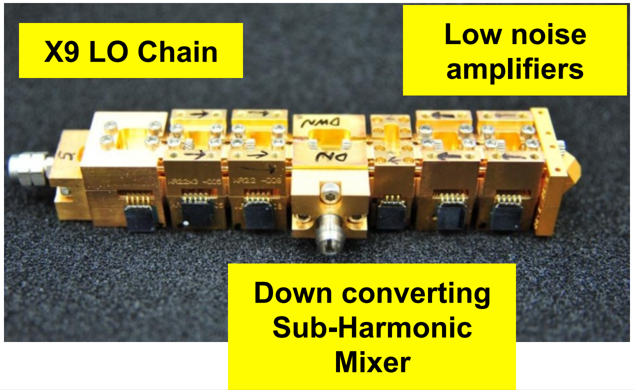
- First prototypes completed in 2010
- Current Effort (THz Ph III) improves performance

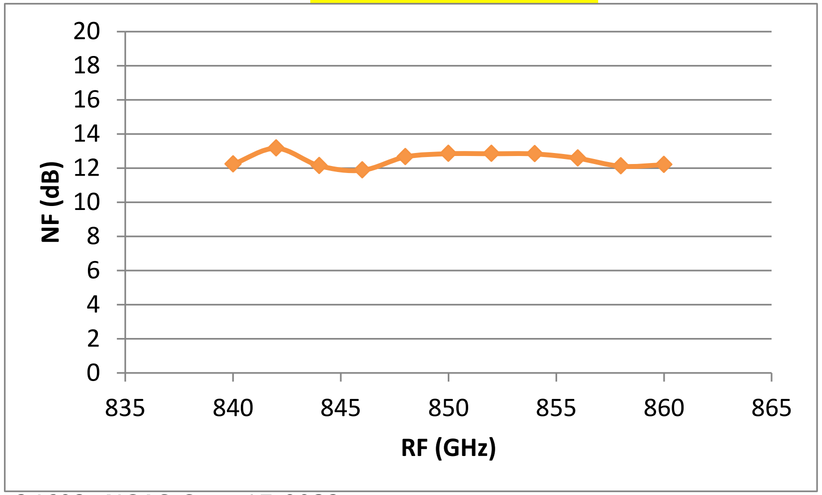




850 GHz Receiver (Completed)

- THz Electronics Phase III
- Data-link demonstration at DARPA MTO Exhibit





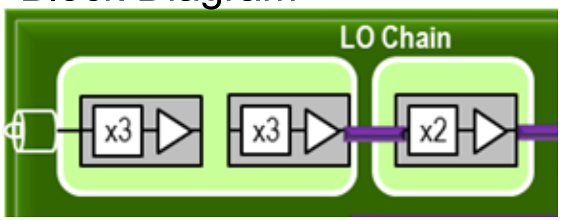
LO Chain Overview Overview

- Amplifier based LO chains show superior DC efficiency for sub-millimeter wave power generation compared to diode based chains
- *May* show improved reliability compared to diode based chains sub-millimeter wave LO chains due to lower millimeter wave mixer drive. *May be useful for radio-astronomy*

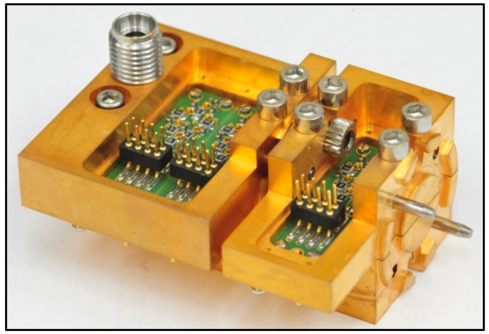
Center Frequency	Technology	Topology
111 GHz	35 nm IACC	X6 single-chip multiplier
340 GHz	25 nm IACC	X18 chipset (three chips)
407 GHz	30 nm IACC	X9 with output buffers

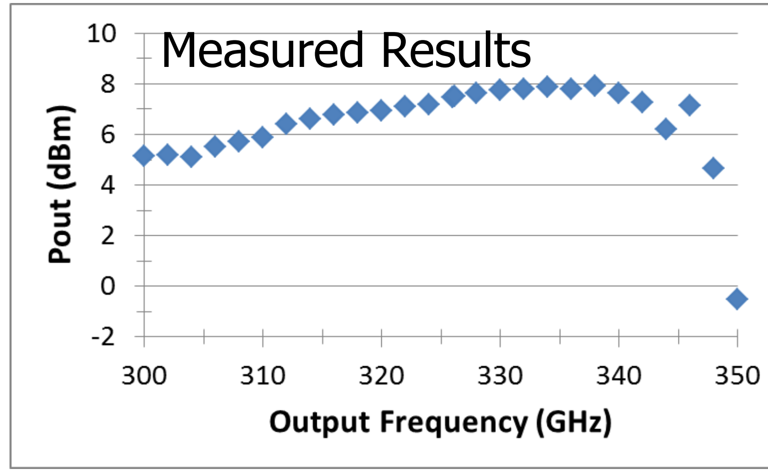
Multiplier Chain (x18)

Block Diagram

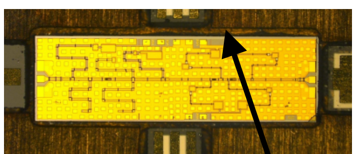


Packaged LO Chain

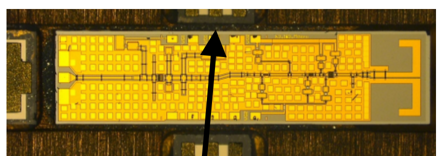




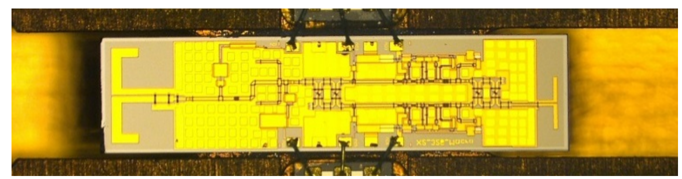
54.3 GHz output X3 with buffer amplifier



163 GHz output X3 with buffer amplifier



326 GHz output X2 with buffer amplifier

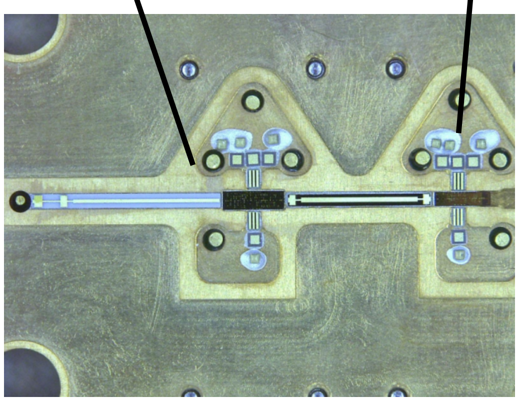


30 mW

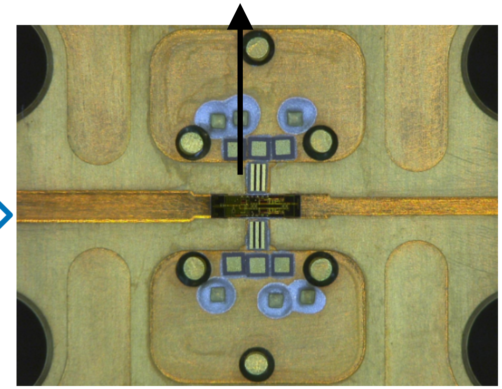
170 mW

245 mW

18.1 GHz Coaxial input



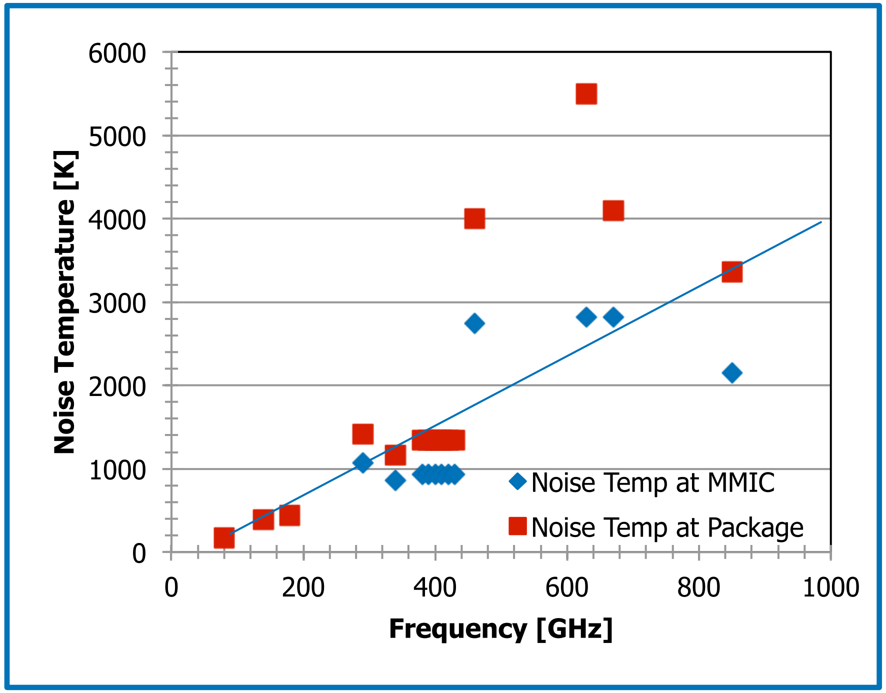
WR6.5 WG

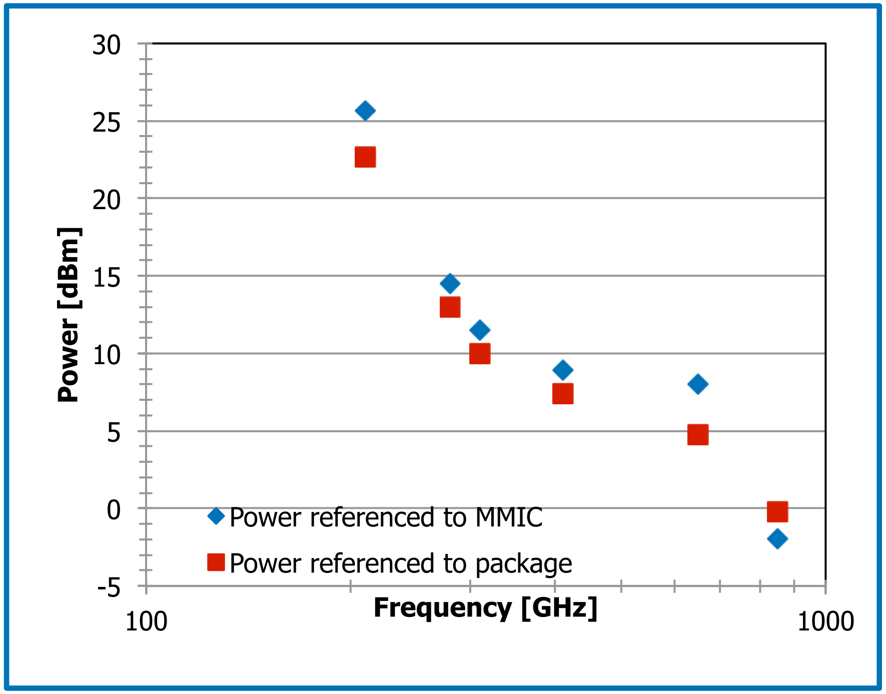


WR2.8

Noise and Power Trends

- Plots include measured NF and power from NGAS 35, 30, and 25 nm processes
- All data on packaged amplifiers at room temperature





Conclusion

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- “THz” MMIC technology will be a key enabler for new types of atmospheric science in the Sub-Millimeter Wave band

- Significant technical challenges must be solved (process maturation)

- More details about applications can be seen in other talks:
  - Tuesday, 1:30, “Submillimeter-Wave Sounders with Cryogenic Amplifier Based Receiver Front-End”, Goutam Chattopadhyay
  - Tuesday, 2:10, “Update on the Compact Adaptable Microwave Limb Sounder (CAMLS)”, Nathaniel Livesey
  - Thursday, 9:30, “Tropospheric Water and Cloud ICE (TWICE) Instrument Development for CubeSat Deployment, Steve Reising

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