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Broadband Receiver Technology for Atmospheric Humidity, Temperature and Precipitation Sounding

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Outline

- Introduction
- Millimeter Wave Instruments for Earth Remote Sensing
- Millimeter Wave Low Noise Receivers
- Conclusion

Introduction

- The atmospheric sciences and weather forecasting have received significant attention in recent years due to hurricanes and predicted global climate change.
- Continuous measurements that are obtained from both airplanes and satellites are required.
- Intergration time of the image is strongly dependent on the sensitivity of the instrumentation
- InP LNA MMICs enable highly sensitive instruments
- More than 80 GHz of bandwidth from 100 to 180 GHz from MMIC InP LNAs.
- Noise figure of the MMIC LNA was 3 dB range based on the measurements in waveguide package

Millimeter Wave Instruments - PATH

- Geostationary microwave sounder is recommended in the NASA decadal survey of Earth science missions.
- Precipitation and All-weather Temperature and Humidity (PATH) sensor will have a primary mission of observing hurricanes and severe storms.
- Operates in two spectral bands: near 60 GHz, with 4-6 channels, for temperature sounding and near 183 GHz, with 4-5 channels, for water vapor sounding.
- Same functionality and capabilities as provided with current and future LEO sounders, such as the AMSU instruments.

Millimeter Wave Instruments - PATH

Baseline capabilities equivalent to products generated with existing LEO systems (except for temporal and spatial characteristics)

Parameter	Horiz. (km)	Vertical (km)	Temporal (min)	Accuracy
Tb (60 GHz)	50	N/A	3 per ch	<1 K
Tb (183 GHz)	25	N/A	5 per ch	<1 K
Temperature	50	2	~ 10	2 K
Water vapor	25	3	~ 20	25%
Liquid water	25	4	~ 20	40%
TPW	25	N/A	~ 20	10%
LWC	25	N/A	~ 20	20%
SST	50	N/A	~ 10	2K
Stability index	50	N/A	~ 20	N/A

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Millimeter Wave Instruments - PATH

- Experimental products are under development that will have particular applicability to hurricanes and severe storms.
- These observations and derived products will be generated continuously, day and night, with a temporal resolution of 10-20 minutes in the central focus area.
- Products include parameters that can currently only be produced from precipitation radar systems: rain rates, atmospheric ice content, convective intensity
- Analysis of microwave sounder data from recent hurricane field campaigns indicate that the radiative effects of scattering from ice in deep convective systems is similar to the backscatter observed by radar – although with a lower vertical resolution.

Parameter	Horiz. (km)	Vertical (km)	Temporal (min)	Accuracy
Rain rate	25	N/A	20	TBD
Convective intensity	25	N/A	20	TBD
IWC	25	N/A	20	TBD
Wind vector	25	2	30	TBD

Millimeter Wave Instruments - HAMSR

- High Altitude MMIC Sounding Radiometer (HAMSR) is an atmospheric sounder which was designed and built at the Jet Propulsion Laboratory under a grant from the NASA Instrument Incubator Program in 2001
- HAMSR has 8 sounding channels near the 60 GHz oxygen line complex, 10 channels near the 118.75 GHz oxygen line and 7 channels near the 183.31 GHz water vapor line
- The typical microwave sounding satellites use primarily the 60 GHz oxygen line for temperature sounding, however, there are several advantages to be gained from observations near the 118.75 GHz oxygen line.
- For fixed aperture dimensions, a diffraction-limited 118 GHz system will yield twice the spatial resolution of a similar 60 GHz system.
- Sensitivity to clouds and precipitation at 118 GHz is typically greater than at 60 GHz.
- Enables improved detection of regions of heavy cloud and precipitation relative to that available using 60 GHz frequency window or sounding channels.

S. Brown, B. Lambrigtsen, A. Tanner, J. Oswald, D. Dawson, R. Denning. "Observations of tropical cyclones with a 60, 118 and 183 GHz microwave sounder" Proc. IEEE Geoscience and Remote Sensing Symposium, July 2007, pp. 3317 – 3320.

Millimeter Wave Instruments - HAMSR

Chan #	Offset from 118.75 GHz [GHz]	Wt-func. Peak [mb or mm]	NEΔT [K]
I-1	-5.500	Sfc/[30 mm]	0.62
I-2	-3.500	Surface	0.46
I-3	-2.550	Surface	0.68
I-4	-2.050	1000 mb	0.92
I-5	-1.600	750 mb	1.2
I-6	-1.200	400 mb	0.83
I-7	±0.800	250 mb	0.48
I-8	±0.450	150 mb	0.51
I-9	±0.235	80 mb	0.60
I-10	±0.120	40 mb	0.67

HAMSR frequencies and measured NEΔTs at ambient

Chan #	Center freq. [GHz]	Wt-func. Peak [mb or mm]	NEΔT [K]
II-1	50.30	**Sfc/[100 mm]**	0.40
II-2	51.76	Surface	0.27
II-3	52.80	**1000 mb**	0.21
II-4	53.596	**750 mb**	0.18
II-5	54.40	**400 mb**	0.17
II-6	54.94	**250 mb**	0.16
II-7	55.50	**150 mb**	0.17
II-8	56.02 & 56.67	90 mb	0.18

Millimeter Wave Instruments - HAMSR

HAMSR frequencies and measured NEΔTs at ambient

Chan #	Center freq. [GHz]	Offset [GHz]	Wt-func. Peak [mb or mm]	NEΔT [K]
III-1	183.31	-17.0	[11 mm]	0.61
III-2	"	±10.0	[6.8 mm]	0.94
III-3	"	±7.0	**[4.2 mm]**	0.98
III-4	"	±4.5	[2.4 mm]	1.0
III-5	"	±3.0	**[1.2 mm]**	1.3
III-6	"	±1.8	[0.6 mm]	1.0
III-7	"	±1.0	**[0.3 mm]**	1.5

Millimeter Wave Instruments - HAMSR

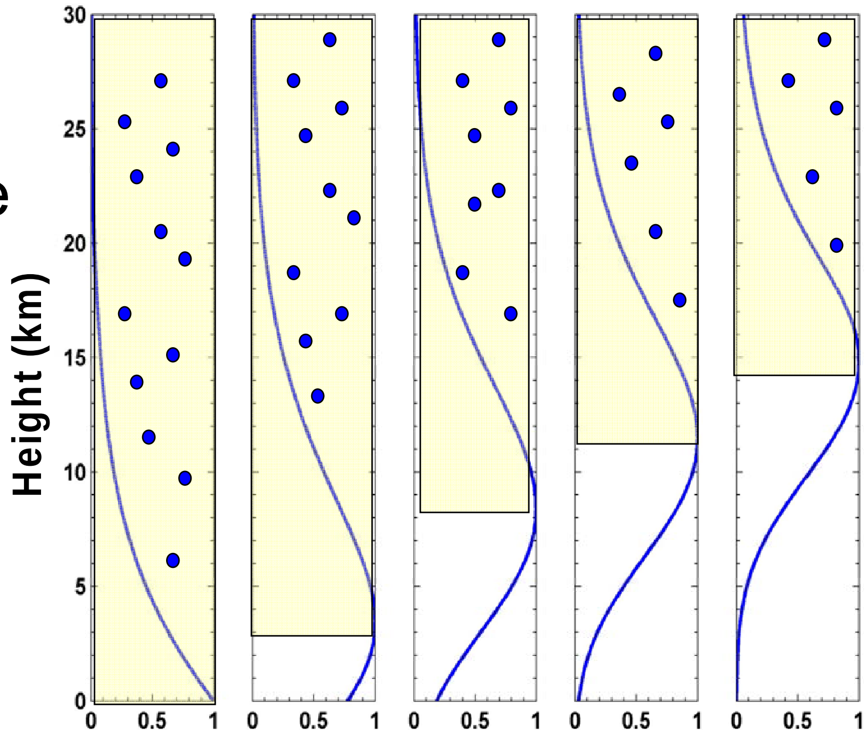
Measurements can be used to
- Indicate the convective intensity of a storm
- Provide precipitation estimates and information on ice microphysics

Five pairs of 60 and 118 GHz channels have nearly matched clear air weighting functions.
- In clear air, the difference between these channels will be nearly zero,
- In the presence of deep convection, the brightness temperature scattering depression due to the ice particle content of the cloud will be much greater at 118 GHz than at 60 GHz.

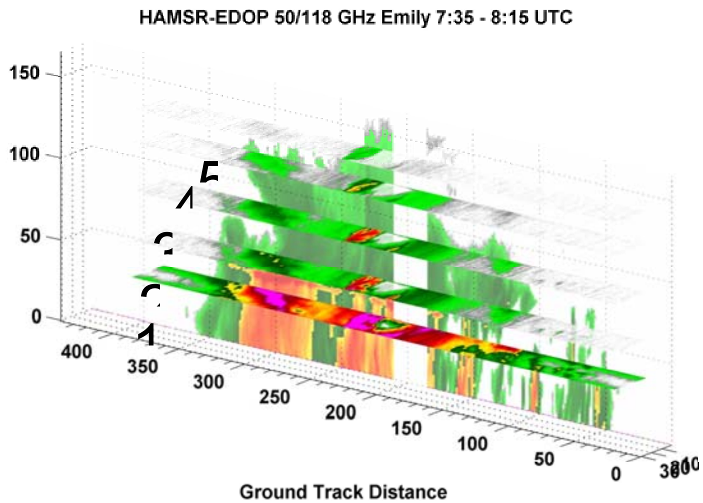
Observing the difference between the matched channels gives an indication of both the intensity and height of the precipitation

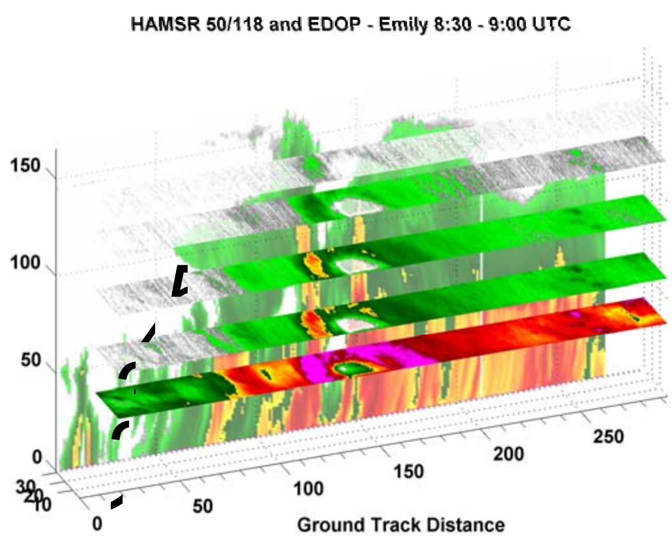
Millimeter Wave Instruments - HAMSR

• The approximate heights in the atmosphere where each difference will be sensitive to precipitation
• For example, the difference between channels I-7 and II-6 give an indication of ice content above about 14 km
• next lower channel pair provides information on the precipitation content above about 11 km.



Millimeter Wave Instruments - HAMSR





- •HAMSR observed Hurricane Emily from the ER-2
- • “cloud slices” reveal intense convection in the eyewall region, with storm tops reaching above 15 km
- •Transits across the eye wall are shown
- •The five HAMSR cloud slicing levels are shown with the nadir ER-2 Doppler Radar (EDOP) X-band reflectivity profile in the background.
- • HAMSR is able to assess the three-dimensional structure of the storm

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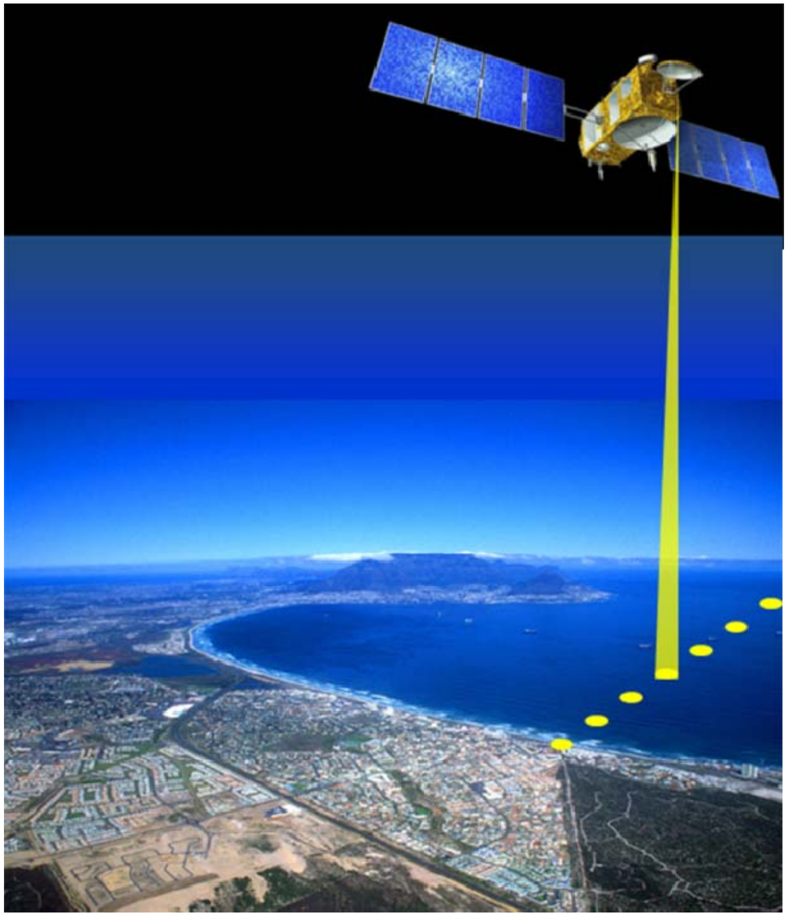
Millimeter Wave Instruments – Altimetry

Radar altimetry missions require calibration of the atmospheric properties to correct for variations in the radar signal path delay (PD)
•Ship based and airborne measurements show significant short scale water vapor variability in coastal areas.
•Variations did not necessarily correlate with distance to land

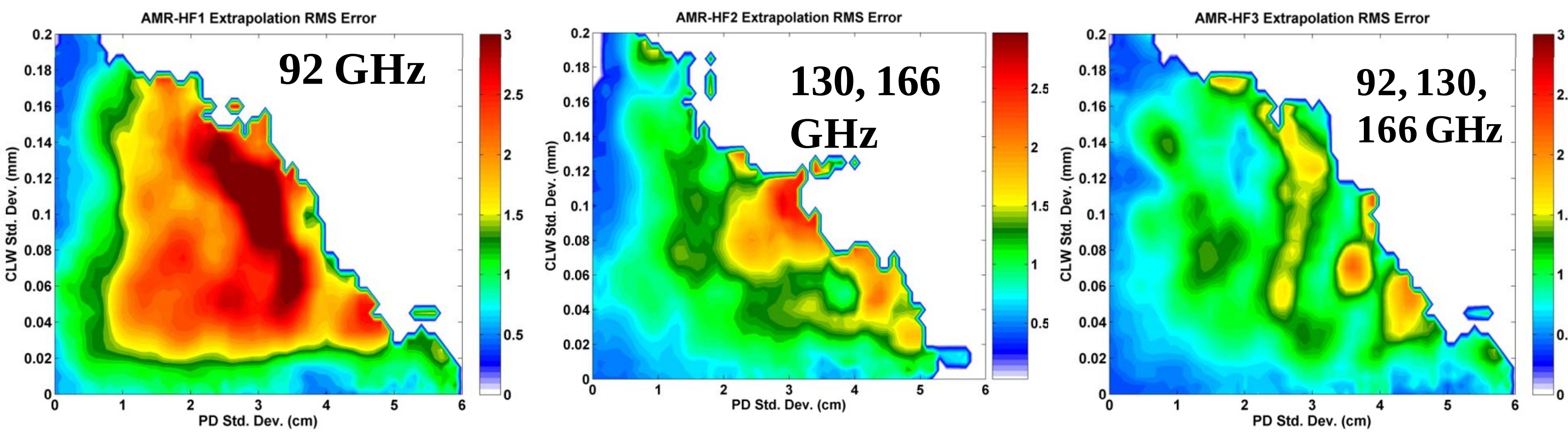
Land contamination will cause errors in the path delay calibration:
1) Far sidelobe contamination (> 75 km from coast) that is correctable to acceptable levels (~ 1mm)
2) Near sidelobe contamination (25 – 75 km from coast) that is more difficult to correct, however, it is possible (~2-4 mm)
3) Main beam contamination (0 – 25 km from coast) that is very difficult to correct (20-40 mm).



S. Brown and B. Khayatian, “Wet Tropospheric Correction in Coastal Regions” Coastal Detection Workshop, Silver Spring, MD, Feb. 2008.

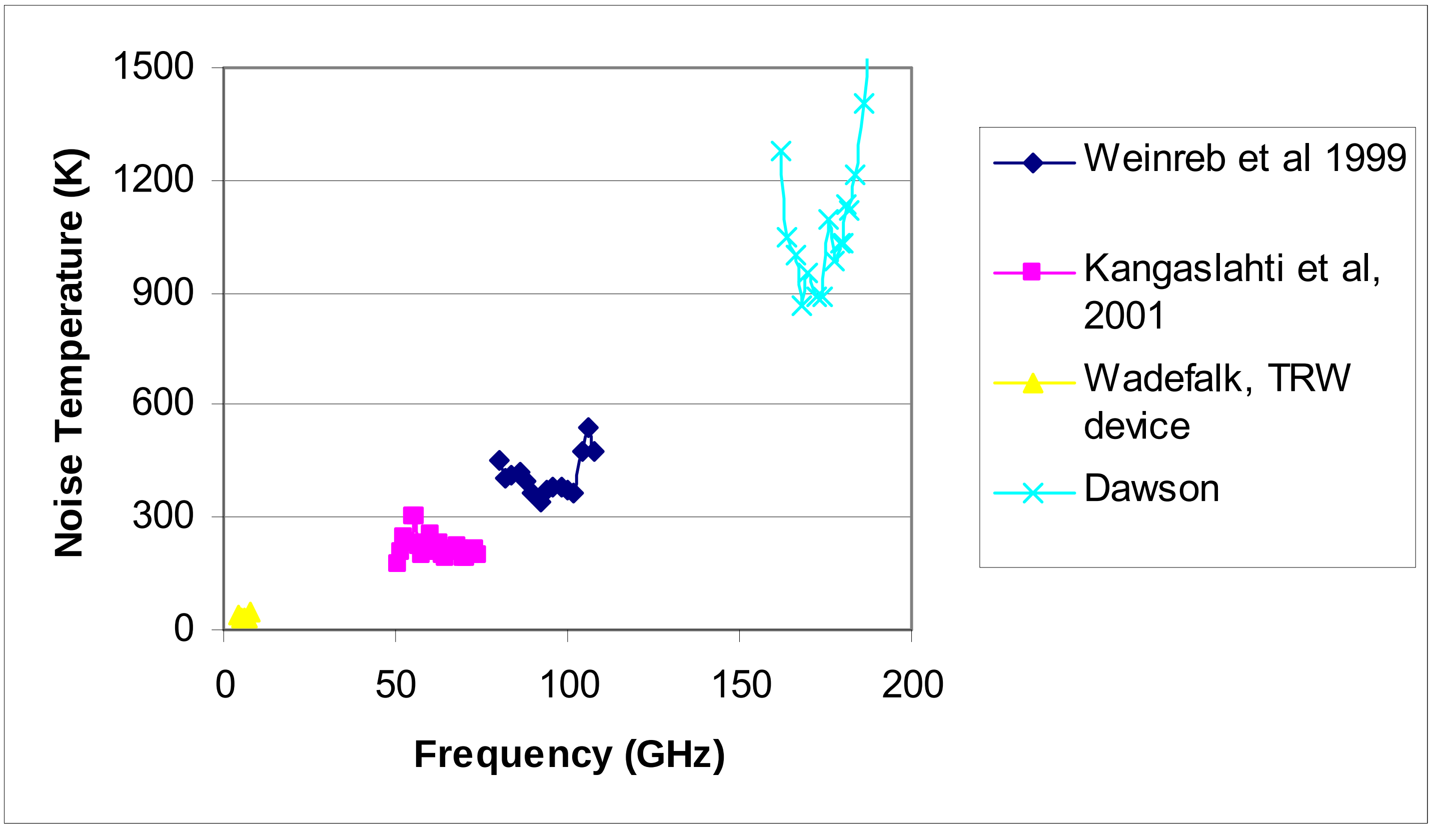
Millimeter Wave Instruments – Altimetry

- Feasibility of 92, 130 and 166 GHz channels (+ traditional 18-37 GHz) were studied
- High frequency channels are used when low-frequency channels become contaminated by land.
- Simulated PD retrieval performance is better than 1 cm at distances of 3 km from land.
- Errors were binned by standard deviation of PD and cloud liquid water (CLW) on coastal approach.
- Errors generally < 1 cm for 3 frequency retrieval and increase as variability of both CLW and PD increase



Millimeter Wave Low Noise Receivers

- We have today demonstrated InP LNAs from 1GHz to 340 GHz
- Previous generation 100 nm technology produced noise temperatures at 900 K range @ 180 GHz

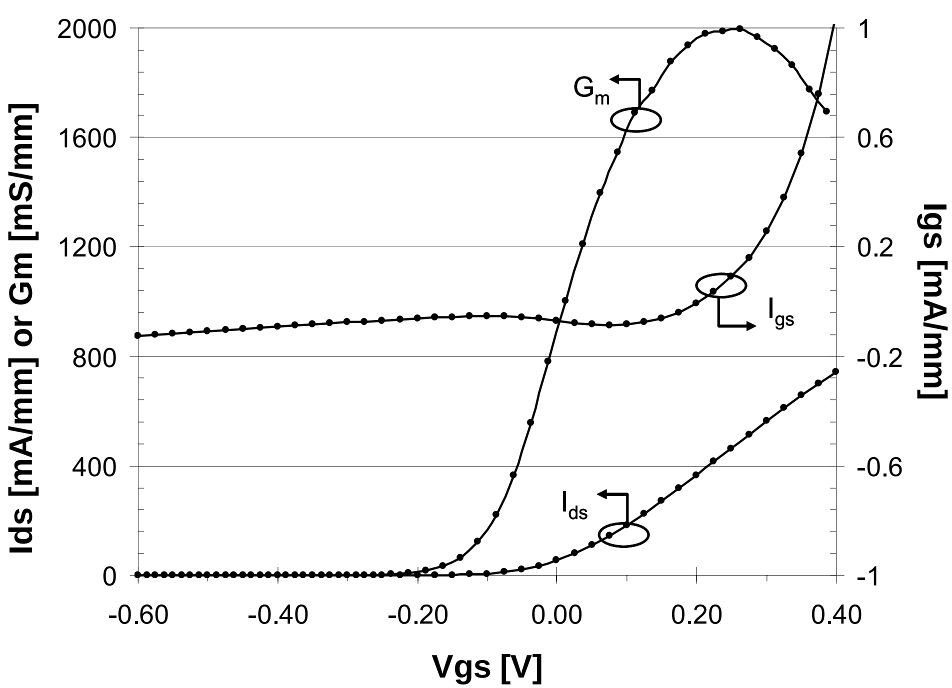


Millimeter Wave Low Noise Receivers

- The latest 35 nm InP device technology epi wafers were grown by MBE and employed a pseudomorphic $In_{0.75}Ga_{0.25}As$ channel, a silicon delta-doping layer as the electron supply, an $In_{0.52}Al_{0.48}As$ buffer layer and an InP substrate.
- Excellent DC characteristic of the HEMTs included a peak Gm of 2000-mS/mm and a breakdown voltage over 2.5V

Measured DC characteristics of a 40 um device (gate length 35 nm).

The figure shows the drain current Ids, transconductance Gm and gate current Igs vs gate voltage Vgs



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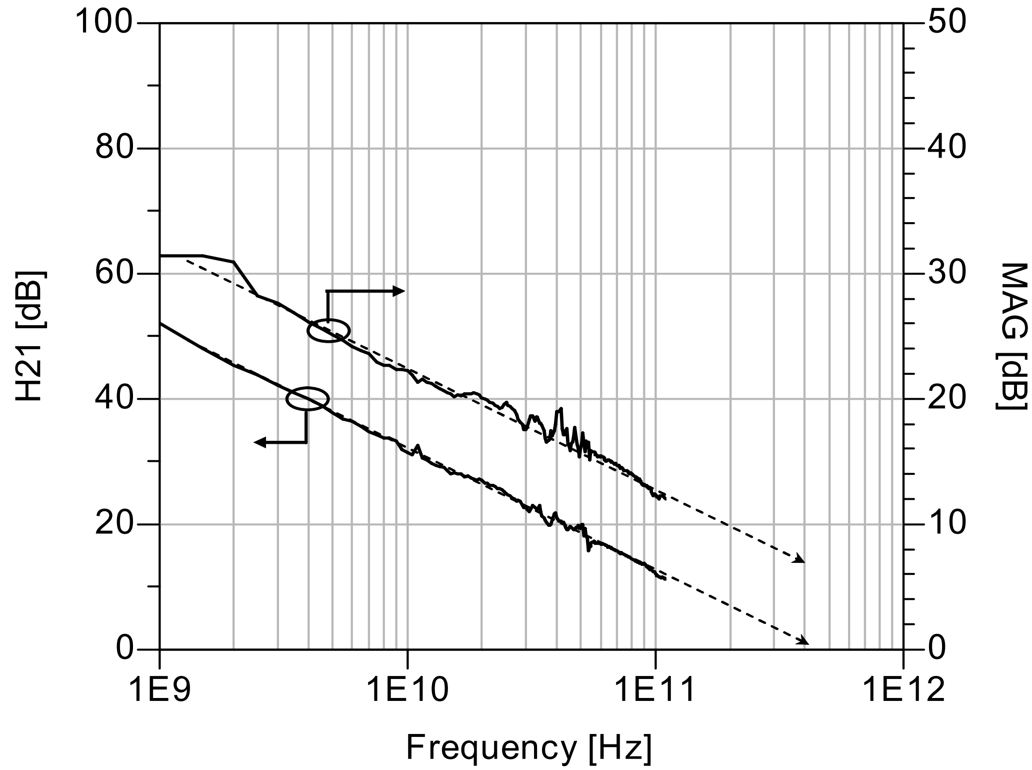
Millimeter Wave Low Noise Receivers

- The result of combining the high performance epi profile and aggressive gate is a device with excellent RF characteristics
- Extrapolated f_T from the H21 trace is ~450-GHz using 20-dB slope/decade
- Extrapolated MAG of the device at 180-GHz is ~10-dB.

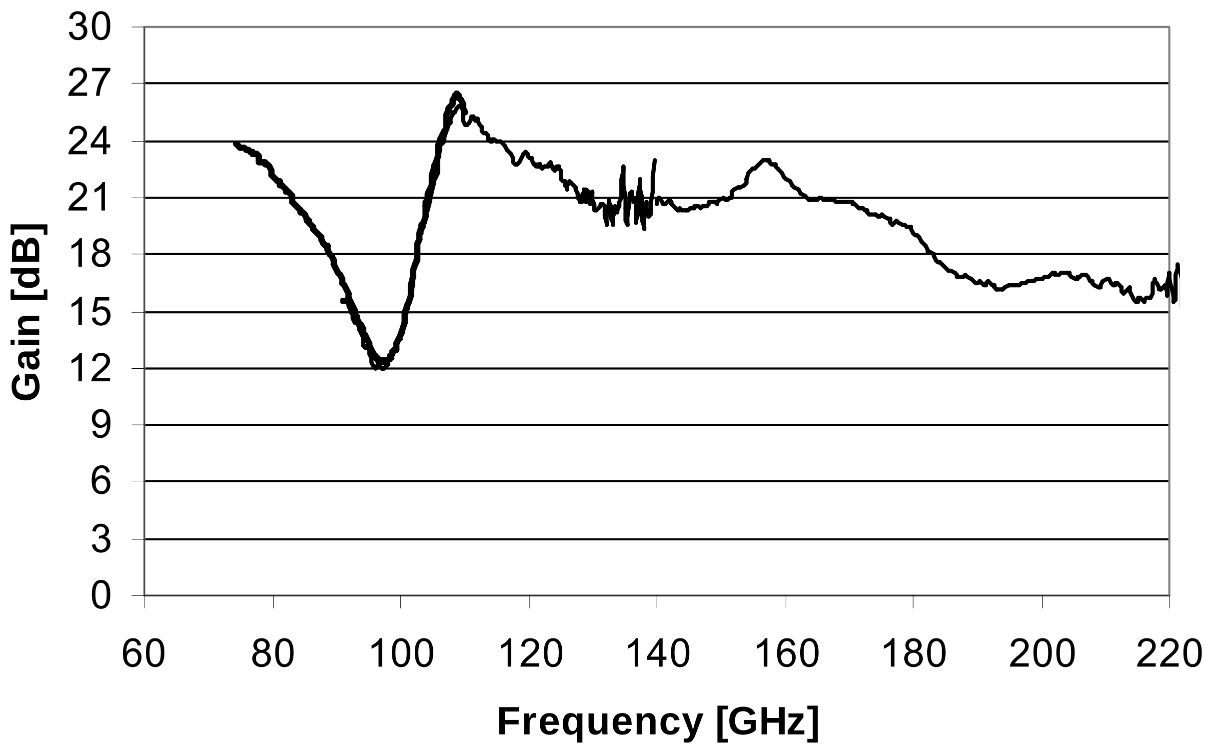
Measured RF characteristics of a 30 um device (gate length 35 nm).

The figure shows the H21 and maximum available gain (MAG) calculated from S-parameters vs. measurement frequency.



Millimeter Wave Low Noise Receivers

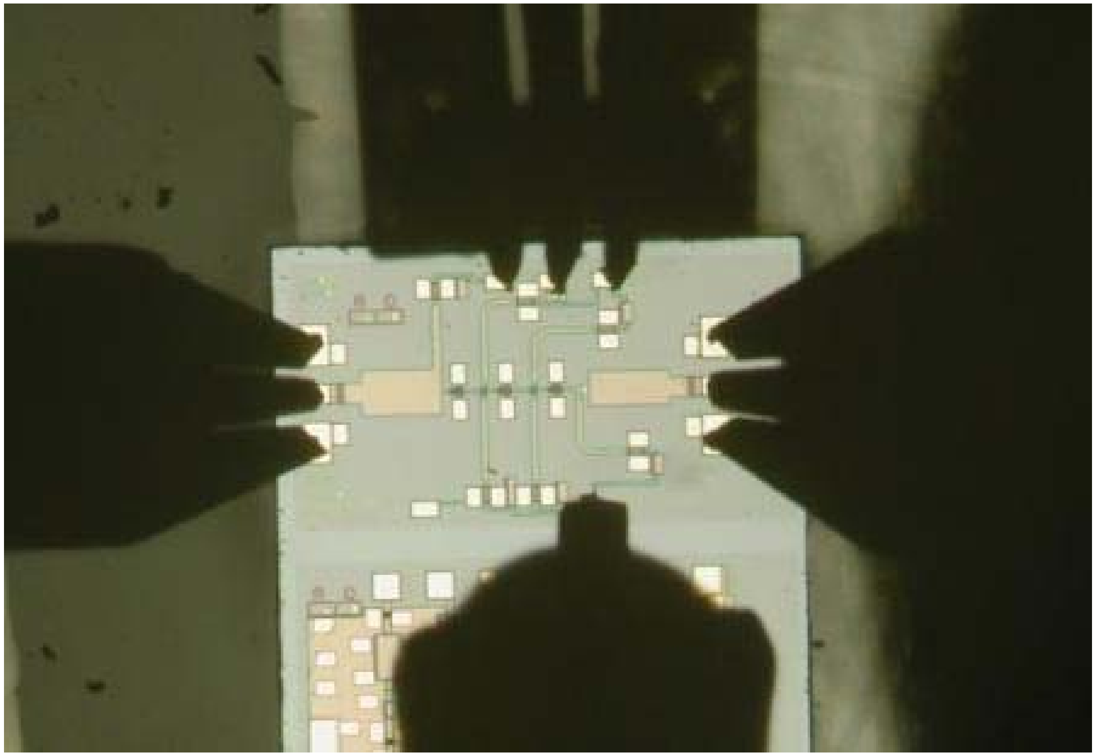
- LNAs were developed based on the 35 nm InP devices with microstrip transmission lines on 2 mil thick substrate
- The design incorporated two-finger HEMT devices having gate widths of 15 um each, for a total gate periphery of 30 um for each transistor stage.
- The amplifier had measured gain of 18 dB from 100 GHz to 180 GHz



P. Kangaslahti, W. R. Deal, X.B. Mei and R. Lai, "Broadband Characterization of a 100 to 180 GHz Amplifier" Proc. IEEE Aerospace Conference, March 1-8, 2008, Big Sky, MT

Millimeter Wave Low Noise Receivers

- LNA was measured on wafer using probes for various frequency bands
- First device in the LNA has a separate gate control and the second and third stage devices gates are connected together on the chip
- The drains of all three devices are connected together



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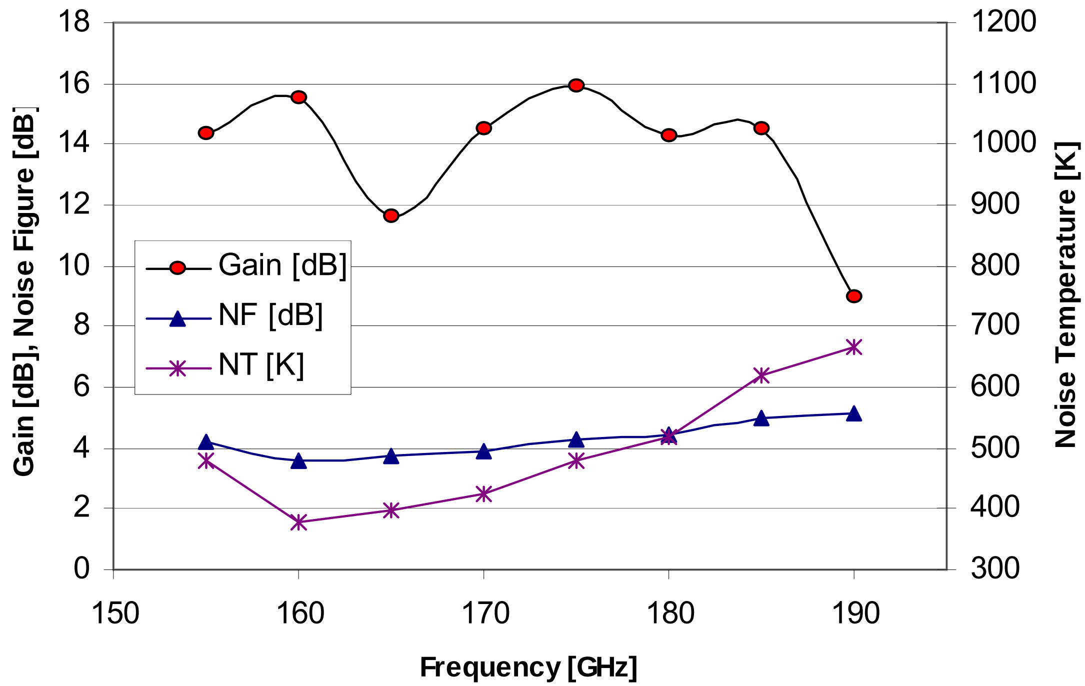
Millimeter Wave Low Noise Receivers

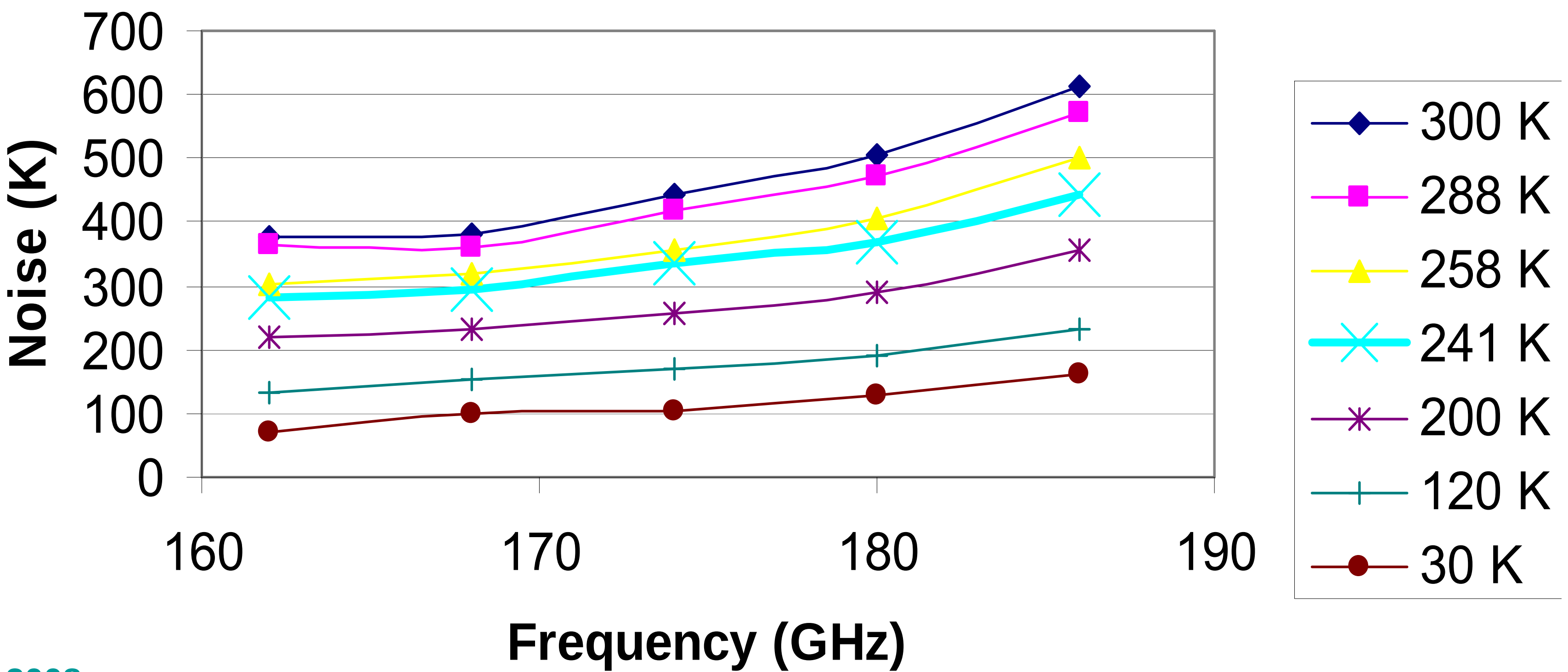
- LNA MMIC was packaged in WR-05 waveguide package
- These results demonstrate a measured noise temperature of 370 K at 160 GHz, which is half of the previous state-of-the-art.
- Input waveguide and waveguide to microstrip transition has a simulated loss of L=0.8 dB. Thus, the noise figure of the LNA MMIC is expected to be roughly NF=3dB



P. Kangaslahti, D. Pukala, T. Gaier, W. R. Deal, X.B. Mei and R. Lai, “Low Noise Amplifier for 180 GHz Frequency Band” *Proc. IEEE IMC,* June 14-18, 2008, Atlanta, GA

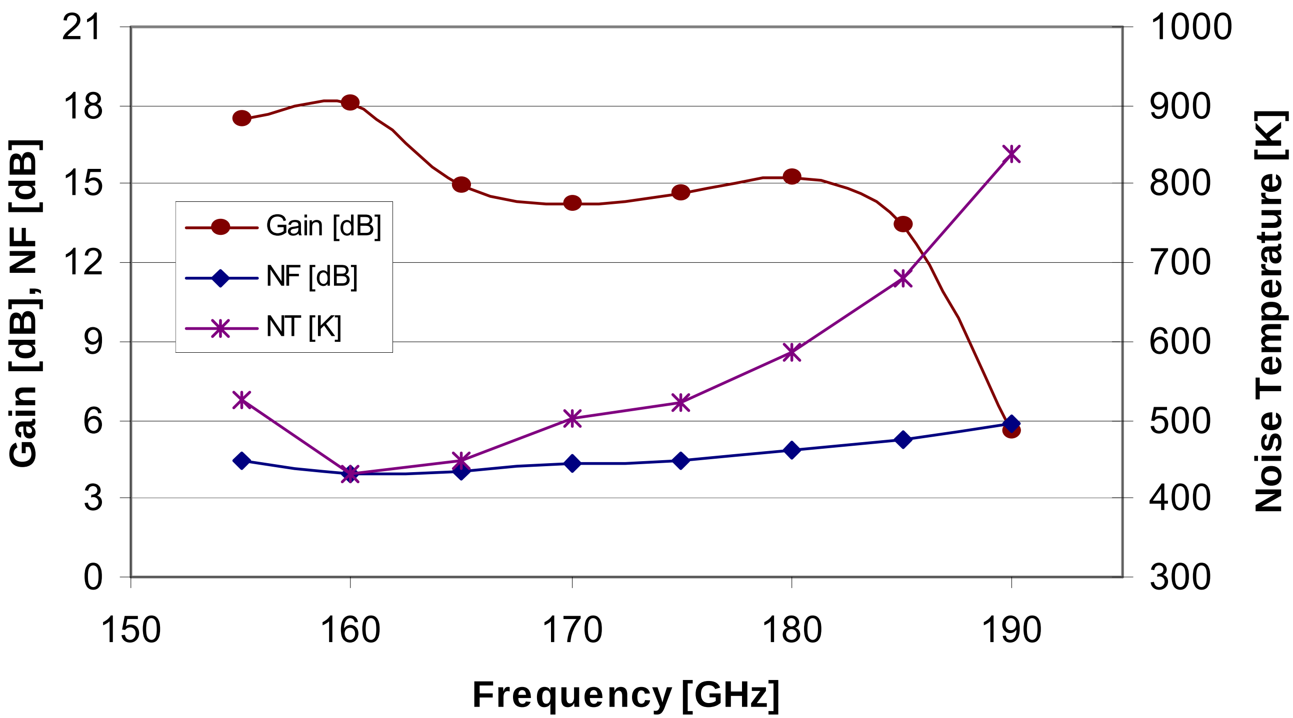
Millimeter Wave Low Noise Receivers

- In space application this LNA would be operated at lower physical temperature than ambient, so we tested the noise temperature of the LNA at different operating temperatures
- Operating temperature of the GeoSTAR receivers will be T_{phys}=240 K and the noise temperature of the LNA is below the required T_n=400 K.
- The LNA has less than 100 K noise temperature at cryogenic temperatures (T_{phys} = 30K) [5].



Millimeter Wave Low Noise Receivers

- Cascaded two waveguide MMIC LNAs with a low LO power VDI diode mixer (low DC bias power (55 mW) +.1 mW of LO power at W-band)
- The receiver has 15 dB of conversion gain from 165 to 183 GHz and noise temperature of 430 to 470 K over the same frequency band



Conclusion

- On-wafer characterization of a broadband millimeter wave InP MMIC LNA showed continuous low noise amplification was shown from 100 GHz to 180 GHz. The amplifier had more than 10 dB gain over the whole measurement range from 75 to 220 GHz.
- Demonstrated a factor of two reduction in noise temperature of MMIC LNAs at 180 GHz frequency band. This result was enabled by the significant improvement in InP MMIC process achieved within the last years.
- Applications of this work include low noise receivers for atmospheric sounding of humidity, temperature and precipitation. The MMIC LNA receiver operates with low DC power and has high gain to enable us to design low noise and low power receivers for large arrays, such as the GeoSTAR synthetic thinned aperture radiometer instrument.

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