Tropospheric Water and Cloud ICE (TWICE) Instrument Development for CubeSat Deployment

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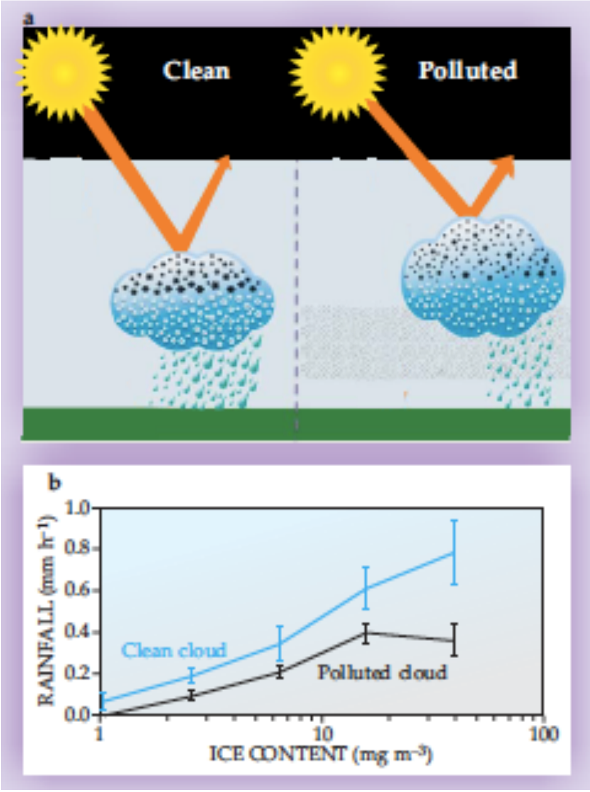
TWICE Scientific Objectives

- **NASA's Earth Science Focus Areas:**
  - Climate Variability and Change
  - Water & Energy Cycle
- **Scientific Needs:**
  - Measure water vapor and ice clouds in upper troposphere
    - At a variety of local times covering the full diurnal cycle, to address current limitations of microwave sensors in sun-synchronous orbits
  - Improve currently limited understanding of upper tropospheric / lower-stratospheric (UTLS) processes in general circulation models (GCMs) for climate modeling
    - Energy and mass fluxes due to cloud ice and water vapor
    - Two phases of water in upper troposphere physically linked in GCMs
    - NASA's A-Train satellite observations have poor performance at 100-200 hPa pressure altitude levels & cannot detect diurnal variations.

TWICE Scientific Motivation

- **Aerosols and Clouds**
  - Clouds represent the largest uncertainty in predictions of climate models.
  - Clouds in polluted environments tend to have smaller water droplets and ice crystals than those in cleaner environments (first indirect effect).
  - Dirty clouds are less likely to generate rainfall, increasing the cloud water content (second indirect effect) and are brighter (have higher albedo) than clean clouds



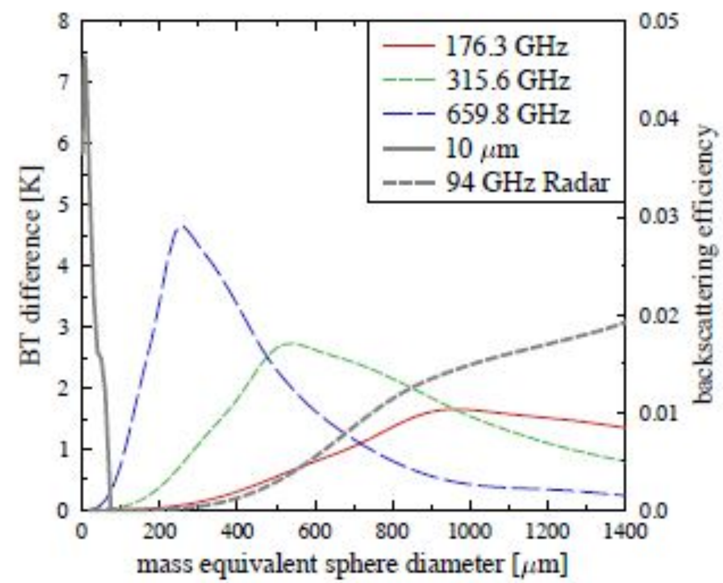
- **TWICE Radiometer Instrument**

  Along with other instruments providing aerosol information, the TWICE instrument:
  - Can provide cloud ice particle size information in both polluted and clean environments
  - Can determine the influence of aerosol pollution on cloud particle size spectrum

TWICE and Ice Clouds

Ice Cloud Particle Size:

- NASA's A-Train provides limited cloud particle size information.
  - CloudSat: 94-GHz radar (> 1 mm)
  - Aqua's MODIS: 10-μm infrared radiometer (< 100 μm)
- Sub-millimeter wave radiometry can fill the gap by providing cloud particle size information between approximately 100 μm and 1 mm.



- High atmospheric opacity at sub-millimeter wavelengths allows the measurement of ice in high cirrus clouds through *scattering.*
- Brightness temperatures *decrease* due to ice particle scattering at sub-mm-wave frequencies below ambient water vapor continuum, as shown in figure.
- Adapted from Buehler et al., *QJRMS*, 2007.

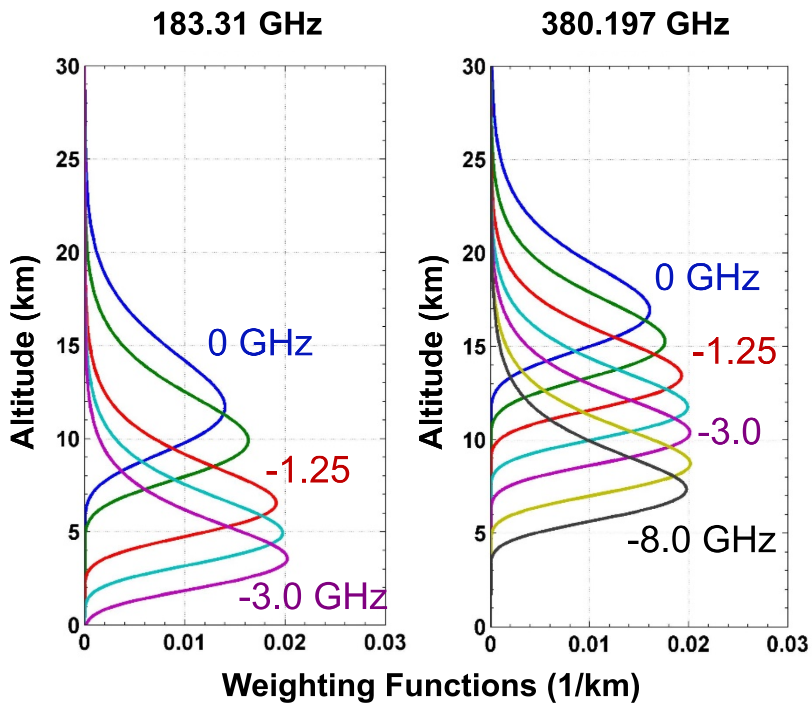
TWICE Water Vapor Profiling

Water Vapor Sounding Channels:

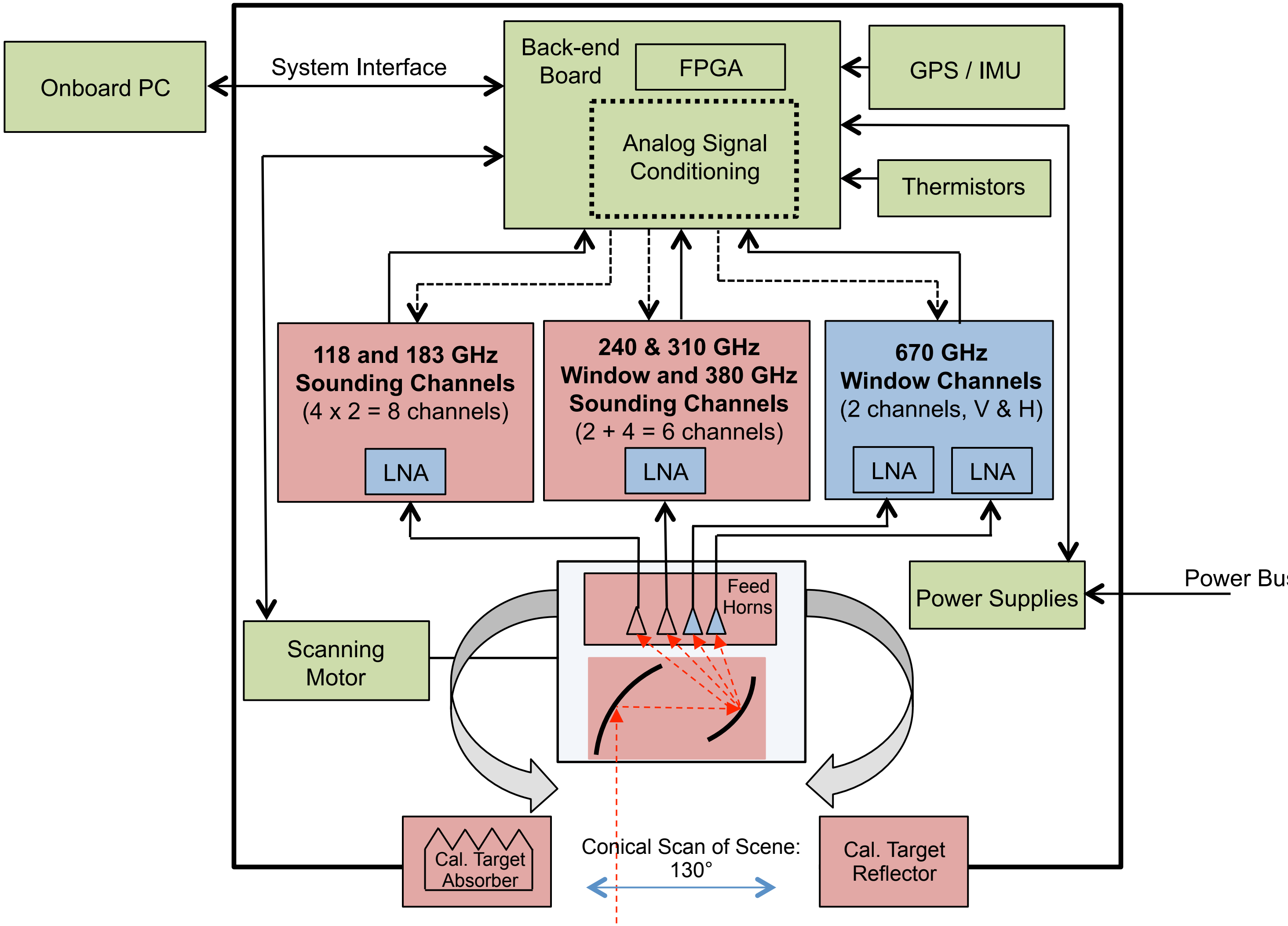
– Measurements near two water vapor absorption lines provide profiling information through pressure broadening

– 183 GHz and 380 GHz are chosen to retrieve water vapor in the troposphere and upper troposphere / lower stratosphere (UTLS)

- Water vapor weighting functions are shown at offsets of 0, 0.75, 1.25, 2, 3, 5 and 8 GHz below lines at 183.31 GHz (left) and 380.20 GHz (right).
- To constrain the water vapor retrievals, 118 GHz channels measure tropospheric temperature profile using O_2 absorption line



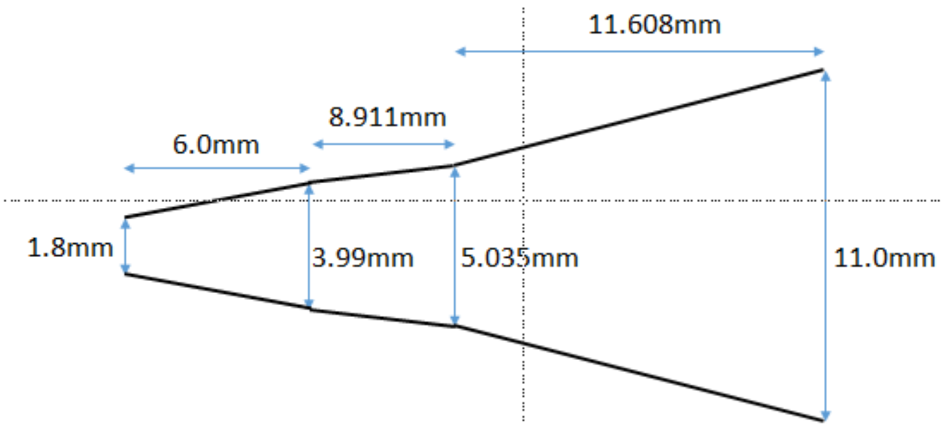
Tropospheric Water and Cloud Ice (TWICE) Radiometer Block Diagram

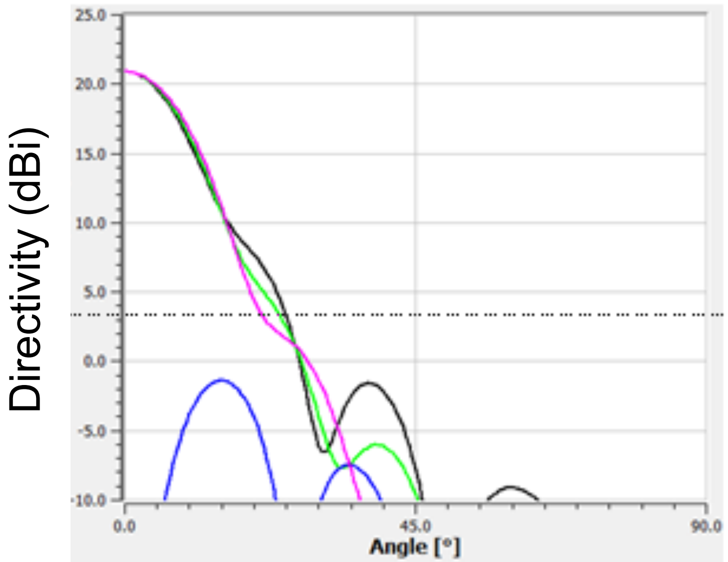


Green = CSU; Red = JPL; Blue = NGC;

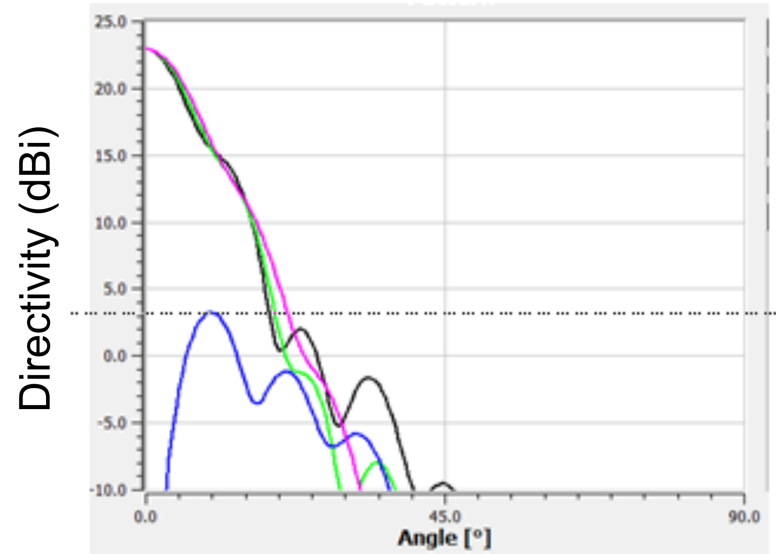
TWICE Feed Horn Design for 118-136 and 165-183 GHz

- Broadband multi-flare horn
- Machinable with a single custom tool
- Compatible with TWICE optical system
- Gain = 20.7 dB
- Half power beamwidth = 16.2°





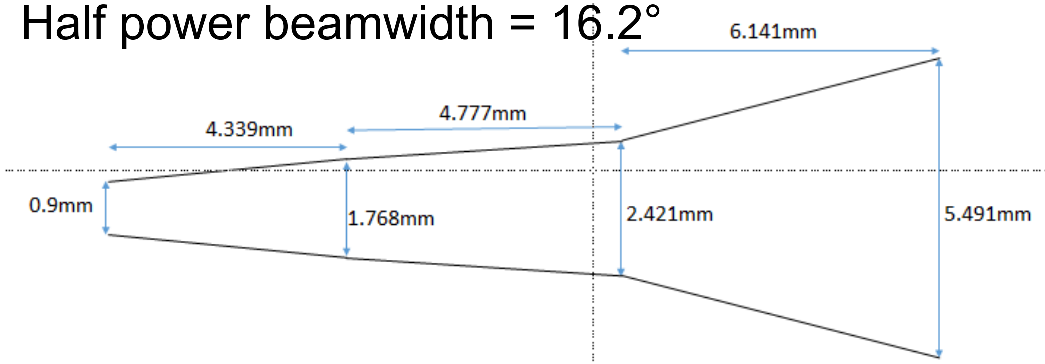
118 GHz

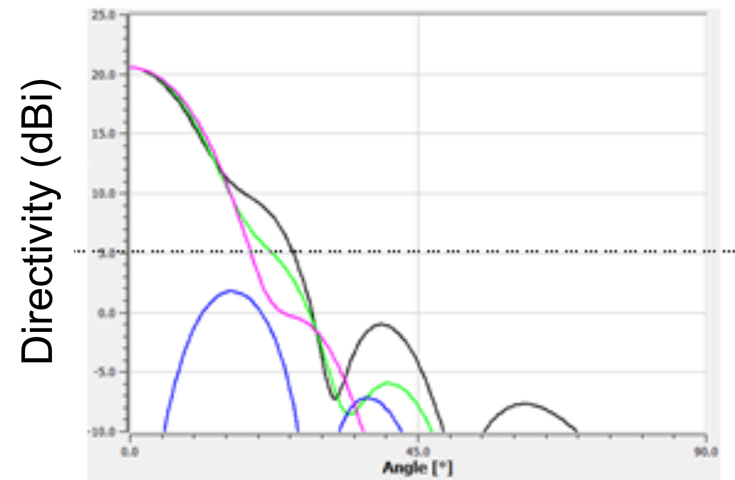


183 GHz

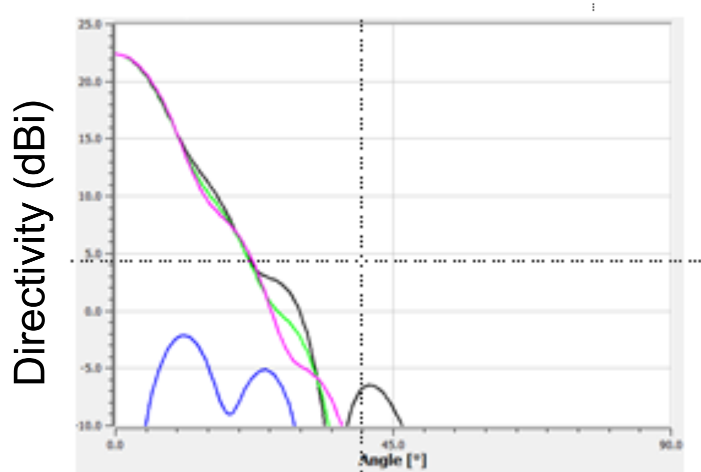
TWICE Feed Horn Design for 230-390 GHz

- Broadband multi-flare horn
- Machinable with a single custom tool
- Compatible with TWICE optical system
- Gain = 20.7 dB
- Half power beamwidth = 16.2°

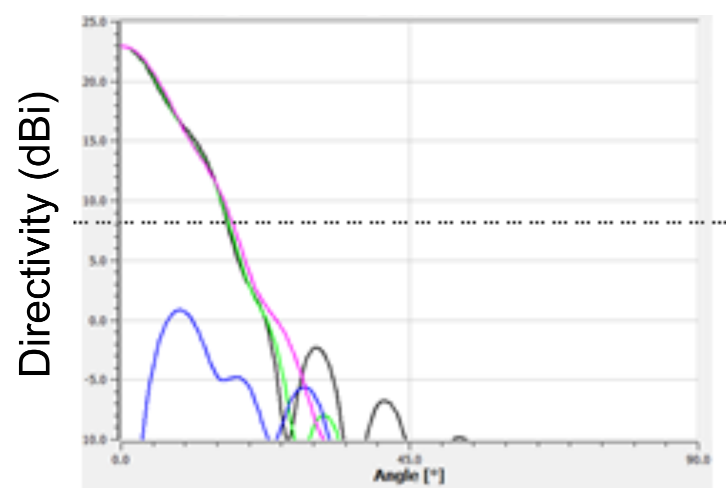




230 GHz



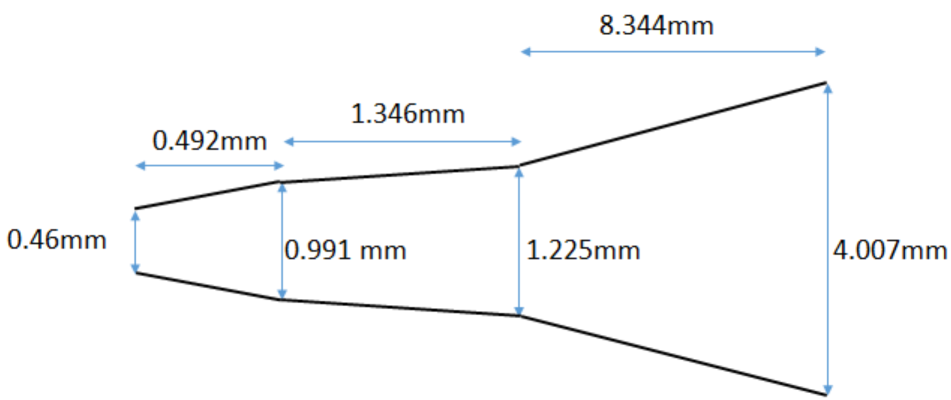
310 GHz

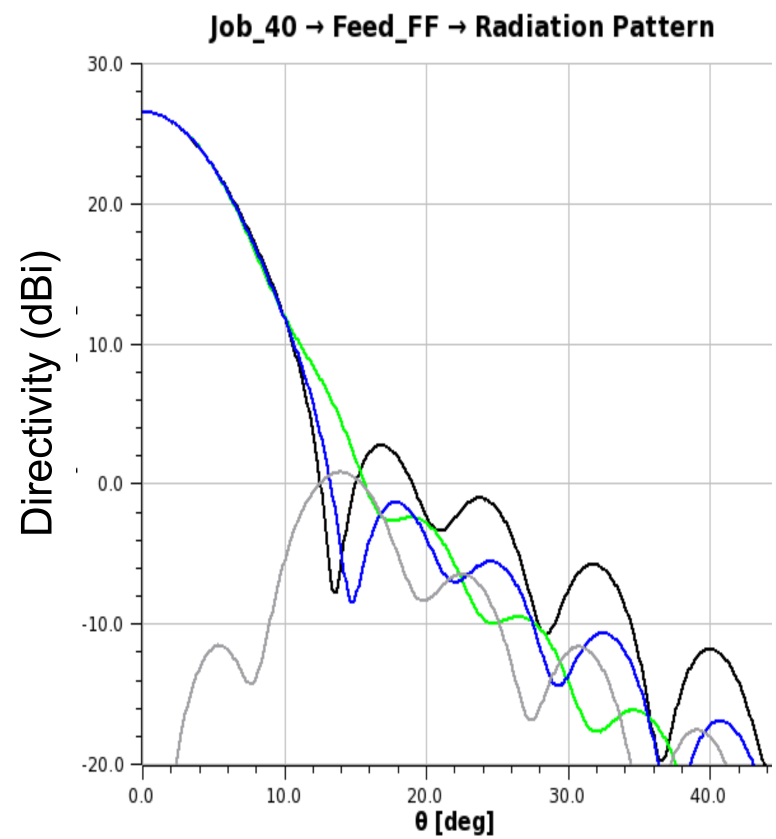


390 GHz

TWICE Feed Horn Design for 650-690 GHz

- Broadband multi-flare horn
- Machinable with a single custom tool
- Compatible with TWICE optical system
- Gain = 26.9 dB
- Half power beamwidth = 8.08°

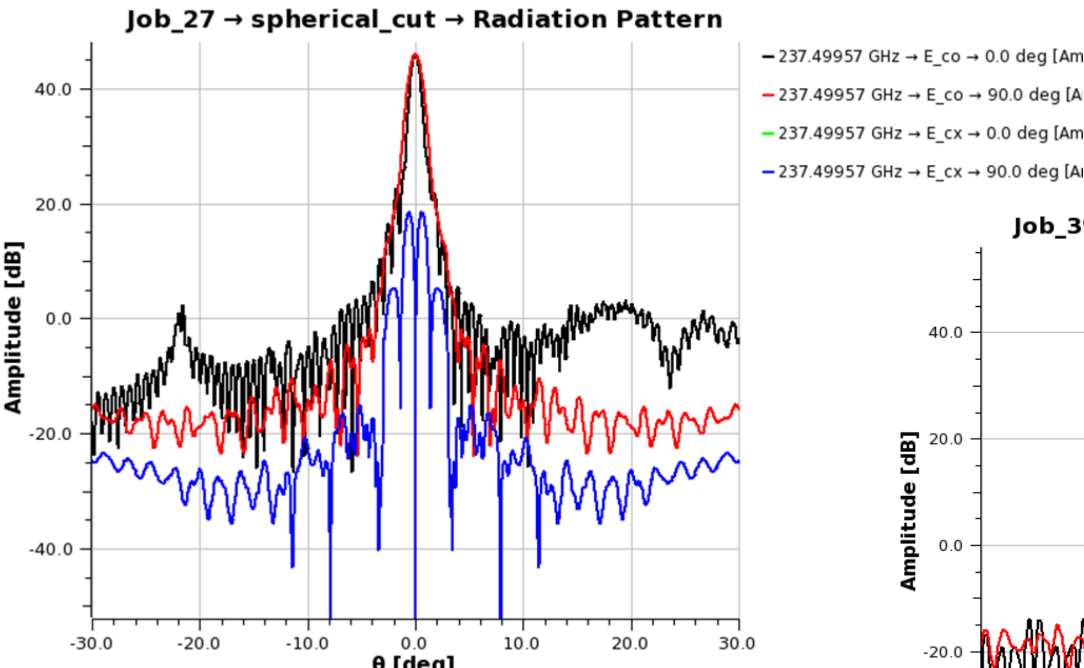


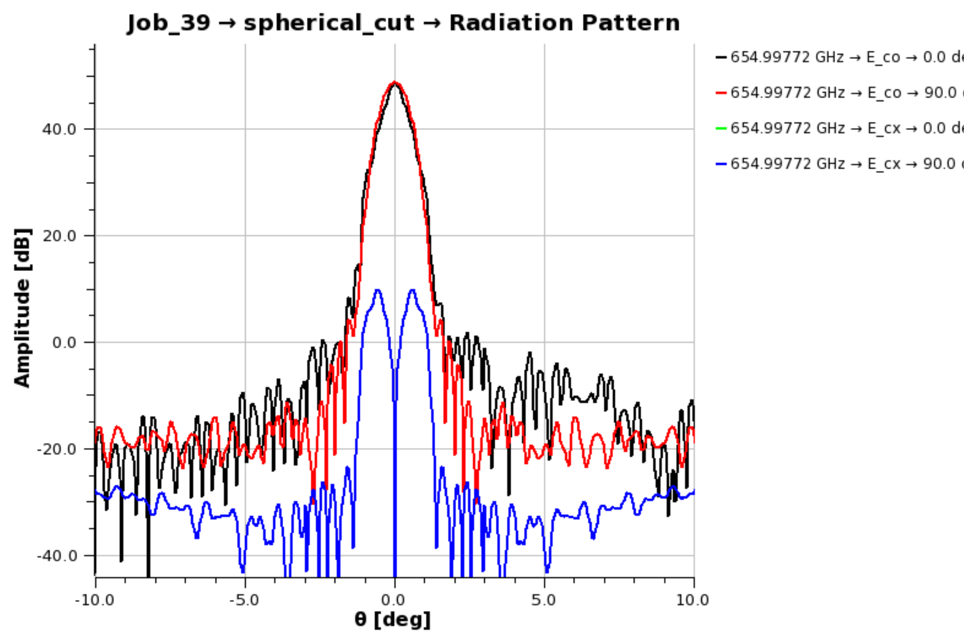


670 GHz

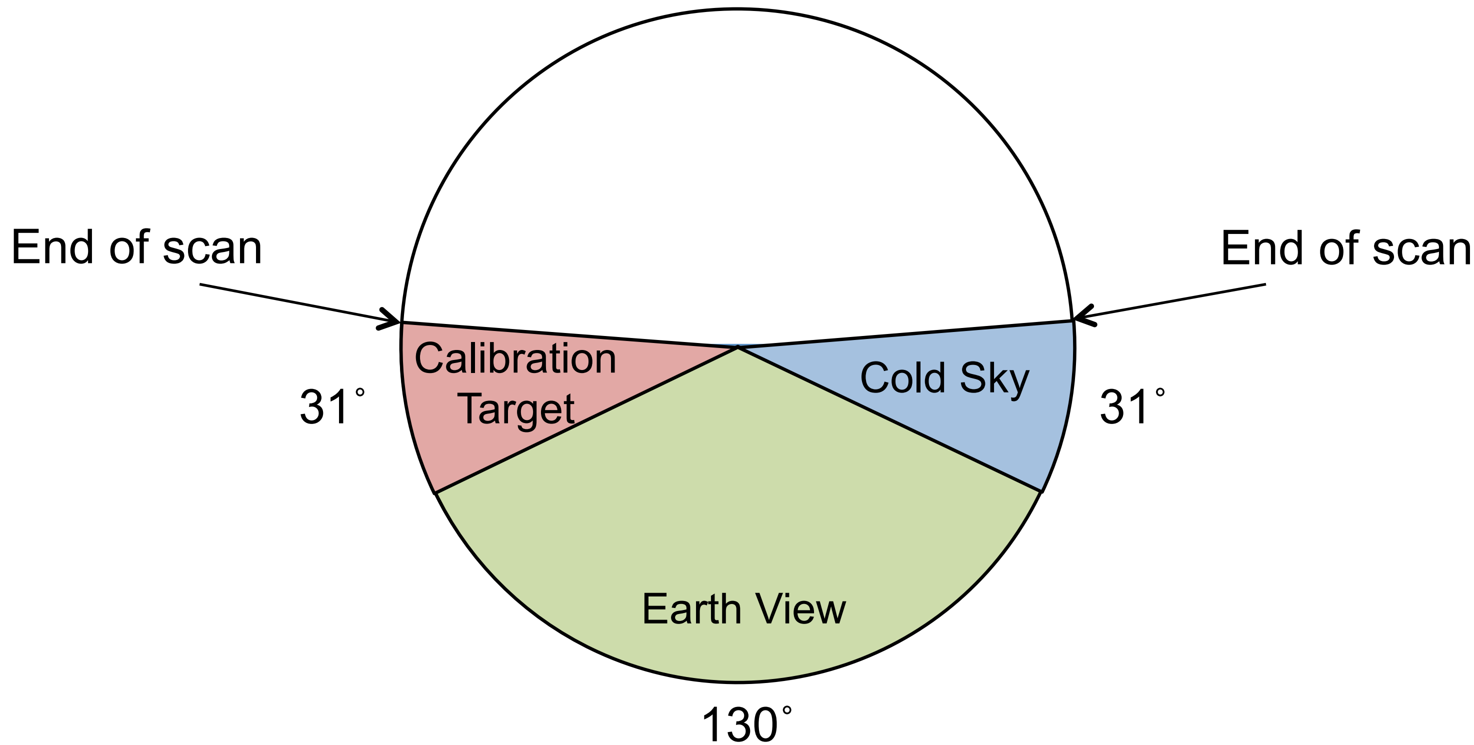
Feed Horn Patterns in TWICE Optical Subsystem Design

- All frequencies simulated, achieving main beam efficiencies > 90%
- Half power beamwidths from 0.6° to 1.6° across frequency range
- This corresponds to 10 km to 24 km spot size from 400 km orbit.





TWICE Scanning and Calibration Strategy



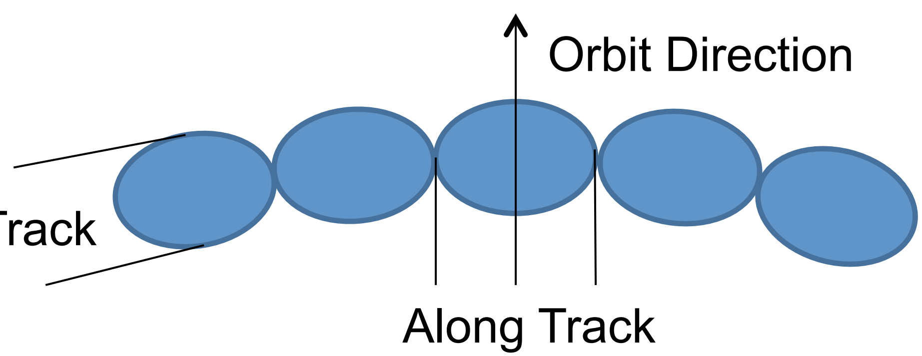
Constant angular speed: 30 RPM

- Zero angular speed at each end of scan
- Total Time to scan 192˚ = $T_{acceleration} + T_{scene} + T_{deceleration}$ = 1 s
- *Tscan revisit*= 1 s
- Contiguous footprint sampling is desired

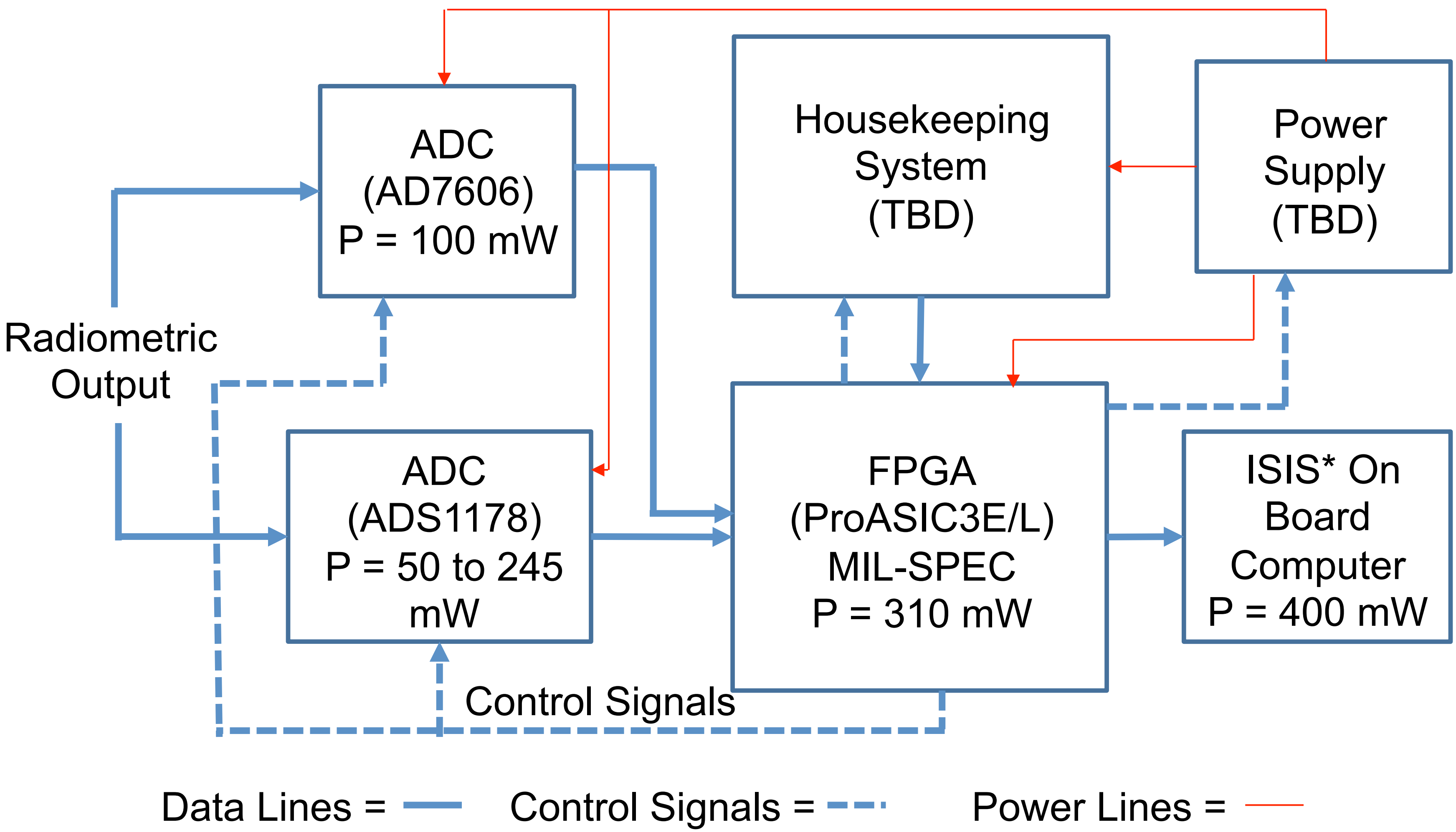
TWICE Surface Footprint Size for 400 km Orbit

Channel Center Frequency (GHz)	Antenna 3-dB Beamwidth (deg)	Cross-Track Footprint (km)	Along-Track Footprint (km)
118	1.56	16.0	24.2
183	1.17	11.9	18.1
240	0.77	7.8	11.8
310	0.64	6.5	9.9
380	0.56	5.8	8.7
670	0.62	6.3	9.6

- Swath width = 749 km
- Scan-to-scan along-track displacement at 30 RPM = 7.2 km



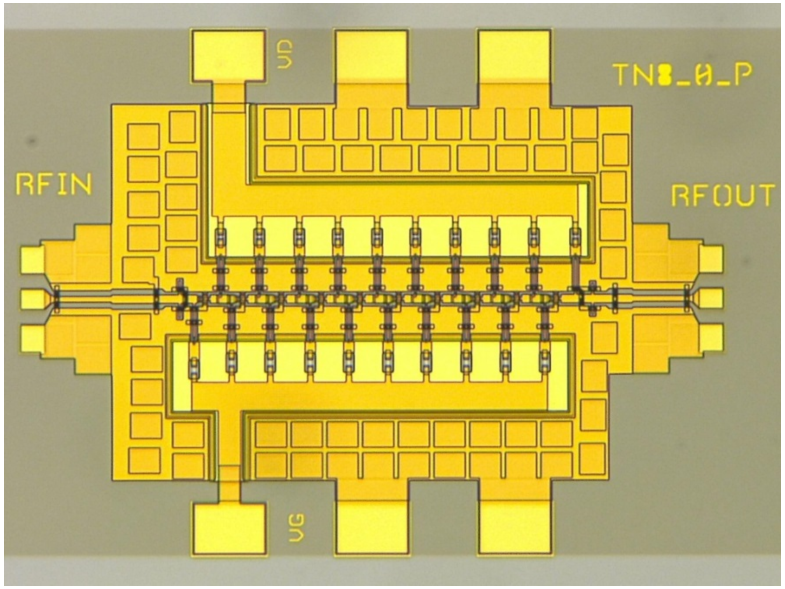
Back-end Subsystem Prototype

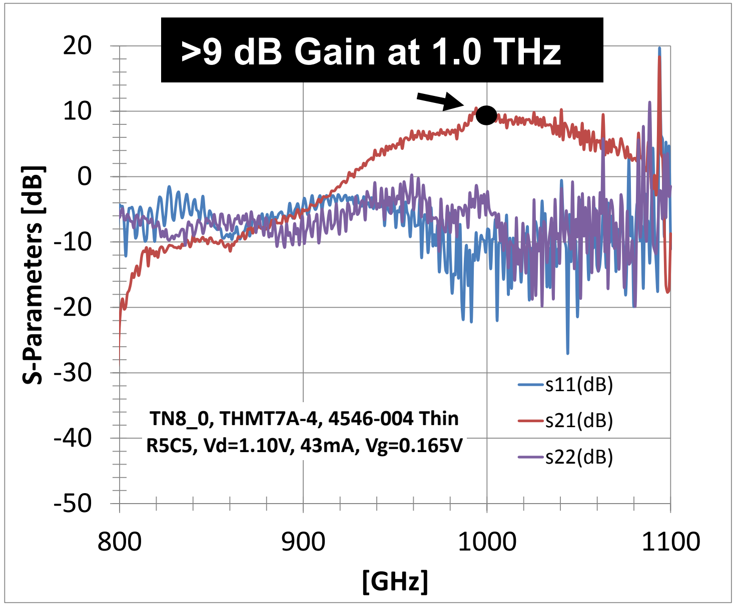


*ISIS = Innovative Solutions in Space, http://www.isispace.nl

InP HEMT Technology

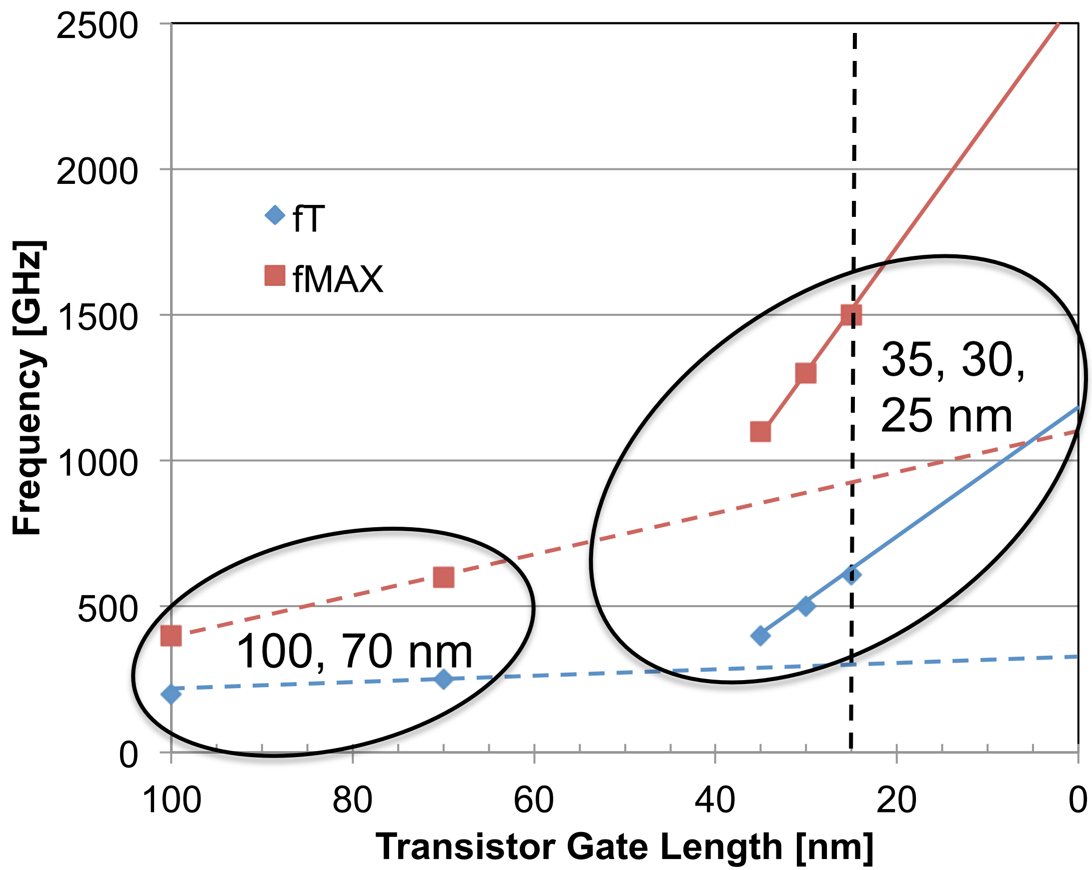
- Northrop Grumman's InP HEMT process demonstrated up to 1 THz (1,000 GHz)





InP HEMT Technology

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



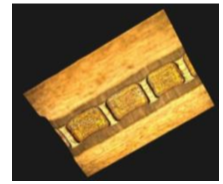
Designs for First TWICE Wafer of 25-nm InP HEMT MMICs

Component	Frequency	No. of Designs	Designers
LNA	110-190 GHz	3	Shih (NGC), Pekka (JPL)
LNA	230-320 GHz	2	Zamora (NGC), Pekka (JPL)
LNA	360-390 GHz	2	Zamora (NGC), Pekka (JPL)
LNA	230-390 GHz	2	Zamora (NGC), Pekka (JPL)
LNA	670 GHz	3	Deal (NGC)
Quadrupler	63 GHz Output	1	Zamora (NGC)
Tripler	190 GHz Output	1	Zamora (NGC)
LO Driver Amplifier	190 GHz	1	Zamora (NGC)
Single-chip X12 Multiplier	190 GHz Output	1	Zamora (NGC)
Doubler	190 GHz for Subharmonic LO	2	Pekka (JPL), Schlecht (JPL)
Second-harmonic Mixer	380 GHz RF Frequency	2	Pekka (JPL), Schlecht (JPL)

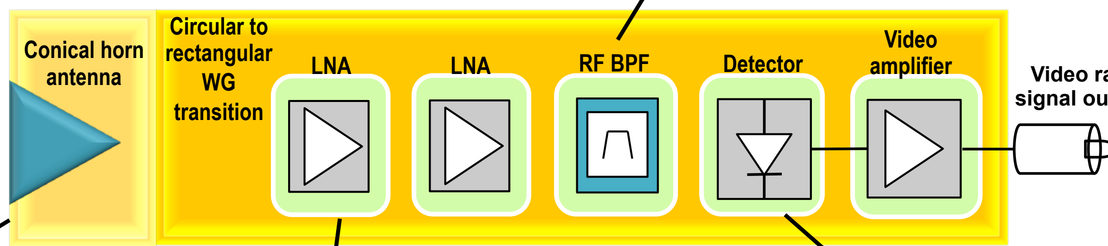
670 GHz Direct-Detection Receiver (NGAS)

- 660-680 GHz direct-detection receiver
  - 11 dB Noise figure (3360 K Noise temperature)
  - High dynamic range
  - Receiver fabricated in a single housing.
  - Legacy designs will be improved for gain flatness and performance

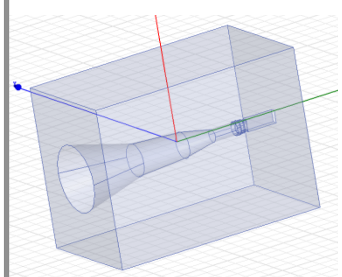
670 GHz Waveguide BPF



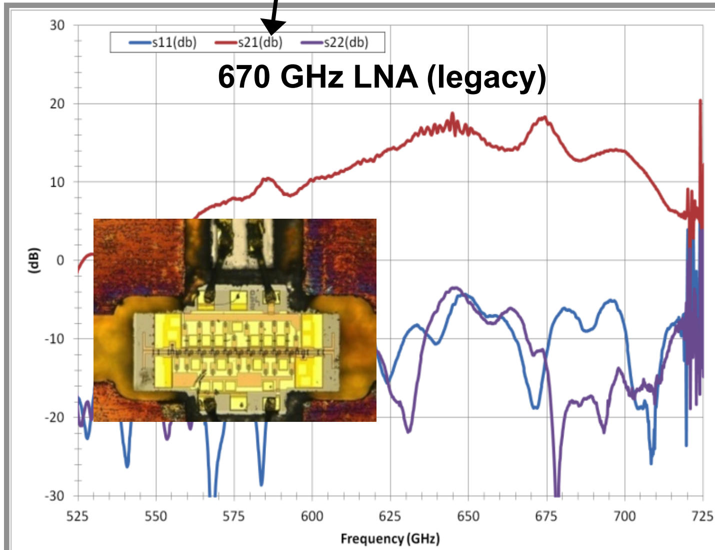
- 20 GHz bandwidth
- CNC machined waveguide
- 0.5 mil accuracy



Conical horn antenna



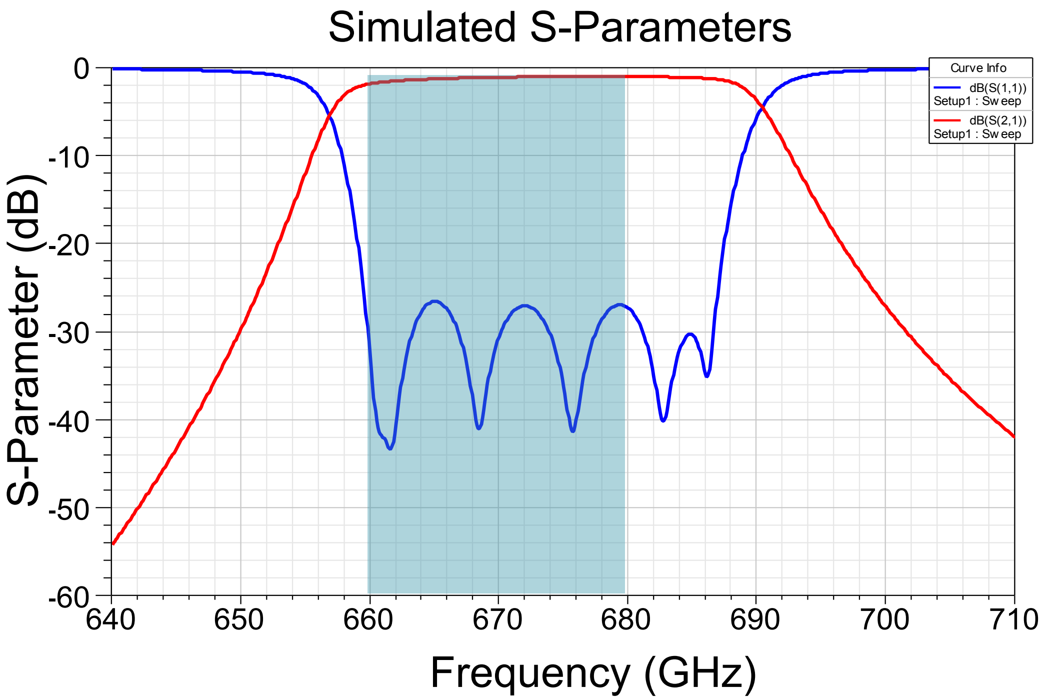
- Designed by JPL
- Beam matched to optics
- CNC machined

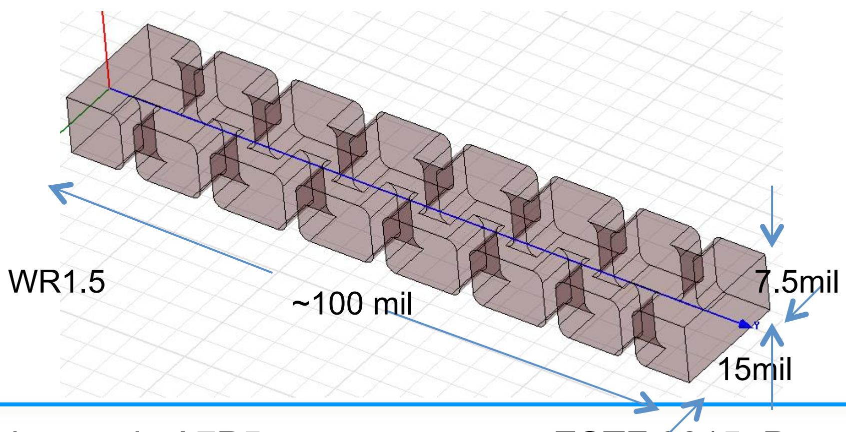


Detector

- Zero-bias diode detector developed by VDI
- Sensitivity: 750 V/W
- NEP: 5.1 pW/Hz^1/2

670 GHz Bandpass Filter (NGAS)





- 6-pole rectangular waveguide design
- Intentionally shifted frequency high to compensate for fabrication tolerance
- Fabricated using CNC machining
- Status:
  - Fabrication complete
  - Test data available by end of June

670-GHz Detector Update

Virginia Diodes, Inc.
Zero-bias detector diode

- Sensitivity: 750 V/W
- Noise-equivalent power (NEP): 5.1 pW/Hz^1/2

- 670-GHz detector designed by VDI
- NGC will integrate chip in receiver housing
- Status:
  - VDI design complete
  - VDI will transfer mechanical drawings to NGC
  - NGC will fabricate housings and evaluate detector

Summary

- The Tropospheric Water and Cloud ICE (TWICE) instrument is under development to measure water vapor and ice clouds in the upper troposphere.
- The scientific motivation is to improve understanding of the energy and mass fluxes of both cloud ice and water vapor, and their coupling. Clouds in the upper troposphere are one of the largest sources of uncertainty in general circulation models for climate predictions.
- Cloud ice particle sizing is needed in both clean and polluted clouds to study the first and second indirect effects of aerosols on a diurnal basis.
- TWICE will perform measurements at 15 frequencies from 118 GHz to 670 GHz to yield ice cloud particle size information as well as water vapor profiling in the upper troposphere.
- Conical scanning will enable external calibration at all frequencies using cold sky and an ambient target.
- The TWICE instrument will meet the size, weight and power (SWaP) requirements for deployment in a 6U-Class satellite.