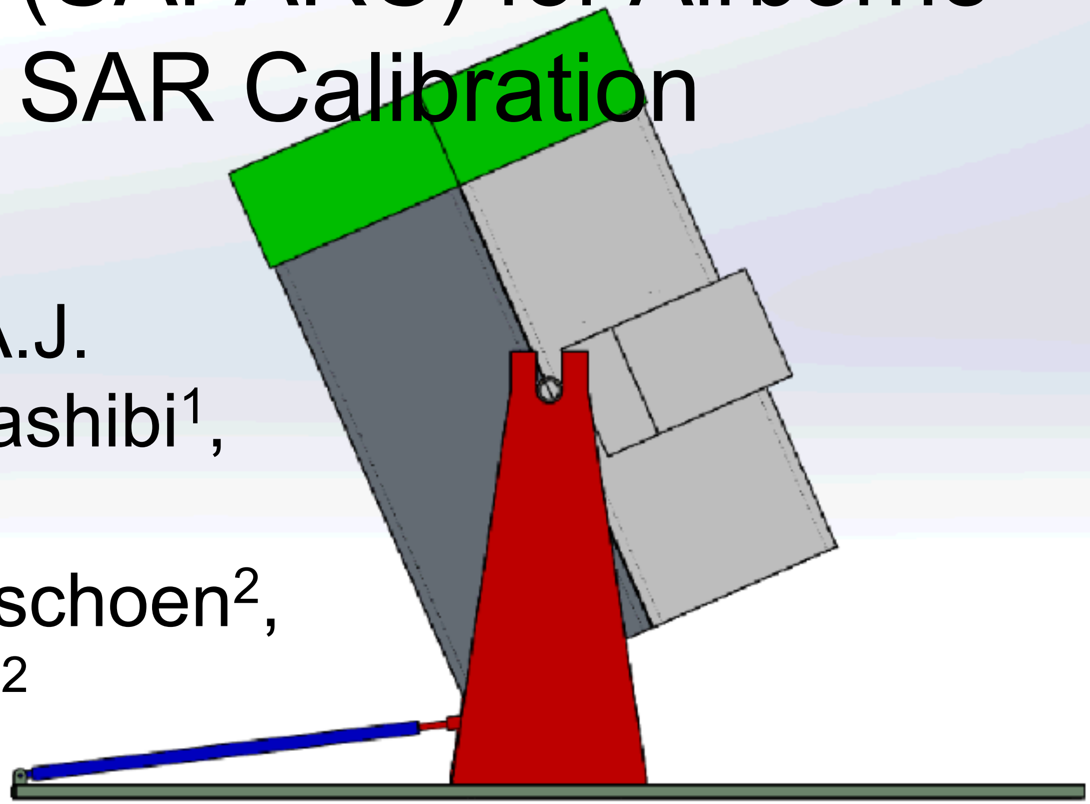
L-band Single Antenna Polarimetric Active Radar Calibrator (SAPARC) for Airborne and Spaceborne SAR Calibration



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Outline

- Calibration Targets
- Active calibration targets
- Operating principles
- Antenna and OMT design
- RF and Control circuit design
- Structure design and fabrication
- Characterization

Calibration Targets

Distributed Targets:

- Stable
- Not always available (Temporal and spatial proximity)
- Not complete for polarimetric calibration (phase is missing)

(Amazon rainforest)

Point Targets:

- Simple calibration
- Susceptible to coherent or incoherent interaction with the background
- Orientation errors
- Instability of active components
- Phase and magnitude ripple due to interference

(Courtesy of JPL)

(Courtesy of Monash University)

(Courtesy of RST-Group)

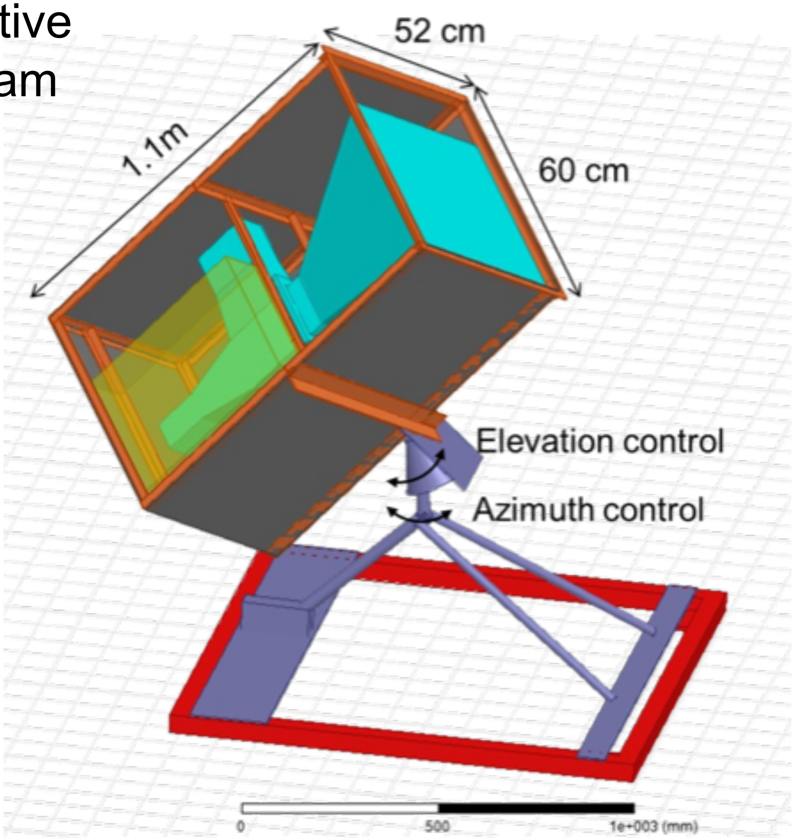
Single Antenna Radar Calibrator

Objectives:

- Development of a novel polarimetric active radar calibrator with a stable and widebeam RCS pattern at L-band (1.26GHz)
  - RCS as high as 80dBsm
  - Wideband (~80MHz)
  - Phase and magnitude stable
  - 3-dB beamwidth:>20° in both E-&H-planes

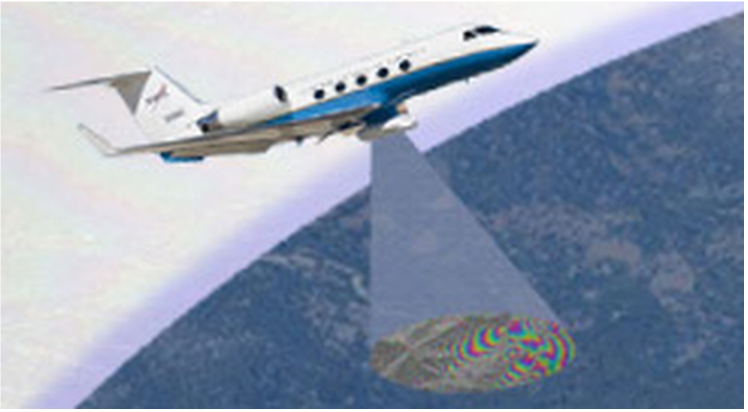
Approach:

- Active radar calibrator with two orthogonal channels using a dual polarized antenna
- Isolation is achieved by
  - Precision OMT
  - Leakage cancellation circuitry (LCC)
- Automatic Gain Control circuitry
- Stable gain with less than 0.1dB variation
- Operating temperature (-40°C to 50°C)
- Remote operation and data collection

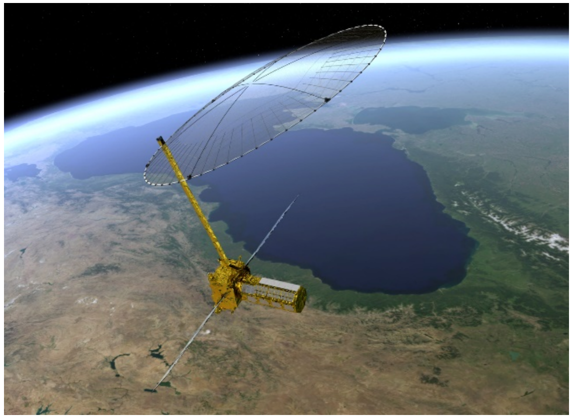


Application: Airborne and Spaceborne L-band SARs

UAVSAR



NISAR

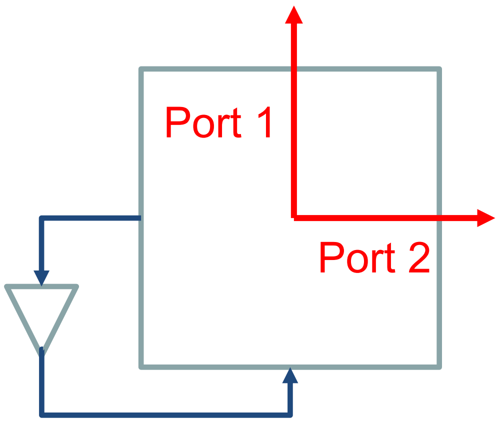


UAVSAR/ NISAR power characteristics		
	UAVSAR	NISAR
Peak transmitted power	3.1kW	1.2kW
Antenna gain	18.9dBi	34.8dBi
Operation Altitude	12.5km	740km
Look angle	25° - 65°	33°-47°
Estimated Clutter		
PARC received power	-19dBm	-41dBsm
PARC active gain	37dB	47dB
PARC transmit power	18dBm	6dBm

PARC SPECS		
	NAVSAR	NISAR
Frequency Range	1217.5MHz to 1297.5MHz	
Bandwidth	80MHz	
Antenna Gain	16.5dBi	
Active Gain	37dB	47dB
RCS	40dBsm	50dBsm
Signal to clutter	44dB	30dB
Max power	20dBm (0.1 Watt)	

➢ Operating principle

- A *two-port* antenna with orthogonal modes of radiation acts as both the transmitter and the receiver antenna.
- An amplifier is placed between the two ports of the antenna to create a large radar cross section.

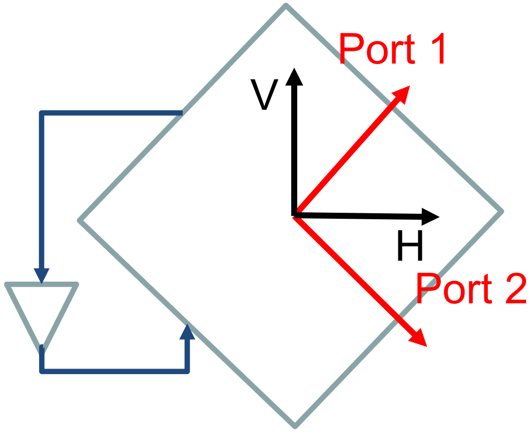


- The scattering matrix of the antenna and amplifier system can be related to the antenna and amplifier gains:

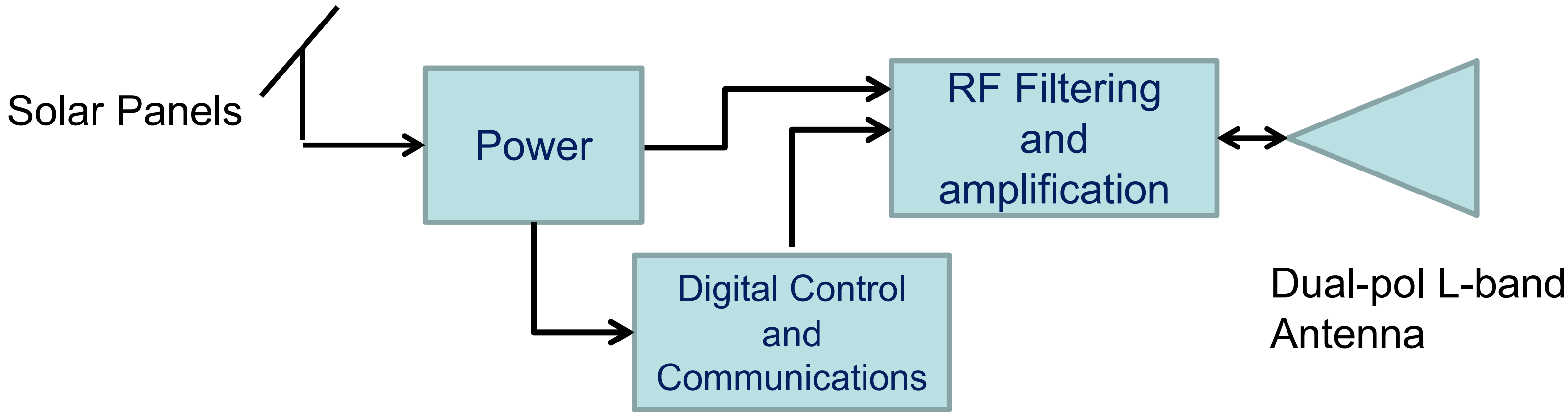
$$\sigma = \frac{\lambda^2}{4\pi} G_{Amp} G_{Antenna}^2 \quad S = \sqrt{\frac{\sigma}{4\pi}} \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}$$

- Rotating the antenna around its axis allows for radiometric calibration of all channels.

$$S^r = R S^o R^T = \frac{1}{2}\sqrt{\frac{\sigma}{4\pi}} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$



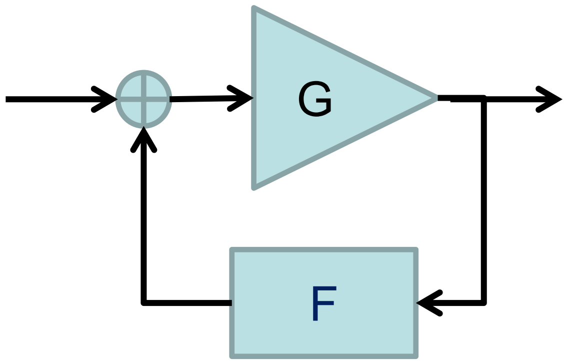
System Block Diagram



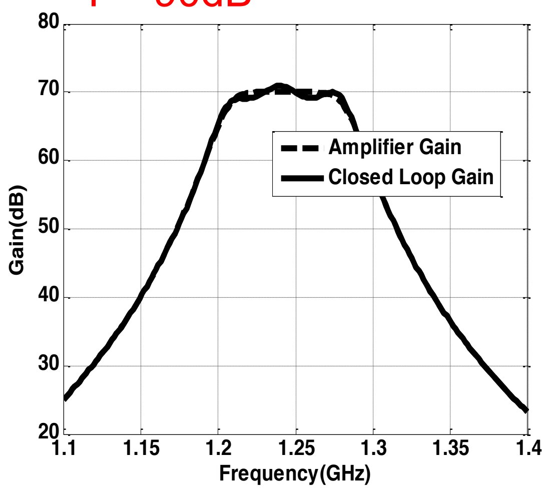
- Dual-Polarized antenna: receives the transmitted H and V pulses, amplifies and retransmits back both H and V.
- RF circuit provides a carefully-controlled 38-53 dB of gain, using Automatic Gain Control for stability
- Digital Control and Communications: measures system status and transmitted power for each overpass. Emails time-stamped data to calibration team.
- Power system: deep-cycle marine batteries, recharged with solar panels.

The leakage effect

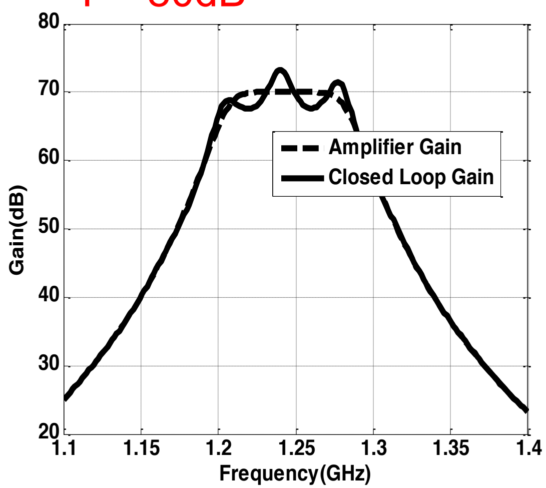
- The weak coupling between the transmit and receive antennas creates a feedback effect that limits the gain of the amplifier
- Total active gain = $\frac{G}{1-GF}$
- If the phase of GF varies severely with frequency the total active gain undergoes a ripple of $\frac{1+GF}{1-GF}$ over the operating frequency band.



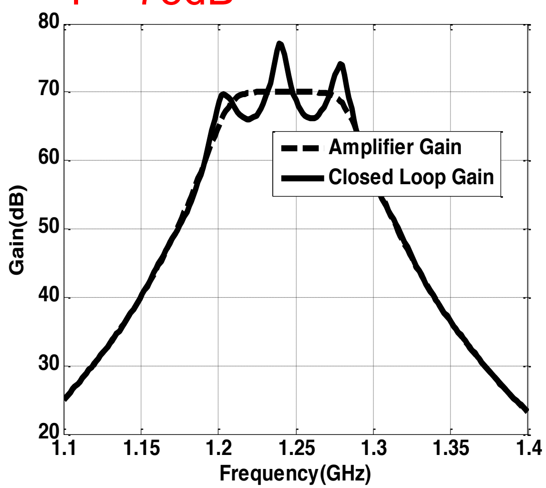
G=70dB
F=-90dB



G=70dB
F=-80dB

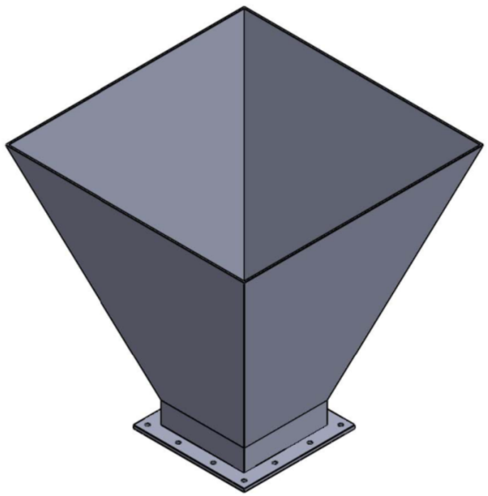


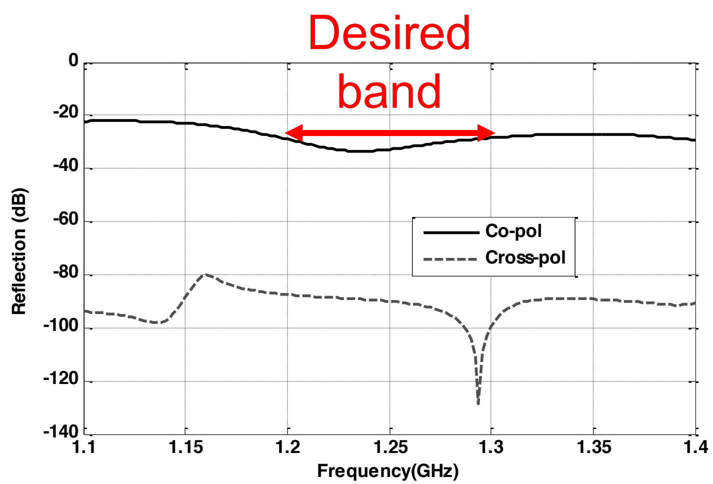
G=70dB
F=-75dB



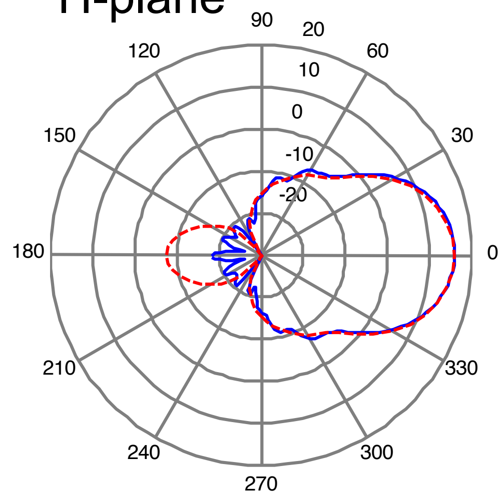
Antenna Design

- Design requirements
  - High gain of 16dB
  - Smooth gain within a 2 degree orientation accuracy (less than 0.1dB error)
  - Better than 30dB gain drop at 90degree from boresight to suppress ground reflection effects
  - The taper length is optimized to maximize the gain while keeping the size of the antenna small

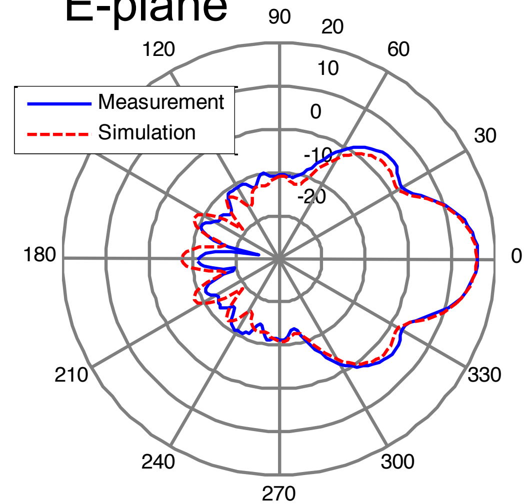




H-plane

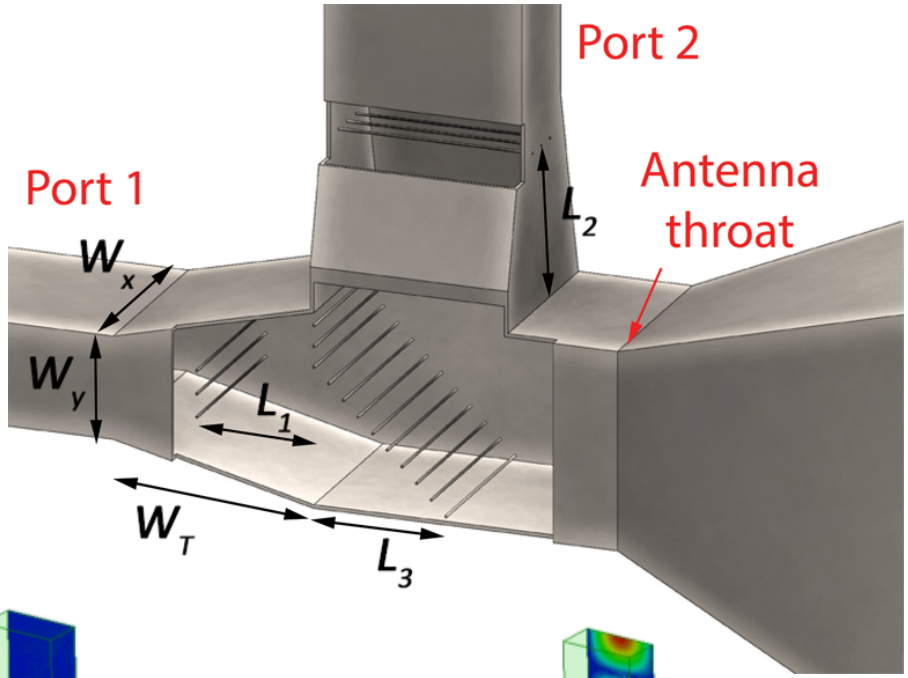


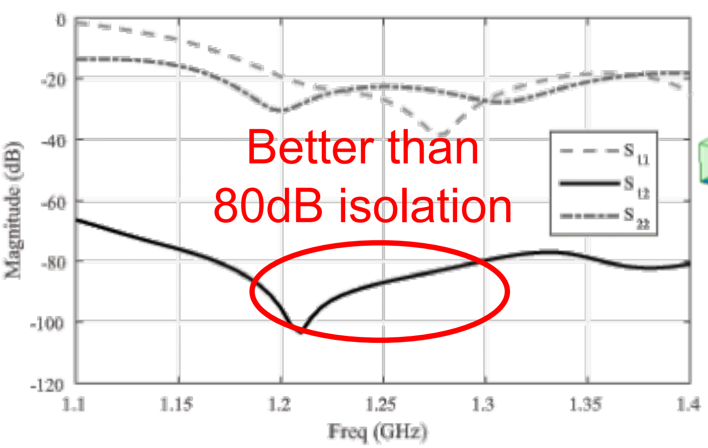
E-plane

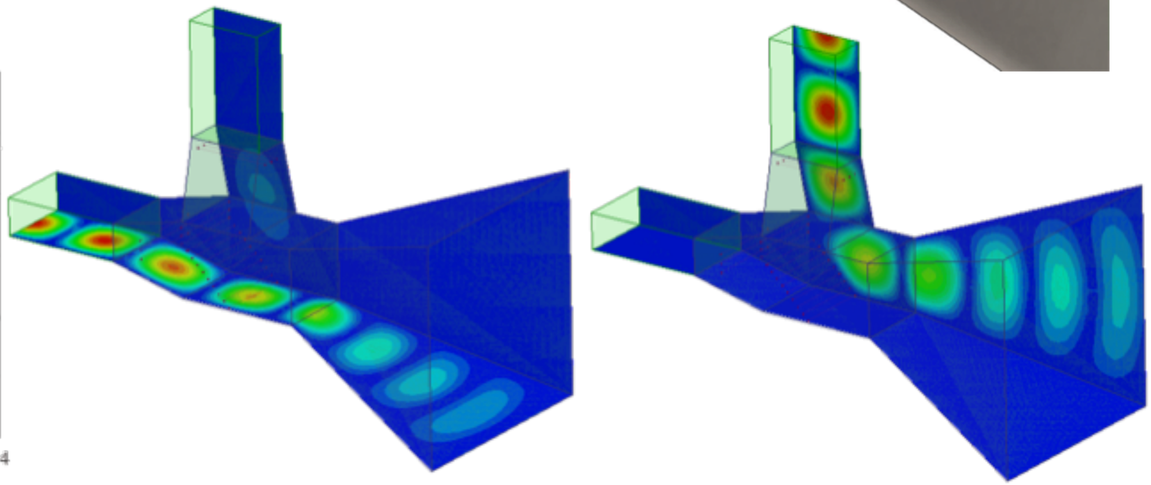


Precision OMT design

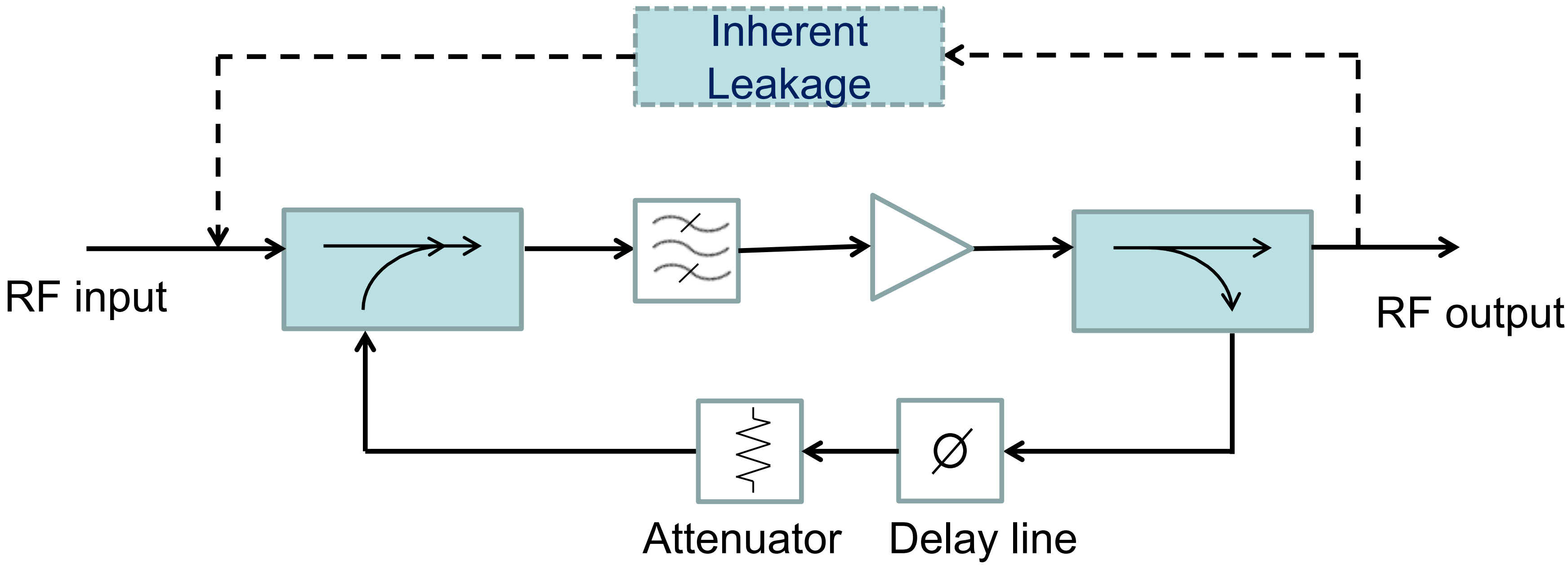
- Horizontal and vertical polarizations can be steered away into two different channels of a 3-way junction by carefully placing polarizing wires in the junction.
- The position of polarizing wires in optimized to achieve the best impedance matching and isolation between the two ports.







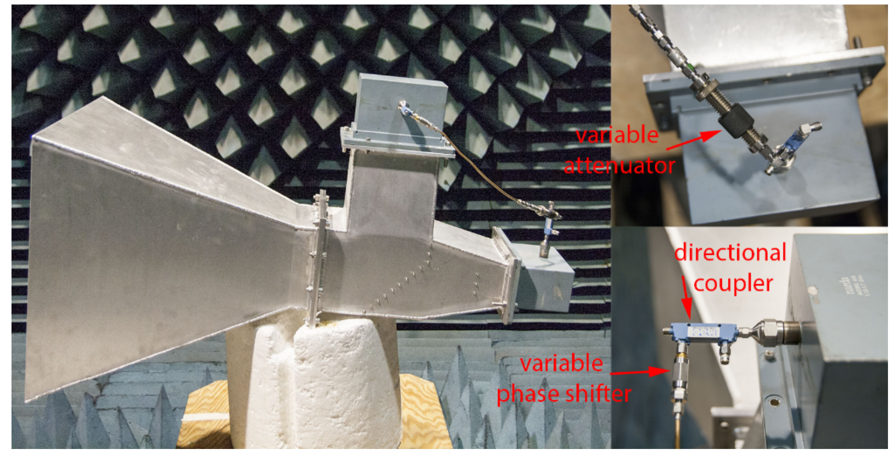
Leakage Cancellation Circuitry



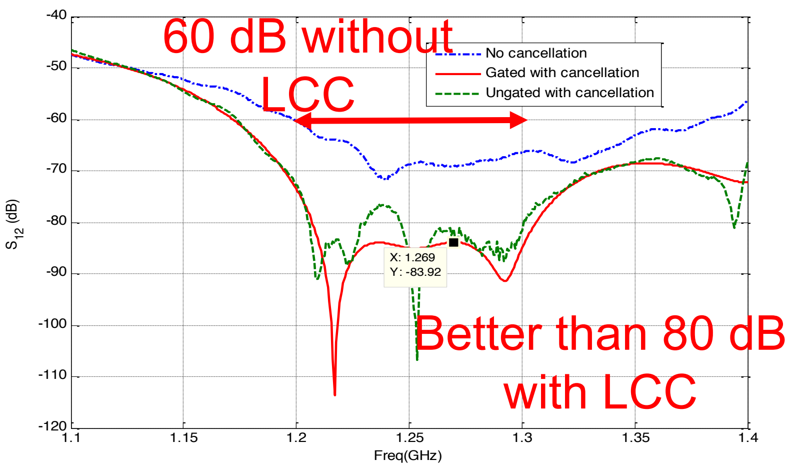
- The coupling between the two ports of the antenna can be reduced using a leakage cancellation circuit consisting of two directional couplers, a delay line and an attenuator.
- The output signal at the transmitter antenna is sampled, and is added to the received signal after the appropriate phase shift and attenuation such that it is out of phase with the leakage and close in magnitude.

OMT and Antenna Fabrication

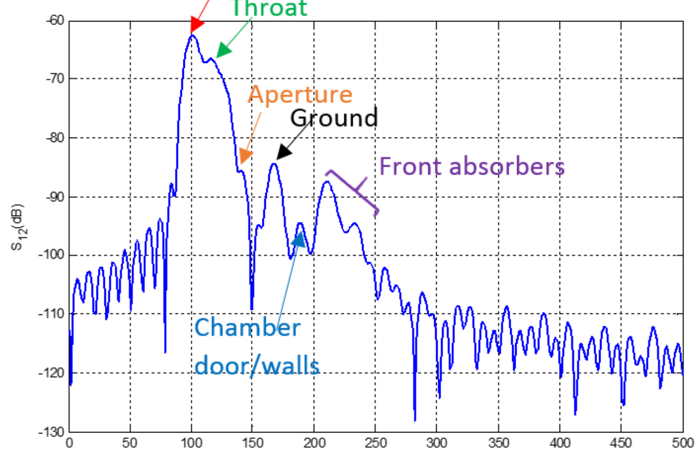
- The leakage between the transmit and receive antenna is due to reflections from multiple points inside the antenna. Unfortunately the reflection from the anechoic chamber absorbers is not negligible and therefore the RCS cannot be accurately measured inside.

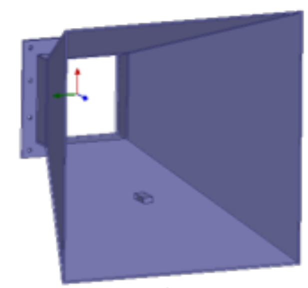


S21 Frequency domain



S21 Time domain

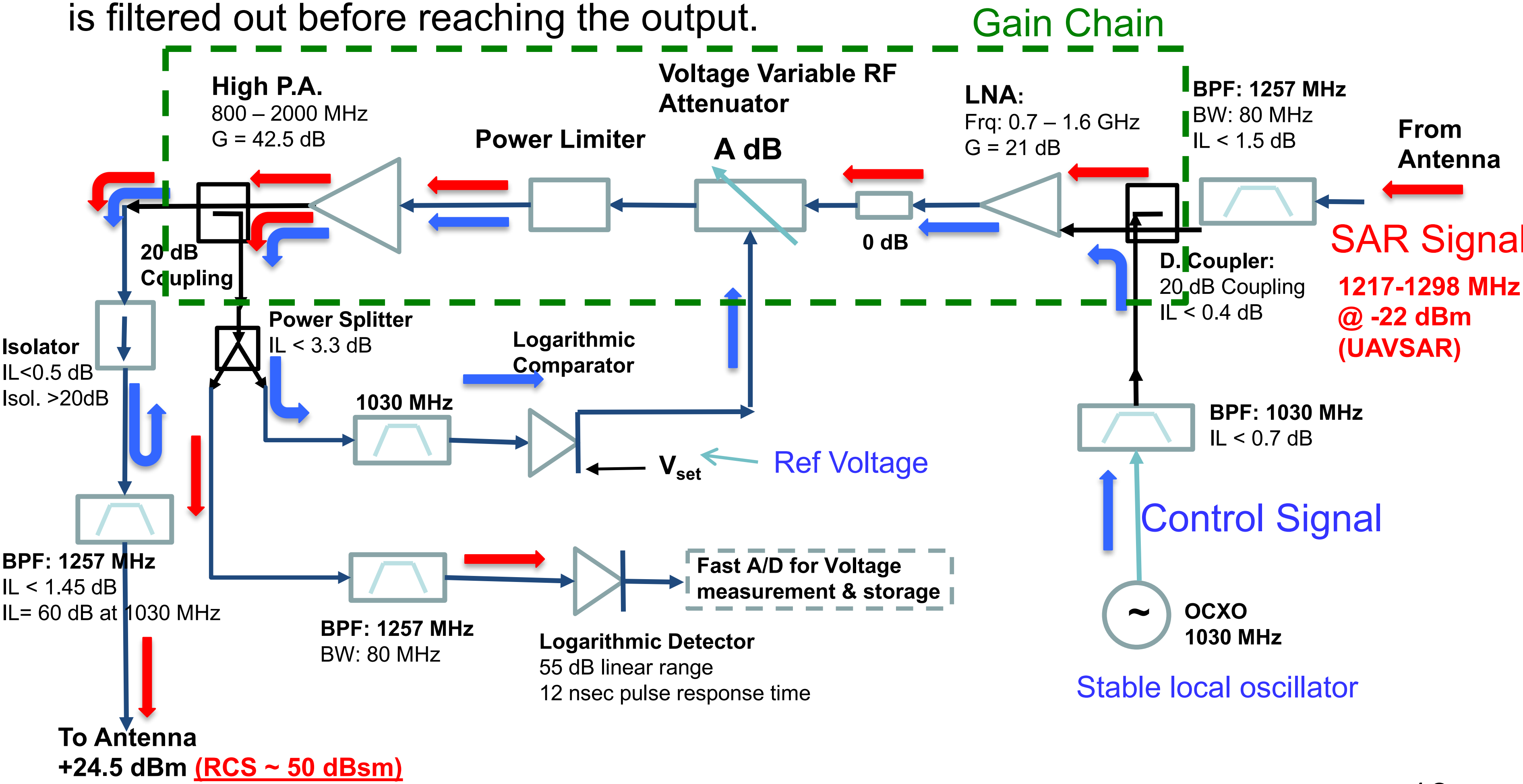




reflective perturbation

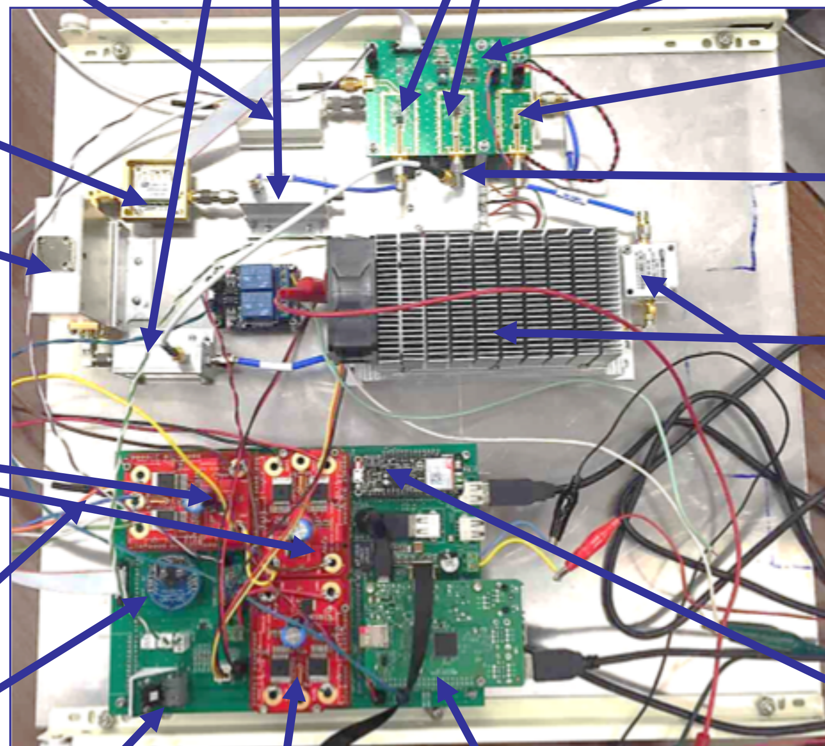
Revised Gain block

- The amplifier gain is controlled by injecting a stable source signal and adjusting a voltage controlled attenuator in real time using a feedback loop. The injected signal is filtered out before reaching the output.



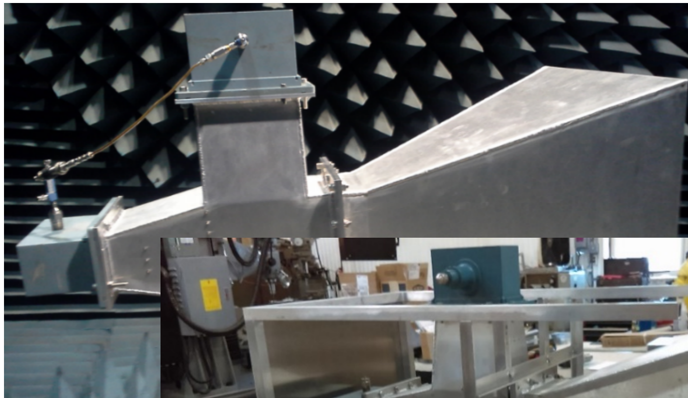
Radiation Laboratory

Final circuit layout



Mechanical Structure

- The antenna and OMT are fabricated using laser-cut aluminum sheets and are therefore lightweight and precise.



An

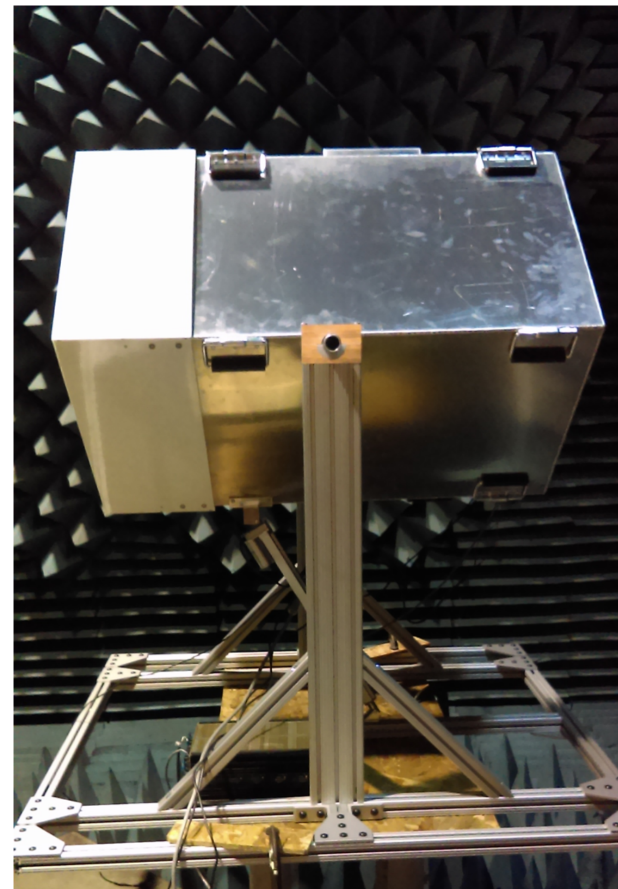
Su

Antenna Radome

Thermally Insolated cavity

Metallic enclosure

Internal circuitry and A/C unit



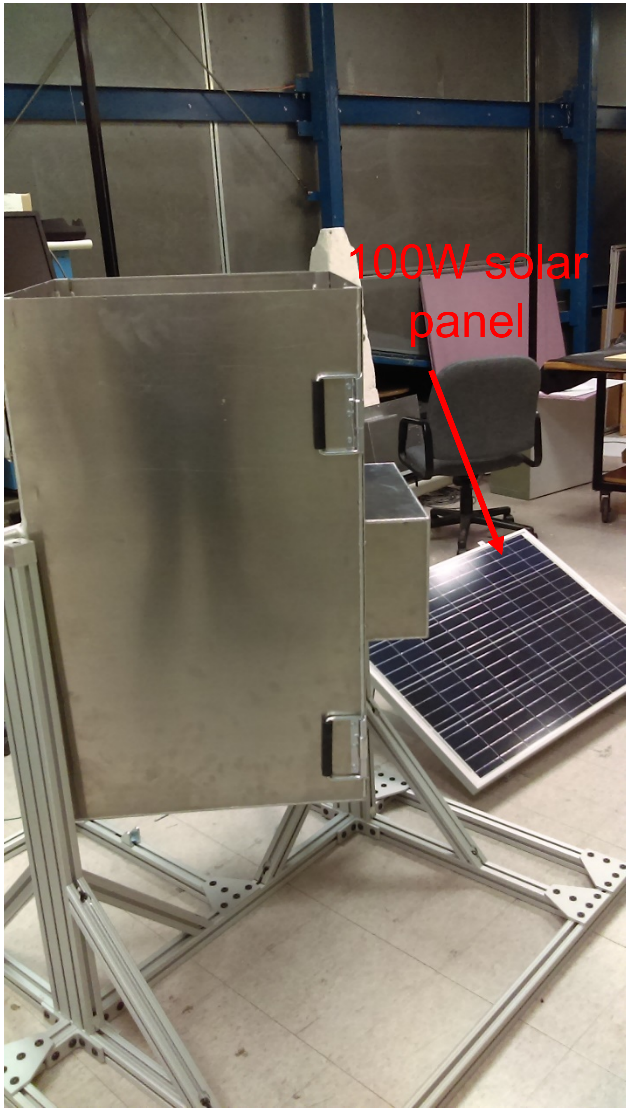
Specifications and Capabilities

Specifications:

- 80MHz BW at L-band.
- RCS settings: 40, 45, 50 and 55 dBsm
- 34 ns group delay
- Power: 28W for continuous operation
- Solar panel capable of producing up to 100W
- Deep cycle marine batteries capable of powering the system for 30 hours without charge
- Data sampling rate of 1.25 MSps
- Up to 32GB of memory for data acquisition

Capabilities:

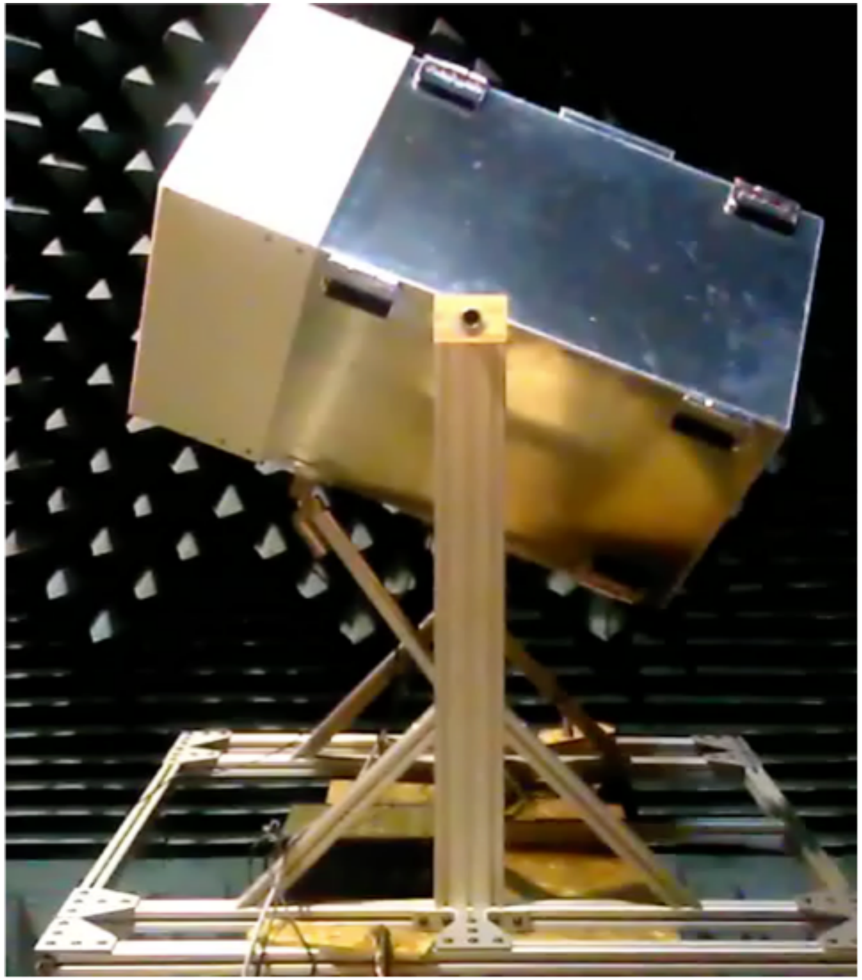
- Automatic inclination setting from 15° to 75°
- Comprehensive system check and diagnostics
- Remotely controllable through SMS and 4G interfaces
- Data compression and collection through a 4G mobile network
- Web programmable automatic wake-up and shutdown.



Absolute Calibration Overpass Process

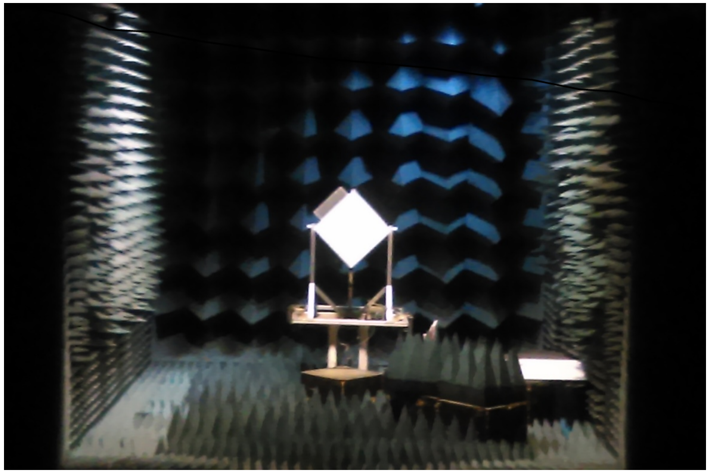
Sequence of events:

- Step 1: The real-time clock triggers the computer to turn on about 30 minutes before the scheduled overpass
- Step 2: Computer downloads the overpass information (i.e. required RCS, inclination angle, etc.)
- Step 3: Computer powers-on the calibration target circuitry and adjusts the parameters.
- Step 3: Computer waits for calibration circuit to reach a stable temperature.
- Step 4: Computer waits for the overpass to complete according to the downloaded schedule.
- Step 5: The High-speed sampler records the power envelope of the received SAR signal
- Step 6: Compressed data, including low-speed sensor readings such as temperature, tilt, etc, is emailed via 3G modem.
- Step 7: Computer sets the next wake-up time, and powers down.

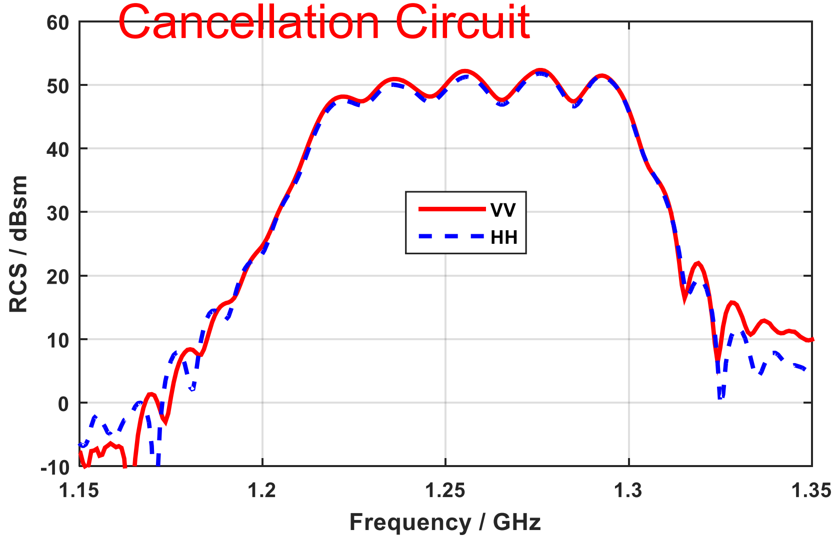


Measurement Setup

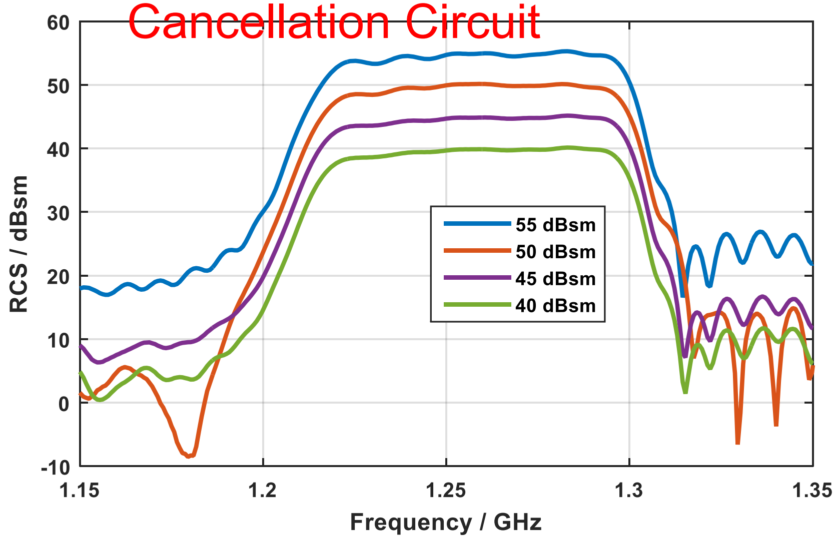
- The initial RCS measurement is performed in our anechoic chamber.
- There are several ripples in the passband as a result of coupling between the two ports.
- The ripples are significantly reduced using the leakage cancellation circuit.



Without Leakage Cancellation Circuit

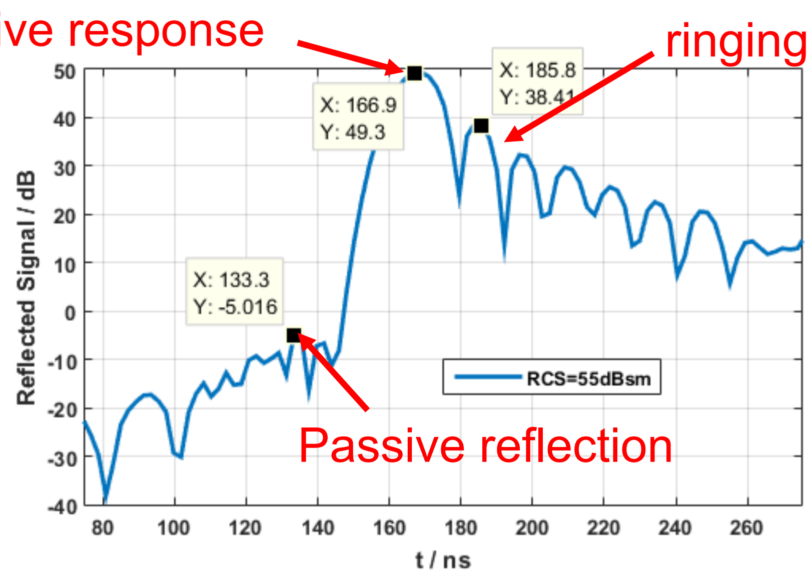


With Leakage Cancellation Circuit

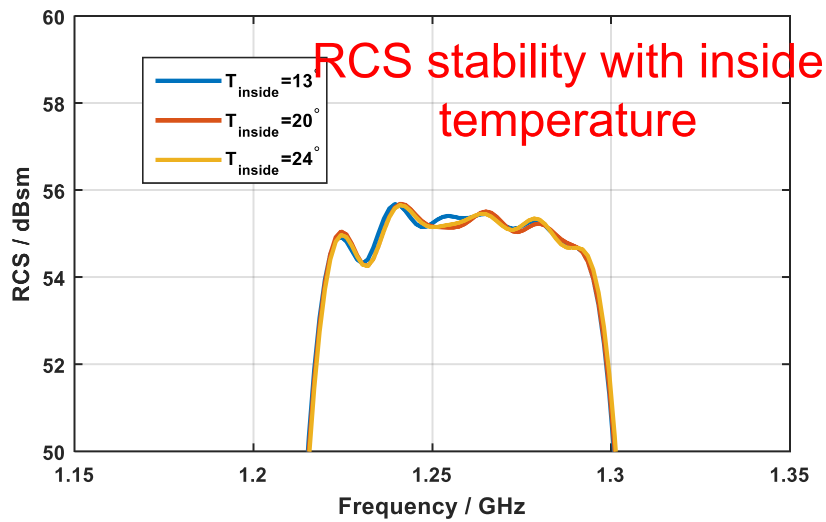


Phase and stability analysis

- The impulse response of the PARC can be obtained through Fourier analysis.
- Because of the delay in the system due to cables and filters, the active response of the PARC appears with a delay of 34 ns after the passive reflection from the PARC structure.



- The temperature inside the insulated cavity is controlled by the PARC computer to an accuracy of ±1 °C at all times.
- Nevertheless, the RCS of the PARC is very stable (up to ±0.1 dBsm) over a reasonable range of internal temperatures.



Conclusion

- A polarimetric active radar calibrator with RCS of 40-55 dBsm and 80 MHz bandwidth was designed and fabricated for calibration of airborne and space borne L-band SARs.
- A leakage cancellation technique as well as antenna perturbation technique was used to reduce the leakage between the transmit and receive antennas
- A stable gain amplifier with variation in gain of less than 0.1dB was fabricated and used with the PARC
- The RCS of the PARC was characterized in an anechoic chamber and was shown to produce a very reliable response in several different operating conditions.