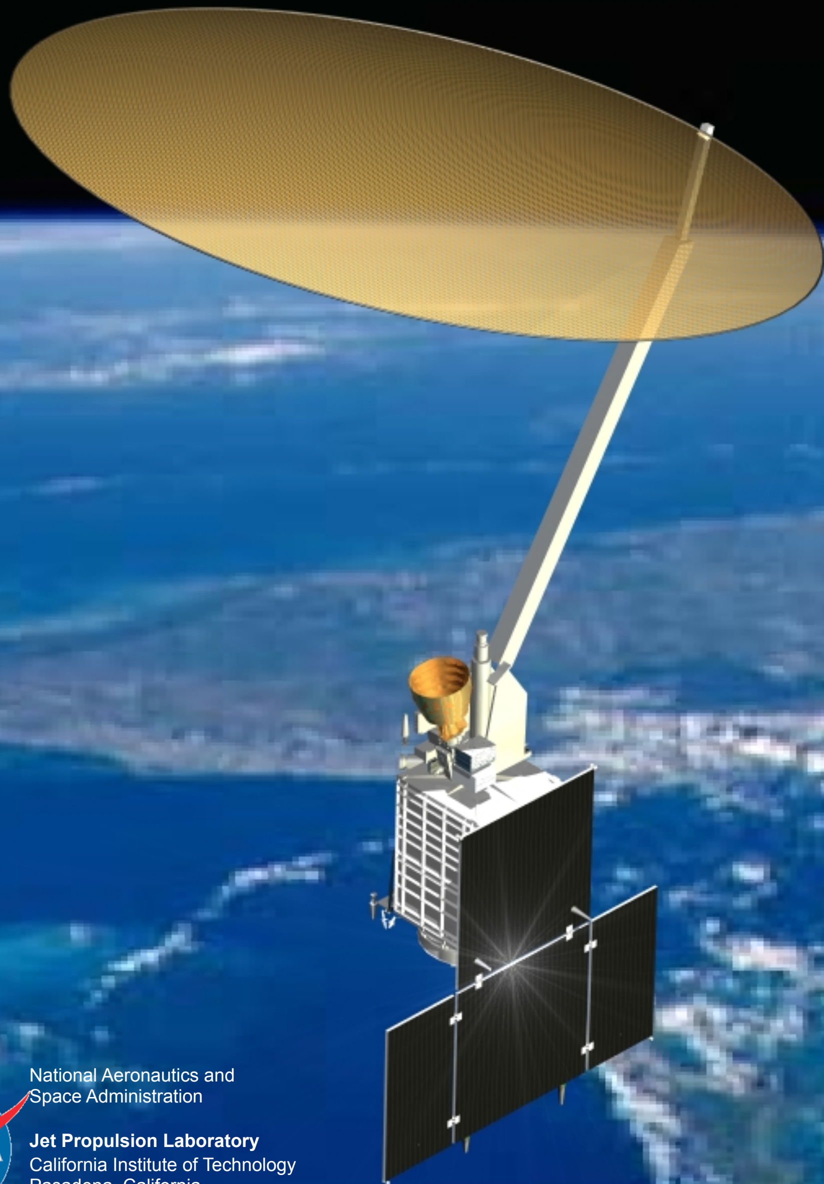
The Soil Moisture Active and Passive (SMAP) Observing System



CEOS Workshop

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Pasadena, CA

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National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Outline

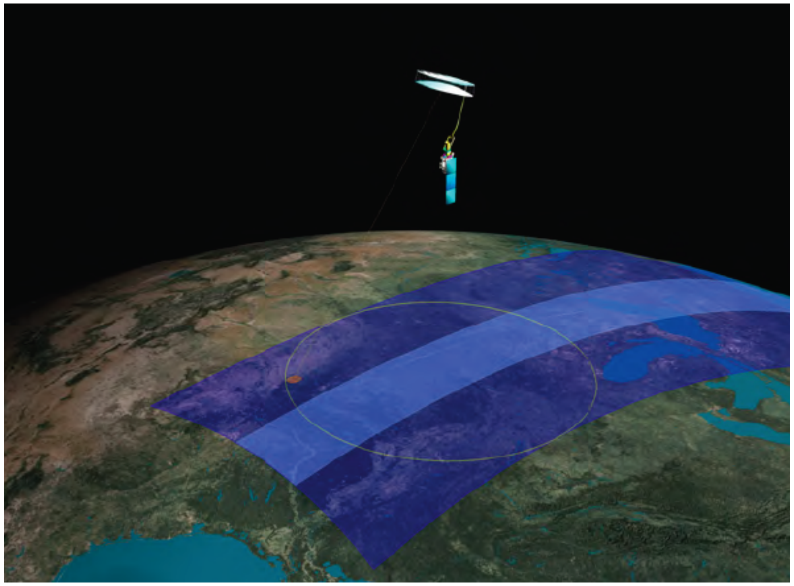
- Key driving science requirements for SMAP mission.
- SMAP observation concept.
  - Real-aperture radiometer
  - High resolution radar product
- SMAP instrument and data product key features.
- Calibration Summary
  - RFI
  - Error budget

SMAP Mission

- The SMAP mission will measure global soil moisture and surface freeze/thaw state from space.
  - Soil moisture products at 10 km resolution, 4% volumetric accuracy.
  - Freeze-thaw products at 3 km resolution.
  - 3-day global coverage.

- SMAP mission currently in Phase A, with a planned launch date in 2014.

- SMAP measurement approach:
  - Passive L-Band radiometer (provided by GSFC) with 40 km resolution
  - Active L-Band Synthetic aperture radar (provided by JPL) with 3 km resolution
  - Shared-aperture rotating mesh antenna.
  - JPL in-house developed S/C.



Level 2 Science Requirements for Instrument Measurements

Coverage/Revisit

- Average revisit time of 3 days for soil moisture globally.
- Morning observation time for soil moisture.

Incidence Angle

- Constant incidence angle for measurement between 35° - 50°.

Radiometer

- Frequency: L-Band (1.4 GHz).
- Polarizations: V, H, U.
- Resolution: 40 km.
- Relative Accuracy: 1.3 K.

Radar

- Frequency: L-Band (1.26 GHz).
- Polarizations: VV, HH, HV (or VH).
- Resolution: 3 km
- Relative measurement accuracy < 1 dB for each channel at 3 km resolution.
- Accuracy requirements met for minimum σ_o of -25 dB.

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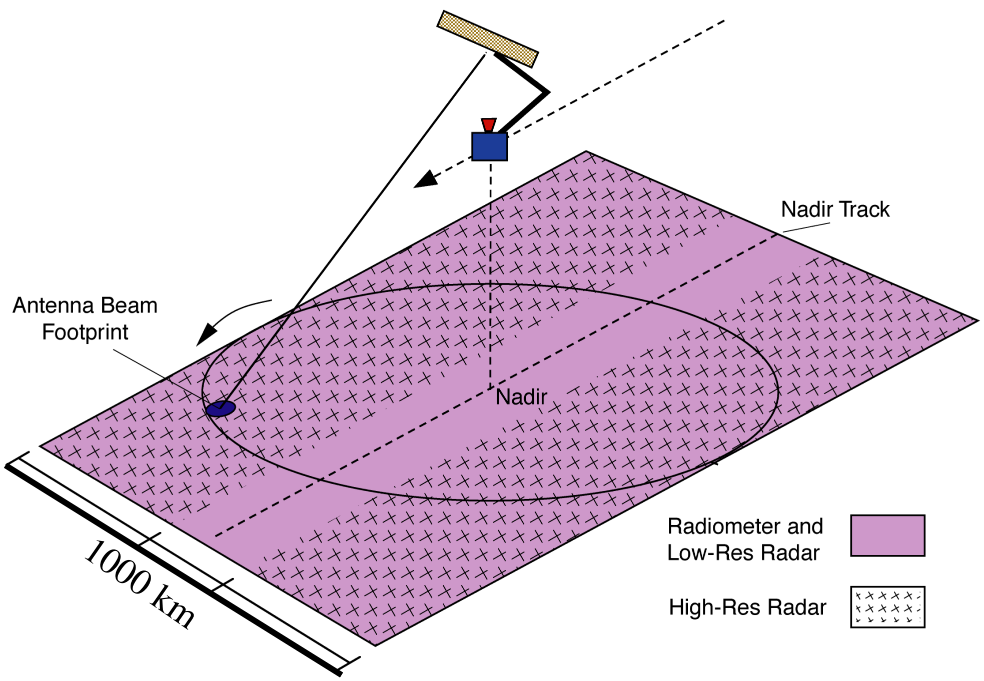
SMAP Instrument Key Features

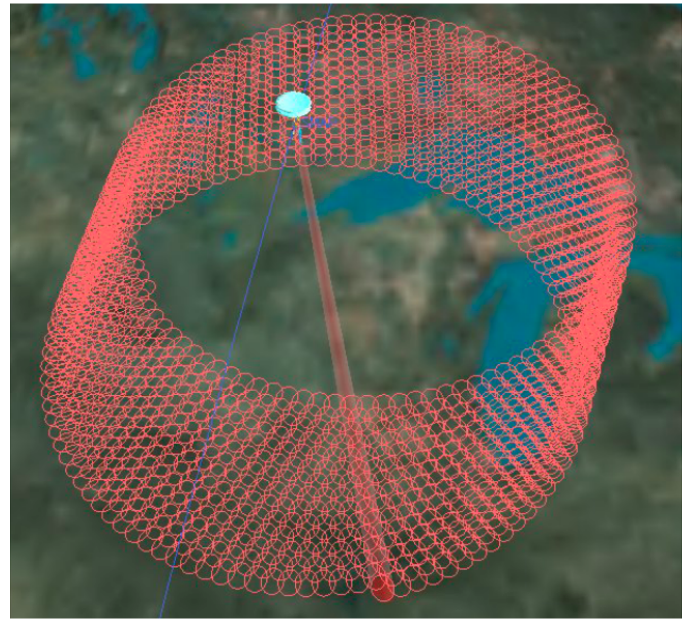
- To meet requirement for 3-day revisit time at AM local time…
  ⇒ *1000 km swath at 670 - 680 km dawn/dusk sun-synchronous orbit.*
- For wide measurement swath of combined L-Band active and passive measurements…
  ⇒ *Conically scanning reflector antenna.*

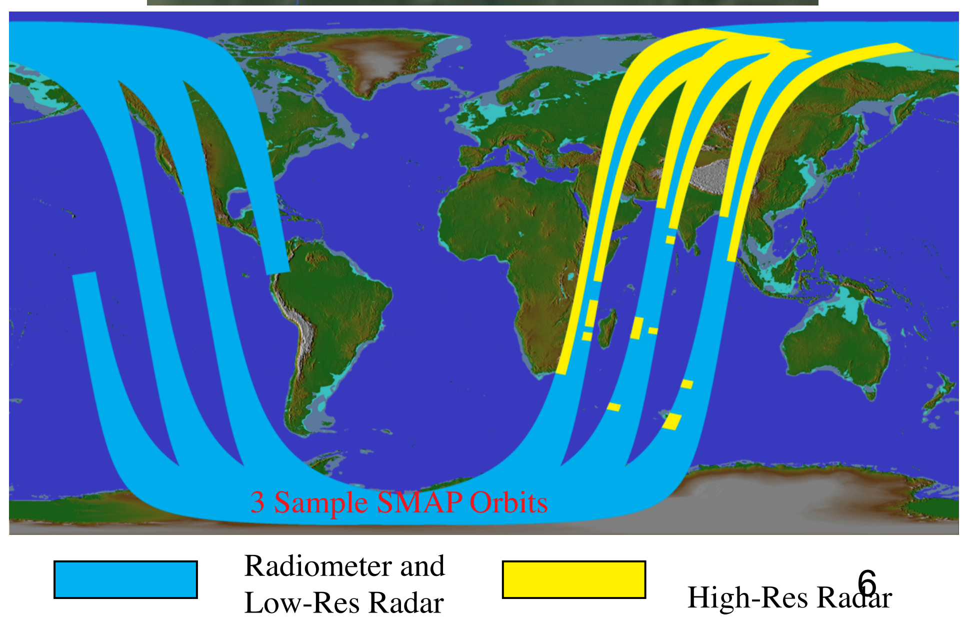


- To achieve L-Band passive resolution of 40 km and and active resolution of 3 km …
  ⇒ *6 meter aperture antenna*
  ⇒ *14.6 rpm rotation rate*
  ⇒ *Real-aperture radiometer*
  ⇒ *Synthetic-aperture radar processing*
- Incidence angle
  ⇒ *Near-constant 40 deg incidence angle*

SMAP Mission Concept: Data Collection

- Radiometer data collected continuously:
  - Entire orbit.
  - All 360 degrees of antenna scan (both forward and aft).
  - Capability for periodic "cold sky" looks.
- High-resolution SAR data:
  - Collected only on forward arc of scan
  - Collected only on morning portion of orbit
  - Collected only over land (using built-in land mask file).
- "Bonus" radar low-resolution, real aperture data
  - Collected continuously like radiometer data; entire orbit, 360 deg

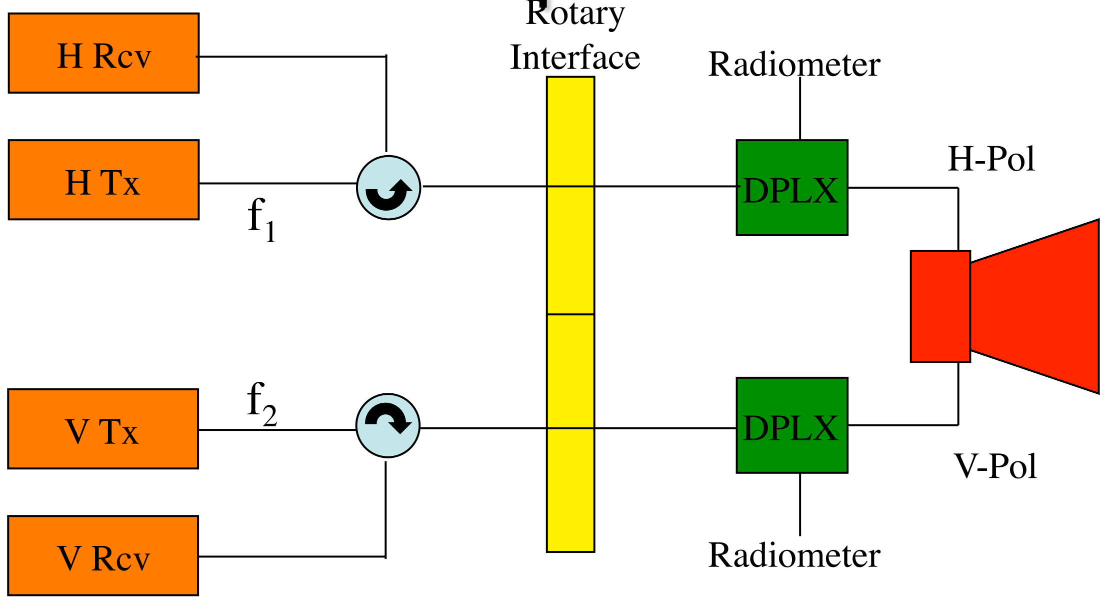


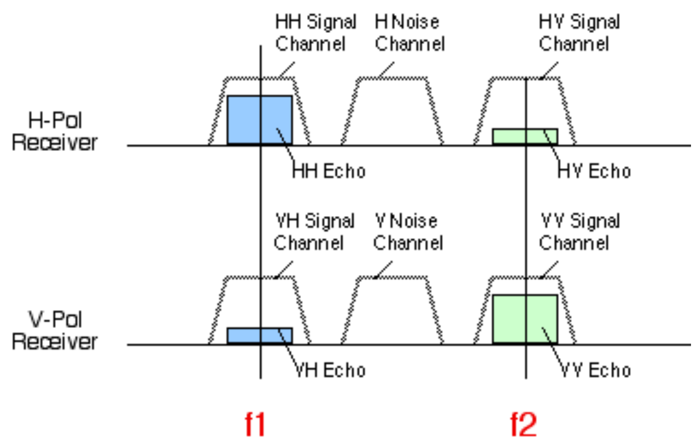


SMAP Radar Concept

Radar Design Characteristics

- Peak transmit power (at output of SSPA unit): 200 W
- PRF: Nominally 3.5 kHz. Adjustable +/- 3% by look-up table once per antenna rotation.
- Pulse length: 40 μs
- Pulse modulation: Linear chirp at 1 MHz
- Channels (HH,VV,HV, noise-only)
- Timing: Simultaneous transmit and receive on H and V ports at two separate frequencies. Tunable over L-Band 80 MHz allocation.
- Cross-Pol Channel: Additional detection channel in HH receiver change at other frequency
- Each of three channels paired with "noise-only measurement





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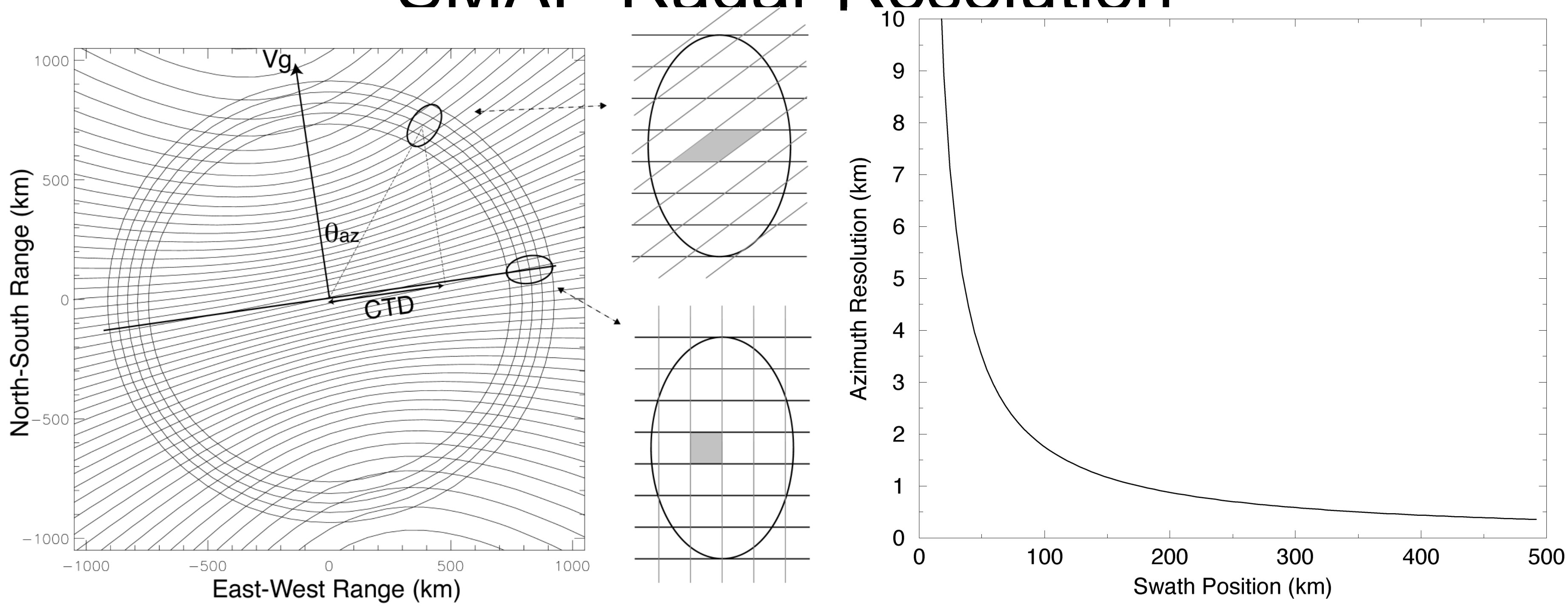
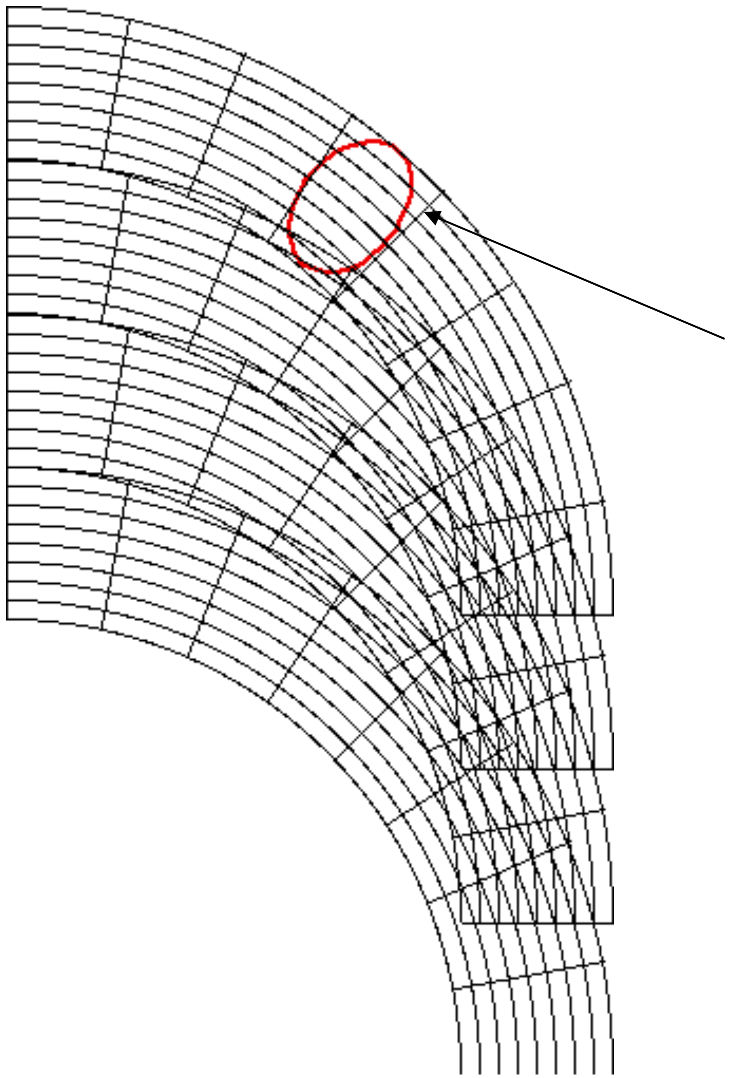
SMAP Radar Resolution



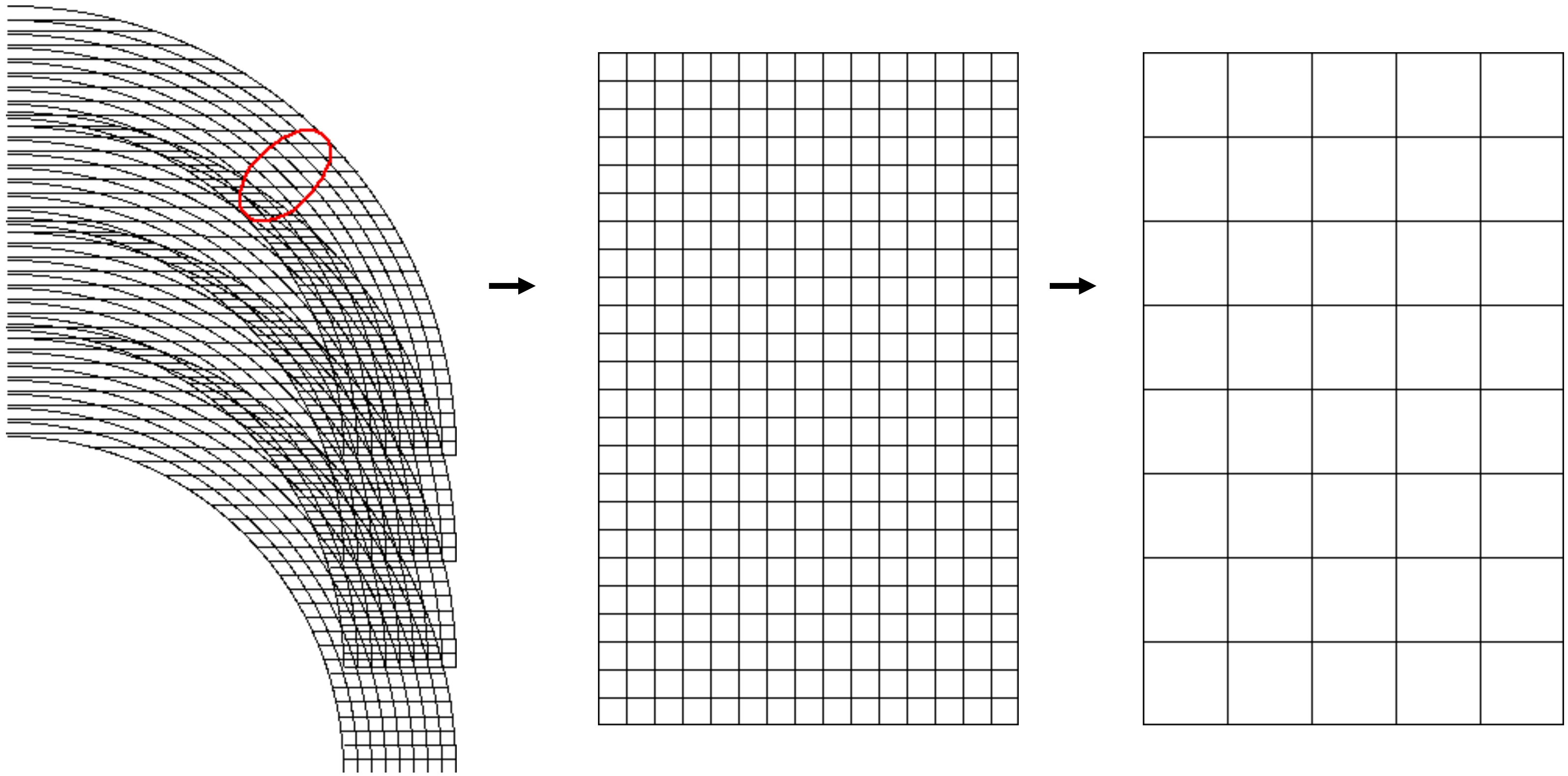
- Unfocused SAR processing.
- Azimuth resolution, and number of azimuth looks, driven by unique scanning geometry.
- High-resolution SAR data that meets science requirements for resolution and accuracy is over outer 70% of the measurement swath.

Low-Resolution (Real Aperture) Products



- Time ordered, 6 km × 30 km range "slices" through antenna footprint (resolution and grid spacing not shown to scale).
- Somewhat similar to SeaWinds Ku-Band backscatter product.

High-Resolution Radar Data Product



Single-Look, Time-Ordered Data (internal use only)

- Native resolution: 250 m in range, 400+ m resolution in azimuth.
- Each resolution element constitutes one independent "look" at surface.

1 km Gridded, Re-Sampled Data (L1C)

- Data resampled and posted on 1 km grid, resolution may still be > 1 km near nadir.
- Each 1 km grid cell now has multiple "looks" at surface, decreased measurement variance.

3 km (or whatever) Average Data

- 1 km posted product can be averaged up to 3 km, 10 km, etc. by investigators (using nested grids).
- Improved number of looks (and hence precision) at expense of spatial resolution.

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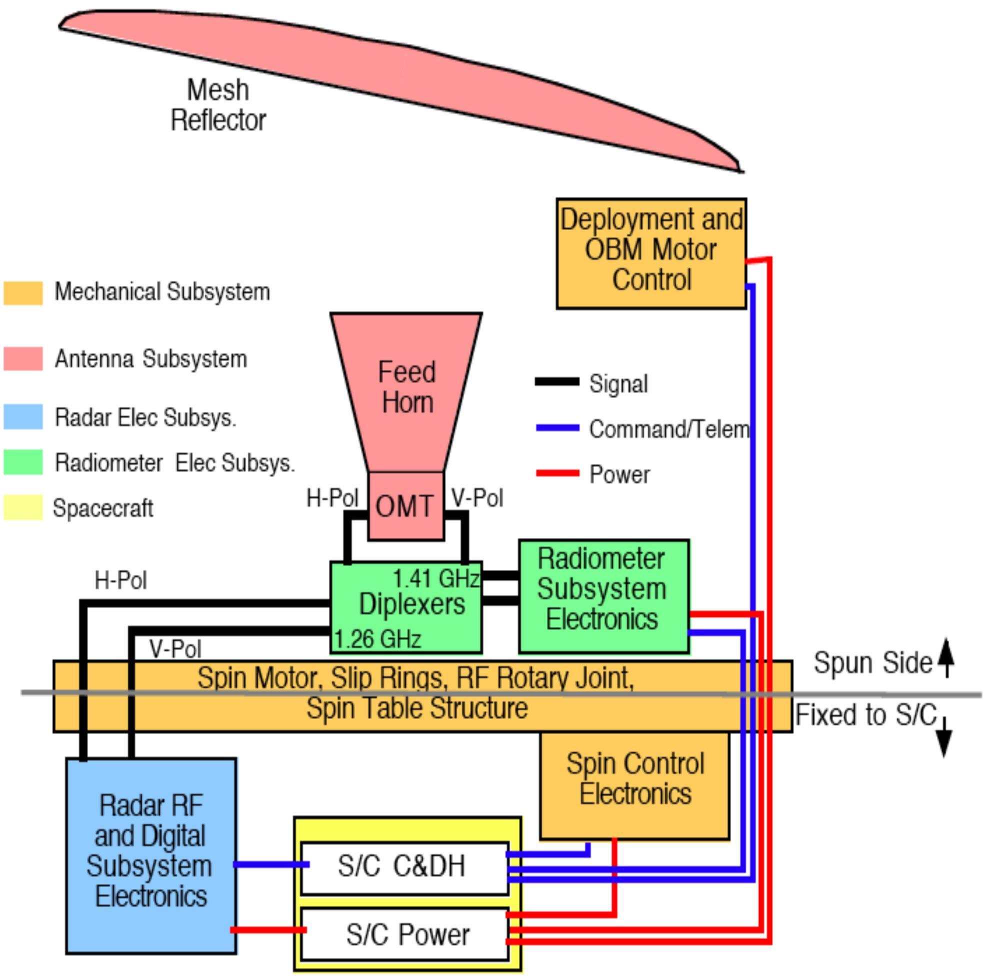
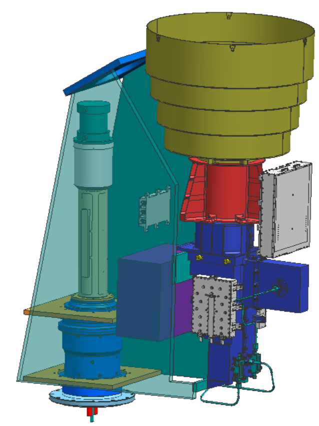
SMAP Instrument Concept

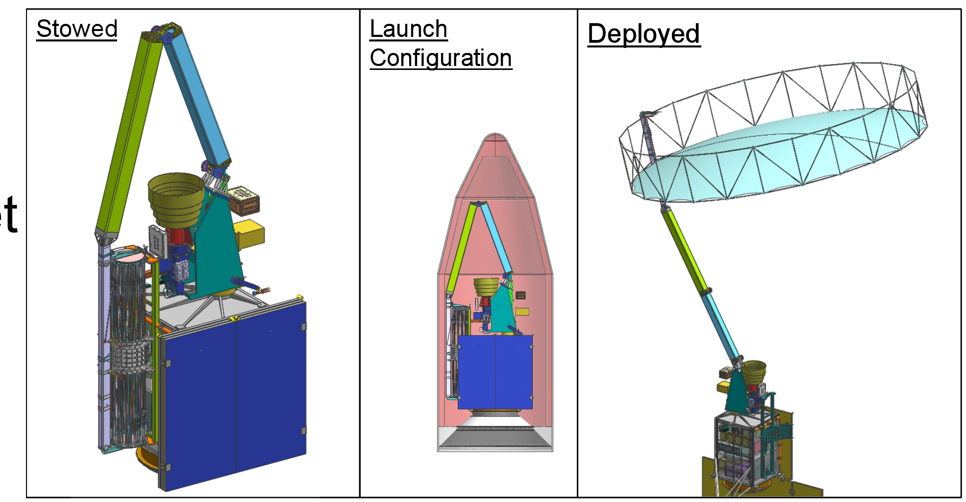


- Antenna Subsystem
  - Deployable mesh antenna, boom
  - Shared L-Band feed horn
  - Spin mechanism, slip rings
- Radar Electronics Subsystem
  - Includes RF interface from despun to spun side
- Radiometer Electronics Subsystem
  - Includes diplexers to separate radar and radiometer frequencies



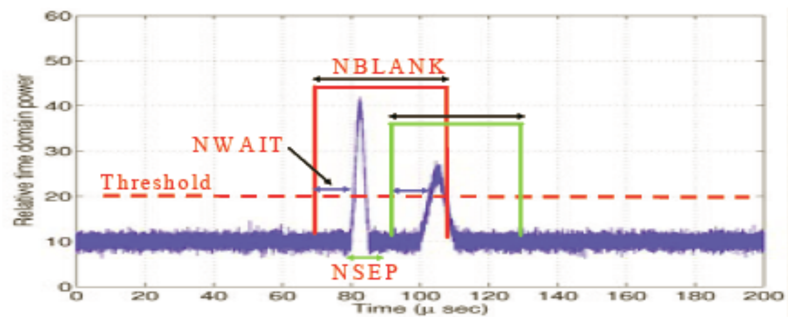
Mesh Reflector

- Key antenna requirements
  - Polarization: Dual-pol L-Band feed
  - Beamwidth: < 2.7 deg at 1.26 GHz
  - Beam Efficiency: 90% at 1.4 GHz
  - Off-nadir look angle: 35.5º
  - Mesh Emissivity: < 0.004 at L-Band
  - Pointing: 0.3º stability, 0.1º knowledge
- Antenna concept uses deployable mesh technology demonstrated in space for communications applications
- Antenna concept has been demonstrated in simulations to meet requirements while rotating.

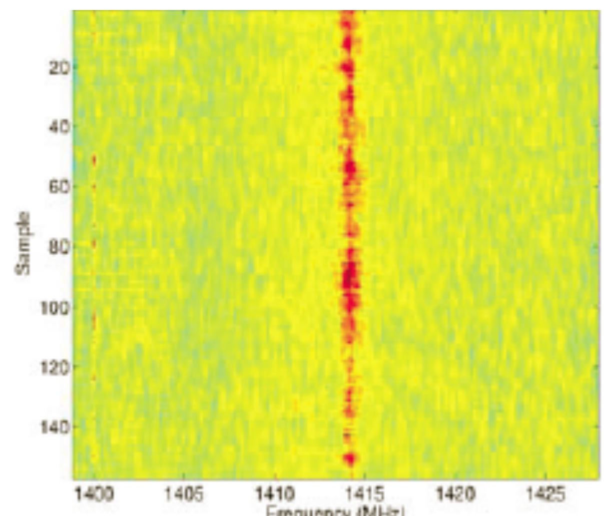


RFI: Passive Radiometer

- Radiometer operates in L-Band "protected band", but might see leakage from adjacent bands.
- Mitigation Approach: Planning on a variety of techniques with impact to HW and ground processing.
- Detection
  - Time: look for pulses
  - Frequency: look for carriers
  - Signal statistics: test for Normality
- Mitigation
  - Remove corrupted time/frequency bins
- Baseline instrument design
  - Time-domain detection and blanking
  - Digitally implemented frequency sub-banding and Kurtosis check being evaluated for inclusion in radiometer design



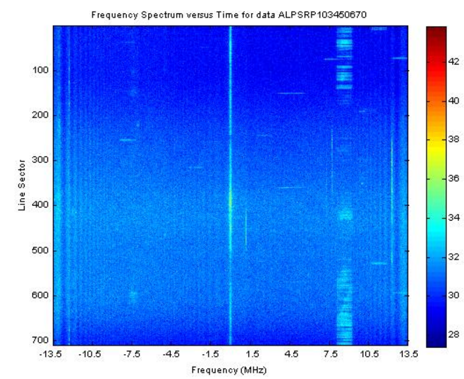
Time domain example
(pulsed RFI)



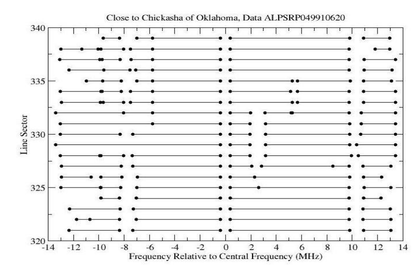
Time-frequency example
(narrow-band RFI)

RFI: Active Radar

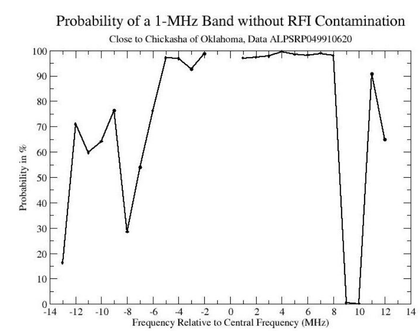
- Radar operates in “shared band” with lots of interferers.
- RFI mitigation strategy:
  1) Avoid “bad” portions of spectrum by tuning carrier according to pre-loaded table.
  2) Filter raw data in ground data processing if RFI is present.
- Characterize the L-Band RFI environment with ALOS/PALSAR data
  - Examine data close to the sites of interest in US and international for all available times.
  - Look for frequency bands which are consistently RFI free.
  - Calculate the probability of being RFI free as a function of frequency.
- Baseline Mitigation Strategy
  - Carrier frequency tunable over entire 80 MHz band
  - Large dynamic range to accommodate strong emitters
  - Residual RFI to be detected and removed in ground processing



Time of Data Take



Frequency band without RFI Contamination, sectors 320 to 340 are shown



Probability of a 1-MHz band without RFI Contamination for the whole data set

Radar Measurement Accuracy Budget

Error Source	Allocation (dB)
Kpc	0.72
Calibration	0.35
Contamination Terms (RFI, ambiguities, etc.)	0.40
Total (RSS)	0.9
Requirement	1.0
Margin (lin)	0.1
Margin (rss)	0.43

- Radar relative accuracy budget is focused on determining *changes* in backscatter cross-section.
- Kpc is purely random term related to radar speckle and thermal noise and is driven by
  - Number of looks
  - SNR
- Radiometric calibration is determined primarily by
  - Knowledge of *changes* in transmit power and receiver gain.
  - Knowledge of *changes* in system RF losses.
  - Knowledge of pointing *changes* (primarily in elevation)
- Dominant contamination effect expected to be from RFI.

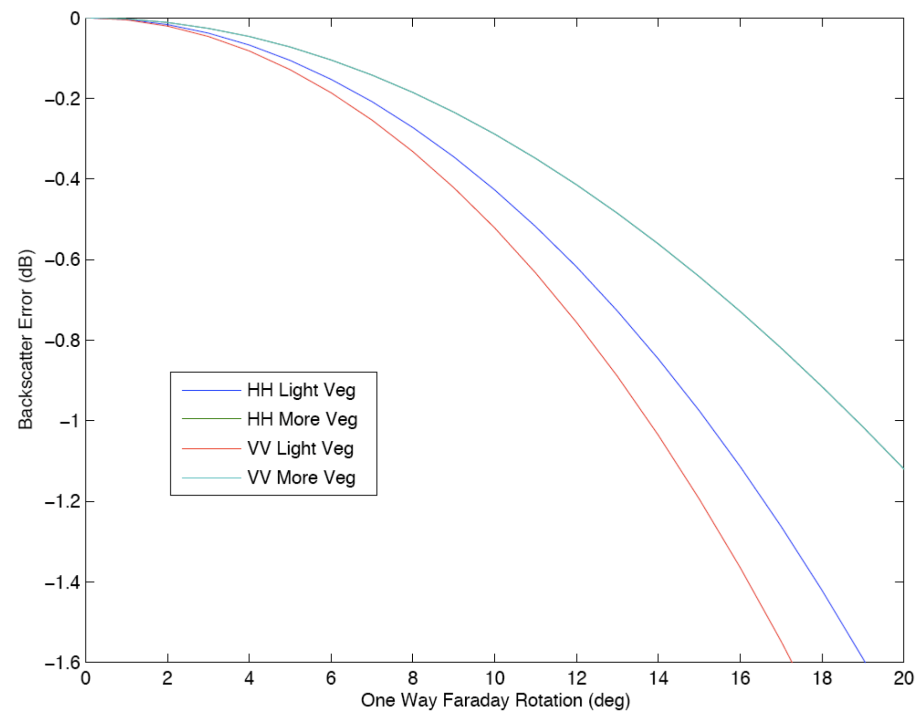
Radiometer Measurement Accuracy Budget

Error Source	Allocation (K)
NEΔT	0.57
Antenna pattern	0.44
Mesh emissivity	0.31
Gain, offset uncertainty	0.4
Faraday rotation	0.2
RFI	0.1
Total	1.1
Requirement	1.3
Margin (lin)	0.2
Margin (rss)	0.7

- NEΔT is set by front-end losses (3.2 dB), integration time (fore+aft), & bandwidth.
- Antenna pattern errors include instability of main beam efficiency; uncertainty in solar, sidelobe, space, and cross-pol contributions.
- Mesh emissivity is due to uncertainty in emissions and in gain.
- Gain & offset uncertainty is due to thermal fluctuation & finite time for internal calibration.
- Faraday rotation: residual remains after using 3rd Stokes to correct for it.
- RFI allocation is residual after mitigation.
- Total is found by adding mesh and gain, offset errors, then RSSing this with everything else and dividing by main beam efficiency (91%).

Faraday Rotation

- L-Band data susceptible to errors due to Faraday rotation (FR).
- FR a function of TEC and viewing geometry.
- Baseline measurement strategy is to use only 6 AM measurements to generate soil moisture.
- Radiometer: U-channel used to compute and apply FR correction
- Radar: For AM measurements, FR is relatively small (< 6 deg 90% of time) and results in small radiometric error (< 0.2 dB) which is likely correctable to better than 0.1 dB with coarse a priori knowledge of TEC.



Conclusions

- SMAP system is combined L-Band radar/radiometer for the measurement of soil moisture and surface freeze/thaw state.
- SMAP uses shared-aperture conically scanning deployable mesh antenna to achieve wide measurement swath, required spatial resolution.
- SMAP utilizes proven technologies in a unique way to meet science requirements.