National Aeronautics and Space Administration

RFI Mitigation and Detection for the SMAP Radar

Samuel Chan, Mark Fischman, and Michael Spencer,

Jet Propulsion Laboratory, California Institute of Technology

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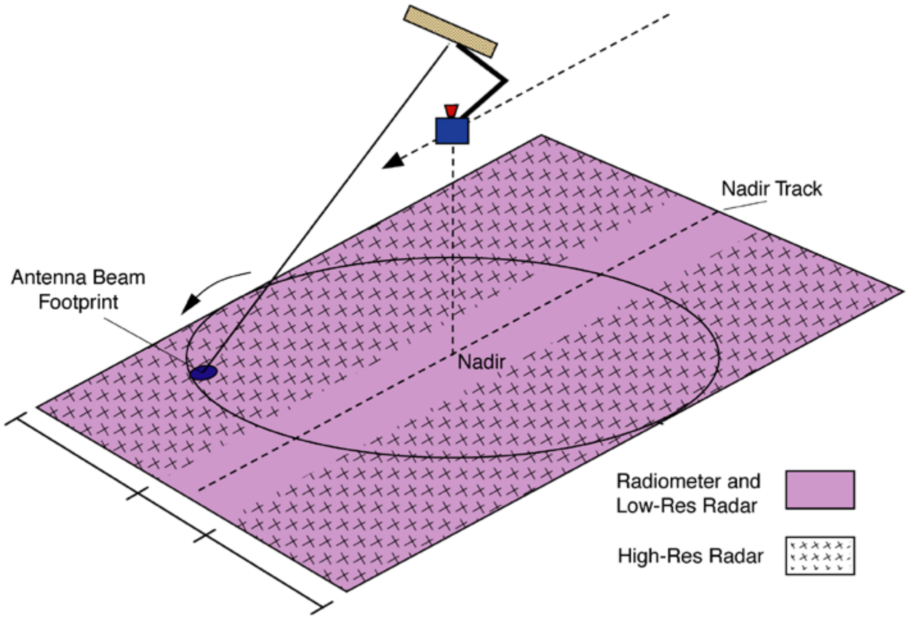
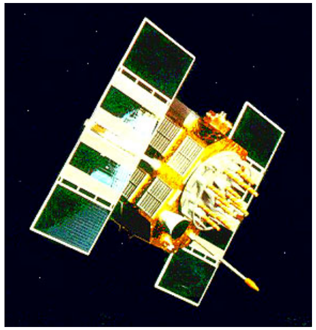
SMAP: Objectives and Requirements

- Instrument Concept: Radiometer and radar share rotating 6 meter diameter reflector antenna.
- Antenna Beam: 13.0 rpm rotation rate, 40 deg incidence angle.
- Orbit: 685 km, sun-synchronous, 6 pm LTAN.

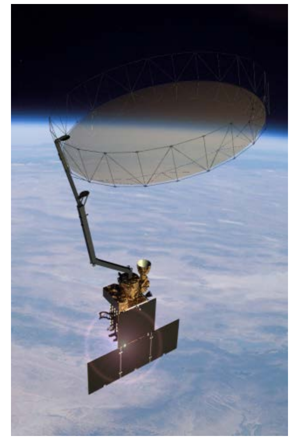


- Scientific objectives of SMAP: measures and monitors changes of the global soil moisture and freeze/thaw state
- Requirements on radar measurements: For co-pol data, the uncertainty from all sources is 1.0 dB or less defined at 3 km spatial resolution for $\sigma_0 > -25$ dB
- Error allocated of RFI: RFI shall not contribute more than 0.4 dB in an error in the backscatter cross-section
- RFI has been identified as one of the biggest risks to project success

SMAP Radar RFI



- Radio navigation signals from multiple satellite constellations are broadcasting continuously.
  - GPS
  - GLONASS
  - COMPASS
  - GALILEO



- Long-range radiolocation radars. Relatively narrow-band pulsed systems.
  - FAA (ARSR, CARSR)
  - DoD (FPS series)
  - Other U.S./Canada radars in data base.
  - Similar radars around the world.

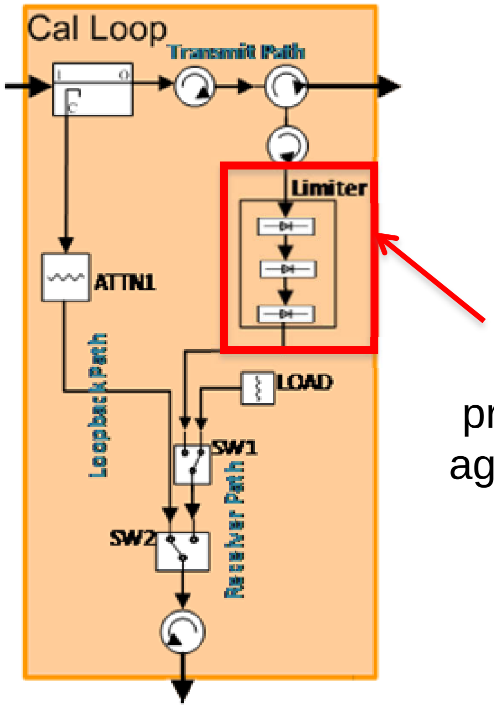
- The 1215-1300 part of the L-band spectrum is heavily used by various systems around the world.

- Other terrestrial sources….
  - Amateur (weak CW signals?)
  - Strong beacons
  - Smorgasbord of signals with all different modulations over urban areas.

Survivability of SMAP Radar

- Some terrestrial radars have high transmit power (e.g. Cobra Dane 15.4 MW), and the SMAP radar is designed to survive in the worst scenario.
- The estimation of the maximum received power of the SMAP radar is 2.4 W.
- Radar is protected from damage with a limiter in the cal-loop assembly (CLA) of the RF Front-End Electronics.

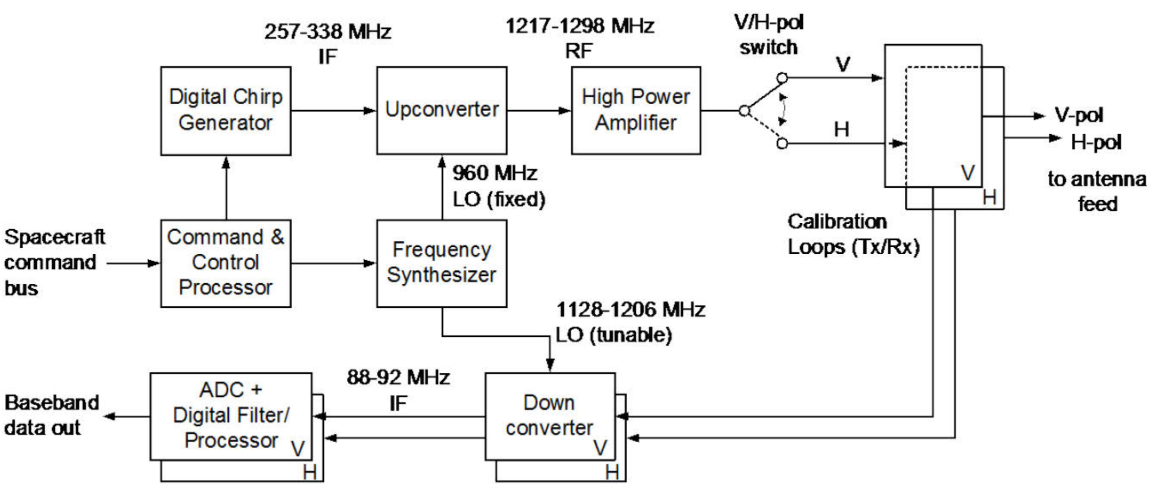
FPS-108 COBRA DANE radar installed by the US Air Force



The Limiter protects the radar against very strong power RFI

Mitigating RFI - Tunable Radar Architecture

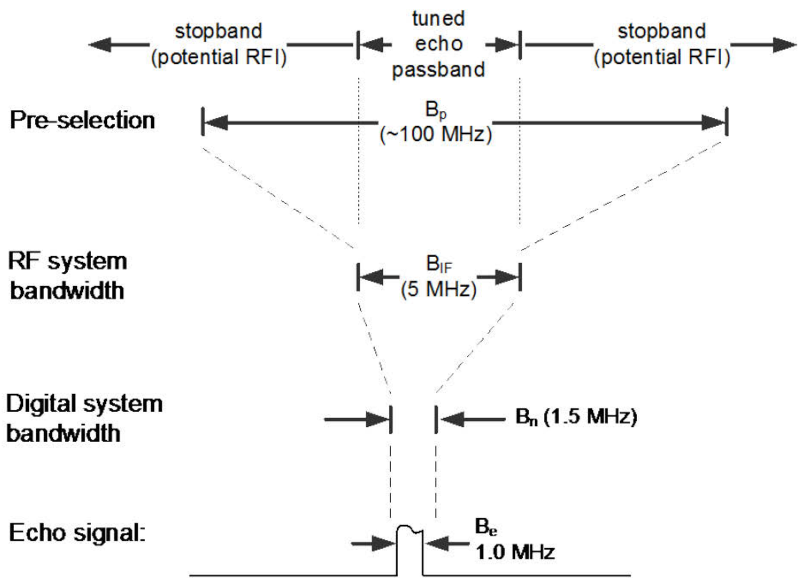
- Terrestrial radars operate at certain frequency bands, and most of them have narrow bandwidth
- The tunable architecture of SMAP radar allows the radar to change its operating center frequency to avoid RFI
- The change can be commanded at different locations of the orbit and different orientations of the antenna
- Block Diagram shown the design of the tunable radar architecture:



- Transmit chain: Direct digital synthesis of tunable V/H chirp pulses from Digital Chirp Generator
- Receive chain: Heterodyne with tunable LO to a fixed IF band

Mitigating RFI – Out-of-band RFI Rejection

- To block RFI, the receiver filter stages are configured as a series of "funnels"
- Filter bandwidth becomes progressively narrower down the chain to maintain receiver dynamic range
- Filtering:
  - Front-end pre-select filter with ~1210-1310 MHz passband and gradual rolloff
  - IF filter centered at 90 MHz with 3 dB bandwidth 6 MHz and sharper rolloff
  - Digital filter of 1.5 MHz bandwidth and very sharp rolloff



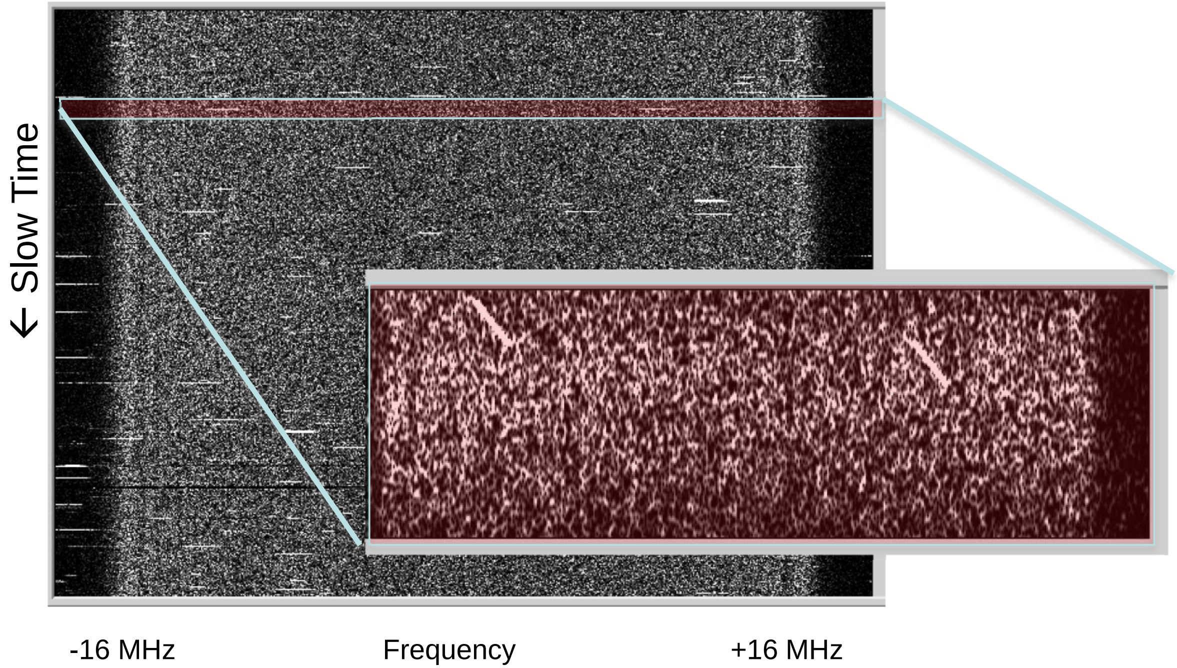
- IF filter rolloff: -60 dB at 6.3 MHz from center of band, and -80 dB at 7.0 MHz from center
- Digital filter rolloff: -72 dB at 1.0 MHz from center of band

Mitigating RFI on Ground –Telemetries

- Telemetry functions are designed into the receiver electronics to flag data blocks corrupted by RFI
  - Receive power monitor: A flag is set whenever strong out-of-band interference causes a gain compression error in the RF front-end
  - A/D converter saturation detection: A saturation flag is triggered as strong in-band RFI causes one or more voltage samples to be clipped in the receive-window period
  - “Noise-only” power measurement: The powers of the data in the noise channel are accumulated in the digital processor on short time scales (every PRI, or ~350 μs). Its variation among pulses will facilitate the detection of RFI

Characteristics of RFI from PALSAR Data

- ALOS/PALSAR Properties:
  - Center frequency 1270 MHz, and receiver bandwidth 32 MHz; it covers 40% of SMAP's allocated bandwidth
  - Circular sun-synchronous orbit with altitude 692 km, which is close to the SMAP altitude of 685 km
- Example of frequency spectrum of PALSAR data of Alaska



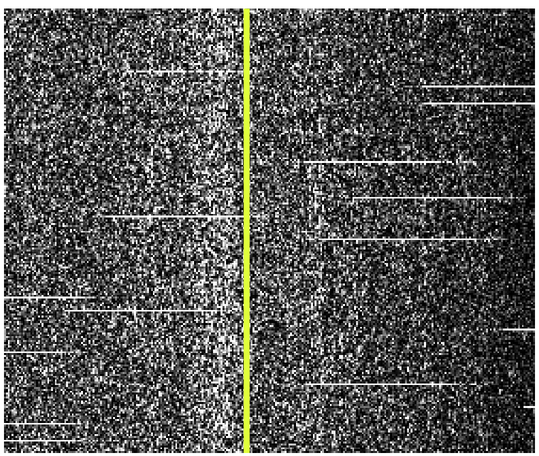
Key result:

- PALSAR data shows primarily pulsed emitters typical of air surveillance radars (87% of occurrences) with another 13% of occurrences miscellaneous (including CW) sources, with high concentration over urban areas
- Pulsing rate much less than the SMAP nominal PRF which is 2.9 kHz

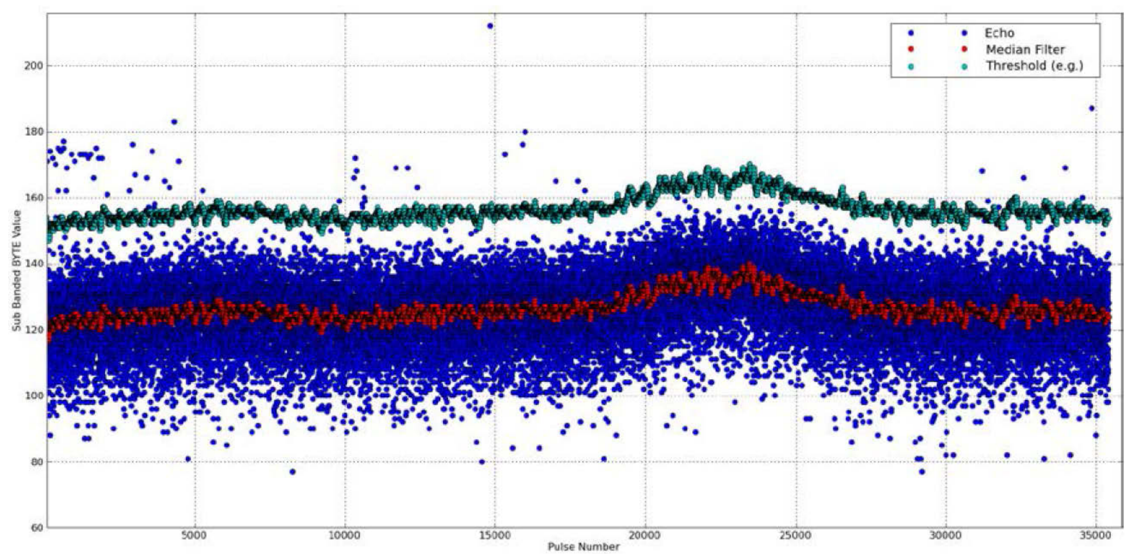
RFI Detection – Slow-Time Thresholding Algorithm

- For a range bin, the slow-time series of (I, Q) data is collected, and their powers are evaluated.
- The medians of the power of neighboring range lines are found with moving median filter. The length of filter is 101 elements in the current design.
- A data is flagged with RFI if the ratio of the power difference to the moving median power is greater than 4 standard deviations

Data from Alaska

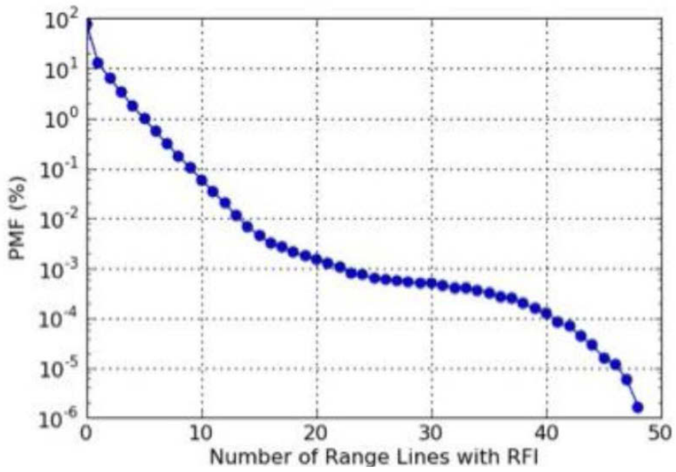


Slow-Time Thresholding Algorithm is applied data along the yellow line



Study of STT Algorithm with Simulated SMAP Data

- This algorithm is tested with the simulated SMAP data from PALSAR data
  - Data are subbanded with 1 MHz bandwidth
  - Data are rearranged in the time domain to align with the SMAP timing – form two-dimensional array
  - RFI is detected by applying the Slow-Time Thresholding technique
- RFI contamination for simulated SMAP data
  - SMAP radar will form high resolution data product with SAR processing, and the synthetic aperture includes 120 range lines for the nominal PRF of 2.9 kHz.
  - With STT algorithm, the number of range lines with detected RFI within the integration time can be found.

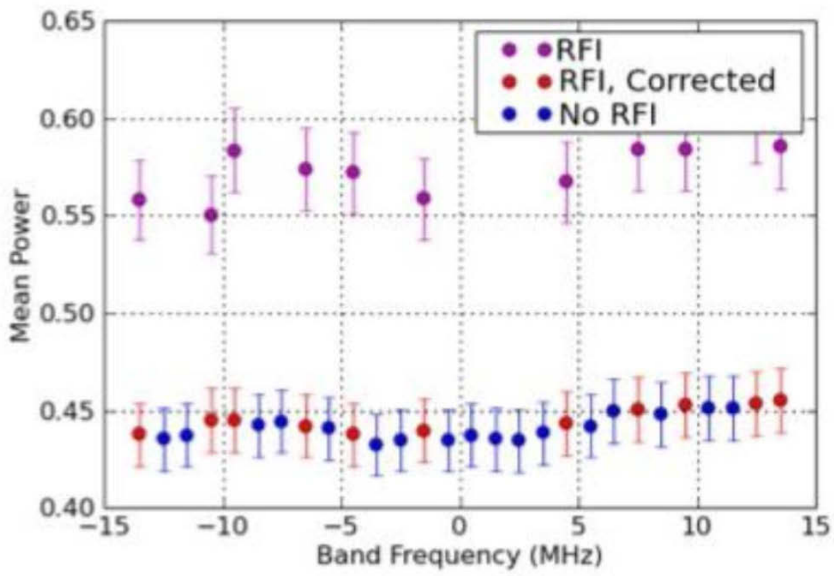


Analysis result:

- Probability of having more than 5 SMAP range lines within a synthetic aperture contaminated by RFI is less than 1% for any randomly chosen 1 MHz over North America

RFI Correction – Replacing Adjacent Neighbor

- Excise data with RFI contaminated and replace by adjacent neighbor
  - If simply replacing an azimuth data by its previous neighbor, a positive radiometric bias is introduced in the backscattering coefficient estimate. It is because the replacing sample is coherent with its previous one.
  - To remove this bias, the correction algorithm is modified to add a random phase to the duplicated range data, which is determined by the statistics of the data.
- Evaluation of the modified correction algorithm



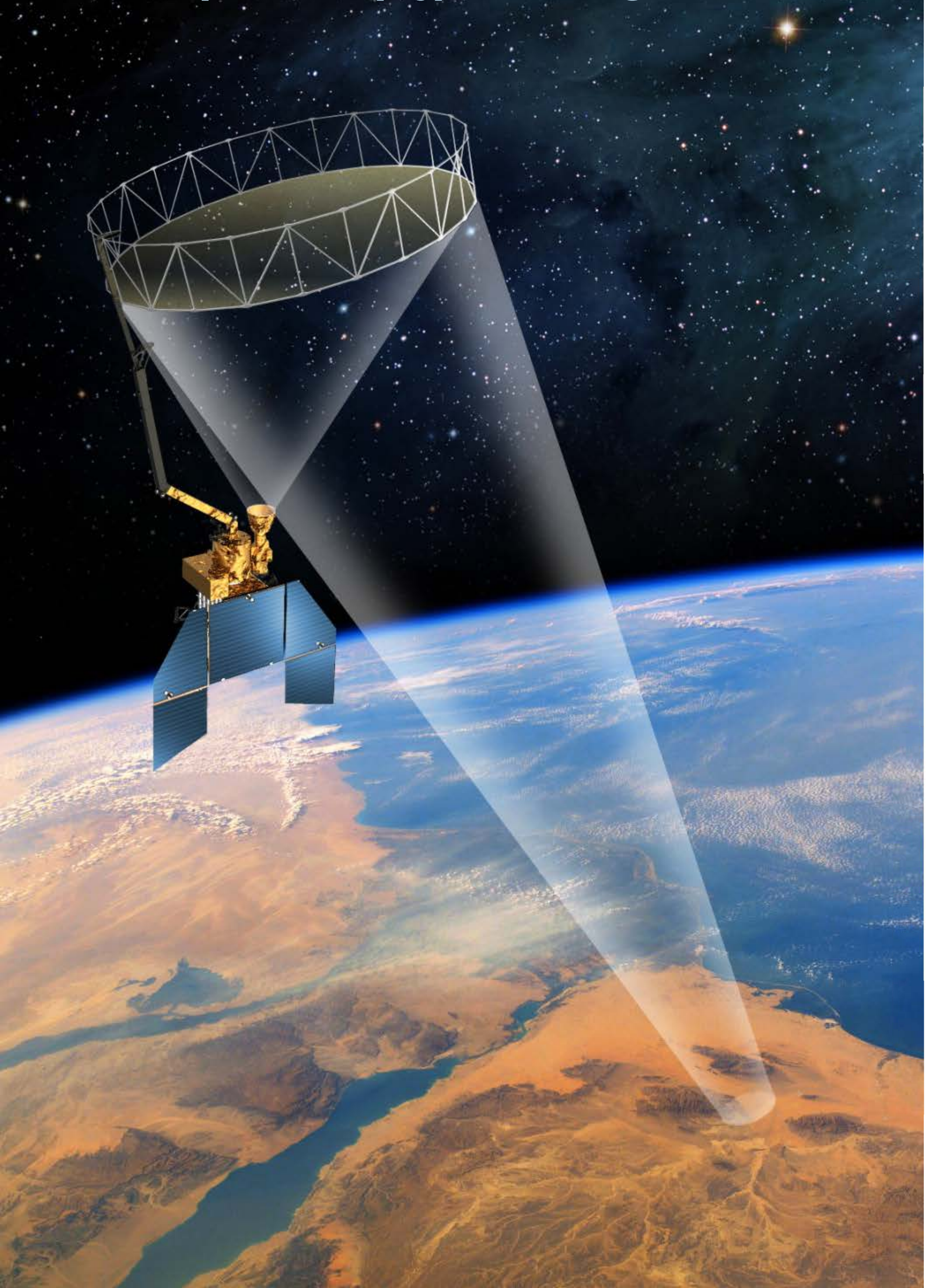
- A data set from New Zealand without detecting RFI is used to calibrate the frequency response of PALSAR receiver (blue)
- A data set from Alaska with strong RFI is going through STT detection and the modified correction algorithm. Its corrected mean power (red) is compared with uncorrected value (purple).

Current Status of SMAP Radar

- SMAP Radar Electronics
  - Fabrication, assembly and test of the SMAP radar RF and digital brassboards will be completed soon.
  - The SMAP radar will be undergo integration and test in September 2011.
  - The hardware design for RFI mitigation and detection will be tested against the requirements. They will be reported in the coming literatures or conferences.
- Detection and Correction Algorithms
  - The Slow-Time Thresholding algorithm and the modified correction algorithm have shown good promise.
  - However, as time evolves, the RFI environment will change. These trends will be tracked, and the optimal detection and correction algorithms will be correspondingly updated.

Backup

http://smap.jpl.nasa.gov/



RFI MITIGATION AND DETECTION FOR THE SMAP RADAR

S. Chan, M. Fischman, and M. Spencer

July 27, 2011

RFI Detection Algorithm

- Ground filtering approach:
  - Primary filtering approach is to simply excise affected range lines (which exceed some threshold) and form image without them.
  - Analysis shows that if pulsed interference is in as many as 15-20 range lines, it can be reliably detected.
  - Resulting image will have degraded Kpc and sidelobes. Analysis shows that approximately 15 range lines can be lost without violating 0.4 dB requirement for that one measurement.
  - CW sources can be easily detected and notched in the frequency domain, provided that the BFPQ does not get saturated (Interference-to-Signal ration > 14 dB).

Impact of GPS on SMAP

- Aerospace Corporation has modeled GPS Block IIF satellite constellation that is expected to be in place at time of SMAP mission.
- At any given time multiple GPS satellites (> 15) can be "seen" by SMAP.
- Most recent SMAP antenna pattern is used to assess interference.
- Interference levels are non-negligible (> 0.1 dB error) for 1 MHz band centered on C/A code at 1228 MHz.
- Interference levels between 1215 MHz and 1240 MHz (for the P and M codes excluding C/A code) appear to be negligible (< 0.1 dB error) for minimum co-pol backscatter measurement, but just non-negligible (near 0.1 dB) for minimum cross-pol backscatter.
- GPS signals are "omni-present" globally.
- Interim Conclusion: Interference levels are relatively low and manageable for GPS constellation if antenna backlobes do not increase significantly.

Summary of RFI Mitigation

- RFI mitigation baseline for radar has been selected:
    - Utilize limited adjustments in frequency hopping scheme to avoid persistent severe RFI.
    - Wide dynamic range to insure low probability of saturation for out of band RFI.
    - Ground mitigation techniques to remove remaining RFI is critical to meeting science performance, particularly with the constraints of frequency hopping.
- Results strictly from PALSAR data suggest that RFI can be effectively detected and removed, even when frequency hopping is employed.
    - Japanese PALSAR data is global, but has sparse sampling and does not (of course) include future emitters.
    - PALSAR has different antenna pattern than SMAP.
- Results from model analysis (performed by ITT) suggest
    - Saturation events are sufficiently low probability.
    - With frequency hopping, about 10% of the data over/near North America will experience RFI contamination which will violate the requirements if not corrected.
- Results from Aerospace analysis suggest spaceborne emitters such as GPS are non-negligible but manageable.