Radar Technology Development at NASA/JPL

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What is Radar Technology?

- Technologies applied to JPL radar missions are typically defined at the *system* and *subsystem* level, for example:
  - Radar Interferometer
  - Membrane Phased-Array Antenna
  - Digital Beam-forming processor
  - Transmit/Receive Module
  - Characterizing stress points in electronics

- These technologies are synthesized from commercially available (flight qualified) components and devices
  - amplifiers, oscillators, circulators, FPGAs, DSPs, multi-layer boards, etc.

- JPL-conceived components devices occasionally needed
  - researched and developed by universities or small business manufacturers under contract
Science-driven technology, focusing on
- Global reach and wide-area coverage
- High-performance, first-of-a-kind science
• Earth Science Technology Office
  – Advanced Component Technology
  – Instrument Incubator Program
  – Airborne Instrument Technology Transition
  – Advanced Information Systems Technology

• Planetary Science
  – Planetary Instrument Definition and Development Program
  – Mars Instrument Definition and Development Program

• Project-specific
  – Technology exploration in the preproject phase
  – Technology risk-reduction in the formulation phase
Early JPL Radar Developments

1966 Rocket L-band Radar

1970- LHH Airborne Radar Image of Death Valley
The Flow of Technology in Airborne and Spaceborne SAR Programs

- Rocket Radar mounted on NASA CV-990. (L-band only.)
- SeaSAT
- AIRSAR re-built on DC-8
- SIR-C
- IFSARE/*3I
- GeoSAR
- UAVSAR

- Solid State Amplifiers
- Digital Recorders
- Digital SAR Processor
- L-band XTI
- C-band
- 40 MHz
- C-band ATI and XTI
- 80 MHz and POLTOP
AIRSAR was a multi-frequency, quad-polarization, multi-baseline (three C-band and three L-band antennas) interferometric radar (TOPSAR).

### Radar Specifications

<table>
<thead>
<tr>
<th>Band</th>
<th>C band</th>
<th>L band</th>
<th>P band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>5.3 GHz</td>
<td>1.3 GHz</td>
<td>440 MHz</td>
</tr>
<tr>
<td>Power</td>
<td>700 W</td>
<td>4 kW</td>
<td>2 kW</td>
</tr>
<tr>
<td>Noise-Equiv. (\sigma_0)</td>
<td>-35 dB</td>
<td>-45 dB</td>
<td>-48 dB</td>
</tr>
<tr>
<td>Polarimetry</td>
<td>Quad</td>
<td>Quad</td>
<td>Quad</td>
</tr>
<tr>
<td>Interferometry</td>
<td>XTI, ATI</td>
<td>XTI, ATI</td>
<td>------</td>
</tr>
<tr>
<td>Height Accuracy</td>
<td>1m / 5m</td>
<td>2m / 10m</td>
<td>------</td>
</tr>
<tr>
<td>Velocity Accuracy</td>
<td>10 cm/s</td>
<td>4 cm/s</td>
<td>------</td>
</tr>
</tbody>
</table>

### Bandwidth

<table>
<thead>
<tr>
<th>Bandwidth</th>
<th>20 MHz</th>
<th>40 MHz</th>
<th>80 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radar C/L/P</td>
<td>C/L/P</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>Data Posting</td>
<td>10 meters</td>
<td>5 meters</td>
<td>3 meters</td>
</tr>
<tr>
<td>Number of Looks</td>
<td>18</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Swath</td>
<td>20 km</td>
<td>10 km</td>
<td>6 km</td>
</tr>
</tbody>
</table>

### NASA Science

- **Solid Earth**
- **Ecology**
- **Hydrology**
- **Land Cover**
- **Physical Oceanography**
- **Cryosphere**
- **Applications Program**
- **Space Science**

### Typical applications:

- Forestry Classification / Biomass Estimation
- Hazards: oil spills, floods, UXO
- Agricultural Monitoring
- Urban Mapping/Telecom Studies
- Geological Mapping
- Oil and Gas Exploration
- Archaeology
- Coastal Currents, River Rates, Hydrology
NRC Earth Science Decadal Survey Missions

ventures-class

Proposed Radar Missions

Near-Term Missions:
Mid-Term Missions:
Late-Term Missions:

SCLP
3D Winds

VENTURE-CLASS
Radar as proposers choose

Pre-decisional – for Planning and Discussion Purposes Only
Soil Moisture Active/Passive (SMAP)*
NASA Decadal Survey Mission
L-band radar/radiometer

Freeze/Thaw from 1 km res SAR
Every other day

Root-zone moisture
using Radiometer,
SAR, and model
Every 3 hours

*Proposed Mission
Pre-decisional – for Planning and Discussion Purposes Only
Proposed SMAP Technology Solution for Required Soil Moisture Measurement

• To meet requirement for 3-day revisit time at AM local time:
  ⇒ 1000 km swath at 685 km dawn/dusk sun-synchronous orbit.

• For wide measurement swath of combined L-Band active and passive measurement at near constant incidence angle:
  ⇒ Conically scanning reflector antenna.

• Resolution required:
  ✷ Radiometer: 40 km
  ✷ Radar: 3 km
  ⇒ 6 meter aperture antenna
  ⇒ 13 rpm rotation rate
  ⇒ Real-aperture radiometer
  ⇒ Synthetic-aperture radar processing exploiting “mechanical TOPS mode”
Radar designs for proposed DESDynI mission being studied in pre-Phase A

L-band 5-80 MHz BW Quad-pol Radar
9-15 m mesh reflector
12-24 element transmit and receive array
12-24 dual-pol receive channels
180-360 km swath, full res, full-pol
Better than -25 dB NES0 at 20 MHz BW

*DESDynI - Deformation, Ecosystem Structure, and Dynamics of Ice

Pre-decisional – for Planning and Discussion Purposes Only
Radar Design to Meet Critical Requirements

- Repeat Period requirement for Deformation science drives the Radar Swath
  - 8M-day Repeat Period => 360/M-km Swath Width
- Sensitivity requirement for Biomass (cross-pol) measurement drives Antenna Size and Radar Power
- Accuracy requirements for Deformation and Biomass drive Electronics & Mechanical Stability and Calibration

- A new SweepSAR technique was adopted as a means to achieve much wider swath than conventional SAR strip-mapping, without the performance sacrifices associated with the traditional ScanSAR technique

Conventional StripMap: <=70km Swath

Resulting ~40 day repeat does NOT meet proposed Deformation and Ice Science Requirements

Conventional ScanSAR: non-uniform along-track sampling

Resulting degradation in effective azimuth looks does NOT meet proposed Ecosystem Science Requirements

Pre-decisional – for Planning and Discussion Purposes Only
SweepSAR Technique

• On Transmit, all Feed Array elements are illuminated (maximum Transmit Power), creating the wide elevation beam

• On Receive, the Feed Array element echo signals are processed individually, taking advantage of the full Reflector area (maximum Antenna Gain)

• Uses digital beamforming to provide wide measurement swath
  – DBF allows multiple simultaneous echoes in the swath to be resolved by angle of arrival

• Uses large reflector to provide high aperture gain
  – Full-size azimuth aperture for both transmit and receive
  – Full-sized elevation aperture on receive

• Only need data from feed array elements being illuminated by an echoes
  – These elements can be predicted a priori

Pre-decisional – for Planning and Discussion Purposes Only
High-level Block Diagram of Beamformer/Calibration and TR Front End Technologies

The First Stage Processor for the proposed DESDynI SAR Instrument...

on Transmit: Receives a coupled replica of the transmitted RF Chirp

on Receive: Receives a Caltone simultaneously with the radar return.

on Bypass Calibration: Receives an RF Chirp or Caltone is directly in the FSP

Signals are used to estimate and correct amplitude and phase fluctuations

A single channel RF/Digital channel, effectively a single functional block

High efficiency GaN TR modules on test fixture

Pre-decisional – for Planning and Discussion Purposes Only
UAVSAR is an L-band fully polarimetric SAR designed to support a wide variety of science key technologies:

- A precision autopilot developed by NASA Dryden that allows the platform to fly repeat trajectories that are mostly within a 5 m tube.
- Compensates for attitude angle changes during and between repeat tracks by electronically pointing the antenna based on attitude angle changes measured by the INU.

**Parameter** | **Value**
--- | ---
Frequency | L-Band 1217.5 to 1297.5 MHz
Bandwidth | 80 MHz
Resolution | 1.67 m Range, 0.8 m Azimuth
Polarization | Full Quad-Polarization
ADC Bits | 2,4,6,8,10 & 12 bit selectable BFPQ, 180Mhz
Waveform | Nominal Chirp/Arbitrary Waveform
Antenna Aperture | 0.5 m range/1.5 azimuth (electrical)
Azimuth Steering | Greater than ±20° (±45° goal)
Transmit Power | > 3.1 kW
Polarization Isolation | <-25 dB (<-30 dB goal)
Swath Width | > 23 km

Project Scientist: Scott Hensley
Project Manager: Yunling Lou
Mapping Kings Canyon Forest Fire Fuel Load with UAVSAR Data

Supports DESDynI Biomass Estimation and Radar/Lidar Fusion Algorithm Development

Pre-decisional – for Planning and Discussion Purposes Only
April 4, 2010 M 7.2 Baja California Earthquake

First earthquake deformation captured by the UAVSAR system using data acquired on October 21, 2009 and April 13, 2010
Proposed Mission Science

Oceanography: Characterize the ocean mesoscale and sub-mesoscale circulation at spatial resolutions of 10 km and greater.

Hydrology: To provide a global inventory of all terrestrial water bodies whose surface area exceeds (250m)$^2$ (lakes, reservoirs, wetlands) and rivers whose width exceeds 100 m (requirement) (50 m goal) (rivers).
  - To measure the global storage change in fresh water bodies at sub-monthly, seasonal, and annual time scales.
  - To estimate the global change in river discharge at sub-monthly, seasonal, and annual time scales.

Mission Architecture

- Ka-band SAR interferometric (KaRIn) system with two swaths, 50 km each (goal of 60 km)
- Would produce heights and co-registered all-weather imagery
- Use conventional Jason-class altimeter for nadir coverage, radiometer for wet-tropospheric delay, and GPS/Doris/LRA for POD.
- On-board data compression over the ocean (1 km$^2$ resolution). No land data compression onboard.

SWOT* Overview

• Partnered mission with CNES
• Mission life of 3 years
• 970 km Orbit, 78° Inclination, 22 day repeat
• Flight System: ~1400Kg, ~2.1kW
• Readiness for launch 2019 (TBC)
The proposed SWOT mission would drive the technology for:

- The stability of the mast, the reflectarray antenna and its deployable support structure
- On-board interferometric SAR processing to meet downlink capabilities
- Ka-band RF electronics:
  - Phase stable RF dual-downconverter
  - High power Amplifier (Extended Interaction Klystron and High-Voltage Power Supply)
Operating parameters:

- 200 MHz signal bandwidth (0.75 m slant range resolution)
- ~5 KHz maximum PRF per channel
- 2 x 60 km cross-track swaths
- Single-look ground resolution: 10-70m in range, ~250m in azimuth
- Output resolution: 1x1 km (~200 kbps; a reduction factor of 1,450)
- Height error budget for OBP: 2 mm @ 1x1 km (∞ SNR)
On-going effort to generate raw data with simulated WaveWatch III wave fields

WaveWatch III Realization (SWH=3m)

Corresponding wave spectrum

Coherence (including OBP+SNR)

random error performance (including OBP+SNR)

Mean error = 9 mm

OBP only mean error ~ 1.0 mm
The interferometer instrument needs to maintain the relative and absolute phase integrity across its elements, in particular:

- RF Ka-band receivers need to phase track to within a few tens of milli-degrees of phase over ~2.5 minutes.
- Antenna and mast distortions due to thermoelastic effects translating into phase errors need to be controlled by design.
- The radar transmitter (and the High Power Amplifiers in particular) needs to meet stringent phase stability requirements.
For the International Polar Year NASA funded a Ka-band single-pass interferometer utilizing UAVSAR for ice surface topography swath-mapping

- Will characterize the interferometric penetration depth of Ka-band into snow cover.
- Critical to the feasibility of a future radar ice surface topography mapping mission.

**First known demonstration of millimeter-wave single-pass interferometry**

Relevant not only for Earth ice-surface topography, but also surface water, ocean surface topography and interplanetary (e.g. Europa) ice cover measurements

**Investigators:** D. Moller (PI), S. Hensley, G. Sadowy, E. Rignot, M. Simard
UAVSAR Instrument Pods – Modular Technology Testbeds for New Systems

Operational L-band pod

Pod in experimental Ka-band configuration (includes a new passive Ka-band antenna)

Also modified for P-band (AIRMOSS)

Planning to further miniaturize electronics to fly multiple pods and on smaller platforms
Membrane Phased Array Technology for very large (>400 m²) MEO/GEO antennas

Roll-up SAR Antenna (stowed)

Roll-up SAR Antenna (partially deployed)

Roll-up SAR Antenna (deployed)

Rigid arrays: 0-20kg/m²

Membrane arrays: 2kg/m², smaller stow volume
Summary

• Radar at JPL and worldwide is enjoying a period of unprecedented development.
• JPL’s science-driven program focuses on exploiting commercially available components to build new technologies to meet NASA’s science goals.
• Investments in onboard-processing, advanced digital systems, and efficient high-power devices, point to a new generation of high-performance scientific SAR systems in the US.
• Partnerships are a key strategy for US missions in the coming decade.