CHRISTIAN JONES

VHF, SAR AND

CHANGE DETECTION
CARABAS-I

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Sabreliner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Altitude</td>
<td>1500-6500 m</td>
</tr>
<tr>
<td>Nominal Ground Speed</td>
<td>100 m/s</td>
</tr>
<tr>
<td>Maximum Slant Range</td>
<td>7.5 km</td>
</tr>
<tr>
<td>Antenna</td>
<td>2 Dipoles</td>
</tr>
<tr>
<td>Polarisation</td>
<td>Horizontal</td>
</tr>
<tr>
<td>Frequency</td>
<td>20-90 MHz</td>
</tr>
<tr>
<td>Number of Frequencies, n</td>
<td>≤ 57</td>
</tr>
<tr>
<td>Frequency Stepping Factor</td>
<td>1.25 MHz</td>
</tr>
<tr>
<td>Pulse Length, T_p</td>
<td>0.5 μs</td>
</tr>
<tr>
<td>RX Bandwidth</td>
<td>2.5 MHz</td>
</tr>
</tbody>
</table>

| TX Peak Power      | 1 kW                 |
| System PRF, PRF_s | 10 kHz               |
| Effective PRF, PRF_e | 10/2/n kHz          |
| Intermediate Frequency | 117.5 MHz      |
| Baseband Center Frequency | 2.5 MHz         |
| Digital Sampling Rate | 10 MHz             |
| Number of bits    | 12                   |
| Data Rate         | 80 Mbits/s           |
| Tape Recorder Capacity | 107 Mbits/s         |
| Cassette Capacity | 60 minutes           |

CARABAS-I ISSUES

• Weak Antenna Structure
  • Structural failure during test in Yuma desert

• Antenna Lobe splitting at high frequencies
  • Failure of proper antenna calibration in conjunction with the aircraft

• Weak Frequency Response at certain bands
  • Hardware issues

• Inadequate Location Information
  • Differential GPS as opposed to exact positioning

• Band is occupied!
**VHF Band Occupation**

- Operation in VHF requires competition with FM radio, Amateur Radios, emergency lines, air traffic control, etc.
- Interference from other illuminators significantly degrades imaging capabilities
- CARABAS-I has no capabilities to combat spectral congestion, preventing use in urban environments
- Rather than just correcting the physical issues a complete overhaul was performed to make the system more robust
### CARABAS-II

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Sabreliner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Altitude</td>
<td>1500-10000 m</td>
</tr>
<tr>
<td>Nominal Ground Speed</td>
<td>100 m/s</td>
</tr>
<tr>
<td>Flying conditions</td>
<td>IMC</td>
</tr>
<tr>
<td>Maximum Slant Range</td>
<td>Programmable</td>
</tr>
<tr>
<td>Full Integration Angle*</td>
<td>120 degrees</td>
</tr>
<tr>
<td>Full Aperture Length*</td>
<td>60 km</td>
</tr>
<tr>
<td>Full Integration Time*</td>
<td>500 s</td>
</tr>
<tr>
<td>Antenna</td>
<td>2 Phased Wide Band Dipoles</td>
</tr>
<tr>
<td>Radiation Pattern</td>
<td>One Side (Backlobe &lt; -15 dB)</td>
</tr>
<tr>
<td>Polarization</td>
<td>Horizontal</td>
</tr>
<tr>
<td>Frequency</td>
<td>20-90 MHz</td>
</tr>
<tr>
<td>Number of Frequencies</td>
<td>1-256</td>
</tr>
<tr>
<td>Frequency Stepping Factor</td>
<td>Programmable</td>
</tr>
<tr>
<td>Pulse Length, $T_p$</td>
<td>≤ 50% duty cycle</td>
</tr>
</tbody>
</table>

| TX Bandwidth | 2 x 2 MHz |
| TX Peak Power | 500 W |
| System PRF, PRF$_s$ | 1-10 kHz |
| Effective PRF, PRF$_e$ | 100 Hz - 10 kHz |
| Intermediate Frequency | 215.25 MHz |
| Baseband Center Frequency | 3.75 MHz |
| TX Notch | 30 dB |
| RX Notch Depth | 90 dB |
| TX & RX Notch BW | 10 kHz |
| RX Dynamic Range | 88 dB (Spurious Free) |
| Digital Sampling Rate | 2 x 5 MHz |
| Number of bits | 2 x 14 |
| Data rate | 160 Mbits/s |
| Tape Recorder Capacity | 240 Mbits/s |
| Cassette Capacity | 28 minutes |

*) Based on an assumed altitude of 10 km and a ground speed of 120 m/s

CARABAS-II COGNITION

- System starts by “listening” to scene to determine the occupied bands
- System puts spectral notches on Tx and Rx in regions interference is present
- Provides 90 dB of suppression on any interference in that band
- Placing a notch is equivalent to multiplying by a rect function in frequency, resulting in a sinc like convolution in range
- This distorts the resulting SAR image due to high sidelobes
- A reconstruction algorithm is performed on the pulse compressed data to compensate
  - Exact algorithm not provided
SAR IMAGING AT VHF, CHALLENGES

• Narrow band/beam assumptions not valid
  • Working with ultra wideband waveforms (variable Doppler shifts)
  • Range and Azimuth Resolution no longer separable
  • Resolution now in terms of area as
    \[ \Delta A \geq \frac{\lambda_c c}{2\Delta \phi 2B} \]
    where \( \Delta \phi \) is angle spanning the synthetic aperture (edge to edge from center)
  • Hypothetical limit of 3 m\(^2\) for the CARABAS-II system with measurements of 10 m\(^2\) in practice

• Requires Large synthetic aperture
  • Aperture size is proportional to wavelength

• Processing becomes more complicated
  • Back Projection implementation requires more dimensionality to compensate for the variable Doppler shift

• Rough Topography (smaller than a wavelength) is hard to image accurately
  • Useful in some circumstances

• Spaceborne operation is not possible
IONOSPHERE EFFECTS AT VHF

- Spaceborne SAR operation is not possible at VHF.
- Below 3 GHz the ionosphere will cause noticeable distortion of a transmission via the Faraday effect.
- Faraday effect will rotate the polarization of a radio wave passing through.
- The angular rotation is defined as [2]
  \[ \chi = 2.365 \times 10^{-14} \frac{B_\parallel}{f^2} N_{TECU} \sec \theta \]

  where B is the magnetic field of the earth in the direction of propagation, and N is the integrated electron density.
- Because VHF is a relatively low frequency, the rotation will vary significantly throughout the band.
- Compensation would require unrealistically precise knowledge of B and N.
SO WHY SAR AT VHF?

• Assuming the processing chain is configured to account for the phenomenology of UWB VHF, the radar system can be used for:
  • Imaging in adverse weather
  • Penetrating Radar (see through something)
    • Depth/Backscatter measurement of
      • Soil, Ice, Snow, Foliage
    • Detecting concealed vehicles

WEATHER AT VHF

- Below 3 GHz absorption and reflection from weather clouds is negligible
- This provides a robustness not offered by standard SAR systems
- Can potentially be to identify civilians in need during natural disasters like hurricanes, typhoons or tornados
- However, this still requires a plane flies in this adverse weather since spaceborne is not possible
ICE AND SNOW AT VHF

• CABRAS-II has been used to measure glacier depth to track climate change

• The VHF system allows for penetration into ice bodies without significant surface echoes

• The lack of a significant surface echo allows for a “layered” back projection implementation where the reflection coefficient at various depths can be estimated

• Normally the sidelobes of the high-powered surface echo will act as a source of interference for later estimates

• Note: the long wavelengths can potentially create issues when significant surface variation is present

[4]
SOIL AT VHF

• VHF should have improved attenuation per meter over higher frequencies
• Different soil layers should still reflect incidence wave, but the lower attenuation allows for much deeper measurements
• Again should be able to perform “layered” back projection to allow for depth imaging
• This will perform better with a steep incidence angle and narrow beam so contribution from surface does not mask contribution from soil
The primary purpose for the design of the CARABAS system is to work with, or around foliage.

Like snow, ice and soil imaging, VHF significantly reduces the backscatter due to the surface foliage.

This allows for both vegetation density measurements with a shallow look angle and penetrative detection with a steep look angle.

Higher frequency systems will predominantly measure return from 2 (upper canopy reflection) only.
FOLIAGE MEASUREMENT EXAMPLES

- The CARABAS-I system was used to verify models for vegetation density vs backscatter at VHF [6]
  - Ironically the Ulaby book also found and cited this source
- The CARABAS-II system was later used to measure the annual forest harvest in Scandinavia [7] using similar models to [6]
  - A statistical analysis of the change in vegetation density detected a degree of deforestation in 1 of 25 plots that was not in accordance with forestry law
Because of the relatively low back scatter of foliage, the CARABAS systems can be used to detect concealed targets in forested areas.

Even compared to the next band up (UHF), the VHF band can significantly improve detection by broadening the specular reflection of manmade objects and lowering contribution due to vegetation.

This discrepancy becomes even more dramatic at higher bands.
AFRL in conjunction with the Swedish Research Agency has provided a set of magnitude only CARABAS-II SAR images for a detection challenge problem [8].


- Data consists of several passes over a forest in Sweden in which vehicles are moved to various locations:
  - Vehicles are concealed by foliage
  - Intentionally shallow look angle so vegetation contribution is noticeable

- **Goal is to use change detection to improve performance**
VHF, SAR AND CHANGE DETECTION

Total Scene

Zoomed to Foliage

Zoomed to Cars
A SIMPLE CHANGE DETECTION IMPLEMENTATION

Scene difference

Scene 1

Scene 2

Scene detection magnitude (dB)
FUTURE PROJECT ADDITIONS

• Cover more details on the soil/snow/vegetation backscatter models and estimation
• Create entropy measurement on change detection dataset
  • Is the tree distribution random enough to separate them from the vehicles
• Estimate foliage parameters for change detection dataset using scattering models and SAR parameters
• Form and apply despeckle filters using foliage parameters
• Synthetically generate different scenarios on change detection dataset via models discussed
  • E.g. make forest more/less dense, add snow, wet soil, change weather, change frequency
  • Should be possible with “inverse” despeckle filters
REFERENCES


