Hardware in the Loop Testing and Evaluation of Seaborne Search Radars

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Outline

- Introduction to CSIR DRFMs
- Introduction to hardware in the loop testing and evaluation of radar systems
  - DRFM hardware history
  - Integrated capability, RCS modelling, Scenario simulation,
- The clutter problem
- Sea clutter - the most complex case
- Modelling sea clutter - K Distribution (why the K distribution)
- Sea clutter measurements
- Simulating a single range line
- Using time multiplexing to simulate a 360 degree scenario
- Technological tradeoffs
Where we are from: South Africa
## Digital Radio Frequency Memory History

<table>
<thead>
<tr>
<th>Year</th>
<th>Technology Development Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>IBW</td>
<td>400 MHz 500 MHz 800 MHz</td>
</tr>
<tr>
<td></td>
<td>Complex targets Clutter 2 GHz</td>
</tr>
</tbody>
</table>
Integrated capability

Scenario simulation & control

System under test

RCS / HRR prediction

HIL simulation

Radar under test
Advances in DRFM technology allows for the real-time simulation of a wide range of targets, ECM techniques, and environmental effects (see reference [3]).

[Radar Environment Simulation]

**Target Simulation**
- Point targets
- Multi scatterer targets

**Electronic Attack**
- Jamming

**Target Environment**
- Clutter

Radar Environment Context

- Radar antenna pattern
- Sidelobes
- Range Resolution
- Target
- ECM
- Intersection with surface
- Clutter patch
- Clutter Statistics
- Jammer
ECM

- Deception techniques to interfere with target detection and tracking
- Non-coherent jamming (injection of high powered noise)
- Manipulation of transmitted radar pulse
  - Range
  - Doppler
  - Amplitude information
- Goal is to have radar interpret false target as actual target
- Common ECM techniques for tracking radar
  - Range gate pull off
  - Velocity gate pull off
Complex Targets

- DRFM simulates a target by simply re-transmitting the radar pulse
- Approximate target as a single scatterer
- Assumption is made that radar target is only present in a single range cell of the radar

Today's radars use High Range Resolution (HRR) profile techniques
- Separation of scattering points on a single target
- This creates a "complex" target return
- Can be used for Non-cooperative target recognition (NCTR)
Complex Targets

- High Range Resolution target profile [1]

Clutter

The Problem:

• Clutter returns interfere with the object of interest (target)
• Operation in clutter is a critical aspect of the radar's performance
• Real world testing of a radar against all types of clutter for all possible types of scenarios is costly and difficult to re-create
• Software simulation cannot take all the finer details of the complete design and implemented system into account
• Severely limited with software simulation if you are required to verify a radar purchased from a 3rd party
Considerations for high fidelity clutter generation

- Clutter Radar Cross Section (RCS)
- Number of discrete scatterers
- Spatial extent of clutter
- Velocity extent of clutter (Doppler spectrum)
- Wavelength dependence
- Amplitude distribution
- Spatial correlation
- Polarization properties

(From D.K. Barton, "Modern Radar System Analysis")
Radar Clutter Simulation

The Solution:

- Hardware in the loop simulation on DRFM based hardware
- Statistical modelling of clutter, NOT recorded data
- (Playback of recorded data is radar and configuration dependent)
Advantages of this approach:

• Cost effective
• Test many different scenarios relatively quickly
• Repeatability of experiment with the same parameters
• DRFM approach to Hardware in the loop simulation is **radar independent**
Sea Clutter Simulation

Current research:
• Clutter simulation from a seaborne platform

The Challenge:
• Sea clutter statistics not straightforward to connect to sea environment, there are no good solutions in literature as of yet
• Clutter statistics are dependent on many variables (wind direction and magnitude, wave direction and magnitude, water depth, etc.)
• Many different scattering mechanisms, complex models
Sea Clutter Simulation

- Scattering mechanisms for sea clutter have large and small scale
- Spiky nature of clutter caused by the small scale scattering mechanisms: ripple, spray and foam.
- Large scale (swell) decorrelates slowly, small scale decorrelates quickly
Compound model for sea clutter:

- Texture (τ): non-negative random process; takes into account the local mean power (large scale)
- Speckle (x): complex Gaussian process, takes into account the local backscattering (small scale)

\[ z(n) = \sqrt{\tau(n)}x(n) \]

- For a Gamma texture the K distribution results (amplitude PDF):

\[ P_R(r) = \frac{\sqrt{4\nu/\mu}}{2^{\nu-1}\Gamma(\nu)} \left( \sqrt{4\nu/\mu} r \right)^\nu \, K_{\nu-1} \left( \sqrt{4\nu/\mu} r \right) u(r) \]
Synthetic Clutter Simulation

Rayleigh distributed clutter
• Sufficient for low resolution radars and for large grazing angles
• Many scattering points in a range cell cause Gaussian statistics
• Magnitude of a Gaussian signal is Rayleigh

K distributed clutter
• K distribution represents sea clutter statistics
• Sea clutter is more spiky
• Fewer scattering points in a range cell causes more spikes
Sea Clutter Measurements
Sea Clutter Measurements
Sea Clutter Measurements [2]

Sea Clutter Measurements [4]

- On-line database freely available of small boats in sea clutter
  - Radar data database of this quality and size are very rare
  - Very well instrumented targets in sea clutter
  - Database is well documented in a user guide
  - Aim is small boat detection in sea clutter
  - Over 100 users from over 16 countries
  - Did I mention it is free?

- Available at:
  http://www.csir.co.za/small_boat_detection/
Synthetic Clutter Simulation

- Wind and wave direction does not change relative to radar because of the constant look angle
- Statistics remain constant
- Range line can be divided up into range segments to re-create the change in properties of the sea surface with range
• Segments contain an arbitrary number of time correlated scatter points
• Each segment is set independently of the other segments
• Each segment has its own statistics
  • Amplitude
  • Spectrum
  • Probability Density Function (PDF)
• All segments combine to produce a single range line
Synthetic Clutter Simulation

- Wind and wave direction changes relative to rotation angle of radar
- Therefore statistics change
- Segments & Sectors are used to re-create a scene
Time multiplexing can be used to create a 360 degree scenario.
Synthetic Clutter Simulation

- Time multiplexing can be used to create a 360 degree scenario
- Scenario divided into sectors based on desired statistics in that direction
  - Divisions based on regions of similar statistical properties
  - Divided in a statistically meaningful way
  - For example: 1 sector of 80 degrees for an area looking at a mountain and 35 sectors of 8 degrees to capture the sea surface with the relative wind and wave direction changes
Synthetic Clutter Simulation
Synthetic Clutter Simulation

Technological tradeoffs:

• Bandwidth spectral shaping quality and accuracy
• Fidelity of clutter (number / update frequency, of clutter samples)
• Complexity of statistical distribution shape
  • Rayleigh (least complex)
  • Weibull (medium complexity)
  • Log-Normal (medium complexity)
  • K-Distribution (most complex)
References


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Or visit our booth at the exhibition