Bringing the Field to the Lab
Radar Echo Generation

Presented by Yassen Mikhailov
A&D Market Segment Manager
Typical navigation radar scenario

Echoes of targets shall be displayed on a radar screen to generate visualization of the situation.

Visualization on a radar screen:
- Echoes are displayed in so called “range cells“
- Coherent radars can also measure speed and can therefore also display an echo in a “doppler cell“
- The larger the radar return signal, the larger the radar cross section i.e. the object, the larger the dot on the screen.
Typical Test Cases for radar systems

- **Sensitivity Testing of a radar**
  - Radar sees different objects with different radar cross sections (RCS)
  - Minimum detectable signal (MDS)
  - RCS dynamic range difference from small to large object can be up to 100 dB

- **Minimum detectable range**
  - How close is the first object? E.g. for collision avoidance

- **Static Objects**
  - Single static target
  - Static objects with different RCS values
  - Multiple static objects

- **Moving objects**
  - Single Moving Object
  - Different velocities for moving objects, change of direction etc. …
  - Multiple moving objects

- **Mixture of all above test cases**
  - Static and moving objects
  - Different RCS values of objects
  - Differentiation of moving objects from static objects (fixed target suppression)
## Typical Objects and Echoes to be simulated

<table>
<thead>
<tr>
<th>Object</th>
<th>f in GHz</th>
<th>Speed in km/h</th>
<th>Speed in m/s</th>
<th>Doppler in kHz</th>
<th>min range in meter</th>
<th>max range in meter</th>
<th>min RCS in square meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian</td>
<td>24</td>
<td>5</td>
<td>1,39</td>
<td>0,22</td>
<td>0</td>
<td>50</td>
<td>1</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>77</td>
<td>5</td>
<td>1,39</td>
<td>0,71</td>
<td>0</td>
<td>50</td>
<td>3</td>
</tr>
<tr>
<td>Car</td>
<td>24</td>
<td>100</td>
<td>27,78</td>
<td>4,44</td>
<td>1</td>
<td>500</td>
<td>8</td>
</tr>
<tr>
<td>Car</td>
<td>77</td>
<td>100</td>
<td>27,78</td>
<td>14,26</td>
<td>1</td>
<td>500</td>
<td>82</td>
</tr>
<tr>
<td>Speed boat</td>
<td>5</td>
<td>200</td>
<td>55,56</td>
<td>1,85</td>
<td>10</td>
<td>1000</td>
<td>15</td>
</tr>
<tr>
<td>Speed boat</td>
<td>10</td>
<td>200</td>
<td>55,56</td>
<td>3,70</td>
<td>10</td>
<td>1000</td>
<td>60</td>
</tr>
<tr>
<td>Civil aircraft</td>
<td>2</td>
<td>800</td>
<td>222,22</td>
<td>2,96</td>
<td>1000</td>
<td>100000</td>
<td>100</td>
</tr>
<tr>
<td>Fighter jet</td>
<td>5</td>
<td>2500</td>
<td>694,44</td>
<td>23,15</td>
<td>1000</td>
<td>10000</td>
<td>5</td>
</tr>
<tr>
<td>Fighter jet</td>
<td>10</td>
<td>2500</td>
<td>694,44</td>
<td>46,30</td>
<td>1000</td>
<td>10000</td>
<td>20</td>
</tr>
<tr>
<td>Missile</td>
<td>10</td>
<td>Mach 4</td>
<td>1200,00</td>
<td>80,00</td>
<td>1000</td>
<td>100000</td>
<td>0,1</td>
</tr>
<tr>
<td>warship</td>
<td>5</td>
<td>30</td>
<td>8,33</td>
<td>0,28</td>
<td>1000</td>
<td>100000</td>
<td>2000</td>
</tr>
</tbody>
</table>
Conventional Test set-up for navigation radar

- **Test Concept for Navigation Radars**
  - Mount a real radar under test on a boat
  - Deploy artificial targets at the sea
- **Test Concept for airborne radars**
  - Set up a flight campaign with artificial targets or use civil aircrafts
- **Test concept for ground radars**
  - Set-up field-test in large area to test performance
COTS solution for conducting radar tests

Reduce
- Total cost of ownership
- Turn around time for service
- Maintenance cost

Improve
- Availability of equipment
- Synergy across projects by re-use of standard T&M equipment

field-to-lab

Software defined off-the-shelf T&M equipment
Radar Target Generation Principle

Typical Approach

- Radar
- Optical fiber delay line: Fiber is of fixed length, no dynamic simulations possible

Symbols:
- \( R_1 \)
- \( R_2 \)
- \( v_{r1} \)
- \( v_{r2} \)
Radar Target Generation Principle
Digital Realization

fully digital solution

Radar

IQ Signal Manipulation

LO

Filter → ADC

Filter → DAC
Radar Target Generator: Radar Test Setup

R&S®SMW200A

R&S®FSW

IQ Data Stream
Reference

RX
TX

Radar RF RX/TX

attenuator
REG vs CEESiM

Offers a sub-set of the full CEESiM capabilities at a fraction of the investment required
Key specifications and features

- Special RADAR GUI that allows to include radar parameters
- Supported Test Setup
  - Conducted or over the air (OTA)
  - Receiver test only (i.e. SMW200A alone) or together with FSW
- FSW fully remote controlled by SMW
- Maximum number of targets 24 (6 per SMW-B14)
- Target Types
  - Moving (one way, round trip)
  - Static
  - Moving and static objects combined
- Maximum Velocity of an object 750 m/s
- Maximum Doppler of an object 190 kHz
- Blind zone: around 2000 m / 0 m in ambiguity mode
- Maximum Range: 10 000 km
- RF output power and time delay of echo of moving objects are updated according to speed
- Update Rate for moving targets
  - Output power: 10 kHz
  - Update rate range: 2 MHz
Radar Echo Generator in brief

- **FSW** serves as receiver and digitizes the radar transmit signal.
- **FSW** transfers the digitized radar signal to the SMW200A via TVR interface.
- **SMW200A** receives the digitized signal via DIG I/Q.
- Special SW option SMW-K78 speaks „radar“ and allows to manipulate the signal:
  - Introduce delay
  - Introduce Doppler
  - Set different RCS values of targets.
- **SMW200A** upconverts the signal into RF or Microwave domain and retransmits to radar receiver.
Connect FSW to SMW

1st Step

2nd Step

3rd Step
Test Concepts
Conducted tests

Manual leveling for echoes

Setting of radar specific parameters i.e. the DUT

Contribution from test setup

Ext attenuator and Radar Tx power set the maximum input power on FSW for manual echo leveling

Leveling concept via radar equation

Additional radar specific parameters i.e. the DUT
Conducted Tests
Setup for manual echo leveling

Test Setup: Conducted Test / REG: Analyzer connected

Radar Tx Power: 0 dBm

Values show configured settings

\[ P_{RX, (FSW)} = P_{Tx, (DUT)} - A \] dBm

Ext. Attenuator (Analyzer): 10 dB

\[ P_{Rx, (DUT)} = P_{TX, (SMW)} = \text{defined manually by user} \]
Conducted Tests
Setup for echo leveling via radar equation

Values show configured settings

\[ P_{Rx} \text{ (FSW)} = P_{Tx\ DUT\ dBm} - A\text{dB} \]

\[ P_{Rx} \text{ (DUT)} = \text{defined by radar equation from radar parameters} \]

\[ P_{Tx} \text{ (SMW)} = P_{Rx} \text{ (DUT)} = P_{Tx\ DUT\ dBm} + G_{Tx\ DUT\ dBi} + G_{Rx\ DUT\ dBi} + \lambda^2\text{dB} + \sigma_{dBsm} - (4\pi)^3\text{dB} - R^4\text{dB} + L\text{dB} \]
Test Concept
Over the air test

Contributions from OTA test
test equipment

Radar specific parameters
i.e. the DUT

- Contributions from OTA test setup
- Manual leveling concept for echoes
  - Ext attenuator, REG antenna & offset range and Radar Tx power & radar antenna Tx gain set the maximum input power on FSW for manual echo leveling

Leveling concept via radar equation

Additional radar specific parameters
i.e. the DUT
Over the air testing
Setup for manual echo leveling

\[ P_{RX} (FSW) = P_{TXDUT} \text{dBm} + G_{TXDUT} \text{dBi} + G_{RXREG} \text{dBi} + \left( \frac{\lambda}{4\pi R} \right)^2 \text{dB} - A \text{dB} \]

\[ P_{Rx} (DUT) \text{dBm} = \text{defined manually by user} \]

\[ P_{Tx} (SMW) = P_{RXDUT} \text{dBm} - G_{TXREG} \text{dBi} - G_{RXDUT} \text{dBi} - \left( \frac{\lambda}{4\pi R} \right)^2 \text{dB} \]
Test Concept
Setup for echo leveling via radar equation

\[ P_{RX} (FSW) = P_{TxDUT} + G_{TxDUT} + G_{RxREG} + \left( \frac{\lambda}{4\pi R} \right)^2 | dB - A | dB \]

\[ P_{Rx} (DUT) | dBm = \text{defined by radar equation} \]

\[ P_{Tx} (SMW) = P_{RxDUT} - G_{TxREG} - G_{RxDUT} - \left( \frac{\lambda}{4\pi R} \right)^2 | dB + L | dB \]
Object Definition for echo generation
Moving objects with constant speed or static objects
Overview of configured scenarios
Range Doppler/Velocity View and Receive Power View

Receive Power Preview
Scenario Preview
Dynamic behavior of echoes for a static and a moving object

- Echo power level of moving object drops by 40 dB per decade
- Update rate of level up to 10 kHz
- Update rate of delay up to 2 MHz
Case study

- Scenario
  - One static object in 2.1 km distance
  - Round trip time for echo pulse: 14 us

- Radar
  - Center frequency: 3.9 GHz
  - Pulsed CW radar
  - Pulse length: 200 us
  - Sinx/x spectrum envelope of single pulse (only one pulse is captured by FFT)
  - First zero in spectrum at +/- 5 kHz offset from carrier
Demo Setup

- IQ
- Trig
- Ref
- Radar Tx signal
- Rx echo signal
- Tx Reference signal for scope trigger
- B14+K78 Radar Echo Generation (REG)
- Radar Tx signal

Files:
- Settings_Doppler_RTO1044.dfl
- SMW_Doppler.savrltxt
Demo: Static Object Return

FFT of single pulse of static object

5 kHz = 1/200 µs

10 kHz
Case study

### Scenario
- One static object in 2.1 km distance
- Round trip time for static object: 14 us
- Moving target from 2.1 km to 15 km with speed of 750 m/s
- Round trip time depending on distance
- Cyclic movement

### Radar
- Center frequency: 3.9 GHz
- Pulsed CW radar
- Pulse length: 200 us
- $\text{Sin}x/x$ spectrum envelope of single pulse (only one pulse is captured by FFT)
- Echo of static object at center frequency with first zero in spectrum at +/- 5 kHz offset from carrier
- Dopper peaks for moving objects
  \[ f = \pm \left( 2 \times \frac{v \times f}{c} \right) = 2 \times 750 \text{ m/s} \times 3.9 \text{ GHz} / 3e8 \text{ m/s} = 19.5 \text{ kHz} \]
Demo: Static Object and approaching Object

Interference of static and dynamic echo

Approaching object

Doppler of moving object

Static object

19.5 kHz
Demo: Static Object and departing Object

Approaching object

Doppler of moving object

Static object

19.5 kHz
Proof of concept - First Results with coast guard vessel

Housed test stand with SMW200A and FSW as echo generator
Proof of concept - First Results with coast guard vessel

Over the air testing with navigation radar in X-band

CW Radar
Tx pulses @ 9.1 GHz

Radar Rx signal with generated radar echoes by SMW200A

Shelter with antenna masts

X-band navigation radar under test
First Results with coast guard vessel
Radar Screen of coast guard vessel with 4 echoes

- Four static taps with different delays configured in SMW
- No Doppler configured
- Same RCS per target
- SMW and FSW in shelter in the harbor
- Azimuth spread of generated echoes result from certain half power beam width of connected antennas at SMW and FSW
Integration with RF Environment Simulation and Signal Analysis
Environment Simulation and Target Simulation

Target

Interferer

Receiver

Emitters
Complete Radar Test in Complex RF Environments: More than just two instruments

R&S® Radar Target Generation

R&S® Pulse Sequencer

R&S® FSW-K6 / -K60

R&S® Radar RX/TX

R&D symposium

R&S® FSW-K6 / -K60

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX

R&S® Radar RX/TX
Demonstration Setup

Target Generation

R&S® SMW

IQ

Ref

R&S® FSW

Radar Transceiver

Furuno Radar RTG.mp4
Our best solutions for the success of our customers