A Flexible System Simulator for Antenna Performance Evaluation of Radar Level Measurements

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I. Introduction

Nowadays, monostatic radar-based process control covers a wide range of applications that rely on precise and reliable storage tank level measurements of almost any kind of liquid and solid media. Within the whole antenna design process trade-off conditions between the frequency and time domain as well as material properties and shapes have to be considered carefully with respect to the application and its applicability.

To evaluate novel antenna designs, the straightforward approach by regarding 3D models is not suitable, due to:

- Numerical complexity even for a height of the vessel of e.g. solely \(26\lambda\)
- Recalculation of the whole 3D tank model for each individual medium level and each antenna version

More efficient method:
- Emulation of a widely used radar test range, in which novel antenna designs are commonly tested by developing a MATLAB-implemented and flexible hybrid system simulator including:
  - arbitrary 3D antenna patterns and reflector models by FIT subdomains (CST MWS, Vers. 2009)
  - ray-based wave propagation as well as FMCW signal processing algorithms

II. Compact Radar Test Range

Exemplarily such a radar test range consists of:

- Two equally sized trihedral corner reflectors (finite edge length of 15 cm) placed at different positions in front of the antennas under test (AUT), one reflector is mounted as a main target on a movable slide positioned by a step motor in an interval ranging within \(Z_{refl} = [30 \ldots 120\ cm]\).

- A commercial VNA to emulate the radar hardware,
- A PC to run common pulse-based signal detection by barycentric processing and to control the step motor serving as a distance reference.

Although available radar sensors cover a maximal distance range of up to 80 m, this rather small experimental setup includes the most interesting effects - the main target passing the parasitic scatterer.

III. Radar System Simulator

In order to accordingly approximate the condition of a compact radar test range for the evaluation of antenna solutions by means of their influence on the overall gauging performance, a fast and efficient radar system simulator is presented, featuring a:

- Unique possibility to arbitrarily combine antennas and reflectors in a multiplicity of different setups by antenna and reflector libraries.
- Flexible scenario reconstruction having no restrictions concerning the spatial reflector positions

Typical output quantities of the system simulator:

- Total reflection coefficient \(\tilde{\gamma}(\omega)\) representing the bandwidth-limited transfer function of the monostatic radar test scenario,
  \[\tilde{\gamma}(\omega) = S_{11} + j\gamma K_1 \left( C_1 + j\gamma K_3 \left( T_{main} + C_2 \right) + j\gamma K_3 T_{main} C_2 \right)\]
  with \(K_1 = \frac{\lambda}{2\sqrt{\epsilon_f}}, K_3 = \frac{\lambda}{4\sqrt{\epsilon_f}}\)
- Corresponding impulse response and its complex envelope \(\tilde{\gamma}_m(t)\) at each main reflector position,
- Distance error \(\varepsilon\) in dependence of various signal processing algorithms

IV. Verification and Measurements

The results obtained by the radar system simulator are verified by measurements concerning the complex pulse envelope \(\tilde{\gamma}_m(t)\) and the measurement error \(\varepsilon\) by using a short metallic horn equipped with a dielectric single cavity insert in a frequency range from 8.5 to 10.5 GHz. The transfer function is processed by means of Hanning windowing in the frequency domain before applying the IFFT.

V. Conclusions

Pulse envelope: Good agreement particularly within the first two stages at:

- AUT (up to 4 ns),
- First reflection (from 4 ns to 11 ns).

Minor deviations due to violation of far-field distance caused by:

- the large metal plate mounted on the AUT's back, thus resulting in too large values within the replica (>11 ns),
- Masking of AUT-inherent reflection in the near-field range.

Distance error: Almost perfect match for the most important fact - the peak error prediction.

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