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

Gunnar Armbrecht, Christian Zietz, Eckhard Denicke, Ilona Rolfes

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.

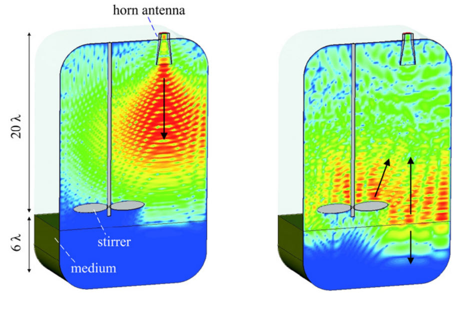
To evaluate **novel antenna designs**, the straight forward approach by regarding 3D models is not suitable, due to

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

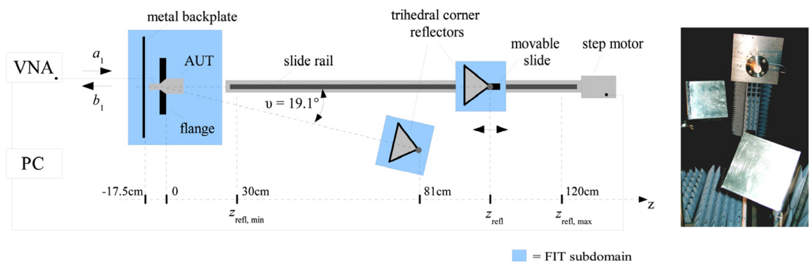
More efficient method:

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**



3D FIT simulation of the radiated electric field within a metallic tank environment of a Gaussian pulse (20 % fractional bandwidth, E-plane)



Compact test range for the evaluation of the antenna impact on radar level measurement accuracy (schematic and photograph)

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 … 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 effect – 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 and flexible 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**.

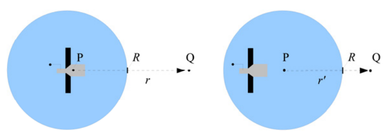
Typical **output quantities** of the system simulator:

- **Total reflection coefficient** $\tilde{G}(j\omega)$ representing the bandwidth-limited transfer function of the monostatic radar test scenario,

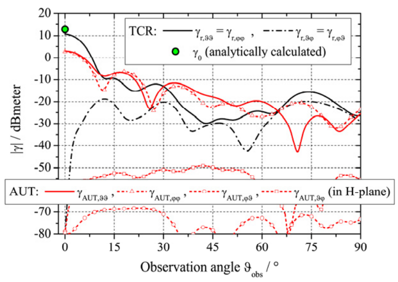
$$\tilde{G}(j\omega) = S_{11} + \gamma_0 K_1 \cdot \left\{ C_\vartheta^2 + C_\varphi^2 + \gamma_0 K_2 \cdot \left(\gamma_{\mathrm{AUT},\vartheta\vartheta} \cdot C_\vartheta^2 + \gamma_{\mathrm{AUT},\varphi\varphi} \cdot C_\varphi^2 \right) \right\},$$

$$\text{with} \quad K_1 = \frac{\lambda}{2\sqrt{\pi}} \cdot \frac{e^{-jk2r}}{4\pi r^2} \quad \text{and} \quad K_2 = \frac{e^{-jk2r}}{4\pi r^2}$$

- Corresponding **impulse response** and its **complex envelope** $g_{ce}(t)$ at each main reflector position,
- **distance error** e in dependence of various signal processing algorithms



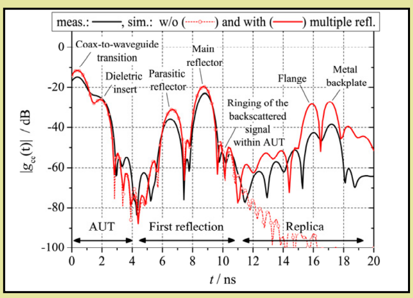
Amplitude mismatch by Fraunhofer approximated far-fields



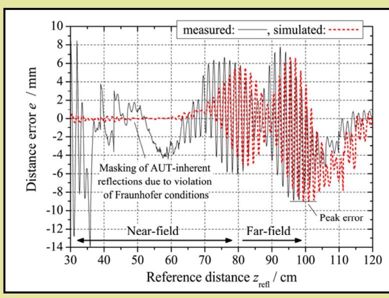
Mono- and bistatic scattering coefficients γ of a trihedral corner reflector (TCR) and the antenna under test (AUT)

IV. Verification and Measurements

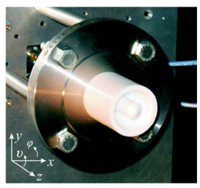
The results obtained by the radar system simulator are verified by measurements concerning the complex pulse envelope $g_{ce}(t)$ and the measurement error e by using **a short metallic horn** equipped with a **dielectric single cavity insert** in a frequency range from **8.5** to **10.5 GHz**. The transfer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



Measured and simulated envelope of the bandwidth-limited impulse response for a main reflector position of z_{refl} = 120 cm



Measured and simulated distance error (spatial filtering is activated to avoid effects due to unlatching algorithms)



AUT close-up view on a short metallic horn equipped with a dielectric single cavity insert

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.

Affiliation
Leibniz Universität Hannover
Institute of Radiofrequency and Microwave Engineering
Appelstraße 9A, D-30167 Hannover (Germany)

Corresponding author
Name: Gunnar Armbrecht
Phone: +49 (0)511 762-19552
E-Mail: armbrecht@hft.uni-hannover.de