2008 IEEE International Conference on Ultra-Wideband
Leibniz Universität Hannover, Hannover, Germany
September 10-12, 2008

Leibniz Universität Hannover

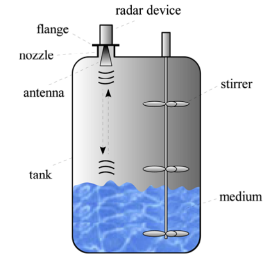
Compact Directional UWB Antenna with Dielectric Insert for Radar Distance Measurements

Gunnar Armbrecht*, Eckhard Denicke*, Nils Pohl#, Thomas Musch##, Ilona Rolfes*

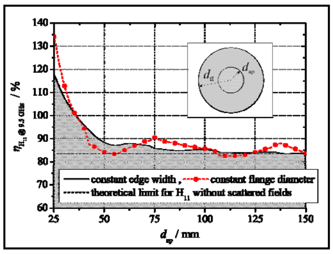
I. Introduction

A variety of applications is exploiting radar technique for **high-precision distance measurements** due to its robustness and flexibility, e.g. **industrial tank level control** in the process instrumentation industry. Common monostatic radar distance measurement approaches seek for highly directional radiating antenna designs over wide bandwidths featuring:

- strong **side lobe suppression** to avoid signal distortions by unwanted scatterers, e.g. tank walls, fixtures or stirrers,
- minimized **main beam widths** at strictly limited geometrical antenna diameters due to standardized nozzle and flange diameters,
- **adaptability** to the **harsh process conditions** by solely utilizing **chemically inert materials** like Teflon (PTFE),
- **dielectric encapsulation/sealing** due to metallic material prohibition under the restriction of hygienic/pharmaceutics process conditions,
- significant **length reduction** compared to well-known travelling-wave **dielectric rod antennas** leading to higher maximum filling levels of the medium stored inside the tank.



Typical radar antenna setup in an industrial tank environment



Impact of scattered fields on the aperture efficiency of radiating H_{11} mode at different flange geometries

II. Aperture Efficiency Enhancement by Scattered Fields

The **aperture efficiency** η is an evaluation criterion for every kind of aperture antenna being a **figure-of-merit** indicating to what extent an aperture is **electromagnetically exploited**, according to:

$$\eta = \frac{A_{\text{eff}}}{A_{\text{ap}}} = \frac{d_{\text{eff}}^2}{d_{\text{ap}}^2} = \frac{\lambda^2}{4\pi} \cdot \frac{D_0}{A_{\text{ap}}}$$

Antennas with increasing values of η exhibit higher directivities D_0 and thus narrower main beam widths. Exemplarily, radiation of open-ended circular waveguides with various inner diameters d_{ap}, excited by the perfect equiphased H_{11} fundamental waveguide mode's field distribution, is theoretically limited to a finite value of η = 83.4 %. But if scattered aperture fields are also considered utilizing a commercial 3D FIT field simulator (CST MICROWAVE STUDIO, Version 2008), higher aperture efficiency values of η > 100 % are achieved (see figure).

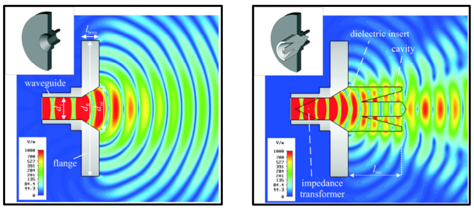
Therefore, **dielectric materials** are utilized to guide the aperture field as well as the scattered horn field to obtain an **efficiency enhancement**, which are capable to exceed the performance limits of even larger solely radiating aperture diameters.

III. Directivity Improvement by Dielectric Inserts

A **cylindrical dielectric insert** is applied to a **short metallic horn** excitation structure, yielding a short high gain antenna in comparison to the solely radiating excitation horn of l_{horn} = 20 mm having similar outer diameters d_{ap} = 50 mm. A dielectric insert with a length of 60 mm effectively exploits the horn's scattered field to enlarge the effective aperture area by expanding the field along the dielectric insert. The **insert** combines different **functional aspects**:

- conical impedance transformer between the unfilled and filled waveguide section
- dielectric encapsulation/sealing
- excitation of a short dielectric rod with tapered cavity.

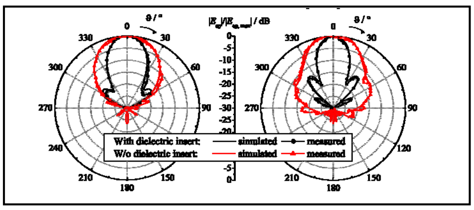
The amplitude and phase distribution in the aperture plane at the insert's end is shaped in terms of a **side lobe suppression** of about 15 dB and reduced **half power beam width** (HBW) by tuning the **material-to-air ratio** at the end of the insert in combination with the **cavity's flare angle** numerically.



Electric field distribution in the E-plane of Horn w/o (left) and with (right) dielectric insert made of Teflon (PTFE) at 9.5 GHz

Horn with dielectric insert	8.5 GHz	9.5 GHz	10.5 GHz
Peak directivity D_0/ dB	16.5	16.9	17.6
3 dB HBW/° (H-/E-plane)	27.9/25.2	27.7/23.3	22.9/23.2
Side lobe level / dB (H-/E-plane)	−20.2/ − 14.6	−17.6/ − 13.5	−14.5/ − 23.3
Aperture efficiency η/ %	225.2	197.7	190.1
$\lvert S_{11}\rvert$ / dB	−21.5	−21.4	−20.6
Horn w/o dielectric insert			
Peak directivity D_0/ dB	11.6	12.0	12.9
3 dB HBW/° (H-/E-plane)	51.4/47.0	48.0/42.9	39.8/37.9
Side lobe level / dB (H-/E-plane)	−24.3/ − 24.6	−23.4/ − 24.3	−23.7/ − 10.7
Aperture efficiency η/ %	72.9	63.9	64.4
$\lvert S_{11}\rvert$ / dB	−21.3	−26.6	−36.1

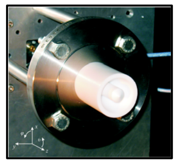
Broadband simulated characteristic antenna parameters at the center frequency of 9.5 GHz and both corner frequencies at 8.5 and 10.5 GHz



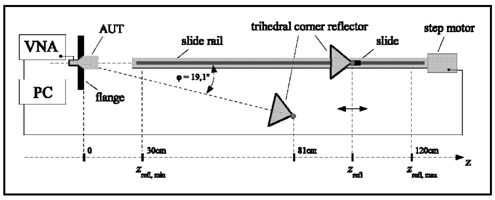
Normalized copolar radiation pattern of both antenna versions in the H- and E-plane

IV. Measurement Results

A **prototype** of the horn excitated dielectric insert antenna was manufactured, as shown on the right. The results derived from **measurements** conducted inside an **anechoic chamber** by a **3D spherical near-field measurement** were subsequently transformed into the antenna's far-field and agree well with the simulated results clarifying the **directional performance gain** of a dielectric-insert-equipped antenna in both cutting planes.

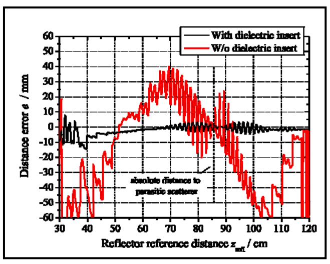

Flange-mounted prototype antenna

For **radar distance measurements** two equally sized **trihedral corner reflectors** are placed at different positions in front of the antennas under test (AUT), as sketched in the figure below. One reflector is mounted as a **main target** on a **movable slide** positioned by a step motor that serves as a distance reference in an interval ranging within z_{refl} = [30 ... 120 cm].



Experimental setup for radar distance measurements to evaluate the impact of various antennas - Sketch of the measured radar scattering scenario

A **commercial VNA** is incorporated for the emulation of a **radar device** and common pulse-based signal detection by **barycentric processing algorithms** is used. The parasitic reflector is arranged offset to the main reflector axis by an angle of approx. 19.1° being located still within the main beam direction in the E-plane for both AUT.



Measured distance error in an experimental scattering scenario with one parasitic reflector

The observed deteriorations due to the parasitic reflector are depicted on the left by evaluating the distance error e over the reflector reference distance z_{refl} (step width of Δz_{refl} =1 mm). The **distance error** directly correlates with the **AUT directivity properties**. The horn structure being equipped with the **proposed dielectric insert** yields an error reduction of approximately **eight times** compared to the solely radiating excitation horn.

Leibniz Universität Hannover
*Institut für Hochfrequenztechnik und Funksysteme
Appelstraße 9A
30167 Hannover (Germany)

Ruhr-Universität Bochum
#Lehrstuhl für Integrierte Systeme
##Institut für Hochfrequenztechnik
Universitätsstraße 150
44801 Bochum (Germany)

Contact:
Dipl.-Ing. Gunnar Armbrecht
Phone: +49 (0)511 762-19552
E-Mail: armbrecht@hft.uni-hannover.de