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A Non-Redundant Hemi-Spherical Scanning for Automotive Antenna Near-Field Measurements

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INTEREST and MOTIVATIONS

Modern vehicles are increasingly dependent on wireless systems and services. As a consequence, more and more antennas are highly integrated with the automotive body for aesthetic, practical and performance reasons.

These antennas must guarantee communications with other vehicles to avoid collision, with terrestrial infrastructures for incident warning, and with satellites for monitoring the vehicle status.

Each antenna is usually designed by including small sections of the surrounding structure where it must be mounted, since the total automotive body cannot be simulated accounting for all its geometrical and material characteristics. Accordingly, the antennas must be properly measured.

INTEREST and MOTIVATIONS

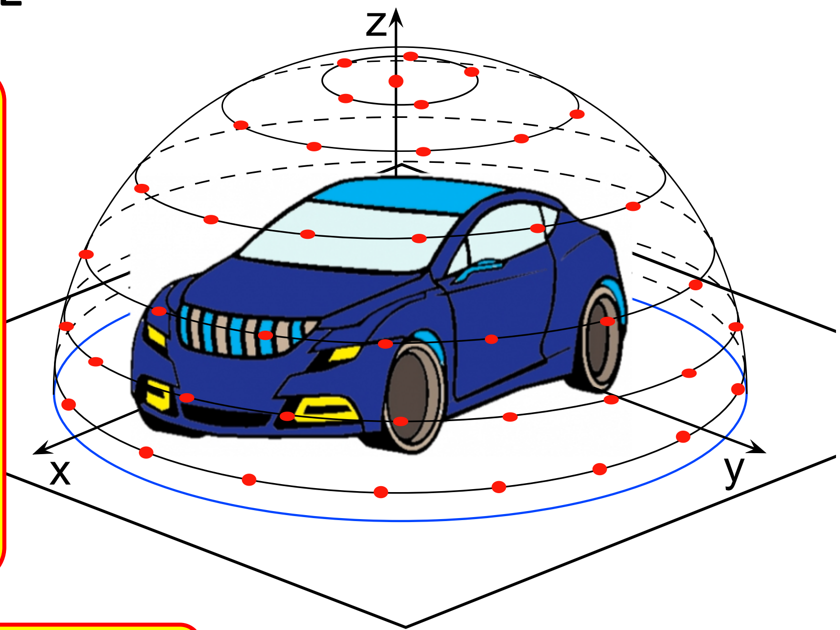
A hemi-spherical near-field (NF) facility can be conveniently considered. In it, the device under test (DUT) is located on a turntable and the probe moved on a fixed arc or mounted on a rotating arm.

The NF data are collected above a metalized ground to obtain a well-controlled environment, which guarantees a good repeatability of the measurements, but allows to collect the NF data only on the upper hemi-sphere.

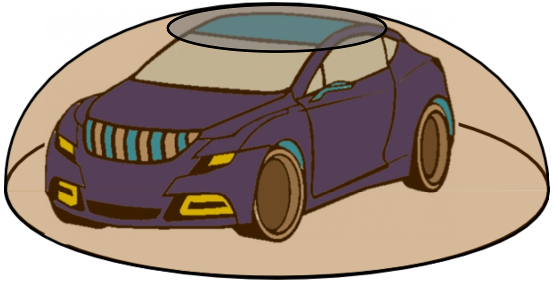
The missing NF data on the lower hemi-sphere can be determined by applying the image principle for a perfectly conducting (PEC) ground to the measured NF samples on the upper hemi-sphere. This enables the data mapping on the full NF sphere and the spherical NF to Far-Field (NFTFF) transformation.

THE GOAL

A non-redundant sampling representation of the probe voltage is proposed to reduce the number of needed NF data for hemi-spherical antenna measurements in an automotive testing set-up with a flat metallic ground.

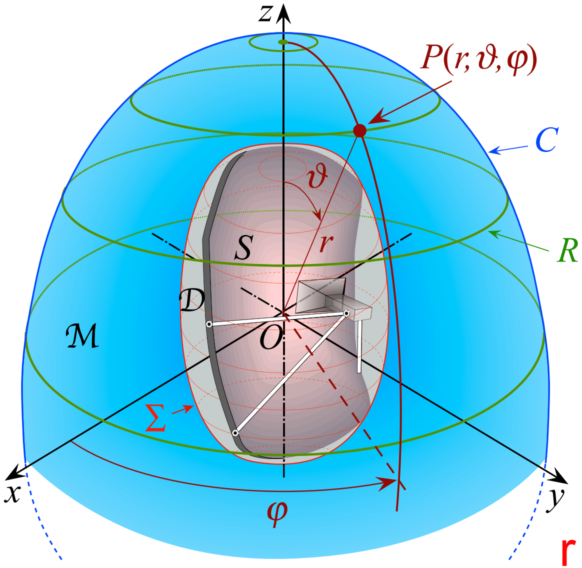


An adaptable convex surface containing the DUT and its image is chosen as source modeling and the optimal parameters are determined for applying the corresponding sampling and interpolation algorithms.



THEORETICAL BACKGROUND

By applying the non-redundant sampling representations of the electromagnetic field to the voltage measured by a small probe, we obtain a heavy reduction of required NF data with respect to the classical approach based on the minimum sphere.



S = source enclosed in a convex domain $\mathcal{D}$ bounded by a surface Σ

$\mathcal{M}$ = observation surface

Both Σ and $\mathcal{M}$ have the same rotational symmetry

C and R are the meridian and azimuthal observation curves

$$\boxed{\tilde{V}(\xi) = V(\xi)e^{j\gamma(\xi)}}$$ **PROBE REDUCED VOLTAGE**

$\gamma(\xi)$ optimal phase function (to be determined)

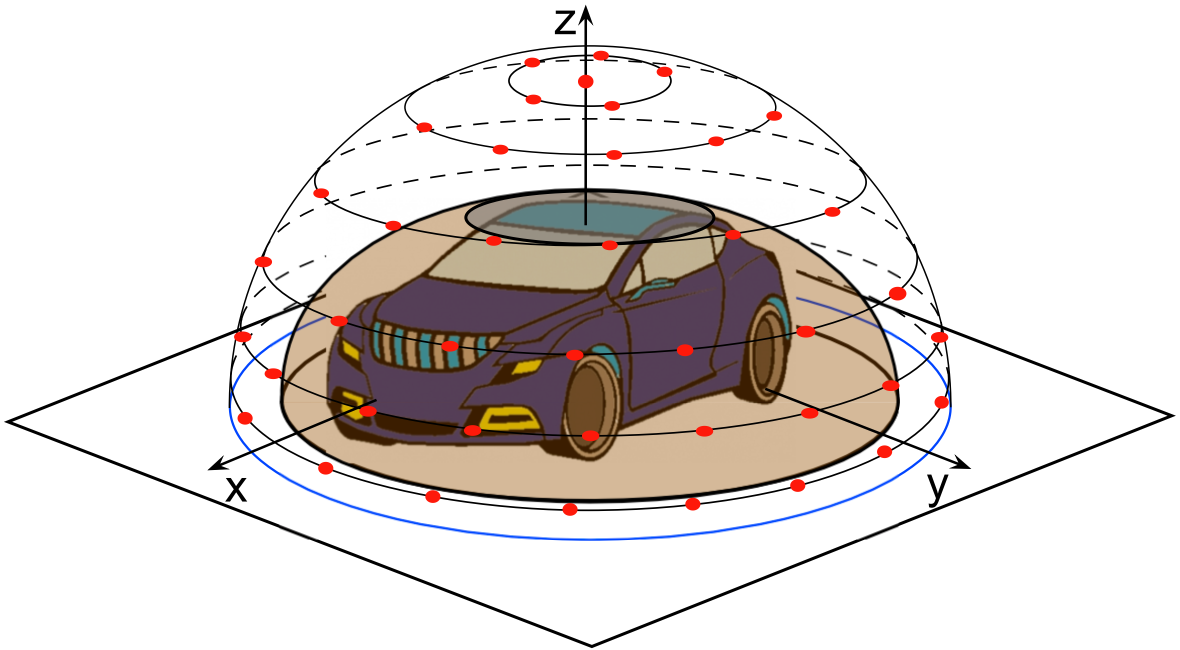
$\underline{r} = \underline{r}(\xi)$ parameterization of the observation curve (to be determined)

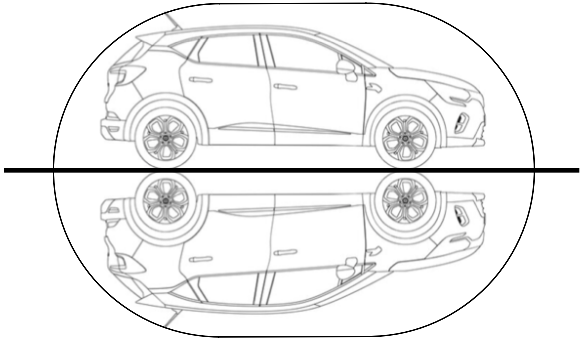
$\tilde{V}$ has practically the same spatial bandwidth W_ξ of the field radiated by the DUT

O.M. Bucci, G. D'Elia, and M.D. Migliore, "Advanced field interpolation from plane-polar samples: experimental verification," *IEEE Trans. Antennas Prop.*, **46**, 2, Feb. 1998, pp. 204-210.

THE DUT MODELING

As the given problem is reformulated by removing the infinite PEC ground plane and mirroring the given DUT with respect to the plane z = 0, the DUT can considered as enclosed in an upside-down bowl so that Σ is a “double bowl”, formed by the DUT bowl and its image.





THE OPTIMAL PHASE FUNCTION AND PARAMETERIZATION

"PROBE REDUCED VOLTAGE" $\tilde{V}(\xi) = V(\xi)e^{j\gamma(\xi)}$

Let a be the radius of the circular aperture at z = 0 and c the curvature radius of the lateral bends, it results:

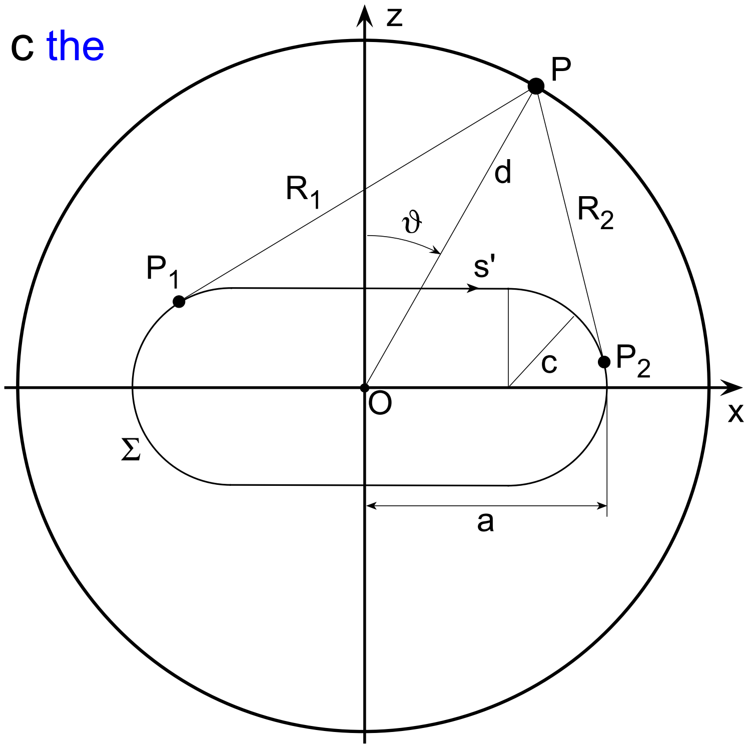
for a meridian

$W_\xi = \beta\ell'$

$\ell' = 4(a-c) + 2\pi c$

$$\gamma = \frac{\beta}{2}\left[R_1 + R_2 + s_1' - s_2'\right]$$

$$\xi = \frac{\pi}{\ell'}\left[R_1 - R_2 + s_1' + s_2'\right]$$



THE OPTIMAL PHASE FUNCTION AND PARAMETERIZATION

for an azimuthal circumference

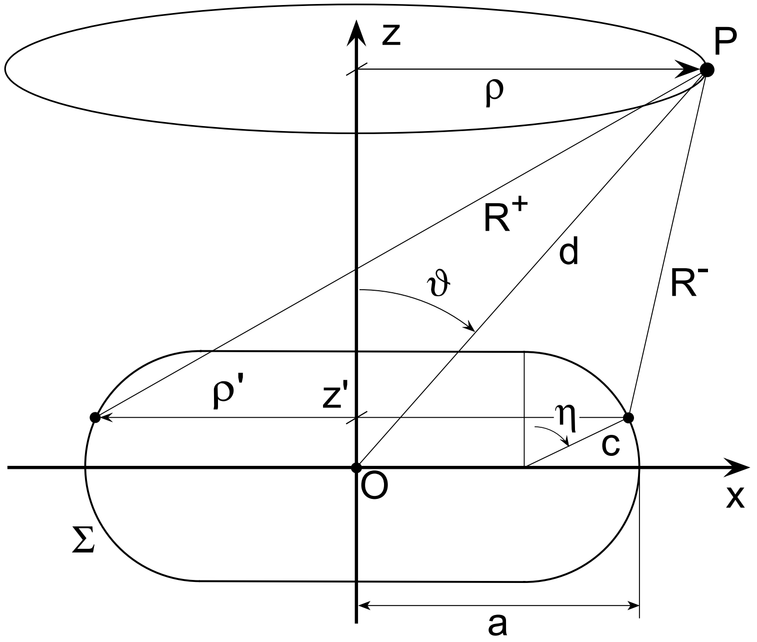
$$W_{\varphi} = \frac{\beta}{2}\max_{z'}\left(R^{+} - R^{-}\right) = \frac{\beta}{2}\max_{z'}\left(\sqrt{(z-z')^2 + \left(\rho+\rho'(z')\right)^2} - \sqrt{(z-z')^2 + \left(\rho-\rho'(z')\right)^2}\right)$$

$\gamma = \text{const.}$

$\xi = \varphi$

$\rho' = (a-c) + c\sin(\eta)$

where $\rho'(z')$ is the equation of Σ, $\rho = d\sin(\vartheta)$, and the maximum is attained on the upside-down bowl.

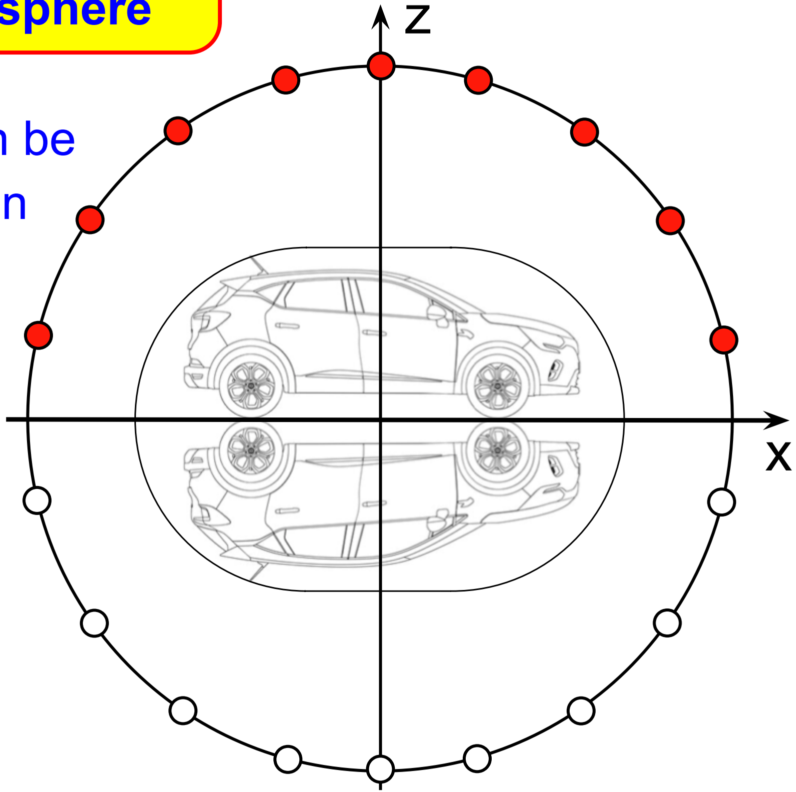


THE SAMPLING TECHNIQUE

The NF samples can be collected only over the upper hemi-sphere

The NF samples on the lower hemi-sphere can be properly synthesized from the collected ones on the upper hemi-sphere by using an opportune "mirroring rule" for the voltages measured by the probe and the rotated probe:

$$\begin{cases} V_p(r,\pi-\vartheta,\varphi) = -V_p(r,\vartheta,\varphi) \\ V_r(r,\pi-\vartheta,\varphi) = V_r(r,\vartheta,\varphi) \end{cases}$$



THE INTERPOLATION SCHEME

$$V\left(\xi(\vartheta),\varphi\right) = e^{-j\gamma(\xi)} \sum_{n=n_0-q+1}^{n_0+q} \left\{ \Omega_N\left(\xi-\xi_n,\bar{\xi}\right) D^{e}_{N''}\left(\xi-\xi_n\right) \sum_{m=m_0-p+1}^{m_0+p} \tilde{V}\left(\xi_n,\varphi_{m,n}\right) \Omega_{M_n}\left(\varphi-\varphi_{m,n},\bar{\varphi}\right) D_{M''_n}\left(\varphi-\varphi_{m,n}\right) \right\}$$

$$n_0 = \left\lfloor \frac{\xi}{\Delta\xi} \right\rfloor \qquad m_0 = \left\lfloor \frac{\varphi}{\Delta\varphi_n} \right\rfloor$$

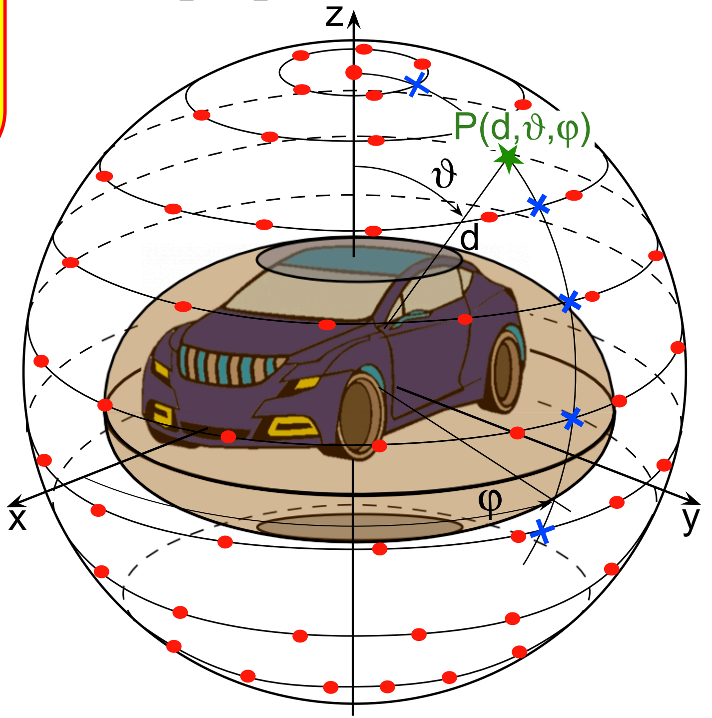
$$\xi_n = n\,\Delta\xi = \frac{\pi n}{N''} \qquad N'' = \lfloor \chi N' \rfloor + 1 \qquad N' = \lfloor \chi' W_\xi \rfloor + 1 \qquad N = N'' - N'$$

$$\varphi_{m,n} = m\,\Delta\varphi_n = \frac{2\pi m}{2M''_n + 1} \qquad M''_n = \lfloor \chi M'_n \rfloor + 1 \qquad M'_{\mathbf{n}} = \lfloor \chi^* W_\varphi(\xi_n) \rfloor + 1$$

$$\bar{\varphi} = p\,\Delta\varphi_n$$

$$M_n = M''_n - M'_{\mathbf{n}} \qquad \chi^* = 1 + (\chi' - 1)\left[\sin\vartheta(\xi_n)\right]^{-2/3}$$

$$\bar{\xi} = q\,\Delta\xi$$



Ω_L is the Tschebyscheff Sampling Function

$D_{L''}$ and $D^{e}_{L''}$ are the Dirichlet Functions for an odd and an even number of samples

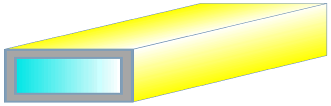
NUMERICAL RESULTS

Let us assume a standard sedan car having the following dimensions:

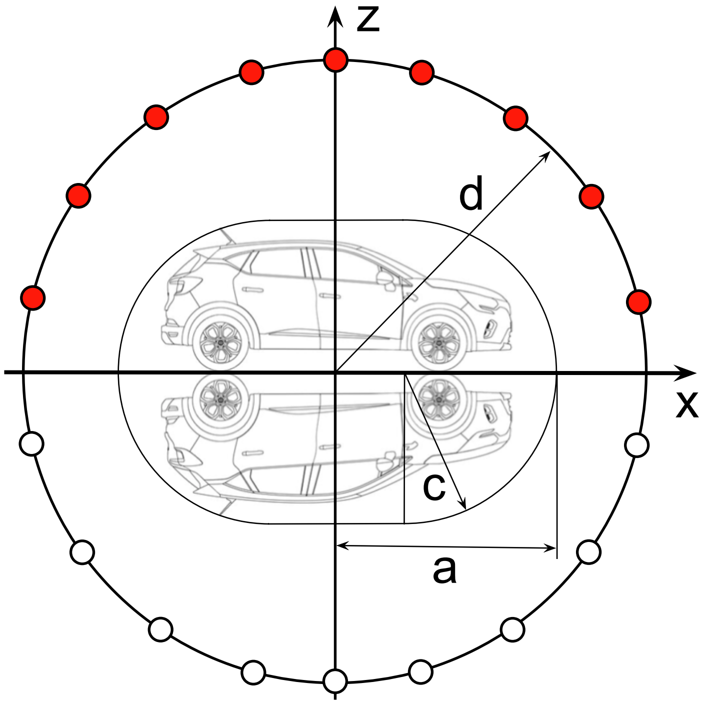
Length $L = 4.2$ m;
Width $W = 1.8$ m;
Height. $H = 1.8$ m.

To simulate eventually distributed sources matching the sedan car dimensions, a rectangular planar array with area $L \times W$ has been located at 1.2 m from the ground.

The array elements have been fed at 5 GHz in such a way to have the maximum of the radiated field along the longitudinal section of the car.

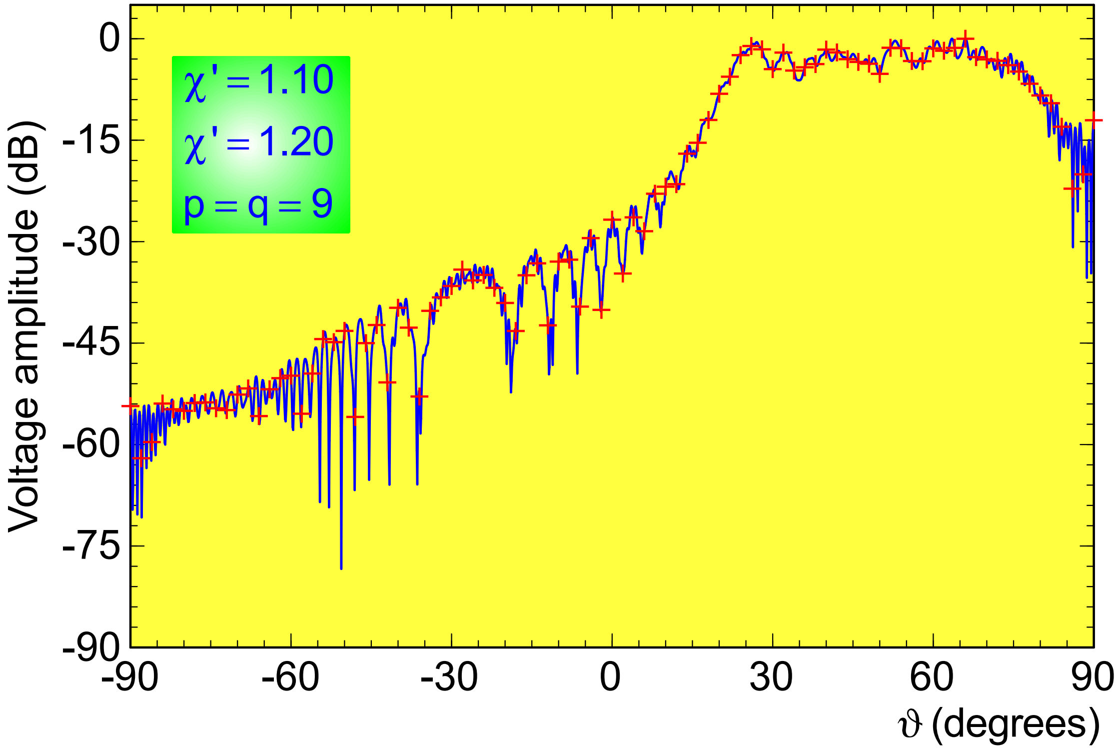


Probe: WR187



a = 53.0 λ, c = 30.0 λ;
d = 75.0 λ
λ = 6.0 cm

NF DATA

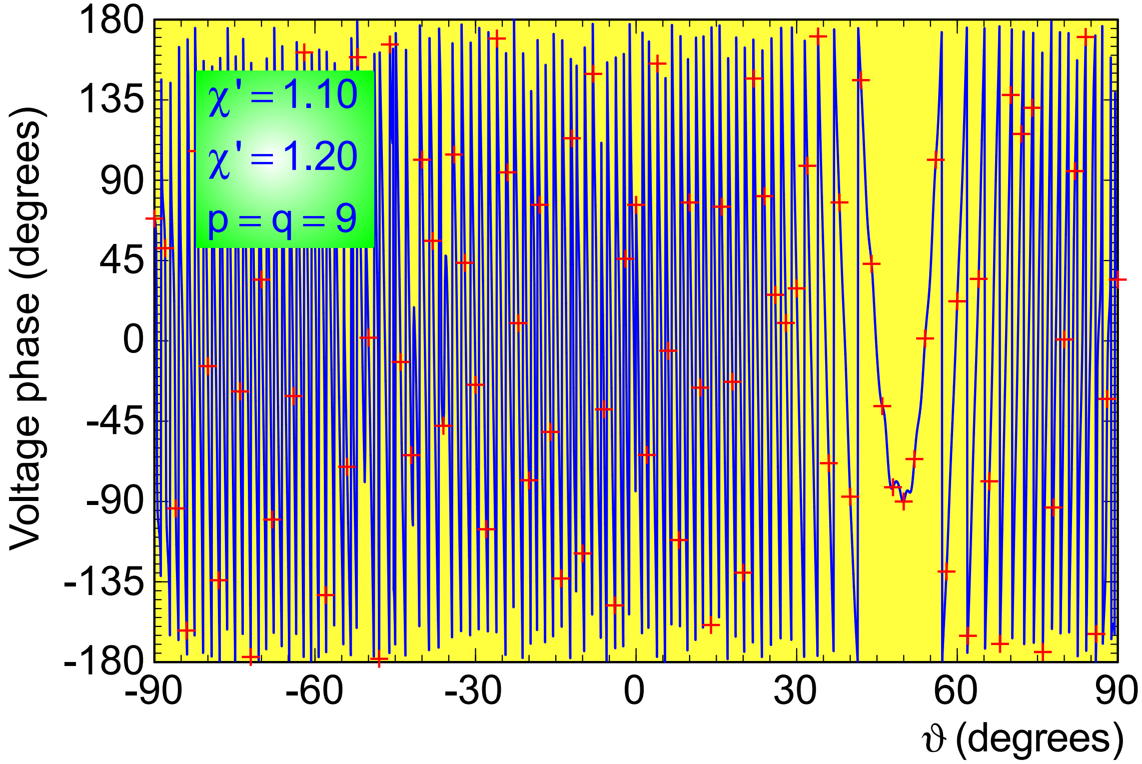


Amplitude of V_r on the cut plane @ $\varphi = 0°$

Solid line: exact.

Crosses: interpolated.

NF DATA

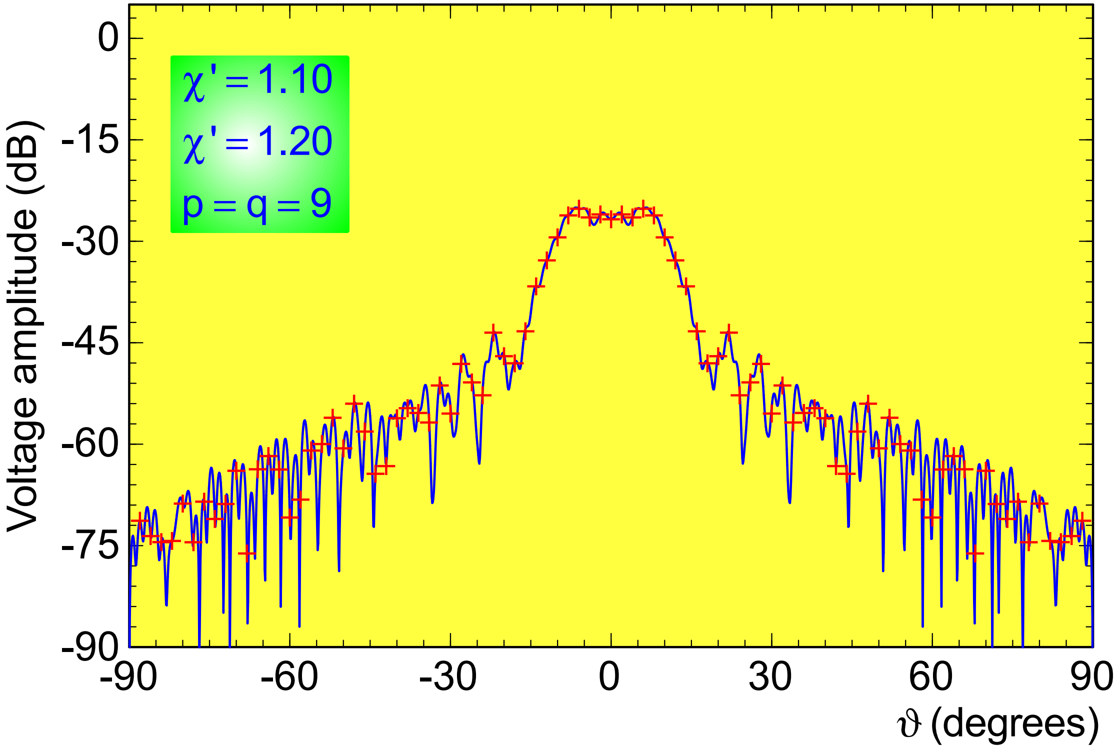


Phase of V_r on the cut plane @ φ = 0°

Solid line: exact.

Crosses: interpolated.

NF DATA

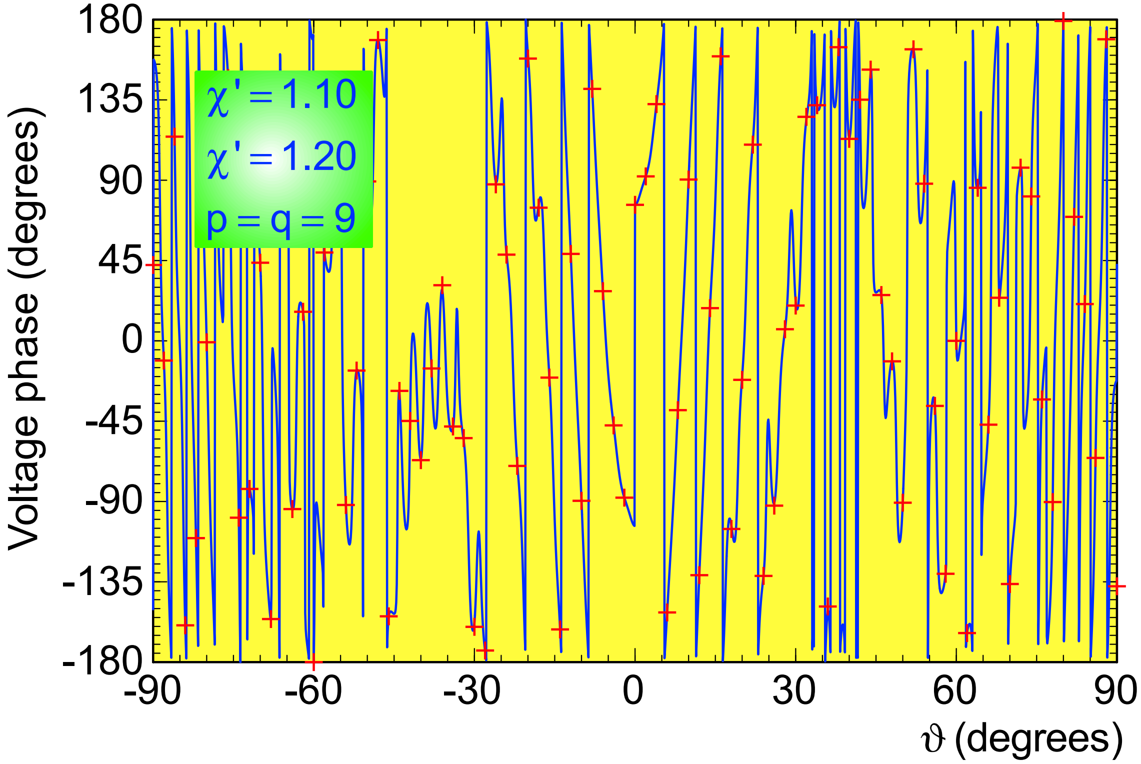


Amplitude of V_p on the cut plane @ φ = 90°

Solid line: exact.

Crosses: interpolated.

NF DATA

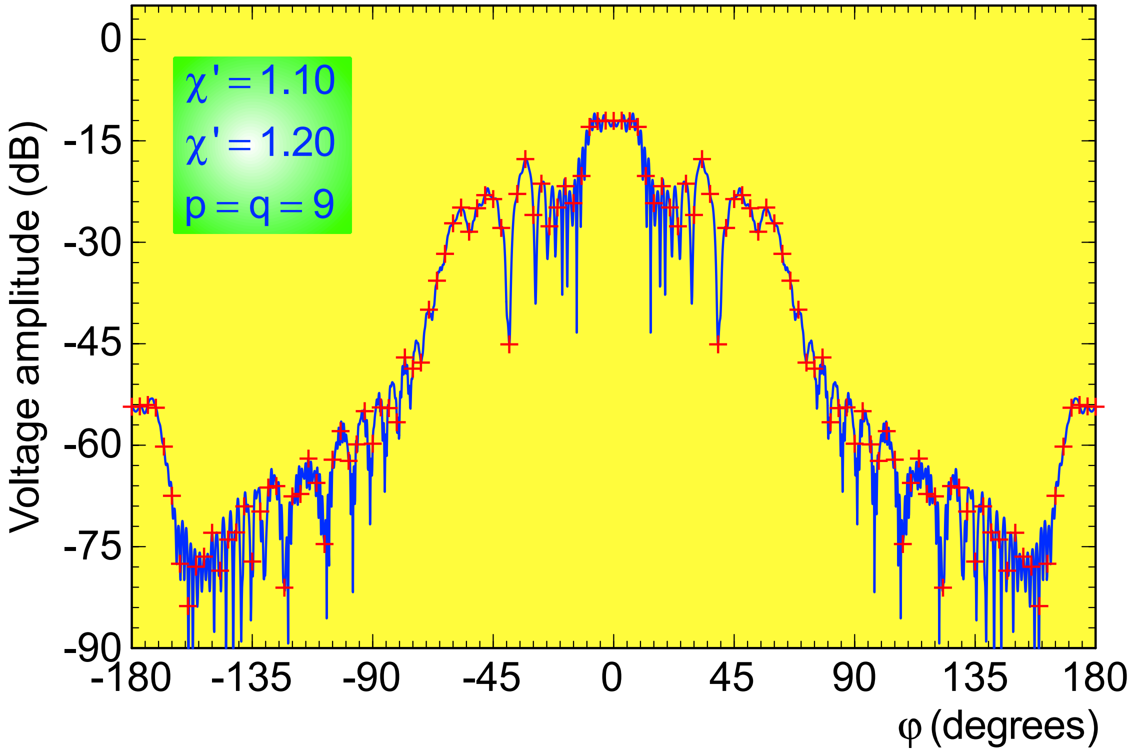


Phase of V_p on the cut plane @ $\varphi = 90°$

Solid line: exact.

Crosses: interpolated.

NF DATA

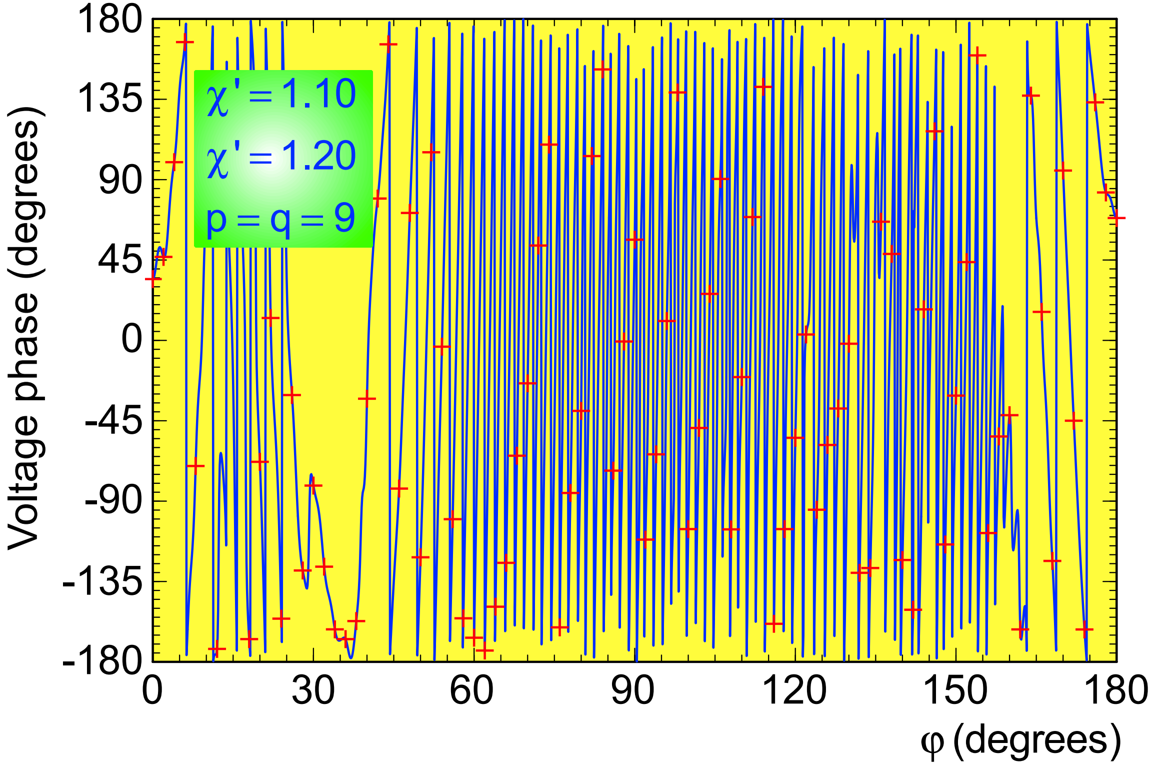


Amplitude of V_r on the PEC ground plane

Solid line: exact.

Crosses: interpolated.

NF DATA



Phase of V_r on the PEC ground plane

Solid line: exact.

Crosses: interpolated.

DATA NEEDED

Technique	# NF data
Classical spherical scan (whole sphere)	129 600
Non-redundant scan (upper hemi-sphere)	42 275