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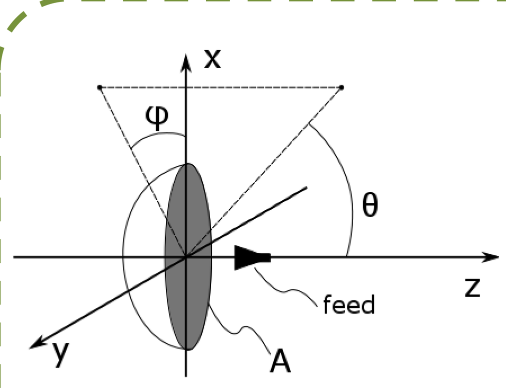
XXX Cycle – 2^{nd} year presentation

Advanced Diagnosis Techniques for Radio and Optical Telescopes in Astronomical Applications

The research activity is focused on advanced diagnosis techniques for radio and optical telescopes for astronomical applications.
To guarantee the high performance required to these systems, a continuous monitoring and reassessment is necessary to suppress deviations from their nominal behavior.
Among the approaches adopted during the decades for radiotelescopes, the electromagnetic monitoring appears today one of the most appealing since it allows in-situ measurements, with reduced direct human intervention, and requiring a relatively simple measurement setup. The approach should be able to retrieve the distortions and the misalignments from amplitude and phase, or only amplitude, field data. The Far Field Pattern (FFP) is typically measured with the Antenna Under Test (AUT) working in the receiving mode, and natural radio star or a satellite beacon as signal sources.
The acquisition of the FFP typically requires a very large number of field samples to get the complete information about the AUT, and the subsequent measurement process may span over several hours. A prolonged acquisition has significant drawbacks related to the continuous tracking of the source and the inconstancy of the environmental conditions. Approaches able to optimize acquisitions are very appealing.



- AUT: reflector antenna
- The xy plane lies in the Aperture plane
- Feed illumination linearly polarized (scalar model)

The relevant relationship between the AF and the x component of the FFP can be expressed via the well-known Fourier Transform relationship:

$$F(u,v) = \cos\theta \iint_A dxdy E_a(x,y)\exp(j\beta(ux+vy)) = \mathcal{T}[E_a]$$

- F: x-component component of the FFP
- E_a: x-component of the Aperture Field
- (u,v): cosine directors of the observation point
- $\beta=2\pi/\lambda$, λ being the wavelength
- $\mathcal{T}$ is the operator mapping the AF onto the FFP

A real valued aberration function Φ is assumed to describe the perturbation of the phase of the nominal AF E_{a0}

$$E_a \cong E_{a0}\exp(j\Phi)$$

The diagnosis of the AUT consists of
1. Determining Ea and then Φ
2. Retrieving the parameters describing its status

By varying the parameters $(p_1,\ldots,p_N)$, the phase term exp(jΦ) defines a N-dimensional manifold $\mathcal{M}$ in the space of functions of two variables (x,y).
To restore a linear relationship, we introduce the following factorization:

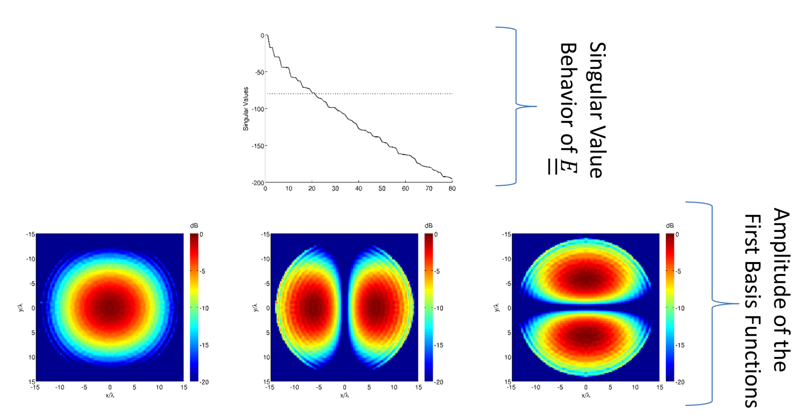
$$\exp\left(j\Phi(x,y,p_1,\ldots,p_N)\right) = \sum_{i=1}^{K} c_k(p_1,\ldots,p_N)\psi_k(x,y)$$

where $\{\psi_1,\ldots,\psi_K\}$ form a basis for a K-dimensional vector subspace containing $\mathcal{M}$.

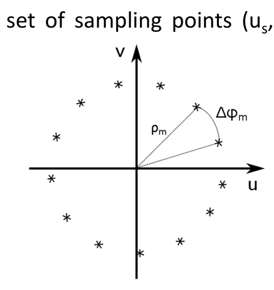
The discretization of $\mathcal{M}$, obtained by considering the function exp(jΦ) on a discrete set of values $p_1,\ldots,p_N$, generates a matrix $\underline{\underline{E}}$, whose Singular Values Decomposition leads to the discrete counterpart of the basis functions $\{\psi_1,\ldots,\psi_K\}$.

The Singular Values Decomposition of $\underline{\underline{E}}$ provides:

- a basis for the vector subspace, represented by its singular vectors;
- a criterion to choose the minimum dimensionality K, required to represent $\mathcal{M}$ within a given accuracy.



We consider a discrete set of sampling points (u_s,v_s) arranged in a plane-polar distribution



The plane-polar distribution is defined by the number of rings M, their radius ρ_m and their angular spacing $\Delta\phi_m$.
The diagnosis problem is then recast into a discrete linear inverse problem:

$$\underline{F} = \underline{\underline{T}}(\underline{\rho},\underline{\Delta\varphi})\underline{C}$$

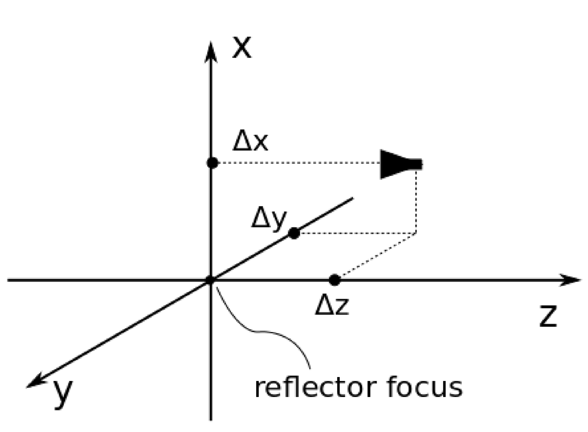
where:
$\underline{F}$: S-dimensional vector containing the field samples
$\underline{\rho}$, Δϕ: M-dimensional vectors containing the radii ρm and the angular steps Δϕm
$\underline{C}$: K-dimensional vector of expansion coefficients c_k
$\underline{\underline{T}}$ matrix whose entries are $T_{sk} = \langle \mathcal{T}[E_{a0}\psi_k], \delta(u-u_s)\delta(v-v_s)\rangle$

The inversion of the linear system can suffer from the ill-conditioning of $\underline{\underline{T}}$ with detrimental effects on the accuracy and on the robustness against noise.
Through the optimization of the Singular Values behavior of $\underline{\underline{T}}$ as a function of M, ρ_m and $\Delta\phi_m$, the samples F_s are selected in order to get the best conditioned linear algebraic system.

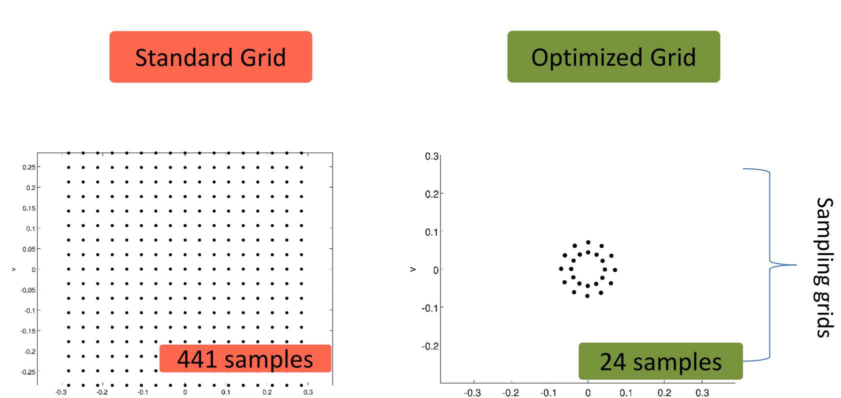
$$\Psi(\underline{\rho},\underline{\Delta\varphi}) = \sum_r \frac{\sigma_r}{\sigma_1}$$

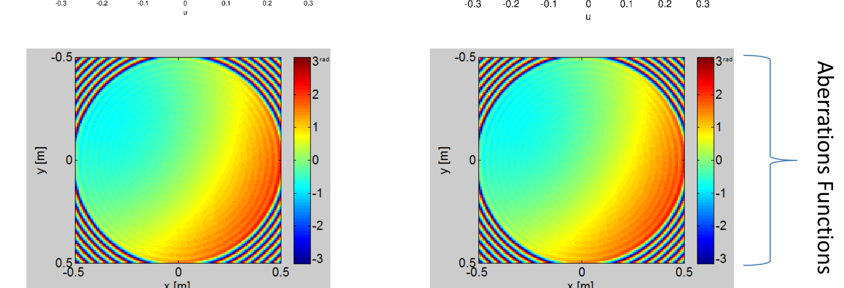
The set-up

- Single reflector AUT with a centered geometry
- Frequency f=10GHz
- Diameter of the reflector D=32λ
- Focal ratio f/D = 0.5
- Feeding: x-polarized beam with a -12dB tapering over the edge of the reflector
- $\Phi = p_1x+p_2y+p_3x^2+p_4y^2+p_5xy$
- 19 basis functions obtained by the PCA



Numerical Results

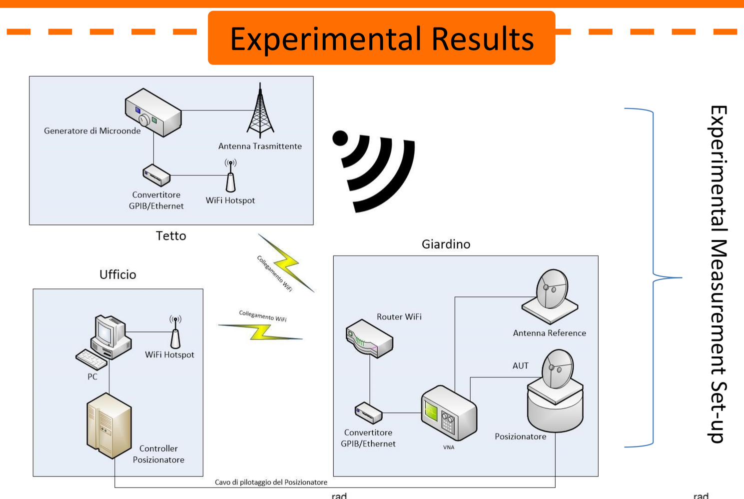


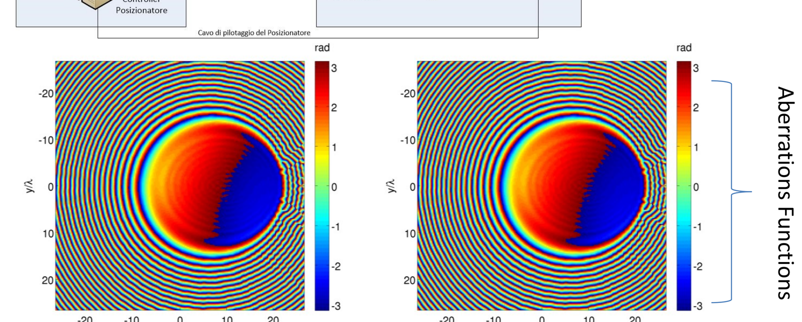


Feed position

	Nominal	Riconstructed
Δx [mm]	7	6.95
Δy [mm]	4	3.89
Δz [mm]	6	5.69

Experimental Results





Feed position

	Nominal	Riconstructed
Δx [mm]	20	20.78
Δy [mm]	0	1.32
Δz [mm]	0	5.23

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Future developments of the optimized diagnosis:
- Extension to the case of feed rotation;
- Extension to more general aberration functions;
- Development of an amplitude only diagnosis approach.