The Observable Field for Generalized Incident Fields

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***Abstract*— The Observable Field is the portion of the incident field that can contribute to the signal received by an antenna. Recently, the Observable Field was estimated for a plane wave incidence. Here, the procedure is extended to general incident fields expressed as superposition of multiple plane waves. As a case study, we consider a communication scenario which involves a base station and distributed receivers embedded in a complex scattering environment. The Observable Field concept provides clear guidelines for the design of the receiving terminal antennas. In particular, it emerges that to maximize the received power, the pattern in transmission of the antenna should be synthesized to reproduce the angular pattern of the Observable Field. This is specifically relevant in cases of no line of sight at high frequencies, where the power received can drop by several orders of magnitude.**

***Index Terms*—Antennas, reception, equivalent circuit**

I. Introduction

In complex scattering scenarios, such as wireless communications, to identify what is the optimal receiving antenna represents an open research question [1,9]. In high frequency wireless links, example of phased array antennas with beam shaping capabilities to overcome limitations due to a line of sight link absence are studied [7,8]. The theoretical tool we chose to optimize the shape of the beam in reception is the Observable Field. This was introduced in [2] as the portion of a single incident plane wave, propagating in direction $\hat{k}_i$, that can contribute to the signal received by an antenna filling a fixed volume (a sphere of radius a), and was obtained by removing from the incident field the remaining field, the portion that provides negligible contributions to the received signal, as $\vec{e}_{obs}(\hat{k}_i, a) = \vec{e}_i(\hat{k}_i) - \vec{e}_{rem}(\hat{k}_i, a)$.

To clarify the usefulness of the Observable Field concept, we generalize the incident field imagining a stadium scenario with tens of thousands of users carrying a mobile terminal antenna (*e.g.* a smartphone) receiving signal coming from a transmitting base station located in the center of the stadium. A possible 120 GHz architecture based on a line of sight power budget analysis to provide on-demand coverage in such scenario was proposed in [3].

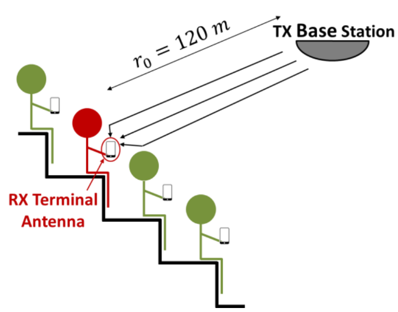


Fig.1 Stadium scenario: geometry, including the base station, and main scattering contributions.

II The Observable Field for Generalized Incidence

The Observable Field for a plane wave propagating in direction $\hat{k}_i$ was defined in [2] in the far field region of an antenna located inside a spherical domain of radius a; it was expressed as the product of a normalized spherical wave, $\vec{e}_{po,rx}$, and an amplitude, C, as $\vec{e}_{obs}(\vec{r}_\infty, \hat{k}_i, a) \approx C(a, \hat{k}_i)\vec{e}_{po,rx}(\vec{r}_\infty, \hat{k}_i, a)$. The pedix *"po"* indicates that these distributions can be obtained from the radiation integral of Physical Optics equivalent currents associated to the incident field, the Ideal Currents ($\vec{J}_{po}^{rx}, \vec{m}_{po}^{rx}$), induced on the surface of an "ideal" antenna operated in reception. $C(a)$ is calculated via a projection based on reciprocity reaction integrals between the incident ($\vec{f}_i$) and Observable ($\vec{f}_{po,tx}$) Fields, electric or magnetic, on the far field of the antenna. In case of general incident fields, these will be expressed as a sum of coherent plane waves via their plane wave spectrum expansion, and for each plane wave component we will apply the present procedure, eventually summing all the contributions.

III Estimations of the Available Power for Two Coherent Plane Waves

Let us consider the case of two plane waves coming from opposite directions $\pm 15^o$. Fig.2 shows the available power as a function of the antenna radius a normalized to λ_0, evaluated using the Ideal Currents procedure. The two plane waves' electric fields have unitary amplitude, and their interaction will give rise to constructive or destructive interference ("additive" or "subtractive" configuration). Fig.2 also shows a comparison between the available power calculated using a spherical modes representation as suggested by [4].

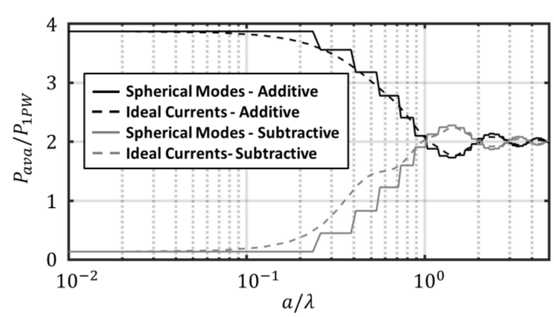


Fig.2 Available power as a function of the antenna domain normalized to the available power obtained from a single incident plane wave. Comparison between Ideal Currents and Spherical Modes. Two plane waves incoming from $\pm 15°$.

IV The Stadium Scenario

With reference to Fig.1, we envision a stadium with tens of thousands of spectators with a wireless system as described in [3]. The wireless link is provided via a centrally positioned base station at $r_0 = 120\ m$ from the spectators, operating at $f = 120\ GHz$, with a gain of $12.5\ cm^2$. A power of $14\ dBm$ is transmitted in each beam the base station generates.

In the present example, the line of sight field reaches the spectator with an angle of $\theta_{BS} = 15^o$ with respect to the horizon (Fig.3). The scatterers permittivity is taken from [6]. A PO tool (GRASP, [5]) is used to calculate the scattered field. The total field on the antenna terminal is shown in Fig.4. The reflection from the torso is the main phenomenon that gives rise to the interference pattern with the line of sight (LOS) field.

Fig.5 shows the power received by an antenna terminal pointing towards the base station and the torso in the trajectories 1 and 2, respectively, and compared with a terminal consisting in a circular aperture of uniform current, *i.e.* an Airy pattern with a $19dB$ directivity.

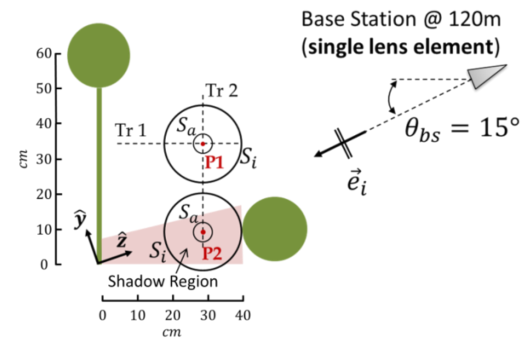


Fig.3 Local geometry surrounding the user terminal antenna. Reference system aligned with the direction of the LOS field. In green are the main scatterers. P1, P2, indicate the two points where the Observable Field is evaluated. S_a indicates the antenna domain (sphere of radius $a = 3.5mm$). The two dotted lines Tr 1, Tr 2 indicates the two trajectories where the received power is estimated.

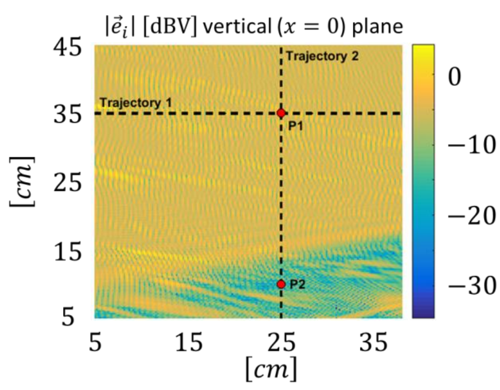
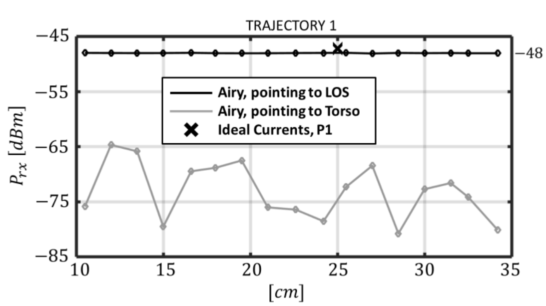
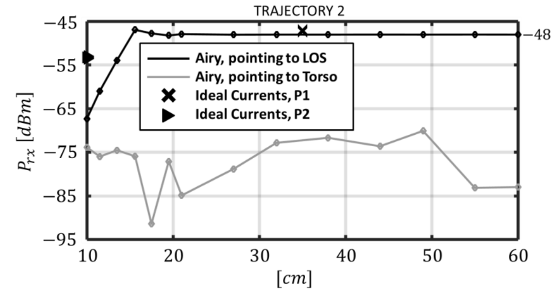


Fig.4 Incident field on the vertical plane of the spectator (plane (x, y) in Fig.3). The trajectory 1 and 2 are shown for completeness.



(a)



(b)

Fig.5 power received by Ideal Currents and circular antenna terminal as a function of the distance along the two trajectory in Fig.3. a) received power along trajectory 1; b) received power along trajectory 2.

V CONCLUSIONS

The Observable Field represents the far field radiated by an ideal antenna that receives the maximum power for a given incident field. This contribution introduced the use of the Observable Field as a tool to synthesize the beams of antennas in reception, so that they can in fact be as efficient as theoretically possible. The procedure is especially beneficial in environments where the incident fields is composed of multiple coherent planes waves, such as in communication scenarios where the receiver is located close to multiple scatterers. In these situations, the knowledge of the amplitude, the phase and the direction of incidence of the different contribution can be used to fine-tune the design of the receiving antenna pattern. The actual design and realization of such antennas that realize these complex patterns will be addressed elsewhere.

ACKNOWLEDGEMENT

This work has been supported by the ERC starting grant Lens Antenna Arrays for Coherent THz Cameras (LAA-THz-CC, 639749)

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