CHALMERS

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Antenna toolbox

Reference manual

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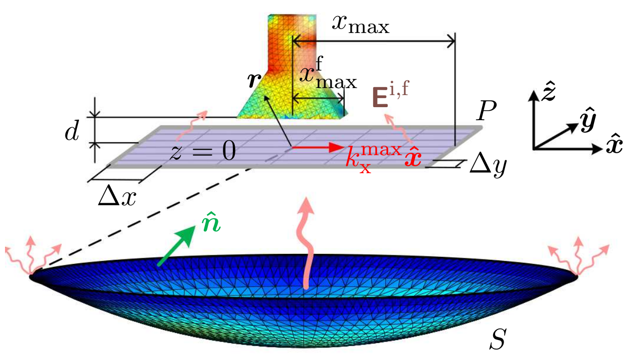

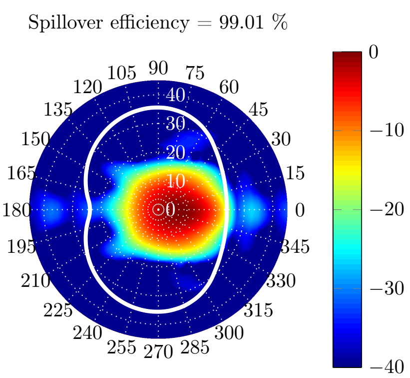

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Chapter

1 Radiation field processing

1.1 Field structure

To store a radiation field from an antenna, we use a MATLAB structure with specially named fields. We will refer to such specially crafted structure as *Field structure*.

An example of a typical Field structure is shown below. The field is stored in the spherical grid (`Field.GridType='spherical'`) with 181 θ-points and 361 ϕ-points. This is a far-field (`Field.NearFar='far'`) of a Y-oriented linear-polarized source (`Field.Ludwig3RefPhi=pi/2`). The field vectors are decomposed into the Ludwig 3rd polarization components (`Field.Polarization='ludwig3'`).

```
Field =

    struct with fields:

                   Freq: 6.9000e+09
                      E: [181x361x2 double]
                  THETA: [181x361 double]
                    PHI: [181x361 double]
           Polarization: 'ludwig3'
                NearFar: 'far'
               GridType: 'spherical'
           GridSymmetry: 'unsymmetrical'
          Ludwig3RefPhi: 1.5708
```

The detailed description of the structure fields is given in Table 1.1 below.

Table 1.1: Fields of the Field structure

`GridType` *Default:* `'spherical'`	Type of the coordinate system in which the field points are defined. It can be one of the following strings: • `'spherical'` – spherical coordinate system (R, θ, ϕ). Point coordinates are stored in the corresponding structure fields `R` (for near-field only), `THETA` and `PHI` • `'rectangular'` – rectangular coordinate system (X, Y, Z). Point coordinates are stored in the corresponding structure fields `X`, `Y` and `Z`. Often field is defined in a plane, and in this case the coordinate `Z` is absent. • `'AzEl'` – azimuth-elevation coordinate system (Az, El, R). Point coordinates are stored in the corresponding structure fields , `AZ`, `EL` and `R` (for near-field only). If field `GridType` is absent, the `'spherical'` grid is considered.

`GridSymmetry`
 	
Default:
`'unsymmetrical'`
	Used only in conjunction with `GridType = 'spherical'`.
	`GridSymmetry` shows how points are distributed in the polar θ-cuts (i.e. constant ϕ, varying θ).
	Can take one of the following values:
	• `'symmetrical'` – θ-cuts are symmetrical about the pole, i.e. $-\theta_{\max} \leq \theta \leq +\theta_{\max}$ for each $\phi = \phi_0$. To cover whole sphere θ and ϕ should span angles $-180° \leq \theta \leq 180°$ and $0° \leq \phi < 180°$.
	• `'unsymmetrical'` – θ-cuts are asymmetrical about the pole, i.e. $0° \leq \theta \leq +\theta_{\max}$ for each $\phi = \phi_0$. To cover whole sphere θ and ϕ should span angles $0° \leq \theta \leq 180°$ and $0° \leq \phi < 360°$.
	• `'custom'` – all other cases.
	If field `GridSymmetry` is absent, the `'unsymmetrical'` grid is assumed by some functions. However, it is not recommended to omit this field.

`R` , [m] (optional)
`THETA` , [rad]
`PHI` , [rad]
 	
OR
 	
`X` , [m]
`Y` , [m]
`Z` , [m] (optional)
 	
OR
 	
`AZ` , [rad]
`EL` , [rad]
`R` , [m] (optional)
	Coordinates of the field points in the coordinate system specified in `GridType`.
	
	Coordinates are defined as a grid
	The coordinate grid can be regular or irregular (both are generated by MATLAB `meshgrid` function).
	A regular grid (the most common case) should be generated as:
	• for `GridType ='spherical'`:
	`[PHI THETA R] = meshgrid(PhiFirst:PhiStep:PhiLast, ThetaFirst:ThetaStep:ThetaLast, RFirst:RStep:RLast);`
	Note that `R` is absent for a far-field.
	• for `GridType ='rectangular'`:
	`[Y X Z] = meshgrid(YFirst:YStep:YLast, XFirst:XStep:XLast, ZFirst:ZStep:ZLast);` Note that `Z` is absent for a field in a plane grid.
	• for `GridType ='AzEl'`:
	`[EL AZ R] = meshgrid(ElFirst:ElStep:ElLast, AzFirst:AzStep:AzLast, RFirst:RStep:RLast);`
	Note that `R` is absent for a far-field.
	
	Coordinates are defined as arbitrary points
	Alternatively, arbitrary points can be provided. In this case these structure fields contain just vectors, and `GridSymmetry` must be `'arbitrary'`. Nevertheless this is a very general format, it is not supported by most of the toolbox functions (unless updated :)). Therefore it is strongly recommended to use grids as described above.

`E`

Values of the electric field components[1]. The format of `E` depends on how the observation points/directions are defined. There are two formats:

1) When points are stored in a grid

In general `E` is 6-D array:

`Field.E(iCoor1, iCoor2, iComp, iExcit, iFreq, iCoor3)`,

where

`iCoor1`	first coordinate of the grid (see *Remark 1*)
`iCoor2`	second coordinate of the grid (see *Remark 1*)
`iCoor3`	third coordinate of the grid (see *Remark 1* and *Remark 2*)
`iComp`	component of the field (see `Polarization` field of the structure)
`iExcit`	index of the excitation. This allows to store several E-fields in a single structure. For example, these fields can be radiation patterns of an antenna array for different excitation scenarios; or they can be embedded element patterns of an array or other multiport antenna, etc.
`iFreq`	index of the frequency from `Freq` structure field.

Remark 1

Meaning of `iCoor1`, `iCoor2` and `iCoor3` depends on the `GridType`, i.e.

`GridType`	(`iCoor1`, `iCoor2`, `iCoor3`)
`'spherical'`	(`iTheta`, `iPhi`, `iR`)
`'rectangular'`	(`iX`, `iY`, `iZ`)
`'AzEl'`	(`iAZ`, `iEL`, `iR`)

Remark 2

Please note that index of the 3rd grid coordinate is in the last dimension of `E`, since it is absent in most practical cases, such as far-fields or a field on a planar grid.

2) When points are stored as arbitrary points

In this case for any `GridType` the dimensions are:

`Field.E(iPt, iComp, iExcit, iFreq)`,

where `iPt` is index of the observation point.

<table>
<tr>
<td><code>Polarization</code></td>
<td>
Specifies what field components are stored in <code>E</code>. It can have one of the following values:
<table>
<tr><th><code>Polarization</code></th><th><code>iComp</code> meaning</th></tr>
<tr><td><code>'rectangular'</code></td><td><code>iComp</code> $= 1$ – x-component of the field;
<code>iComp</code> $= 2$ – y-component of the field;
<code>iComp</code> $= 3$ – z-component of the field.</td></tr>
<tr><td><code>'spherical'</code></td><td><code>iComp</code> $= 1$ – r-component of the field;
<code>iComp</code> $= 2$ – θ-component of the field;
<code>iComp</code> $= 3$ – ϕ-component of the field.

Note that for a far-field r-component of the field is zero, but these useless values are still stored in the structure (because the r-component corresponds to <code>iComp</code> $= 1$). I.e. <code>size(Field.E,3)=3</code> always. This is done for compatibility reasons.</td></tr>
<tr><td><code>'ludwig3'</code></td><td><code>iComp</code> $= 1$ – Co-component of the field;
<code>iComp</code> $= 2$ – Xp-component of the field;
<code>iComp</code> $= 3$ – r-component of the field.

Note that for a far-field r-component of the field is zero, and there is no sense to keep it in the structure. Therefore <code>size(Field.E,3)=2</code> for a far-field.

Additionally, <code>Polarization = 'ludwig3'</code> requires to specify <code>Ludwig3RefPhi</code> field of the structure.

The second definition from Appendix A is used to describe the Ludwig3 field components.</td></tr>
<tr><td><code>'circular'</code></td><td><code>iComp</code> $= 1$ – RH-component of the field;
<code>iComp</code> $= 2$ – LH-component of the field;
<code>iComp</code> $= 3$ – r-component of the field.

Note that for a far-field r-component of the field is zero, and there is no sense to keep it in the structure. Therefore <code>size(Field.E,3)=2</code> for a far-field.</td></tr>
</table>
</td>
</tr>
<tr>
<td><code>Ludwig3RefPhi</code> , [rad]</td>
<td>
This angle describes polarization of the field source, and equal to ξ in Appendix A (see, in particular, Fig. A.2). It is used only in conjunction with <code>Polarization = 'ludwig3'</code>.
For example, if the far-field source is X-oriented dipole, the co-polar unit vector coincides with the X-axis of the field coordinate system <code>CoorSys</code> for the broadside direction ($\theta = 0$), and it coincides with the x'-axis for all directions (see Fig. A.2). In this case $\xi =$ <code>Ludwig3RefPhi</code> $= 0$. Then, the co-polar component is stored in <code>E(:,:,1,:,:,:)</code> and the cross-polar component is in <code>E(:,:,2,:,:,:)</code>. If we now change the $(\widehat{\boldsymbol{co}}, \widehat{\boldsymbol{xp}})$-basis by executing <code>Field = ConvertFieldPolarization(Field,'ludwig3',90)</code>, $\xi =$ <code>Ludwig3RefPhi</code> will become equal to $\pi/2$, which means that vectors $\widehat{\boldsymbol{co}}$ and $\widehat{\boldsymbol{xp}}$ are 90° rotated in the primed coordinate system. Since our real co-polarized vector (radiated by the X-oriented dipole) coincides with x'-axis, its complex magnitude will be stored in <code>-E(:,:,2,:,:,:)</code> (note the “–” sign), and the complex magnitude of the radiated cross-polarized vector – in <code>E(:,:,1,:,:,:)</code>.
</td>
</tr>
</table>

<table>
<tr><td>Freq , [Hz]</td><td>Freq contains the frequency corresponding to the field stored in this structure. It can be a vector if there are several fields stored in E.

The condition length(Field.Freq)==size(Field.E,5) must be always satisfied.</td></tr>
<tr><td>NearFar
(optional)

Default: 'far'</td><td>Shows if a near-field of far-field is stored in the structure. Can take one of the values:
<table>
<tr><th>NearFar</th><th>Description</th></tr>
<tr><td>'near'</td><td>A near-field stored in E</td></tr>
<tr><td>'far'</td><td>A far-field stored in E.

In this case 3rd component (r-component) is absent in 'ludwig3' and 'circular' polarization notations. The 'spherical' notation always contains r-component ($=0$), but it is ignored in functions.</td></tr>
</table></td></tr>
<tr><td>CoorSys</td><td></td></tr>
</table>

It worth to note that nevertheless the structure format supports storage of both far- and near-fields, most of the functions in this toolbox are designed to work only with far-fields. Therefore, some fields of the structure are omitted in most cases.

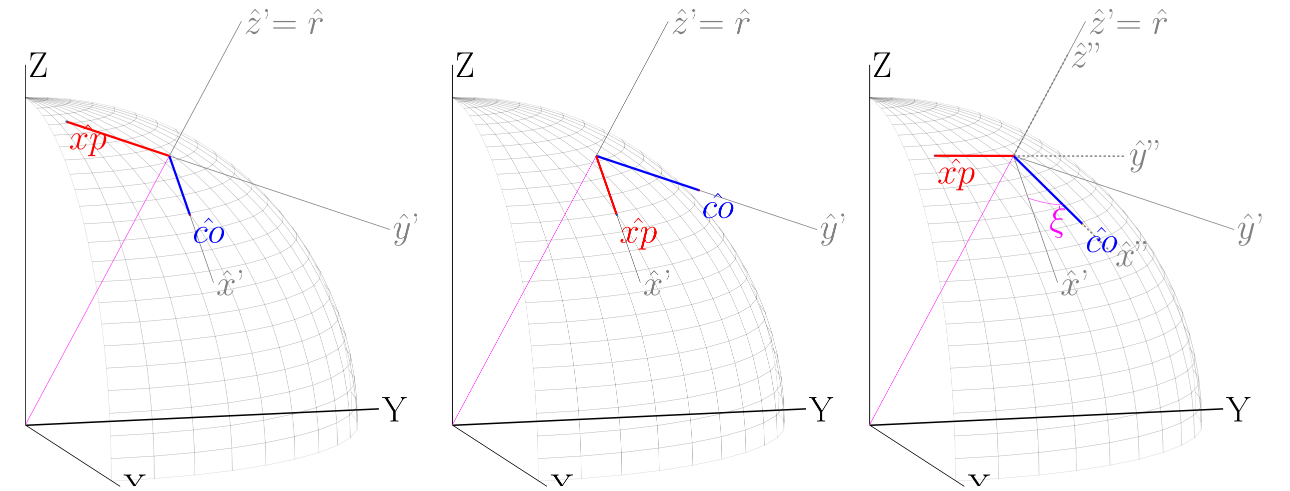
Appendix

A Two definitions of Ludwig3 Field components

If we assume that the radiating antenna is X-polarized, then according to the Ludwig's 3rd definition the primed coordinate system can defined for every direction as

$$\begin{aligned}\hat{\boldsymbol{x}}' &= \hat{\boldsymbol{\theta}}\cos\phi - \hat{\boldsymbol{\phi}}\sin\phi \\ \hat{\boldsymbol{y}}' &= \hat{\boldsymbol{\theta}}\sin\phi + \hat{\boldsymbol{\phi}}\cos\phi \\ \hat{\boldsymbol{z}}' &= \hat{\boldsymbol{r}}\end{aligned} \tag{A.1}$$

This coordinate system is depicted in Fig. A.1.



(a) X-polarized source (b) Y-polarized source (c) Arbitrary-polarized source

Figure A.1: Co- and Xp- basis vectors definition 1 (as in Per-Simon's book)

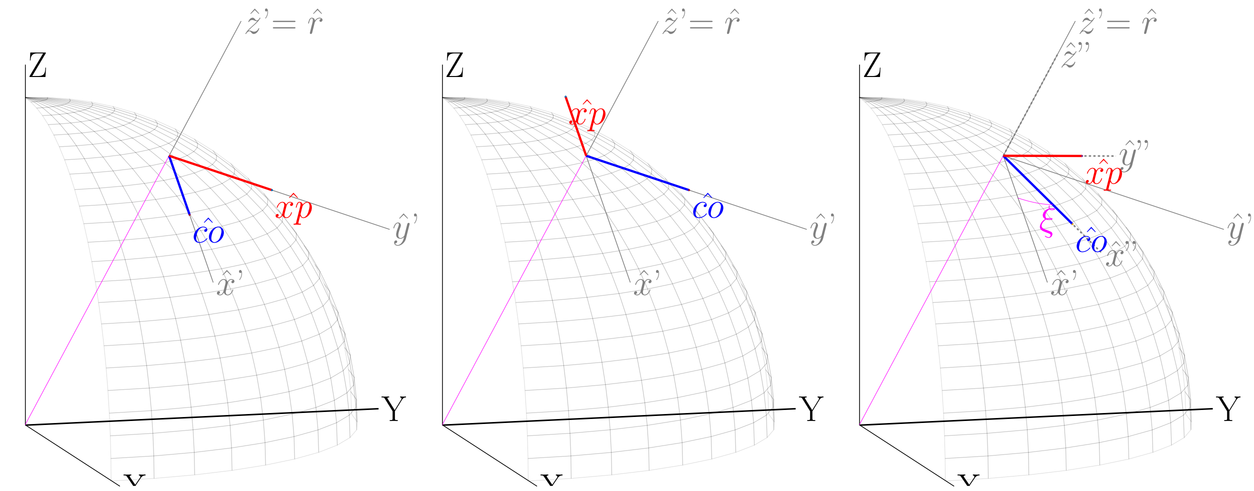
If we consider an antenna pattern measurement setup, the axis $\hat{\boldsymbol{z}}'$ points to the probe, and axis $\hat{\boldsymbol{x}}'$ is parallel to the probe polarization axis. In such setup the co-polarization unit vector $\widehat{\boldsymbol{co}}$ will be aligned with the $\hat{\boldsymbol{x}}'$ axis (Fig. A.1a)

Now the cross-polarization unit vector $\widehat{\boldsymbol{xp}}$ should be defined. Since it must be orthogonal to both $\widehat{\boldsymbol{co}}$ and $\hat{\boldsymbol{r}}$, only two possible possibilities exist:

1. **Definition 1** (see Fig. A.1(a,b)): $\widehat{\boldsymbol{xp}} \times \widehat{\boldsymbol{co}} = \hat{\boldsymbol{r}}$. This definition is used in the Kildal's book [1]. According to it, for x-polarized sources $\widehat{\boldsymbol{co}} = \hat{\boldsymbol{x}}'$ and $\widehat{\boldsymbol{xp}} = -\hat{\boldsymbol{y}}'$; for y-polarized sources $\widehat{\boldsymbol{co}} = \hat{\boldsymbol{y}}'$ and $\widehat{\boldsymbol{xp}} = \hat{\boldsymbol{x}}'$ (see also [1, p.24]).

2. **Definition 2** (see Fig. A.2(a,b)): $\widehat{\boldsymbol{co}} \times \widehat{\boldsymbol{xp}} = \hat{\boldsymbol{r}}$. This definition is used in GRASP and in many other publications, e.g. [2], so it is more commonly used. According to it, for x-polarized sources $\widehat{\boldsymbol{co}} = \hat{\boldsymbol{x}}'$ and $\widehat{\boldsymbol{xp}} = \hat{\boldsymbol{y}}'$; for y-polarized sources $\widehat{\boldsymbol{co}} = \hat{\boldsymbol{y}}'$ and $\widehat{\boldsymbol{xp}} = -\hat{\boldsymbol{x}}'$.

In order to define the arbitrary linear polarization of the radiated field, it is convenient to introduce the double-prime coordinate system which is rotated at angle ξ about z-axis of the primed coordinate system, see Fig. A.1c and Fig. A.2c. In this case the angle ξ is chosen such that the field polarization



(a) X-polarized source (b) Y-polarized source (c) Arbitrary-polarized source

Figure A.2: Co- and Xp- basis vectors definition 2 (as in GRASP and many articles)

vector is parallel to the axis $\hat{\boldsymbol{x}}''$. I this case for the ideal linear polarization the cross-polar component is equal to zero.

In practice the angle ξ is determined only for the boreside direction to correct the probe polarization misalignment in a measurement setup, and then this angle is used for all other directions where the radiation pattern have been measured.

Below we show the co- and cross-polar components of the field are related to the spherical components for the arbitrary polarized source.

Definition 1

It can be seen from the Fig. A.1c that

$$\begin{aligned} \widehat{\boldsymbol{co}} &= \widehat{\boldsymbol{x}}' \cos\xi + \widehat{\boldsymbol{y}}' \sin\xi \\ \widehat{\boldsymbol{xp}} &= \widehat{\boldsymbol{x}}' \sin\xi - \widehat{\boldsymbol{y}}' \cos\xi \end{aligned} \tag{A.2}$$

If we substitute (A.1) into (A.2), we get

$$\begin{aligned} \widehat{\boldsymbol{co}} &= \hat{\boldsymbol{\theta}} \cos(\phi-\xi) - \hat{\boldsymbol{\phi}} \sin(\phi-\xi) \\ \widehat{\boldsymbol{xp}} &= -\hat{\boldsymbol{\theta}} \sin(\phi-\xi) - \hat{\boldsymbol{\phi}} \cos(\phi-\xi) \end{aligned} \tag{A.3}$$

Definition 2

In the same way, with the help of Fig. A.2c we can write

$$\begin{aligned} \widehat{\boldsymbol{co}} &= \widehat{\boldsymbol{x}}' \cos\xi + \widehat{\boldsymbol{y}}' \sin\xi \\ \widehat{\boldsymbol{xp}} &= -\widehat{\boldsymbol{x}}' \sin\xi + \widehat{\boldsymbol{y}}' \cos\xi \end{aligned} \tag{A.4}$$

and if we substitute (A.1) into (A.4), we get

$$\begin{aligned} \widehat{\boldsymbol{co}} &= \hat{\boldsymbol{\theta}} \cos(\phi-\xi) - \hat{\boldsymbol{\phi}} \sin(\phi-\xi) \\ \widehat{\boldsymbol{xp}} &= \hat{\boldsymbol{\theta}} \sin(\phi-\xi) + \hat{\boldsymbol{\phi}} \cos(\phi-\xi) \end{aligned} \tag{A.5}$$

Bibliography

[1] P.-S. Kildal. *Foundations of Antenna Engineering – A Unified Approach for Line-Of-Sight and Multipath*. Kildal Antenn AB, 2015.

[2] Allen C. Newel and Greg Hindman. Antenna spherical coordinate systems and their application in combining results from different antenna orientations. Technical report, Nearfield Systems Incorporated, 1999. https://www.nearfield.com/aboutus/documents/1999ESTEC_AN_GH_Antenna_Spherical_Coordinate_Systems_and_Application_in_Combining_Result_000.pdf.