TABULATED FEED

Purpose

This menu groups *Feed*s which are given in a tabular form. In spite of the menu name, *Tabulated Feed*, the patterns are not restricted to be patterns of a proper feed but may be representing any radiating source.

The table may either contain pattern data (e.g. a measured pattern)

Tabulated Pattern

or the table may contain mode coefficients for an mode expansion of the pattern.

Tabulated SWE Coefficients

Links

Classes→*Electrical Objects*→*Feed*→*Tabulated Feed*

TABULATED PATTERN (tabulated_pattern)

Purpose

The *Tabulated Pattern* class defines a source by means of field data tabulated on a spherical surface. The tabulated data shall be provided on a file in polar cuts, i.e. cuts for constant ϕ-values and varying θ, with θ and ϕ being usual spherical coordinates. The cuts shall be equidistant in ϕ, and must be either symmetric cuts, i.e. from $-\theta_{\max}$ to $+\theta_{\max}$, or asymmetric cuts from 0° to $\theta_{\max}$. The number of cuts must be chosen to adequately sample the field from 0° to 360° in ϕ. An efficient interpolation is used to obtain the field at intermediate points.

The input field may be a far field or a near field.

Links

Classes→*Electrical Objects*→*Feed*→*Tabulated Feed*→*Tabulated Pattern*

Remarks

Syntax

<object name> *tabulated_pattern*
(

frequency	: ref(<n>),
coor_sys	: ref(<n>),
file_name	: <f>,
file_format	: <si>,
number_of_cuts	: <i>,
power_norm	: <si>,
phase_reference	: struct(*x*:<rl>, *y*:<rl>, *z*:<rl>),
on_axis_adjust	: <si>,
ij_notation	: <si>,
near_far	: <si>,
near_dist	: <rl>,
max_m_mode_index	: <i>,
max_n_mode_index	: <i>,
far_forced	: <si>,
factor	: struct(*db*:<r>, *deg*:<r>),
frequency_index_for_plot	: <i>,
obsolete_cut_def	: <si>

)

where

<i> = integer

<n> = name of an object

<r> = real number

<rl> = real number with unit of length

<f> = file name

<si> = item from a list of character strings

Attributes

Frequency (*frequency*) [name of an object].

Reference to a *Frequency* object, defining the frequencies at which the source operates. See the remarks below.

Coordinate System (*coor_sys*) [name of an object], default: **blank**.

Reference to an object of one of the *Coordinate Systems* classes to which the tabulated pattern refers. The phase reference may be changed to a different point, see the remarks below.

File Name (*file_name*) [file name].

Name of file containing the tabulated field data, usually a far-field pattern, cf. `Near Far` below. The file format shall be in accordance with TICRA *.cut*-files (not *.grd* files) as described in Section *Tabulated Pattern Data* for far fields, and Section *Field Data in Cuts*, spherical cuts for near fields. A far field is specified by two orthogonal field components. The near field must also contain the r-component.

File Format (*file_format*) [item from a list of character strings], default: **TICRA**.

Format of file.

TICRA

ASCII file in standard TICRA format. See Section *Tabulated Pattern Data* for far fields and *Field Data in Cuts* for near fields.

EDI

Obsolete file format name. The same as EDX.

EDX

Format according to the Electromagnetic Data Exchange (EDX) standard.

Number of Cuts (*number_of_cuts*) [integer], default: **0**.

Number of equidistant polar cuts per frequency in the file; at least one cut for each 90 degrees in phi. If the file contains cuts for only one frequency the value 0 may be specified. The number of cuts will then be determined from the file (see also the remarks below).

Power Normalisation (*power_norm*) [item from a list of character strings], default: **off**.

If on, the total radiated power is equal to 4π Watts, which then expresses the pattern in dBi.

off

No normalisation.

on

The field is power normalised to 4π.

Phase Reference (*phase_reference*) [struct].

When the input field is a far field (Near Far is 'far') the phase reference of the cuts may be altered. Assume the tabulated field data originate in a measurement. The phase of the input field then refers to the centre of rotation in the measurement. If the phase shall refer to another point (x, y, z) in the input coordinate system (given by attribute Coordinate System above) then the Phase Reference shall be specified to this point. See also the remarks below.

x (*x*) [real number with unit of length], default: **0**.

x-coordinate of new the phase-reference point.

y (*y*) [real number with unit of length], default: **0**.

y-coordinate of new the phase-reference point.

z (*z*) [real number with unit of length], default: **0**.

z-coordinate of new the phase-reference point.

On-Axis Adjustment (*on_axis_adjust*) [item from a list of character strings], default: **off**.

Determines a possible on-axis adjustment of the field level in the input cuts.

off

No adjustments made.

on

All cuts are scaled by a complex factor so that the amplitude, phase and polarization at $\theta = 0°$ are the same as in the first read cut.

ij-Notation (*ij_notation*) [item from a list of character strings], default: **j**.

Specifies the time-factor for the field data.

j

The time factor is $e^{+j\omega t}$.

i

The time factor is $e^{-i\omega t}$.

Near Far (*near_far*) [item from a list of character strings], default: **automatic**.

Specifies whether the tabulated field is a near or a far field. A far field requires two orthogonal field components, a near field contains an additional r-component, although this component is not used.

far

The tabulated field is a far field. Two field components will be read.

near

The tabulated field is a near field. Two field components will be read. Although near-field data contain an additional r-component this is not used.

automatic

It is automatically detected if the tabulated field is a near- or far-field.

Near-Field Distance (*near_dist*) [real number with unit of length], default: **0**.

Radius of the sphere on which the near-field data is specified. Not used when `Near Far` is specified to 'far'.

Max m-Mode Index (*max_m_mode_index*) [integer], default: **-1**.

Maximum number of azimuthal (m) modes to be used in the azimuthal ϕ-interpolation of the tabulated data and to be included in the spherical-wave expansion of the field. If negative, all azimuthal modes are retained.`Max m-Mode Index` shall not exceed the following `Max n-Mode Index`.

Max n-Mode Index (*max_n_mode_index*) [integer], default: **-1**.

Maximum polar mode index (n) to be included in the spherical-wave expansion of the field. If negative, all n-modes are included. Note: It is recommended to limit the number of modes according to the extent of the source. The field may not be determined correctly at distances less than `Max n-Mode Index`/k, k being the wavenumber. See the Remarks for details.

Far-Field Forced (*far_forced*) [item from a list of character strings], default: **off**.

Determines how a near field will be calculated (for details, see the section on *Near-Field Calculations*).

off

As a spherical wave expansion derived from the far-field pattern.

on

The far-field pattern is multiplied by a distance factor.

Factor (*factor*) [struct].

The radiated field will be multiplied by a complex factor (after a possible power normalisation).

Amplitude in dB (*db*) [real number], default: **0**.

Amplitude of the factor, in dB.

Phase in degrees (*deg*) [real number], default: **0**.

Phase of the factor, in degrees.

Frequency Index for Plot (*frequency_index_for_plot*) [integer], default: **1**.

Determines the frequency (wavelength) for which the source shall be plotted. In the attribute `Frequency` above a sequence of frequencies (wavelengths) is listed. The `Frequency Index for Plot` points to the number to be applied of the frequency (wavelength) in this sequence.

Cut Definition (Obsolete) (*obsolete_cut_def*) [item from a list of character strings], default: **automatic**.

Defines the type of the polar cuts (see the remarks below for restrictions and polarisation).

asymmetric

The cuts are from $0°$ to θ_n ($\theta_n > 0°$).

symmetric

The cuts are from $-\theta_n$ to $+\theta_n$ ($\theta_n > 0°$). The number of samples in each cut must be odd, so that the boresight direction is included.

automatic

Detect automatically if cuts are symmetric or asymmetric.

Remarks

This section contains discussions on the following topics

- Power normalisation
- Handling more than one frequency
- Changing the phase reference
- Polarisation conventions
- Restrictions on θ and ϕ in the tabulated grid
- Method of field determination
- Maximum spacing for the tabulated field data
- Maximum number of modes to be included
- Illustration of too coarse azimuthal sampling (too few m-modes)

Power normalisation

When `Power Normalisation` is specified to 'on', the feed pattern is normalised to dBi, i.e. to radiate 4π watts. The total radiated power will be 4π times the value of `Factor` (converted from dB to power).

More than one frequency

The file with input patterns must contain a pattern for each frequency specified in the *Frequency* object and the patterns must be stored in the same order as the frequencies. For each frequency the number of pattern cuts is given by `Number of Cuts`.

If the `Frequency` attribute is specified, the file with input patterns must contain a pattern for each frequency. The number of patterns must agree with the number of frequencies and must be stored in the same order as the frequencies. The patterns for each of the frequencies must contain a number of pattern cuts as given by `Number of Cuts`.

If only one frequency is given then `Number of Cuts` may be specified to zero and the number of cuts is determined by scanning through the file.

If the *Tabulated Pattern* object is specified in an object of one of the classes in *Feed* then it is required that the *Frequency* object specified in the *Feed* object is the same as the *Frequency* object in the *Tabulated Pattern* object. However, it is permitted not to specify a *Frequency* object in the *Tabulated Pattern* object. The file must then only contain one pattern, and this pattern will then be used for all frequencies.

Phase reference

The input pattern refers to a coordinate system, the input coordinate system, specified by the attribute `Coordinate System`. The origin of the input coordinate system is the phase reference point for the specified tabulated field.

Typically, the pattern originates in a measurement in which a source is rotated around two perpendicular axes. The point of intersection of the two axis is denoted the centre point for rotation and the input coordinate system has origin at this point.

If the tabulated pattern originates in a calculation the input coordinate system is equivalent to the coordinate system in which the calculated field is specified.

Consider for example a horn which is to be applied as feed for a reflector antenna. The horn pattern is measured (or calculated) in cuts of which a single is shown in Figure 1. The centre of the cut (the centre point for rotation) is denoted M, and the horn is aligned so this centre is in the middle of the aperture. This is normally not the phase centre for the pattern as the phase centre is positioned slightly behind the aperture, at O (shown exaggerated in Figure 1).

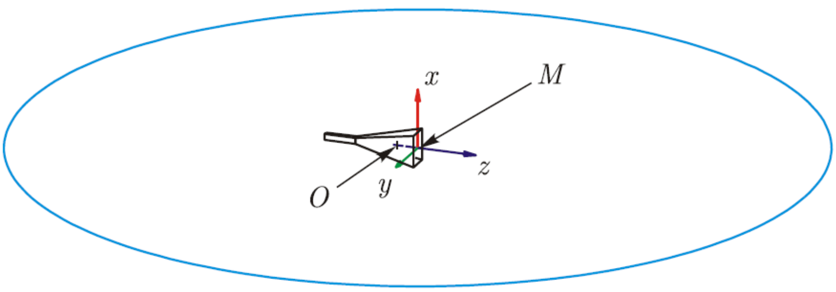


Figure 1 Measuring the field of a horn in cuts centred at the centre of the aperture, M (only a horizontal cut is shown). M is then the phase reference point. The phase centre of the horn is at O.

When this horn is applied as feed for a paraboloidal reflector antenna, Figure 3, it shall ideally be positioned with its phase centre, O, at the focal point of the paraboloidal reflector. There is, however, no geometrical information in a measured pattern apart from the measurement coordinate system given by its origin and the directions of its axes as illustrated in Figure 1.

The phase reference point may be changed for a far-field pattern. This is the same as in a measurement to change the position of the horn relative to the centre point for rotation. By specifying a phase centre as the position of O relative to M, the tabulated pattern will be modified to have reference to the point O, cf. Figure 2, by multiplying the field by the factor

$$e^{-jk\bar{V}\cdot\hat{r}}$$

where $k = 2\pi/\lambda$ is the wavenumber, $\vec{V}$ is the vector $\overrightarrow{MO}$ and $\widehat{r}$ is the far-field direction for the actual data point,

$$\hat{r} = \hat{x}\sin\theta\cos\phi + \hat{y}\sin\theta\sin\phi + \hat{z}\cos\theta$$

This phase change is performed on the input field automatically when the attribute `Phase Reference` is specified to the values of x, y and z where $\bar{V} = (x, y, z)$ is the vector $\overrightarrow{MO}$.

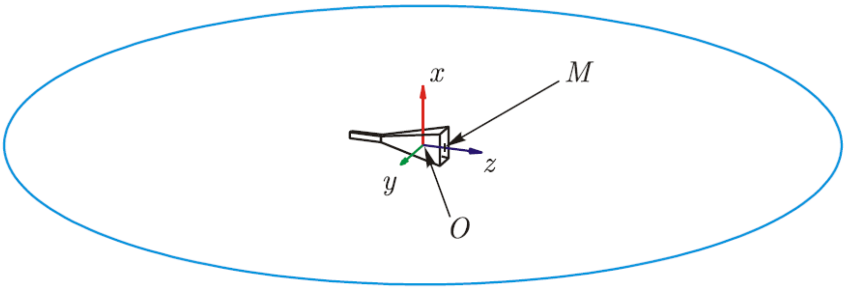


Figure 2 Redefining the phase reference point to O. Far-field cuts are then centred at O. The previous phase reference point is at the centre of the aperture, M.

When the tabulated pattern is applied as source it will now be positioned with its xyz-coordinate system (as shown in Figure 2) congruent to the input coordinate system specified in the attribute `Coordinate System`. Shall, for example, the horn be applied as feed for a paraboloidal reflector antenna, Figure 3, it shall be positioned with its xyz-coordinate system identical to the feed coordinate system, $x_f y_f z_f$, which is defined at F, the focal point of the paraboloidal reflector.

If the tabulated pattern is a near field, the change of the phase reference can not be carried out as described above. Instead, the far field of the tabulated pattern can be calculated. This far field may then be printed on a file and this file may be applied as input to a new *Tabulated Pattern* for which the phase reference may be changed as described.

Polarisation conventions

For asymmetric cuts, the θ-polarisation vector must point away from the pole $\theta = 0°$ and the ϕ-polarisation vector must be counter-clockwise, see Figure 9-4(a).

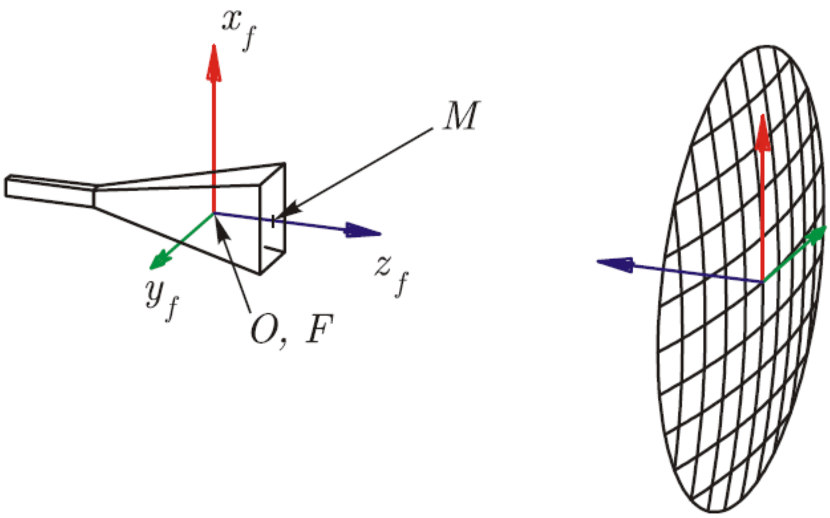
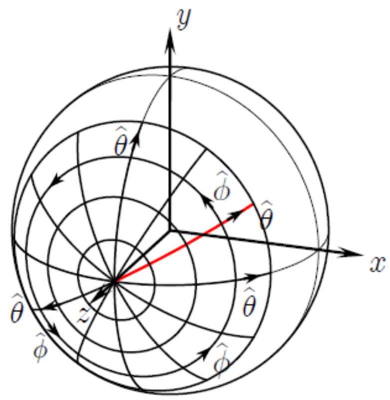
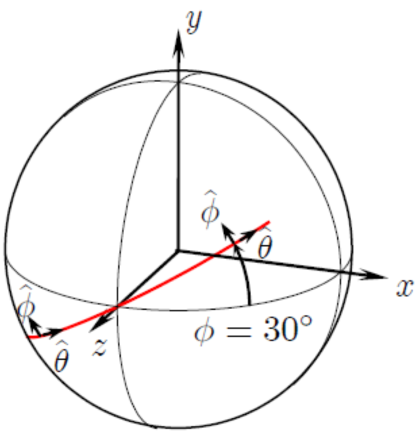


Figure 3 The horn mounted as feed for a paraboloidal reflector. The phase reference point O is positioned at the focal point F of the paraboloid.



(a) $\theta\phi$-polarisation for asymmetric cuts (for $0° \leq \theta \leq 60°, 0° \leq \phi < 360°$)



(b) $\theta\phi$-polarisation for symmetric cuts (for $-60° \leq \theta \leq 60°, \phi = 30°$)

Figure 4 Orientation of the θ- and ϕ-polarisation vectors for asymmetric cuts (a) and for symmetric cuts (b). One cut is shown in red for both cases; for the latter case only this single cut is shown.

For symmetric cuts, the θ- and ϕ-polarisations shall follow the conventional definition as for the asymmetric cuts when θ is positive. But for negative θ-values, the θ- and ϕ-polarisation vectors must point opposite the conventional definition in order to ensure a continuous polarisation definition across the pole.

See the Technical Description for the other polarisation definitions, and the appendix *Ludwig's 3rd Definition of Polarization* for important details of the definition at the poles $\theta = 0°$ and $\theta = 180°$.

Restrictions on θ and ϕ in the tabulated grid

The spacing in θ, as well as the spacing in ϕ, must be equidistant. The ϕ-samples shall cover full azimuthal circles, the θ-samples may be truncated, i.e. θ may run from 0° to $\theta_{\max}$ with $\theta_{\max} \leq 180°$. The cuts must appear as scans in θ.

Each input cut must then be defined in either the interval from 0° to $\theta_{\max}$ (asymmetric cuts) or in the interval from $-\theta_{\max}$ to $\theta_{\max}$ (symmetric cuts). With, say, $N_{\phi,A}$ asymmetric cuts over $360°$, the ϕ-values of the cuts must be given by

$$\phi_i = \phi_0 + \frac{360°}{N_{\phi,A}}(i-1), \quad i = 1, \ldots, N_{\phi,A} \tag{1}$$

where ϕ_0 is the ϕ-value of the first cut. $N_{\phi,A}$ must be an even number, larger than or equal to 4.

Similarly, with $N_{\phi,S}$ symmetric cuts over 180°, the ϕ-values of the cuts must be at

$$\phi_i = \phi_0 + \frac{180°}{N_{\phi,S}}(i-1), \quad i = 1, \ldots, N_{\phi,S} \tag{2}$$

where $N_{\phi,S}$ must now be larger than or equal to 2.

The spacing of the field values in these cuts shall also be constant, i.e. for asymmetric cuts with $N_{\theta,A}$ field points

$$\theta_i = \frac{\theta_{\max}}{(N_{\theta,A}-1)}(i-1), \quad i = 1, \ldots, N_{\theta,A} \tag{3}$$

Irrespective of the type of cuts, symmetric or asymmetric, the pole at $\theta = 0°$ must always be included. As a consequence, the number of θ-values from $-\theta_n$ to θ_n, $N_{\theta,S}$, in a symmetric cut must be odd and the θ-values are

$$\theta_i = \frac{2\theta_{\max}}{(N_{\theta,S}-1)}(i - \frac{N_{\theta,S}+1}{2}), \quad i = 1, \ldots, N_{\theta,S}. \tag{4}$$

If the last θ-value, $\theta_{\max}$, is not $180°$ then it must be assured that the field has a low value at $\theta_{\max}$ for all values of ϕ. The interpolation inaccuracies which will occur around the truncation at $\theta_{\max}$ will be proportional to the input field values at $\theta_{\max}$.

Method of field determination

If `Far-Field Forced` is specified to 'off' which is recommended, then the input field will be expanded in spherical modes from which the field is then determined.

The spherical wave expansion requires field information for a full sphere and field values zero will be inserted at the grid points with $\theta > \theta_{\max}$. It is further required that $\theta = 180°$ is a point in this extended grid. If the given θ-spacing is not divisor in $180°$ the spacing will be changed (decreased) to include both $\theta = 0°$ and $\theta = 180°$. The field values will be interpolated by third order polynomial (cubic) interpolation to the new sample points within $|\theta| < \theta_{\max}$(note: the cubic interpolation requests a much denser sampling, see the next section).

If `Far-Field Forced` is specified to 'on' the field will be calculated based on the input field scaled to the requested distance. Field values at points different from the tabulated input points will be interpolated. In the azimuthal angle ϕ the interpolation will be based on a Fourier expansion (similarly to the spherical modes). In the polar angle, θ, a cubic interpolation will be applied. It is noted that this requests a much denser sampling of the tabulated field as compared to the spherical wave expansion normally used when `Far-Field Forced` is specified to 'off'.

For both cases field values determined for $\theta > \theta_{\max}$ will be set to zero.

Maximum spacing for the tabulated field data

In order to be able to regenerate a radiation pattern from tabulated data, it is necessary that the data spacing fulfils the Nyquist sampling criterion. This results in requirements to a maximum spacing for the tabulated data.

Theoretically, if the radiating or scattering structure is confined within a spherical volume with radius r_0, measured from the reference centre for the tabulated field data (defined by the attribute `Phase Reference`), then the sample spacing shall be $\lambda/2$ or less over this spherical surface. The minimum number of samples for $0° \leq \theta \leq 180°$ is denoted N_θ so we have $N_\theta - 1$ intervals. This gives a minimum value for N_θ

$$N_\theta - 1 = \frac{\pi r_0}{\lambda/2} = kr_0 \tag{5}$$

The theoretical number of polar modes is hereby $N = N_\theta - 1$. Modes with a higher polar index will drop in amplitude for increasing index value and in order to ensure a sufficient accuracy, the number of polar modes, and hereby the number of samples, shall be increased so that at least

$$N_\theta - 1 = N = kr_0 + \max(10, 3.6\sqrt[3]{kr_0}) \tag{6}$$

shall be applied (rounded up to an integer). Polar modes may then be determined with mode indices n

$$n = 1, 2, 3, ..., N \tag{7}$$

The maximum allowed angular spacing, $\Delta\theta$, in the polar cut occurs with the minimum value of N:

$$\Delta\theta = \frac{\pi}{N} = \frac{180°}{N} \tag{8}$$

with N given by Eq. (6).

However, when a cubic interpolation procedure in the θ-coordinate is applied (see 'Method of field determination' above), a spacing at least four times denser is required, i.e.

$$\Delta\theta \leq \frac{180°}{4N}. \tag{9}$$

The sampling may be truncated in θ when the field level at the truncation angle, $\theta_{\max}$, is low. For $\theta_{\max} < 90°$, the circumference of the largest circle in

ϕ is $2\pi r_0 \sin\theta_{\max} < 2\pi r_0$. On this circle there shall be at least N_ϕ samples spaced by $\lambda/2$, thus N_ϕ is given by

$$N_\phi = \frac{2\pi r_0 \sin\theta_{\max}}{\lambda/2} = 2N \sin\theta_{\max} \tag{10}$$

where N_ϕ shall be rounded up to an even integer. The required maximum spacing in ϕ is therefore

$$\Delta\phi = \frac{2\pi}{N_\phi} = \frac{180^\circ}{N \sin\theta_{\max}} \tag{11}$$

With this sample spacing azimuthal modes may be determined with mode indices m

$$m = 0, \pm 1, \pm 2, ..., \pm M \tag{12}$$

i.e. N_ϕ samples may result in $2M + 1$ mode coefficients, and M cannot exceed

$$M = \frac{N_\phi}{2} - 1 \tag{13}$$

Some information is lost as we determine $2M + 1$ coefficients from N_ϕ samples, and

$$2M + 1 = N_\phi - 1 \tag{14}$$

The lost information is the coefficients for the modes with $m = N_\phi/2$ and $m = -N_\phi/2$ which can not be separated as a consequence of the applied Fourier technique. If the sampling is too sparse the power content of the modes with $|m| = N_\phi/2$ will be important and the tabulated pattern values can not be reproduced from the input.

If the tabulated pattern is not available with spacing in θ and ϕ as fine as requested in Eqs. (9) and (11) the interpolated pattern will not be accurate. This is illustrated in a later section.

Maximum number of modes to be included

The data may be sampled in a denser grid, than that required for the interpolation procedure. This may be utilized in the spherical wave expansion by restricting the number of applied modes to the physical relevant. Irregularities in the sampled data, resulting from e.g. noise, instrumentation errors or other sources, may then be filtered out, provided they manifest themselves in the higher order harmonics.

In addition to saving computation time there is thus a reason of noise reduction to reduce the number of applied spherical modes. Further, care shall be taken such that N does not exceed kr, r being the input field distance `Near-Field Distance` (the measurement distance). This will not be a problem for far-field measurements.

The maximum value of the polar mode index (n) may thus be reduced from $N_\theta - 1$ to N as given by Eq. (6) by specifying

$$\texttt{Max n-Mode Index} = N = kr_0 + \max(10, 3.6\sqrt[3]{kr_0}) \tag{15}$$

Otherwise

$$\texttt{Max n-Mode Index} = N = N_\theta - 1 = \frac{180°}{\Delta\theta} \qquad (16)$$

will be applied.

Modes with polar index n may represent sources out to a radius r given by $n = kr$, i.e.

$$r = n/k \qquad (17)$$

If the spacing is dense, Nas given by Eq. (16) may represent sources further out than the measurement distance r (`Near-Field Distance`). But this is unphysical. The mode number must then be reduced to

$$\texttt{Max n-Mode Index} \le kr \qquad (18)$$

In order to ensure convergence N shall be determined from Eq. (15) and may hereby represent sources out to

$$r = N/k \qquad (19)$$

As a consequence it is thus not possible to determine the field closer than 1.6λ from the source-surrounding minimum sphere given by the radius r_0 (the value 1.6λ corresponds to 10 is applied in Eq. (6) or Eq. (15)).

Correspondingly, a tabulated pattern shall be characterised from measurements at a distance which is at least a few wavelengths larger than r_0.

For critical cases a careful analysis of the mode spectrum (printed in the standard output file) is necessary to determine the best value of N to be applied. For further discussions on an example of a mode spectrum see class *Spherical Wave Expansion (SWE)*.

As for the polar modes, the azimuthal mode index m may be reduced according to Eqs. (10) and (13)

$$\texttt{max\_m\_mode\_index} = (\texttt{Max n-Mode Index}) \sin\theta_{\max} - 1 \qquad (20)$$

for truncation at $\theta_n < 90°$. Otherwise the program will apply

$$\texttt{max\_m\_mode\_index} = \frac{N_\phi}{2} - 1 \qquad (21)$$

cf. Eq. (13), or

$$\texttt{max\_m\_mode\_index} = N \qquad (22)$$

whichever is the smallest.

Illustration of too coarse azimuthal sampling (too few m-modes)

It happens that only a very few azimuthal cuts are available, for example the cuts in the principal planes of the pattern ($\Delta\phi = 90°$).

A too coarse spacing in azimuth ($\Delta\phi$ is too large) will result in an insufficient number of m-modes to be calculated. The power of the omitted high-order modes will be distributed in the calculated modes which therefore are incorrect. The phenomenon is well-known in Fourier analysis and is denoted aliasing.

The effect is illustrated in the following example where, for three different horns, the patterns have been accurately calculated, each in $N_\phi = 12$ asymmetric cuts from $\theta = 0°$ to $\theta_{\max} = 90°$ (see Figure 5). The sample spacing in ϕ, $\Delta\phi = 30°$, means that the maximum azimuthal mode index is restricted to $M = 5$, cf. Eq. (13).

For each horn, the phase reference is at the centre of the aperture. The spherical modes have been calculated, and the pattern at $\phi = 45°$ has been determined from the modes. A comparison to the directly calculated patterns at $\phi = 45°$ then allows an estimate of the accuracy.

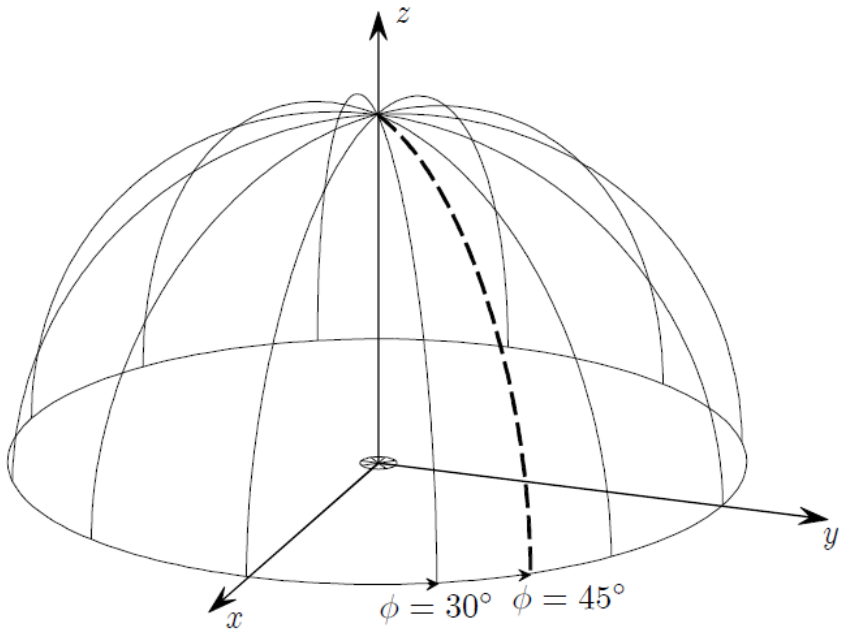


Figure 5 Polar pattern cuts from the pole at $\theta = 0°$ to the equator plane, for every $30°$ in ϕ for azimuthal mode generation. The pattern is to be reconstructed at $\phi = 45°$ as shown dashed. Even though the pattern cuts are shown in the near field, the calculations are carried out in the far field. A circular aperture is shown at origin.

In Figure 6 the three horns are shown: Horn 1 is a circular horn, 1λ in diameter, excited by the fundamental TE_{11} -mode, horn 2 a rectangular horn with side-lengths 4λ by 1λ excited with the fundamental TE_{10}-mode (H-plane horn), and finally horn 3 shows a square horn with a side-length of 1λ, also carrying a TE_{10}-mode.

The radius r_0 of the horns are given in Table 1 along with the theoretical maximum limits for the number of modes, N and M, as given by Eqs. (6) and (10), the latter with $\theta_n = 90°$ resulting in the upper limit for M is N. It is seen that M shall be specified to at least 14, 23 and 15 for the three horns, if determined only by the size of the horn.

However for horn 1, the TE_{11}-mode excitation in the circular horn only contains azimuthal modes with $m = \pm 1$. Since the circular geometry cannot generate higher order m-modes, $M = 1$ will be sufficient for this horn with this excitation.

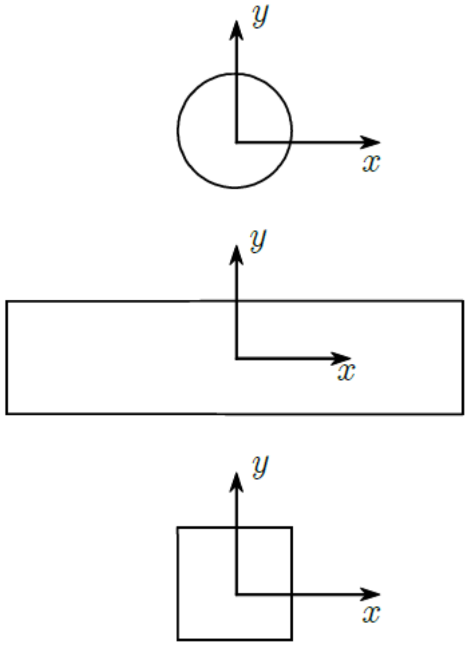


Figure 6 Aperture geometries of investigated horns: Circular, rectangular and square, respectively. The horns are y-polarised.

	Horn		
	Circular	Rectangular	Square
r_0	0.5λ	2.06λ	0.71λ
kr_0	3.1	13.0	4.4
$M = N = kr_0 + 10$	14	23	15
$\theta_{\max,M=5}$	21°	13°	19°

Table 1 Theoretical minimum number of modes for the three horns.

We can with the given ϕ-spacing determine azimuthal modes only up to $M = 5$ which is insufficient for the rectangular and the square horns.

The limit on the azimuthal mode index may be used to determine the maximum polar angle, up to which the field may be reconstructed, cf. Eq. (10)

$$\sin\theta_{\max,M=5} = 5/N \tag{23}$$

where $M = 5$ has been inserted. The values of $\theta_{\max,M=5}$ for the three horns are also given in Table 1.

The power content in each of the available m-modes has been determined and is listed in Table 2. As expected, it is seen that the circular horn contains modes for $m = \pm 1$ only.

	Horn		
	Circular	Rectangular	Square
0	0.000000	0.000000	0.000000
±1	0.500000	0.257131	0.492881
±2	0.000000	0.000000	0.000000
±3	0.000000	0.126948	0.007031
±4	0.000000	0.000000	0.000000
±5	0.000000	0.115922	0.000088

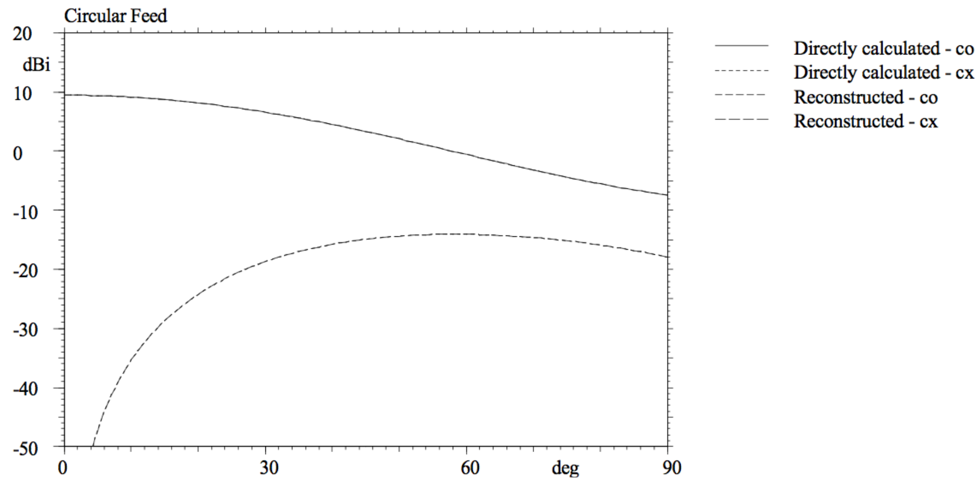
Table 2 Power content in azimuthal modes.

We now compare the patterns reconstructed from the modes of Table 2 with the directly calculated patterns for $\phi = 45°$. The total power is normalised to 4π for all patterns.

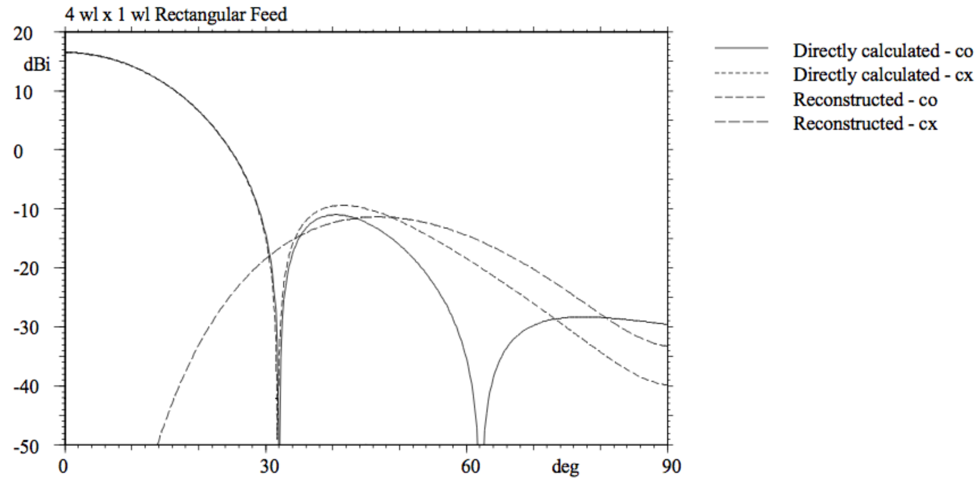
The pattern of the circular horn is completely described by modes with $m = \pm1$. Hence, truncation of modes with indices larger than $M = 5$ does not deteriorate the pattern. This is confirmed by the plot in Figure 9-7(a) in which the patterns calculated by the two methods are identical.

With respect to the rectangular horn, Table 2 shows that the modes with $m = \pm5$ contain almost half as much power as the modes with $m = \pm1$. Since the required M is $23 \gg 5$, it is expected that there will be a significant difference between the true pattern at $\phi = 45°$ and the pattern reconstructed from the azimuthal modes. This is seen in Figure 9-7(b). But a good correlation between the co-polar components exists close to boresight. According to the last line in Table 1 the patterns shall agree up to $\theta = 13°$. To improve the correlation for larger θ the number of cuts from which the azimuthal modes are generated must be increased.

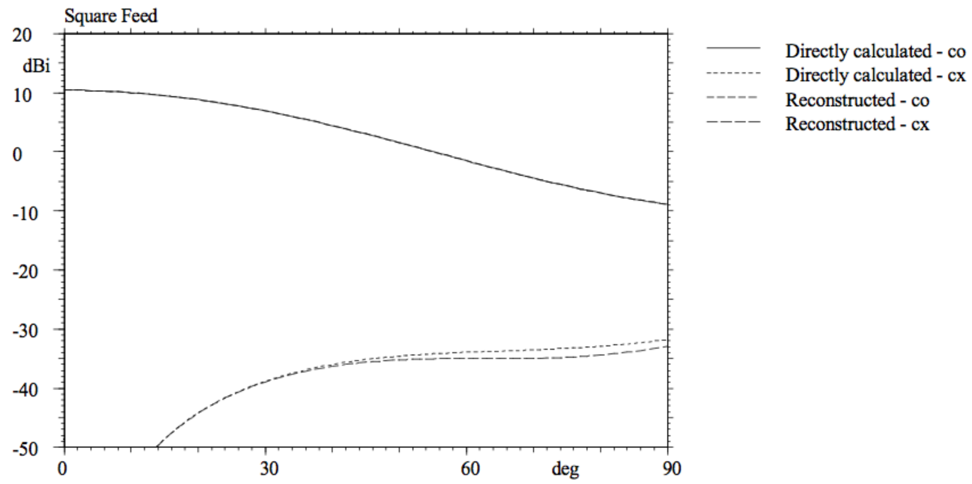
The pattern from the square horn also contains higher-order modes. However, the power content of the modes falls off much faster than that of the rectangular horn, Table 2. The comparison of the patterns, Figure 9-7(c), also shows that only a small discrepancy exists and only at the low level in the cross-polarisation.



(a)



(b)



(c)

Figure 7 Comparison between horn patterns calculated directly and reconstructed from azimuthal mode expansion at $\phi = 45°$.

TABULATED SWE COEFFICIENTS (tabulated_swe_coefficients)

Purpose

The class *Tabulated SWE Coefficients* defines a feed pattern by means of a spherical wave expansion. The coefficients to the expansion are read from a user supplied file. The spherical expansion may be evaluated at the appropriate distance, which ensures a correct near field.

In some GTD applications, it is desirable to have a near field phase that behaves as the phase from a point source. This can be accomplished by enforcing `Far-Field Forced` to 'on'. The near field is then simply calculated by multiplying the far-field pattern by the distance factor $\exp(-jkr)/kr$. This procedure is not recommended for PO calculations, which should use the correct near field to ensure maximum accuracy.

Links

Classes→Electrical Objects→Feed→Tabulated Feed→Tabulated SWE Coefficients

Remarks

Syntax

<object name> *tabulated_swe_coefficients*
(

frequency	: ref(<n>),
coor_sys	: ref(<n>),
file_name	: <f>,
file_format	: <si>,
power_norm	: <si>,
max_m_mode_index	: <i>,
max_n_mode_index	: <i>,
excluded_m_modes	: sequence(<i>, ...),
power_threshold	: <r>,
far_forced	: <si>,
factor	: struct(*db*:<r>, *deg*:<r>),
frequency_index_for_plot	: <i>,
obsolete_coef_def	: <si>

)

where

<i> = integer

<n> = name of an object

<r> = real number

<f> = file name

<si> = item from a list of character strings

Attributes

Frequency (*frequency*) [name of an object].

Reference to a *Frequency* object, defining the frequencies at which the source operates. See the remarks below.

Coordinate System (*coor_sys*) [name of an object], default: **blank**.

Reference to an object of one of the *Coordinate Systems* classes. The feed is located in the origin of this coordinate system (denoted x_f, y_f, z_f) and the feed axis points along the z_f-axis.

File Name (*file_name*) [file name].

Name of file containing one or more sets of spherical wave coefficients. The contents and format of the file are described in the sections *Spherical Wave Q-Coefficients* and *Spherical Wave ab-Coefficients* and depend on the value of the attribute `Coefficients Definition (Obsolete)` below.

File Format (*file_format*) [item from a list of character strings], default: **TICRA**.

Format of file.

TICRA

Standard TICRA format, see Section *Spherical Wave Q-Coefficients*.

EDX

Read data in the Electromagnetic Data Exchange (EDX) format.

Power Normalisation (*power_norm*) [item from a list of character strings], default: **off**.

If on, the power contained in the SWE is equal to 4π, and the field is given in dBi.

off

The field is not normalised.

on

The power contained in the spherical wave expansion which forms the basis for the field calculation, is normalised to 4π, so that the calculated field is given relative to isotropic level.

Max m-Mode Index (*max_m_mode_index*) [integer], default: **-1**.

Maximum azimuthal mode index (m) to be included from the expansion. If negative, all azimuthal modes present in the file will be used.

Max n-Mode Index (*max_n_mode_index*) [integer], default: **-1**.

Maximum polar mode index (n) to be included from the expansion. If negative, all polar modes present in the file will be used.

Exclude m-Modes (*excluded_m_modes*) [sequence of integers], default: **-1**.

List of non-negative azimuthal mode indices, m, that shall be excluded from the expansion. Azimuthal modes with index m as well as $-m$ will be excluded. If a negative number is specified, the option is not in effect.

Power Threshold (*power_threshold*) [real number], default: **-1**.

Power threshold level given relative to the input power. Azimuthal modes with a relative power less than this threshold will be excluded in the field calculation. The azimuthal-mode power content for a given index $|m|$, is calculated by summing the power of all polar modes with index m and $-m$, see the remarks below. If a negative number is specified, no threshold is considered.

Far-Field Forced (*far_forced*) [item from a list of character strings], default: **off**.

Determines how a near field will be calculated (for details, see the section on *Near-Field Calculations*):

off

Directly by the spherical wave expansion.

on

The far-field pattern is multiplied by a distance factor.

Factor (*factor*) [struct].

The radiated field will be multiplied by a complex factor (after a possible power normalisation).

Amplitude in dB (*db*) [real number], default: **0**.

Amplitude of the factor, in dB.

Phase in degrees (*deg*) [real number], default: **0**.

Phase of the factor, in degrees.

Frequency Index for Plot (*frequency_index_for_plot*) [integer], default: **1**.

Determines the frequency (wavelength) for which the feed shall be plotted. In the attribute `Frequency` above a sequence of frequencies (wavelengths) is listed. The `Frequency Index for Plot` points to the number to be applied of the frequency (wavelength) in this sequence.

Coefficients Definition (Obsolete) (*obsolete_coef_def*) [item from a list of character strings], default: **Q**.

The spherical wave coefficients of GRASP derives from two different formulations. The difference is due to the choice of the spherical vector wave functions. One is denoted the Q-notation, the other the ab-notation, with coefficients designated accordingly. The Q-coefficients provide higher numerical accuracy and stability, and can expand fields from larger structures than the ab-coefficients. See the GRASP Technical Description for a detailed documentation.

Q

The coefficients have been generated by an object of class *Spherical Wave Expansion (SWE)*, or by an external spherical wave expansion program, e.g. SWEPQ, SNIFTD, ROSCOE and CHAMP.

ab

The coefficients have been generated by an external spherical wave expansion program, e.g. SWEP (the SWEPQ predecessor). This format is obsolete.

Remarks

Spherical wave coefficients for a source may be generated by an object of class *Spherical Wave Expansion (SWE)*.

When `Power Normalisation` is specified to 'on', the feed pattern is normalised to dBi, i.e. to radiate 4π watts. The total radiated power will be 4π times the value of `Factor` (converted from dB to power).

Frequency specification

The attribute `Frequency` must refer to a *Frequency* object, which defines as many frequencies as there are sets of spherical wave coefficients in the file. For a field calculation at, say the third frequency, the third set of wave coefficients is employed. Note that there is no information about the frequency in the coefficient file. If the file contains only a single set of coefficients, then this set will be used at all field calculations, independent of the frequency.

Plotting

When a *Tabulated SWE Coefficients* source is visualised by *Feed Plot*, it will be drawn as a sphere of radius $N_{\max}/k$, which provides a convenient check on whether the scattering geometry penetrates this sphere, and hence violates the equation above. See the examples given in *Feed Plot* and in *Polygonal Struts Plot*.

Content of modes

The size of a radiating or scattering object determines the limits on the azimuthal (m) and polar (n) mode indices. For the polar modes, index n is in the range

$$1 \leq n \leq N$$

while for each polar index n, the azimuthal index m is within the range

$$-n \leq m \leq n$$

The value of N is

$$N = kr_0 + \max(10, 3.6\sqrt[3]{kr_0})$$

k being the wavenumber and r_0 the radius of the smallest sphere surrounding all sources and centred at the origin of the reference coordinate system.

The modes in a spherical wave expansion may be depicted as a distribution in the mn-plane, as shown in Figure 1 below. Each dot with indices (m,n) represents two modes, either two ab-modes, a_{mn} and b_{mn} , or two Q-modes, Q_{1mn} and Q_{2mn}, since the Q-coefficients have 3 indices, s, m, and n, where s may be 1 or 2.

A mode truncation of both azimuthal and polar modes may be employed, as shown in the following Figure 2, Figure 3 and Figure 4.

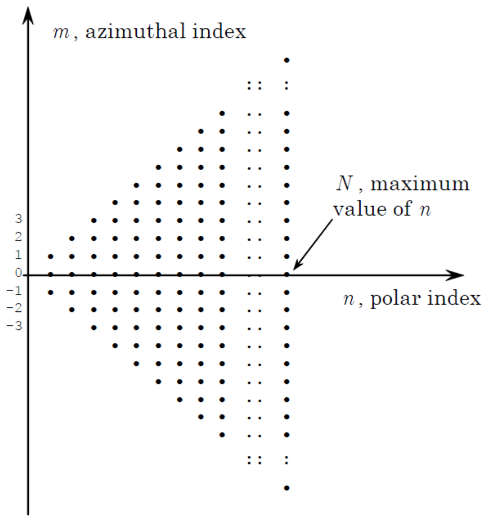


Figure 1 All mn-modes, limited by $n \leq N$, N given by the size of the radiating object.

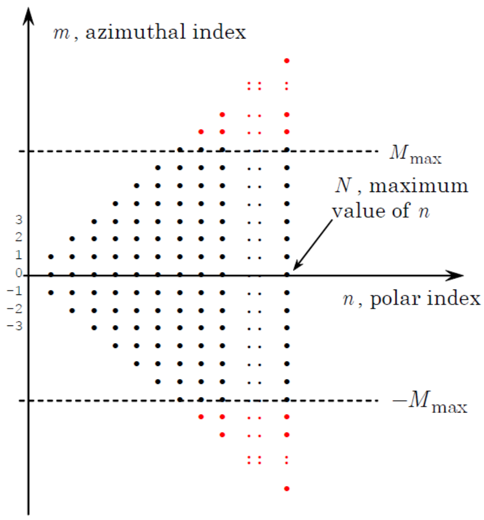


Figure 2 `Max m-Mode Index` is specified to $M_{\max}$, only the modes $-M_{\max} \leq m \leq M_{\max}$ are included (shown in black).

Finally, azimuthal modes with a relative power content less than the `Power Threshold` may be excluded in the field calculation. Let P_m denote the power of all modes with the same $|m|$ (the two rows for $+m$ and $-m$ in the mn-plane as in the above figures). Then all azimuthal modes for which the

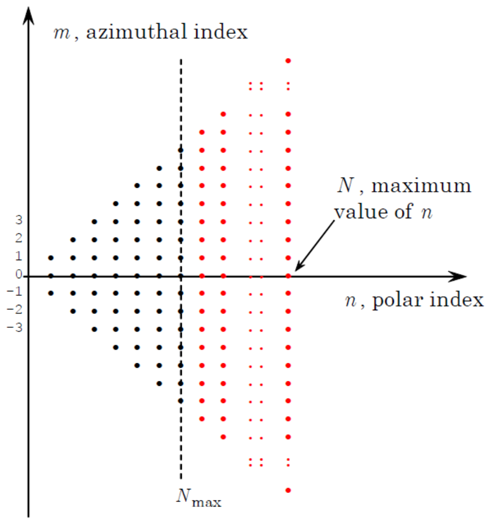


Figure 3 `Max m-Mode Index` is specified to $N_{\max}$, only the modes $n \leq N_{\max}$ are included (shown in black).

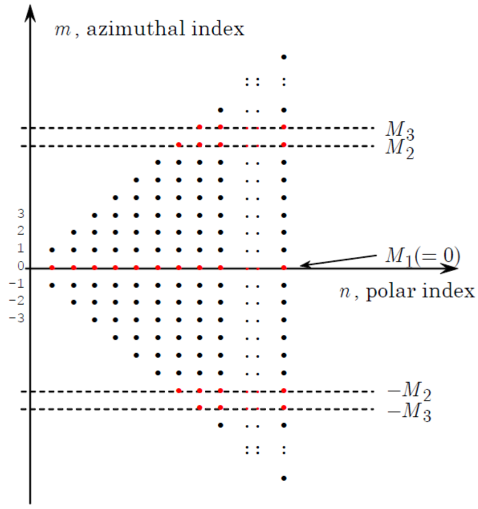


Figure 4 `azimuthal_mode` is specified to M_1, M_2 and M_3. Only the modes with $|m| \neq M_1, M_2, M_3$ are included (shown in black, M_1 is in this example chosen to 0.)

relative power content P_m is below the `Power Threshold`

$$\frac{P_m}{\sum_{|m|} P_m} < \texttt{Power Threshold}$$

will be excluded.

When the set of modes has been defined, possibly after truncation and filtering, then the field may be computed from these modes at all points in space for which

$$r > N_{\max}/k$$

where $N_{\max}$ is the highest value of the polar index n in the chosen mode set and k is the wavenumber. Depending on the sources from which the mode set derives, the field may be determined for smaller values of r in some part of the space, but a warning will be issued.