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# **sofia-py Documentation**

***Release 0.2***

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Contents:



## 1.1 Requirements

Obviously, you'll need [Python](#). The code has been developed and tested on Python 3.x only. [NumPy](#) and [SciPy](#) are needed for calculations. .. If you also want to plot the resulting sound fields, you'll need [matplotlib](#).

Instead of installing all of them separately, you should probably get a Python distribution that already includes everything, e.g. [Anaconda](#).

## 1.2 How to Get Started

Various jupyter notebooks are located in the root directory/

- **AE1\_IdealPlaneWave.ipynb**: Ideal unity plane wave simulation

## 1.3 Reference

Feel free to check out the full [:doc:reference](#).





## GENERATORS

Generators explanation. Module contains various generator functions:

***awgn*** Generate additive White Gaussian noise

***gaussGrid*** Gauss-Legendre quadrature grid and weights

***lebedev*** Lebedev quadrature grid and weights

***mf*** Modal Radial Filter

***swg*** Sampled Wave Generator, emulating discrete sampling

***wgc*** Wave Generator, returns spatial Fourier coefficients



## PROCESSING

Processing explanation. Processing functions:

*fdt* Frequency to time transform

*itc* Fast Inverse Spatial Fourier Transform

*pdc* Plane Wave Decomposition

*rfi* Radial filter Improvement

*stc* Fast Spatial Fourier Transform

*tdt* Time Domain Reconstruction

Not yet implemented:

*bsa* BEMA Spatial Anti-Aliasing

*sfe* Sound field extrapolation

*wdr* Wigner-D Rotation



## PLOTTING

Plotting explanation. Plotting functions - makeMTX: Generate 3D-matrix data - visualize3D: Draw matrix data in 3D



## REFERENCE

### 5.1 Generators

Module contains various generator functions:

**awgn** Generate additive White Gaussian noise

**gaussGrid** Gauss-Legendre quadrature grid and weights

**lebedev** Lebedev quadrature grid and weights

**mf** Modal Radial Filter

**swg** Sampled Wave Generator, emulating discrete sampling

**wgc** Wave Generator, returns spatial Fourier coefficients

`sofia.gen.awgn (fftData, noiseLevel=80, printInfo=True)`

Adds White Gaussian Noise of approx. 16dB crest to a FFT block. :param fftData: Input fftData block (e.g. from F/D/T or S/W/G) :type fftData: array of complex floats :param noiseLevel: Average noise Level in dB [Default: -80dB] :type noiseLevel: int, optional :param printInfo: Toggle print statements [Default: True] :type printInfo: bool, optional

**Returns** **noisyData** – Output fftData block including white gaussian noise

**Return type** array of complex floats

`sofia.gen.gaussGrid (AZnodes=10, ELnodes=5, plot=False)`

Compute Gauss-Legendre quadrature nodes and weights in the SOFiA/VariSphear data format.

#### Parameters

- **ELnodes** (*AZnodes*,) – Number of azimuthal / elevation nodes [Default: 10 / 5]
- **plot** (*bool*, *optional*) – Show a globe plot of the selected grid [Default: False]

#### Returns

- **gridData** (*matrix of floats*) – Gauss-Legendre quadrature positions and weights

[AZ_0, EL_0, W_0
...
AZ_n, EL_n, W_n]

- **Npoints** (*int*) – Total number of nodes
- **Nmax** (*int*) – Highest stable grid order

`sofia.gen.lebedev (degree, plot=False, printInfo=True)`

Compute Lebedev quadrature nodes and weights.

**Parameters**

- **Degree** (*int*) – Lebedev Degree. Currently available: 6, 14, 26, 38, 50, 74, 86, 110, 146, 170, 194
- **plot** (*bool, optional*) – Plot selected Lebedev grid [Default: False]

**Returns**

- **gridData** (*array of floats*) – Lebedev quadrature positions and weights: [AZ, EL, W]
- **Nmax** (*int*) – Highest stable grid order

`sofia.gen.mf(N, kr, ac, amp_maxdB=0, plc=0, fadeover=0, printInfo=True)`  
Generate modal radial filters

**Parameters**

- **N** (*int*) – Maximum Order
- **kr** (*array of floats*) – Vector or Matrix of kr values

First Row (M=1) N: kr values microphone radius  
Second Row (M=2) N: kr values sphere/microphone radius  
[kr\_mic;kr\_sphere] for rigid/dual sphere configurations  
! If only one kr-vector is given using a rigid/dual sphere  
Configuration: kr\_sphere = kr\_mic

- **ac** (*int {0, 1, 2, 3, 4}*) –

**Array Configuration:**

- 0: Open Sphere with p Transducers (NO plc!)
- 1: Open Sphere with pGrad Transducers
- 2: Rigid Sphere with p Transducers
- 3: Rigid Sphere with pGrad Transducers
- 4: Dual Open Sphere with p Transducers

- **amp\_maxdB** (*int, optional*) – Maximum modal amplification limit in dB [Default: 0]
- **plc** (*int {0, 1, 2}, optional*) – OnAxis powerloss-compensation: - 0: Off [Default] - 1: Full kr-spectrum plc - 2: Low kr only -> set fadeover
- **fadeover** (*int, optional*) – :: Number of kr values to fade over +/- around min-distance gap of powerloss compensated filter and normal N0 filters. 0 is auto fadeover [Default]

**Returns**

- **dn** (*array of floats*) – Vector of modal 0-N frequency domain filters
- **beam** (*array of floats*) – Expected free field on-axis kr-response

`sofia.gen.swg(r=0.01, gridData=None, ac=0, FS=48000, NFFT=512, AZ=0, EL=1.5707963267948966, c=343, wavetype=0, ds=1, Nlim=120, printInfo=True)`  
Sampled Wave Generator Wrapper

**Parameters**

- **r** (*array of floats, optional*) – Microphone Radius [Default: 0.01]



```
Can also be a vector for rigid sphere configurations:
[1,1] => rm Microphone Radius
[2,1] => rs Sphere Radius (Scatterer)
```

- **gridData** (*array of floats*) – Quadrature grid [Default: 110 Lebedev grid]

```
Columns : Position Number 1...M
Rows    : [AZ EL Weight]
```

- **ac** (*int {0, 1, 2, 3, 4}*) –

#### Array Configuration:

- 0: Open Sphere with p Transducers (NO plc!) [Default]
- 1: Open Sphere with pGrad Transducers
- 2: Rigid Sphere with p Transducers
- 3: Rigid Sphere with pGrad Transducers
- 4: Dual Open Sphere with p Transducers

- **FS** (*int, optional*) – Sampling frequency [Default: 48000 Hz]
- **NFFT** (*int, optional*) – Order of FFT (number of bins), should be a power of 2. [Default: 512]
- **AZ** (*float, optional*) – Azimuth angle in radians [0-2pi]. [Default: 0]
- **EL** (*float, optional*) – Elevation angle in radians [0-pi]. [Default: pi / 2]
- **c** (*float, optional*) – Speed of sound in [m/s] [Default: 343 m/s]
- **wavetype** (*int {0, 1}, optional*) –

#### Type of the Wave:

- 0: Plane Wave [Default]
- 1: Spherical Wave

- **ds** (*float, optional*) – Distance of the source in [m] (For wavetype = 1 only)

```
Warning: If NFFT is smaller than the time the wavefront
needs to travel from the source to the array, the impulse
response will be cyclically shifted (cyclic convolution).
```

- **Nlim** (*int, optional*) – Internal generator transform order limit [Default: 120]

#### Returns

- **fftData** (*array of floats*) – Complex sound pressures of size [(N+1)^2 x NFFT]
- **kr** (*array of floats*) – kr-vector

```
Can also be a matrix [krm; krs] for rigid sphere configurations:
[1,:] => krm referring to the microphone radius
[2,:] => krs referring to the sphere radius (scatterer)
```

## Notes

This file is a wrapper generating the complex pressures at the positions given in 'gridData' for a full spectrum 0-FS/2 Hz (NFFT Bins) wave impinging to an array. The wrapper involves the W/G/C wave generator core and the I/T/C spatial transform core.

S/W/G emulates discrete sampling. You can observe alias artifacts.

```
sofia.gen.wgc(N, r, ac, fs, F_NFFT, az, el, t=0.0, c=343.0, wavetype=0, ds=1.0, lowerSegLim=0,
              SegN=None, upperSegLim=None, printInfo=True)
```

Wave Generator Core: Returns Spatial Fourier Coefficients *Pnm* and *kr* vector

### Parameters

- **N**(*int*) – Maximum transform order.
- **r**(*list of ints*) – Microphone radius

Can also be a vector for rigid/dual sphere configurations:  
[1,1] => rm Microphone radius  
[2,1] => rs Sphere or microphone radius  
! If only one radius (rm) is given using a rigid/dual sphere  
Configuration: rs = rm and only one kr-vector is returned!

- **ac**(*int {0, 1, 2, 3, 4}*) –

#### Array Configuration:

- 0: Open Sphere with p Transducers (NO plc!)
- 1: Open Sphere with pGrad Transducers
- 2: Rigid Sphere with p Transducers
- 3: Rigid Sphere with pGrad Transducers
- 4: Dual Open Sphere with p Transducers

- **FS**(*int*) – Sampling frequency
- **NFFT**(*int*) – Order of FFT (number of bins), should be a power of 2.
- **AZ**(*float*) – Azimuth angle in radians [0-2pi].
- **EL**(*float*) – Elevation angle in in radians [0-pi].
- **t**(*float, optional*) – Time Delay in s.
- **c**(*float, optional*) – Speed of sound in [m/s] [Default: 343m/s]
- **wavetype**(*int {0, 1}, optional*) –

#### Type of the Wave:

- 0: Plane Wave [Default]
- 1: Spherical Wave

- **ds**(*float, optional*) – Distance of the source in [m] (For wavetype = 1 only)

**Warning:** If NFFT **is** smaller than the time the wavefront needs to travel **from the** source to the array, the impulse response will be cyclically shifted (cyclic convolution).

- **lSegLim**(*int, optional*) – (Lower Segment Limit) Used by the S/W/G wrapper

- **uSegLim**(*int*, *optional*) – (Upper Segment Limit) Used by the S/W/G wrapper
- **SegN**(*int*, *optional*) – (Sement Order) Used by the S/W/G wrapper
- **printInfo**(*bool*, *optional*) – Toggle print statements

#### Returns

- **Pnm** (*array of complex floats*) – Spatial Fourier Coefficients with nm coeffs in cols and FFT coeffs in rows
- **kr** (*array of floats*) – kr-vector

Can also be a matrix [krm; krs] **for** rigid sphere configurations:  
 [1,:] => krm referring to the microphone radius  
 [2,:] => krs referring to the sphere radius (scatterer)

## 5.2 Processing

Processing functions:

**fdt** Frequency to time transform

**itc** Fast Inverse Spatial Fourier Transform

**pdw** Plane Wave Decomposition

**rft** Radial filter Improvement

**stc** Fast Spatial Fourier Transform

**tdt** Time Domain Reconstruction

Not yet implemented:

**bsa** BEMA Spatial Anti-Aliasing

**sfe** Sound field extrapolation

**wdr** Wigner-D Rotation

`sofia.process.bsa(Pnm, ctSig, dn, transition, avgBandwidth, fade=True)`  
 B/S/A BEMA Spatial Anti-Aliasing - NOT YET IMPLEMENTED

#### Parameters

- **Pnm** (*array\_like*) – Spatial Fourier coefficients
- **ctSig** (*array\_like*) – Signal of the center microphone
- **dn** (*array\_like*) – Radial filters for the current array configuration
- **transition** (*int*) – Highest stable bin, approx:  $\text{transition} = (\text{NFFT}/\text{FS} + 1) * (\text{N} * \text{c}) / (2 * \text{pi} * \text{r})$
- **avgBandwidth** (*int*) – Averaging Bandwidth in oct
- **fade** (*bool*, *optional*) – Fade over if True, else hard cut {false} [Default: True]

**Returns** **Pnm** – Alias-free spatial Fourier coefficients

**Return type** *array\_like*

## Notes

This was presented at the 2012 AES convention, see <sup>1</sup>.

## References

`sofia.process.fdt (timeData, FFToversize=1, firstSample=0, lastSample=None)`  
F/D/T frequency domain transform

### Parameters

- **timeData** (*named tuple*) – timeData tuple with following fields

```
.impulseResponses [Channels X Samples]
.FS
.radius           Array radius
.averageAirTemp   Temperature in [C]
(.centerIR       [1 x Samples] )
```

- **FFToversize** (*int, optional*) – FFToversize rises the FFT Blocksize. [Default: 1]

```
A FFT of the blocksize (FFToversize*NFFT) is applied
to the time domain data, where NFFT is determined
as the next power of two of the signalSize which is
signalSize = (lastSample-firstSample).
The function will pick a window of (lastSample-firstSample)
for the FFT.
```

- **firstSample** (*int, optional*) – First time domain sample to be included. [Default: 0]
- **lastSample** (*int, optional*) – Last time domain sample to be included. [Default: -1]

### Returns

- **fftData** (*array of floats*) – Frequency domain data ready for the Spatial Fourier Transform (stc)
- **kr** (*array of floats*) – kr-Values of the delivered data
- **f** (*array of floats*) – Absolute frequency scale
- **ctSig** (*array of floats*) – Center signal, if available

## Notes

Call this function with a running window (firstSample+td->lastSample+td) iteration increasing td to obtain time slices. This way you resolve the temporal information within the captured sound field.

`sofia.process.itc (Pnm, angles, N=None, printInfo=True)`  
I/T/C Fast Inverse spatial Fourier Transform Core

### Parameters

---

<sup>1</sup> B. Bernschütz, "Bandwidth Extension for Microphone Arrays", AES Convention 2012, Convention Paper 8751, 2012. <http://www.aes.org/e-lib/browse.cfm?elib=16493>

- **Pnm** (*array of floats*) – Spatial Fourier coefficients with FFT bins as cols and nm coeffs as rows (e.g. from SOFiA S/T/C)
- **angles** (*array of floats*) – Target angles of shape

```
[AZ1, EL1;
 AZ2, EL2;
 ...
 AZn, ELn]
```

- **[N]** (*int, optional*) – Maximum transform order [Default: highest available order]

**Returns** **p** – Sound pressures with FFT bins in cols and specified angles in rows

**Return type** array of complex floats

## Notes

This is a pure ISFT core that does not involve extrapolation. (=The pressures are referred to the original radius)

`sofia.process.pdc(N, OmegaL, Pnm, dn, cn=None, printInfo=True)`

P/D/C - Plane Wave Decomposition

### Parameters

- **N** (*int*) – Decomposition order
- **OmegaL** (*array of floats*) – Look directions of shape

```
[AZ1, EL1;
 AZ2, EL2;
 ...
 AZn, ELn]
```

- **Pnm** (*matrix of complex floats*) – Spatial Fourier Coefficients (e.g. from SOFiA S/T/C)
- **dn** (*matrix of complex floats*) – Modal array filters (e.g. from SOFiA M/F)
- **cn** (*array of floats, optional*) – Weighting Function. Either frequency invariant weights as 1xN array or with kr bins in rows over N cols. [Default: None]

**Returns** **Y** – MxN Matrix of the decomposed wavefield with kr bins in rows

**Return type** matrix of floats

`sofia.process.rfi(dn, kernelDownScale=2, highPass=0.0)`

R/F/I Radial Filter Improvement [NOT YET IMPLEMENTED!]

### Parameters

- **dn** (*array of floats*) – Analytical frequency domain radial filters (e.g. SOFiA M/F)
- **kernelDownScale** (*int, optional*) – Downscale factor for the filter kernel [Default: 2]
- **highPass** (*float, optional*) – Highpass Filter from 0.0 (off) to 1.0 (maximum kr) [Default: 0.0]

### Returns

- **dn** (*array of floats*) – Improved radial filters

- **kernelSize** (*int*) – Filter kernel size (total)
- **latency** (*float*) – Approximate signal latency due to the filters

## Notes

This function improves the FIR radial filters from SOFiA M/F. The filters are made causal and are windowed in time domain. The DC components are estimated. The R/F/I module should always be inserted to the filter path when treating measured data even if no use is made of the included kernel downscaling or highpass filters.

Do NOT use R/F/I for single open sphere filters (e.g.simulations).

**IMPORTANT: Remember to choose a fft-oversize factor (F/D/T) being large enough** to cover all filter latencies and reponse slopes. Otherwise undesired cyclic convolution artifacts may appear in the output signal.

**HIGHPASS: If HPF is on (highPass>0) the radial filter kernel is** downscaled by a factor of two. Radial Filters and HPF share the available taps and the latency keeps constant. Be careful using very small signal blocks because there may remain too few taps. Observe the filters by plotting their spectra and impulse responses. > Be very carefull if  $NFFT/\max(kr) < 25$  > Do not use R/F/I if  $NFFT/\max(kr) < 15$

```
sofia.process.sfe(Pnm_kra, kra, krb, problem='interior')
```

S/F/E Sound Field Extrapolation. CURRENTLY WIP :param Pnm\_kra: Spatial Fourier Coefficients (e.g. from SOFiA S/T/C) :type Pnm\_kra: array of floats :param kra, krb:  $k * r_a/r_b$  vector :type kra, krb: array of floats :param problem: Select between interior and exterior problem [Default: interior] :type problem: string{ 'interior', 'exterior' }

```
sofia.process.stc(N,fftData,grid)
```

S/T/C Fast Spatial Fourier Transform

### Parameters

- **N** (*int*) – Maximum transform order
- **fftData** (*array of floats*) – Frequency domain sounfield data, (e.g. from SOFiA FDT) with spatial sampling positions in cols and FFT bins in rows
- **grid** (*array of floats*) – Grid configuration of AZ [0 ... 2pi], EL [0...pi] and W of shape

```
[AZ1, EL1, W1;
 AZ2, EL2, W2;
 ...
 AZn, ELn, Wn]
```

**Returns Pnm** – Spatial Fourier Coefficients with nm coeffs in cols and FFT bins in rows

**Return type** array of floats

```
sofia.process.tdt(Y,win=0,minPhase=False,resampleFactor=1,printInfo=True)
```

T/D/T - Time Domain Transform

### Parameters

- **Y** (*array of floats*) – Frequency domain data over multiple channels (cols) with FFT data in rows
- **float, optional** (*win*) – Window Signal tail [0...1] with a HANN window [Default: 0] - NOT YET IMPLEMENTED
- **int, optional** (*resampleFactor*) – Resampling factor ( $FS_{target}/FS_{source}$ )

- **bool, optional** (*minPhase*) –
- **minimum phase reduction** – NOT YET IMPLEMENTED [Default (*Ensure*) –

**Returns** **y** – Reconstructed time-domain signal of channels in cols and impulse responses in rows

**Return type** array of floats

## Notes

This function recombines time domain signals for multiple channels from frequency domain data. It is made to work with half-sided spectrum FFT data. The impulse responses can be windowed. The IFFT blocklength is determined by the Y data itself:

Y should have a size [NumberOfChannels x ((2<sup>n</sup>)/2)+1] with n=[1,2,3,...] and the function returns [NumberOfChannels x resampleFactor\*2<sup>n</sup>] samples.

`sofia.process.wdr(Pnm, xAngle, yAngle, zAngle)`  
W/D/R Wigner-D Rotation - NOT YET IMPLEMENTED

### Parameters

- **Pnm** (*array\_like*) – Spatial Fourier coefficients
- **yAngle, zAngle** (*xAngle,*) – Rotation angle around the x/y/z-Axis

**Returns** **PnmRot** – Rotated spatial Fourier coefficients

**Return type** *array\_like*

## 5.3 Plotting

Plotting functions - **makeMTX**: Generate 3D-matrix data - **visualize3D**: Draw matrix data in 3D

`sofia.plot.genScatter(vizMTX, colorize=False)`  
`sofia.plot.genShape(vizMTX, offset=0, scale=1.0, colorize=False)`  
`sofia.plot.genSphere(vizMTX, colorize=False)`  
`sofia.plot.genVisual(vizMTX, style='shape', colorize=False, offset=0, scale=1.0, normalize=True)`  
`sofia.plot.generateAngles()`  
 Returns a [65160 x 1] grid of all radiant angles in 1 deg steps  
`sofia.plot.makeMTX(Pnm, dn, Nviz=3, krIndex=1, oversize=1)`  
 mtxData = makeMTX(Nviz=3, Pnm, dn, krIndex)

### Parameters

- **Spatial Fourier Coefficients (from S/T/C)** (*Pnm*) –
- **Modal Radial Filters (from M/F)** (*dn*) –
- **Order of the spatial fourier transform** [default = 3] (*N*) –
- **Index of kr Vector** [default = 1] (*krIndex*) –
- **Integer Factor to increase the resolution. Set oversize = 1** (*oversize*) – (default) to use the mtxData matrix for visual3D(), map3D().
- **#Returns** –

- -----
- **3D-matrix-data in 1[deg] steps** (*mtxData*) –

### Notes

The file generates a SOFiA *mtxData* Matrix of 181x360 pixels for the visualisation with `visualize3D()` in 1[deg] Steps (65160 plane waves). The HD version generally allows to raise the resolution (`oversize > 1`). (`visual3D()`, `map3D()` admit 1[deg] data only, `oversize = 1`)

```
sofia.plot.normalizeMTX(vizMTX)
```

```
sofia.plot.plotGrid(rows, cols, vizMTX, bgcolor='white', style='shape', colorize=False, normalize=True)
```

```
sofia.plot.visualize3D(vizMTX, style='sphere', colorize=True, offset=0.0, scale=1.0, **kargs)
```

Visualize matrix data, such as from `makeMTX(Pnm, dn)`

### Parameters

- **SOFiA 3D-matrix-data [1[deg] steps]** (*vizMTX*) –
- **'sphere', surface colors indicate the intensity (default)** (*style*) – 'flat', surface colors indicate the intensity (TODO) 'scatter', extension indicates the intensity 'shape', extension indicates the intensity
- **linear offset for shape (Default (offset))** –
- **scaling factor for shape (Default (scale))** –

### Notes

TODO: Implement flat style, fix color position in sphere and shape, make colormap selectable, move grid generation into function

## 5.4 Sphericals

Collection of spherical helper functions:

**sph\_harm** More robust spherical harmonic coefficients

**spbessel / dspbessel** Spherical Bessel and derivative

**spneumann / dspneumann** Spherical Neumann (Bessel 2nd kind) and derivative

**sphankel / dsphankel** Spherical Hankel and derivative

**cart2sph / sph2cart** Convert cartesian to spherical coordinates and vice versa

```
sofia.sph.besselh(n, z)
```

Bessel function of third kind (Hankel function). Wraps `scipy.special.hankel1(n, z)` :param *n*: Order (float) :type *n*: array\_like :param *z*: Argument (float or complex) :type *z*: array\_like

**Returns** **H** – Values of Hankel function of order *n* at position *z*

**Return type** array\_like

```
sofia.sph.besselj(n, z)
```

Bessel function of first kind. Wraps `scipy.special.jn(n, z)` :param *n*: Order (float) :type *n*: array\_like :param *z*: Argument (float or complex) :type *z*: array\_like



**Returns J** – Values of Bessel function of order  $n$  at position  $z$

**Return type** array\_like

`sofia.sph.bn(n, krm, krs, ac)`

`sofia.sph.bn_dualOpenP(n, kr1, kr2)`

`sofia.sph.bn_npf(n, krm, krs, ac)`

Microphone scaling

#### Parameters

- **n** (*int*) – Order
- **krm** (*array of floats*) – Microphone radius
- **krs** (*array of floats*) – Sphere radius
- **ac** (*int {0, 1, 2, 3, 4}*) –

#### Array Configuration:

- 0: Open Sphere with p Transducers (NO plc!) [Default]
- 1: Open Sphere with pGrad Transducers
- 2: Rigid Sphere with p Transducers
- 3: Rigid Sphere with pGrad Transducers
- 4: Dual Open Sphere with p Transducers

**Returns b**

**Return type** array of floats

`sofia.sph.bn_openP(n, krm)`

`sofia.sph.bn_openPG(n, krm)`

`sofia.sph.bn_rigidP(n, krm, krs)`

`sofia.sph.bn_rigidPG(n, krm, krs)`

`sofia.sph.cart2sph(x, y, z)`

Converts cartesian coordinates  $x, y, z$  to spherical coordinates  $az, el, r$ .

`sofia.sph.dspbessel(n, kr)`

Derivative of spherical Bessel

#### Parameters

- **n** (*int*) – Order
- **kr** (*int*) – Degree

**Returns J'** – Derivative of spherical Bessel

**Return type** complex float

`sofia.sph.dsphankel(n, kr)`

Derivative spherical Hankel function  $hn'$

#### Parameters

- **n** (*int*) – Order
- **kr** (*int*) – Degree

**Returns**  $h_n'$  – Derivative of spherical Hankel function  $h_n$

**Return type** complex float

`sofia.sph.dspneumann(n, kr)`

Derivative spherical Neumann (Bessel second kind) of order n

**Parameters**

- `n(int)` – Order
- `kr(int)` – Degree

**Returns**  $Y_n'$  – Derivative of spherical Neumann (Bessel second kind)

**Return type** complex float

`sofia.sph.spbessel(n, kr)`

Spherical Bessel function

**Parameters**

- `n(int)` – Order
- `kr(int)` – Degree

**Returns**  $J$  – Spherical Bessel

**Return type** complex float

`sofia.sph.sph2cart(az, el, r)`

Converts spherical coordinates az, el, r to cartesian coordinates x, y, z.

`sofia.sph.sph_harm(m, n, az, el)`

Compute spherical harmonics

**Parameters**

- `m(int)` – Order of the spherical harmonic.  $\text{abs}(m) \leq n$
- `n(int)` – Degree of the harmonic, sometimes called  $l$ .  $n \geq 0$
- `az(float)` – Azimuthal (longitudinal) coordinate  $[0, 2\pi]$ , also called Theta.
- `el(float)` – Elevation (colatitudinal) coordinate  $[0, \pi]$ , also called Phi.

**Returns**

- `y_mn(complex float)` – Complex spherical harmonic of order  $m$  and degree  $n$ , sampled at  $\text{theta} = \text{az}$ ,  $\text{phi} = \text{el}$
- $Y_{n,m}(\text{theta}, \text{phi}) = ((n - m)! * (2l + 1)) / (4\pi * (l + m)!^{0.5} * \exp(i * m * \text{phi}) * P_n^m(\cos(\text{theta}))$
- as per <http://dlmf.nist.gov/14.30>
- $P_{mn}(z)$  is the associated Legendre function of the first kind, like `scipy.special.lpmv`
- `scipy.special.lpmn` calculates  $P(0...m, 0...n)$  and its derivative but won't return  $+\infty$  at high orders

`sofia.sph.sphankel(n, kr)`

Spherical Hankel  $h_n$

**Parameters**

- `n(int)` – Order
- `kr(int)` – Degree

**Returns** `hn` – Spherical Hankel function `hn`

**Return type** complex float

`sofia.sph.spneumann(n, kr)`

Spherical Neumann (Bessel second kind)

**Parameters**

- `n(int)` – Order
- `kr(int)` – Degree

**Returns** `Yv` – Spherical Neumann (Bessel second kind)

**Return type** complex float

## 5.5 I/O

Input-Output functions

`sofia.io.readMiroStruct(matFile)`

Reads miro matlab files.

**Parameters** `matFile(filepath)` – .miro file that has been exported as a struct like so

```
load SOFiA_A1;
SOFiA_A1_struct = struct(SOFiA_A1);
save('SOFiA_A1_struct.mat', 'SOFiA_A1_struct');
```

**Returns**

- **timeData** (*named tuple*)
- *timeData* tuple with following fields
- `:` – .impulseResponses [Channels X Samples] .FS .radius Array radius .averageAirTemp Temperature in [C] (.centerIR [1 x Samples] )

## 5.6 lebedev

Generate Lebedev grid and coefficients This module only exposes the function `lebGrid = lebedev.genGrid(degree)`.

`lebGrid` is a named tuple containing the coordinates `.x`, `.y`, `.z` and the weights `.w` Possible degrees: 6, 14, 26, 38, 50, 74, 86, 110, 146, 170, 194

Adapted from Richard P. Mullers Python version, [https://github.com/gabrielelanaro/pyquante/blob/master/Data/lebedev\\_write.py](https://github.com/gabrielelanaro/pyquante/blob/master/Data/lebedev_write.py) C version: Dmitri Laikov F77 version: Christoph van Wuelen, <http://www.ccl.net>

Users of this code are asked to include reference [1] in their publications, and in the user- and programmers-manuals describing their codes.

[1] V.I. Lebedev, and D.N. Laikov ‘A quadrature formula for the sphere of the 131st algebraic order of accuracy’ Doklady Mathematics, Vol. 59, No. 3, 1999, pp. 477-481.

`sofia.lebedev.genGrid(n)`

Returns Lebedev coefficients of `n`’th degree

**Parameters** `n (int{6, 14, 26, 38, 50, 74, 86, 110, 146, 170, 194})` –  
Lebedev degree

**Returns** `lebGrid` – `lebGrid` is a named tuple containing `.x`, `.y`, `.z` and `.w`

**Return type** named tuple

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