Part I

Scientific Documentation

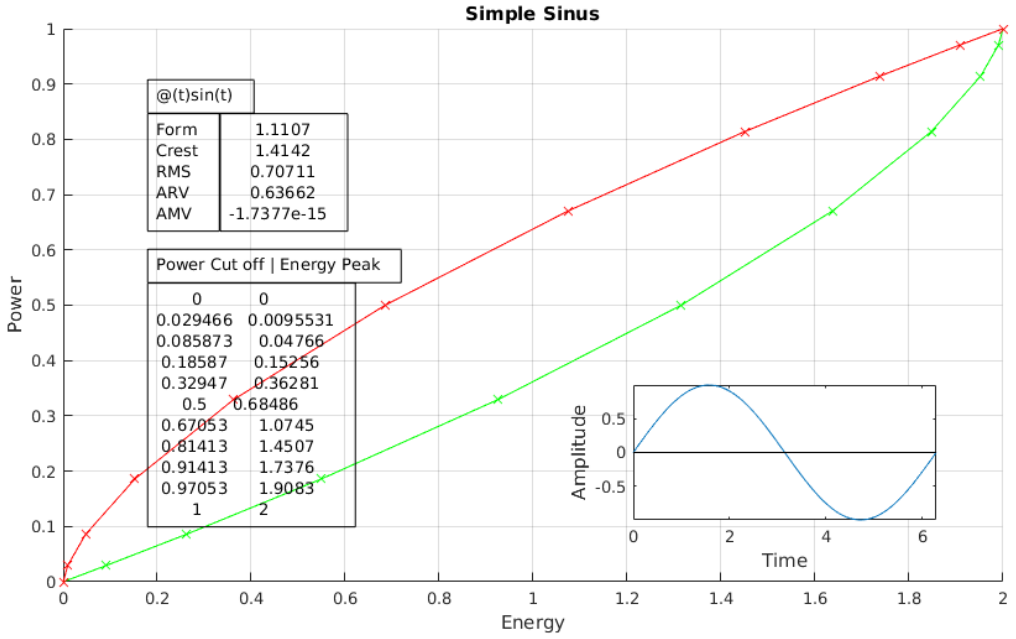
Last Update: Thu 29. Sep 2016

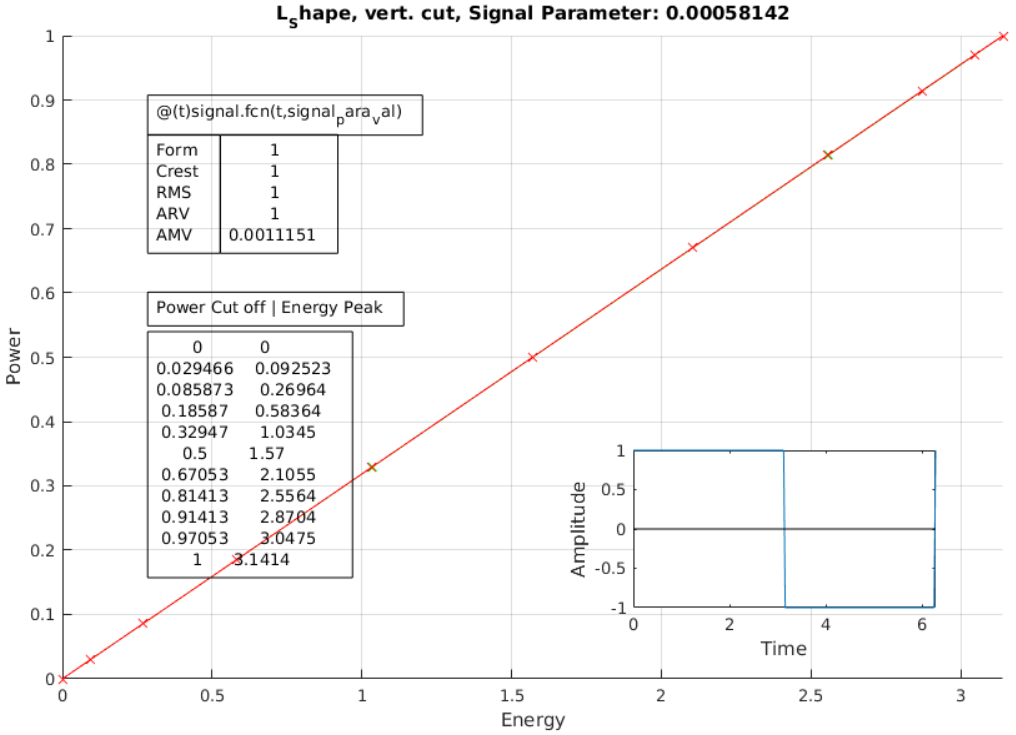
1 Outline

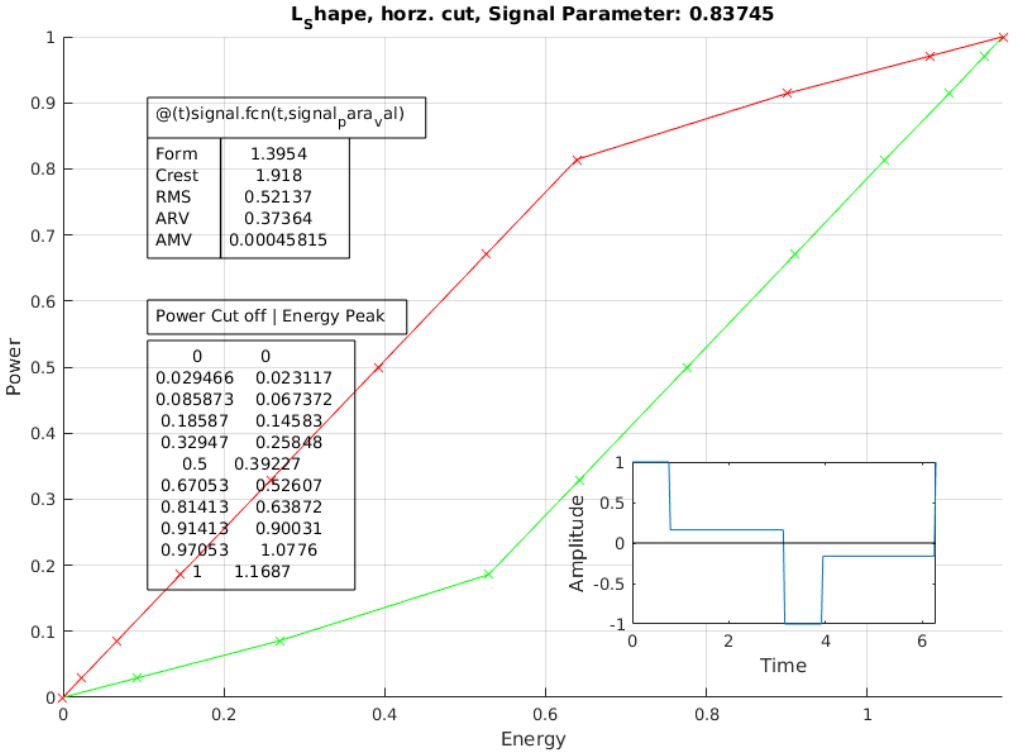
- Theory Description - Leaf theory description, proposed leaf diagram, summary, purpose, findings
- Signal Parameters - Properties and characteristics
- Investigated Signals - Parametric signal study w/resulting leaf diagrams
- Data Fitting - Efforts to find analytical description of leaf
- Results - Major insights and discoveries
- Open Questions, Not Analyzed - Not considered and investigated aspects
- Short Toolbox Description - Quickstart/How to get started with program code
- Development History/Git Log Summary - Short chronological description of work
- Project Folder Tree - File Structure in Folder

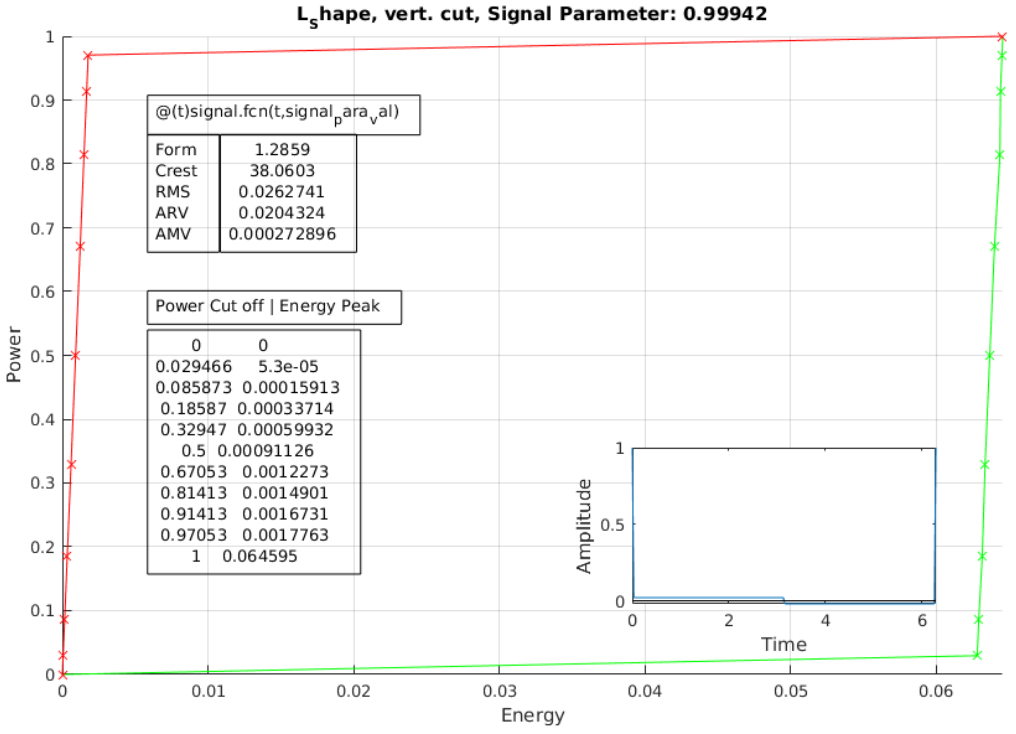
2 Theory Description

- Idea: divide every incomming signal, respectively storage profile, into base and peak signal, handed to a base and peak storage.
- The signal is divided at a specified power cut, which is a fraction of the maximum peak power. Everything above this cut is handles by the peak storage, everything below by the base storage.
- No complicated operating strategy or model prediction neccessary. Works without dynamic/ history.
- Works on every artificial and real signal. At the moment: point symmetric signal needed, rendering the discharge phase equal to the charging phase. This prevents a separate treatment and simplifies the matter for first insights into the problem.
- Strategy ensures that the added power and energy of the hybrid storage is always equal to a single storage solution.
- With this strategy, the split signals usually have another power to energy ratio than the original complete signal. For the peak storage, it is higher, for the base storage, it is lower. Depending on the input signal, and depending on the cut off value, the spread between original and divided power ratios gets higher or lower.
- This relationship can be represented in a power(energy) diagram, the lines build a leaf-alike shape. As peak storage size increases, starting from the lower left, base storage size decreases, starting from the upper right. A typical shape can be seen below
- This basic leave shape can degenerate for certain signals:
  - To a line: Square wave input, there is no spread for peak an base as both always have the same power/energy ratio as the original single storage
  - To a diamond: for l_shaped and step like discrete functions
  - To a square: For an impulse like signal with a remaining base power:


Simple Sinus
@(t)sin(t)
Form 1.1107
Crest 1.4142
RMS 0.70711
ARV 0.63662
AMV -1.7377e-15
Power Cut off | Energy Peak
0 0
0.029466 0.0095531
0.085873 0.04766
0.18587 0.15256
0.32947 0.36281
0.5 0.68486
0.67053 1.0745
0.81413 1.4507
0.91413 1.7376
0.97053 1.9083
1 2
Power
Energy
Amplitude
Time


L_shape, vert. cut, Signal Parameter: 0.00058142
@(t)signal.fcn(t,signal_para_val)
Form 1
Crest 1
RMS 1
ARV 1
AMV 0.0011151
Power Cut off | Energy Peak
0 0
0.029466 0.092523
0.085873 0.26964
0.18587 0.58364
0.32947 1.0345
0.5 1.57
0.67053 2.1055
0.81413 2.5564
0.91413 2.8704
0.97053 3.0475
1 3.1414
Power
Energy
Amplitude
Time





- Every point in diagram is calculated via simulation, making the generation expensive.

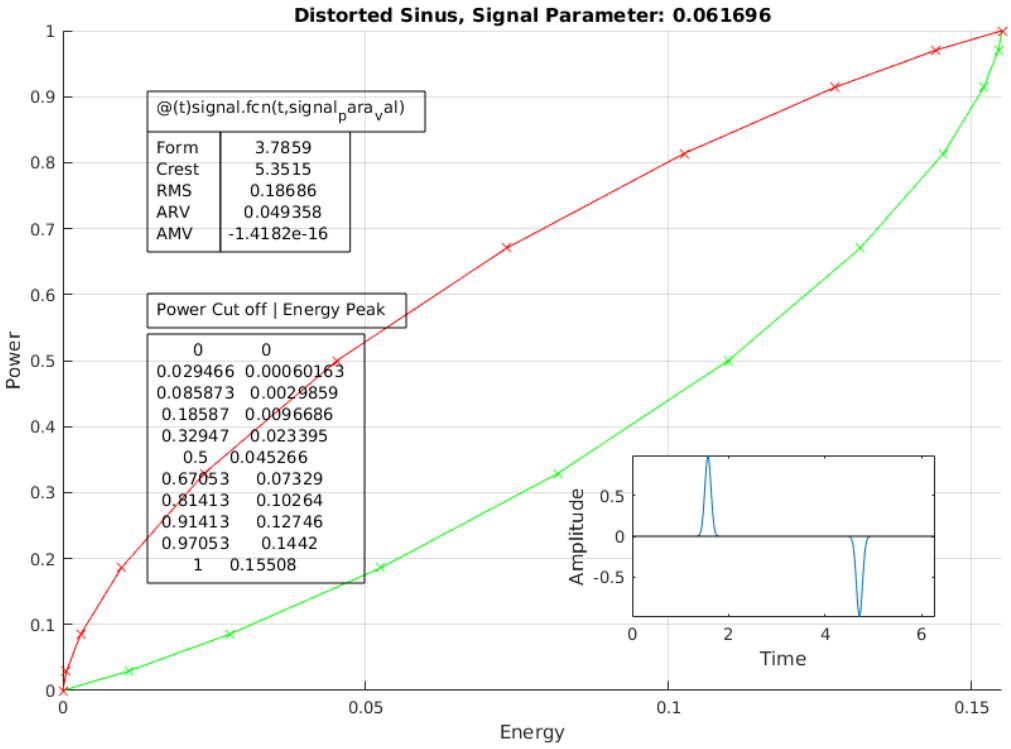
- Idea: Signal can be described by a few key parameters:
  - Root Mean Square (RMS),
  - Average Rectified Value (ARV),
  - Form Factor (F) or
  - Crest Factor (C) which are sufficient to fully describe the leaf shape
- Turned out to be invalid or not sufficient: Signals found with identical parameter but different leaf shape
- New Idea: sorted power profile contains all information needed for leaf shape
- Questionable if there is any numerical advantage
- Theory must be extented to allow non-symmetrical input signals.
- Theory must be extented to allow inter storage power flow.

3 Parameters

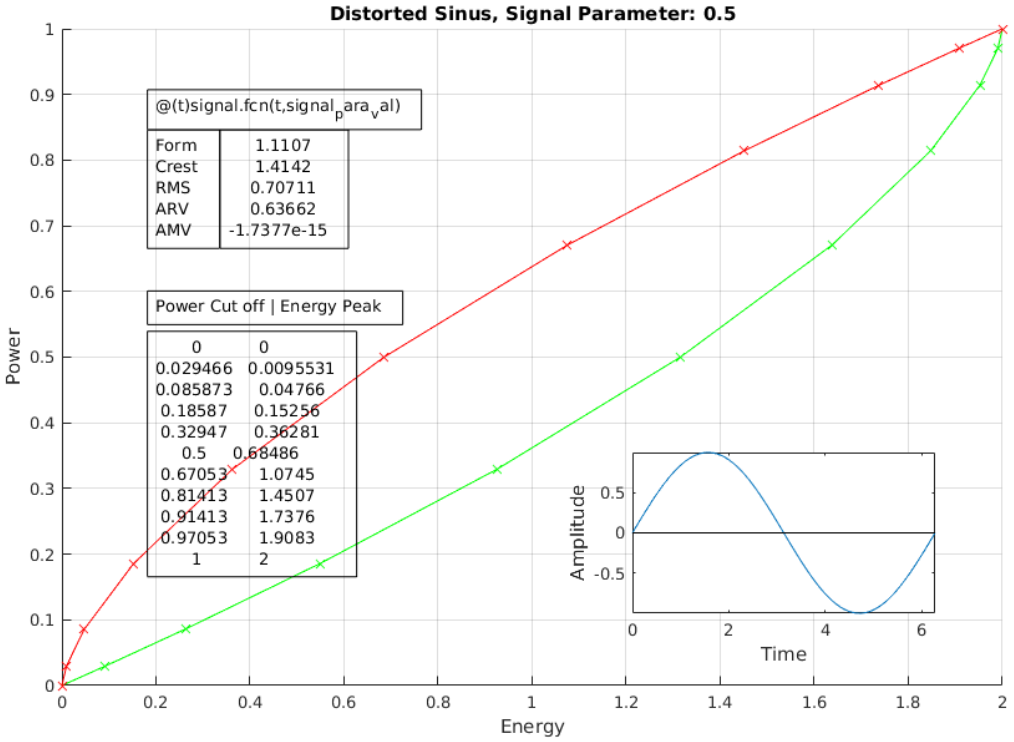
- Average rectified value, ARV
  - $\overline{|x|} = \frac{1}{T}\int_0^T x(t)dt$
  - Only used indirectly in Form Factor
- Root mean square, RMS
  - $X = \sqrt{\frac{1}{T}\int_0^T x^2(t)dt}$
  - Only used indirectly in Form and Crest Factor
- Crest Factor
  - $C = \frac{\hat{x}}{X}$
  - Ranges from 1 to infinity
  - Tendency:
    - Low Factors: little spreading potential, narrow leaf shape
    - High Factors: high spreading potential, strongly pronounced leaf shape
- Form Factor
  - $F = \frac{X}{\overline{|x|}}$
  - Ranges from 1 to infinity
  - Tendency:
    - Low Factors: little spreading potential, narrow leaf shape
    - High Factors: high spreading potential, strongly pronounced leaf shape
- Total Harmonic Distortion, THD
  - $THD = \frac{sqrtU^2 - U_1^2}{U}$
  - Not considered in investigation

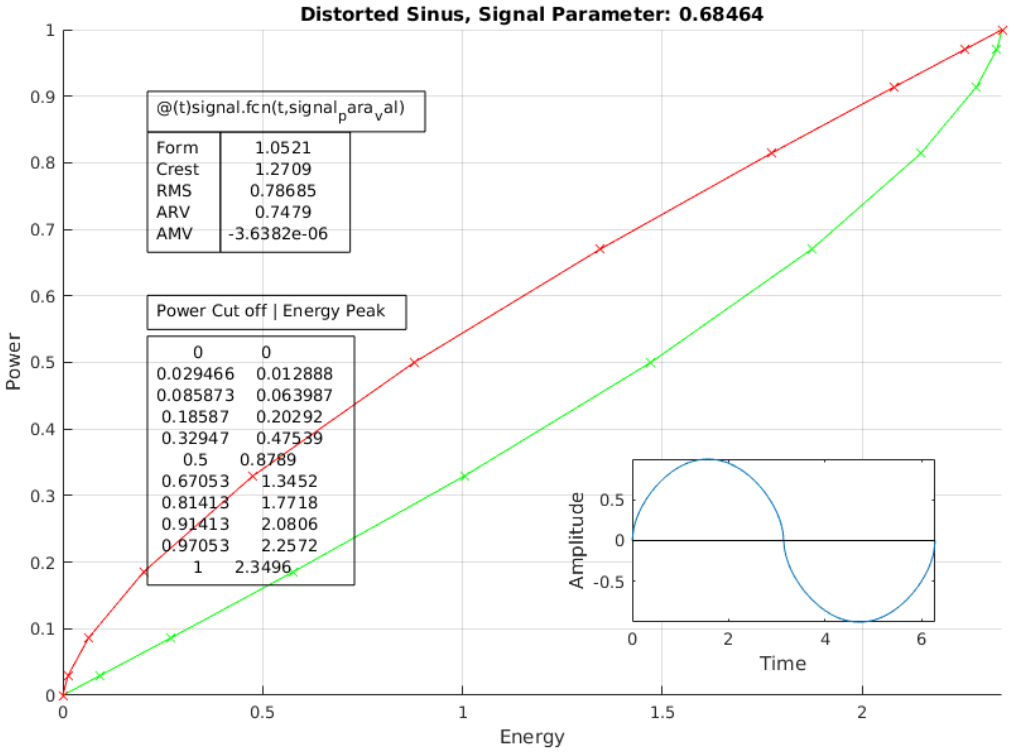
4 Investigated Signals

- Distorted Sinus Shapes

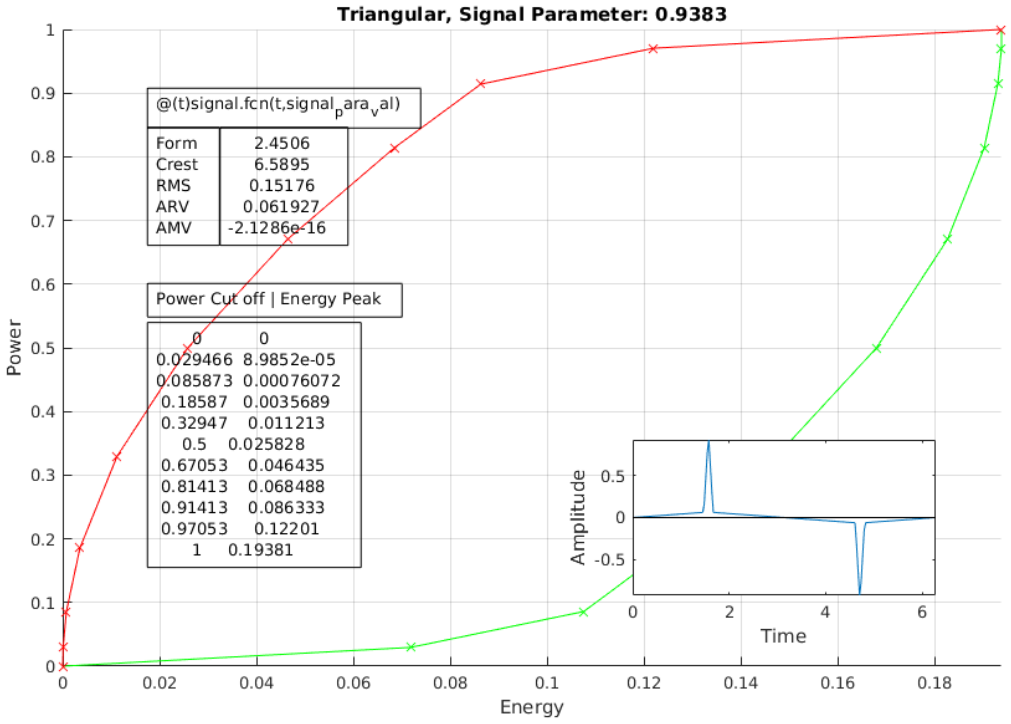


-

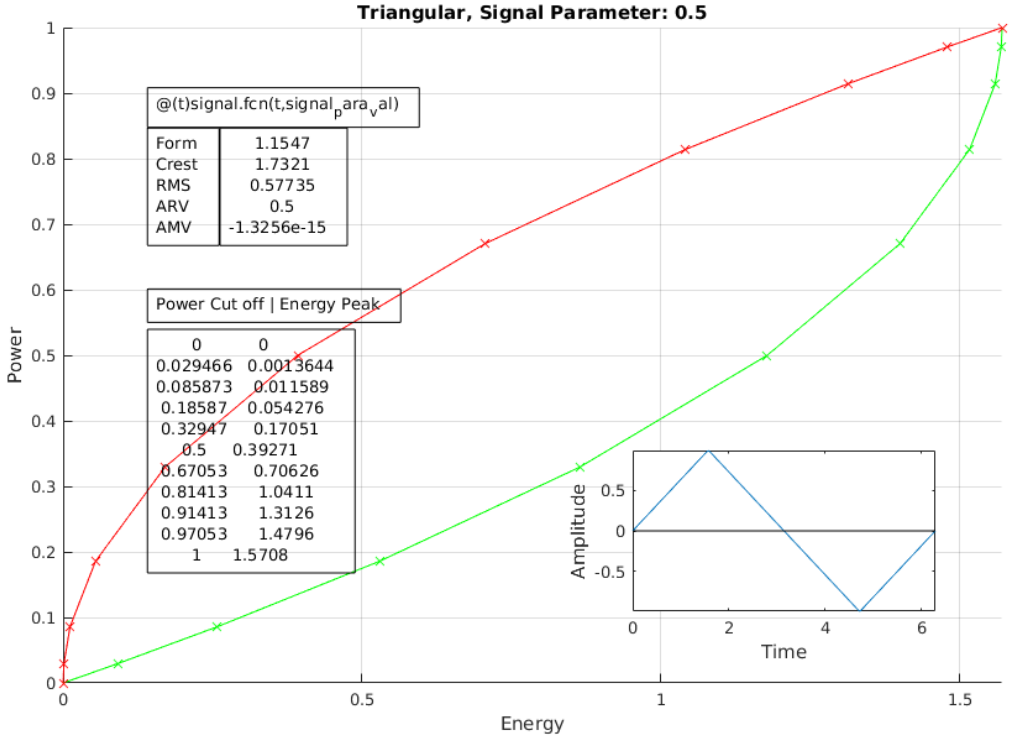


- 

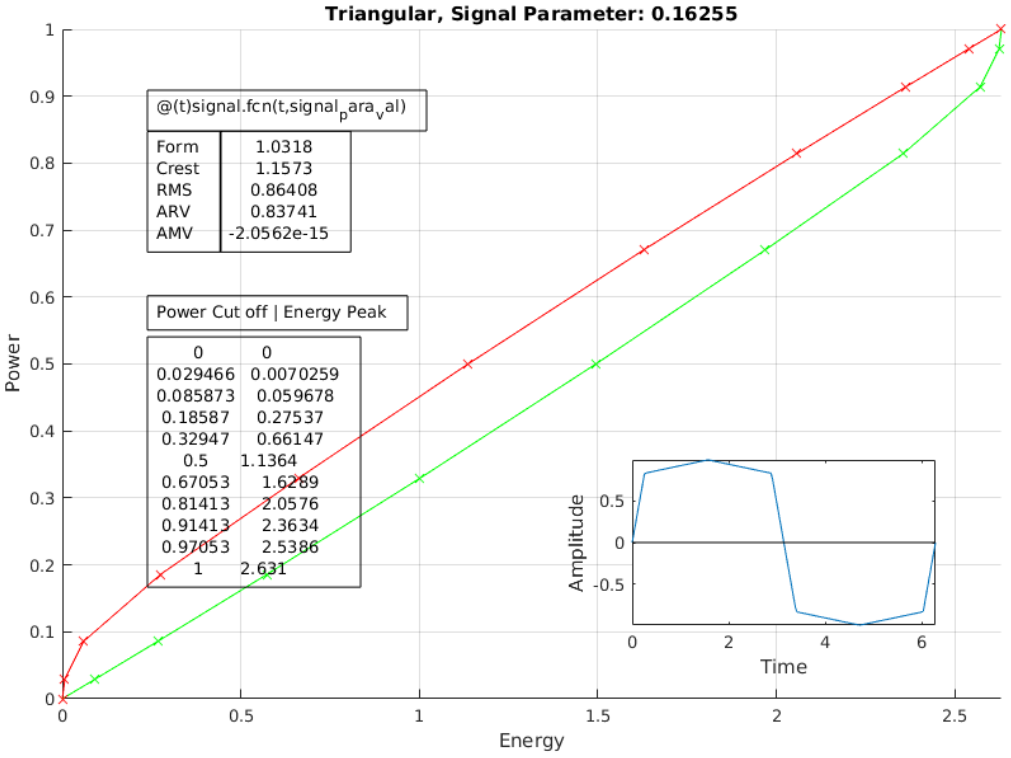
- Triangle shaped signal


Triangular, Signal Parameter: 0.9383
@(t)signal.fcn(t,signal_para_val)
Form 2.4506
Crest 6.5895
RMS 0.15176
ARV 0.061927
AMV -2.1286e-16
Power Cut off | Energy Peak
0 0
0.029466 8.9852e-05
0.085873 0.00076072
0.18587 0.0035689
0.32947 0.011213
0.5 0.025828
0.67053 0.046435
0.81413 0.068488
0.91413 0.086333
0.97053 0.12201
1 0.19381
Power
Energy
Amplitude
Time

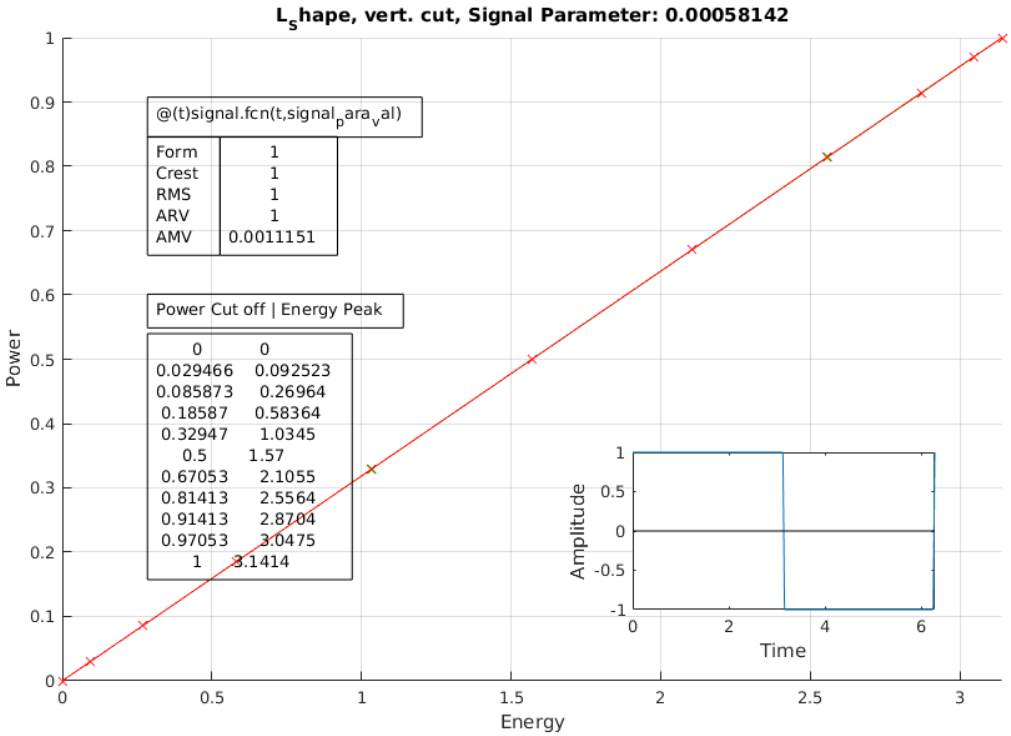
-

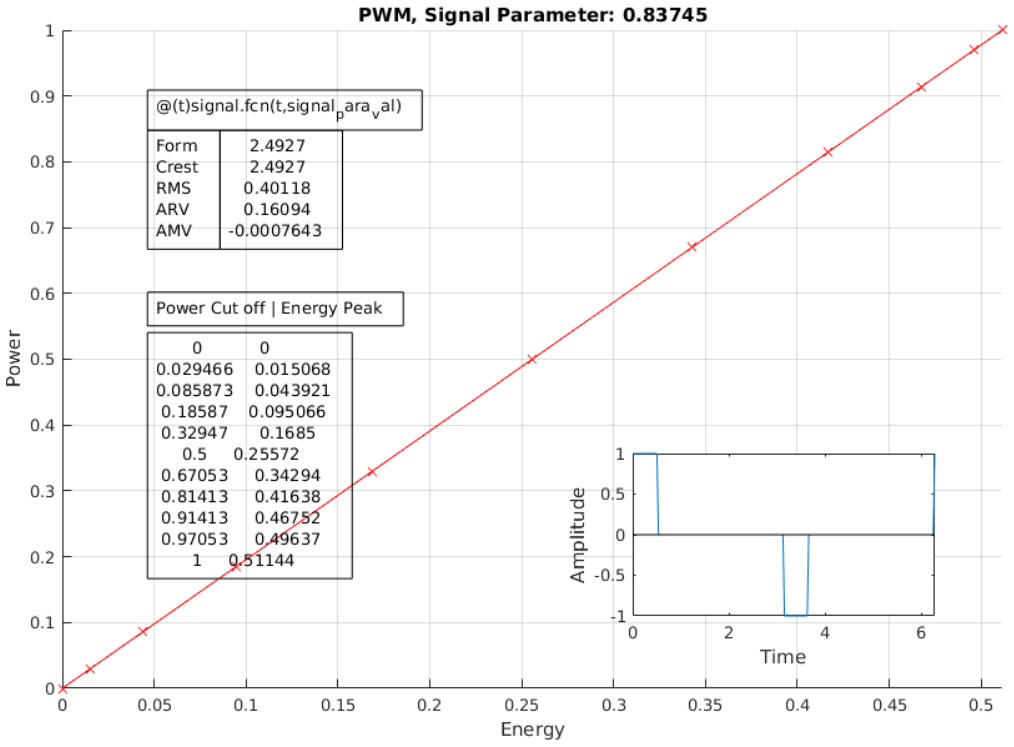

Triangular, Signal Parameter: 0.5
@(t)signal.fcn(t,signal_para_val)
Form 1.1547
Crest 1.7321
RMS 0.57735
ARV 0.5
AMV -1.3256e-15
Power Cut off | Energy Peak
0 0
0.029466 0.0013644
0.085873 0.011589
0.18587 0.054276
0.32947 0.17051
0.5 0.39271
0.67053 0.70626
0.81413 1.0411
0.91413 1.3126
0.97053 1.4796
1 1.5708
Power
Energy
Amplitude
Time

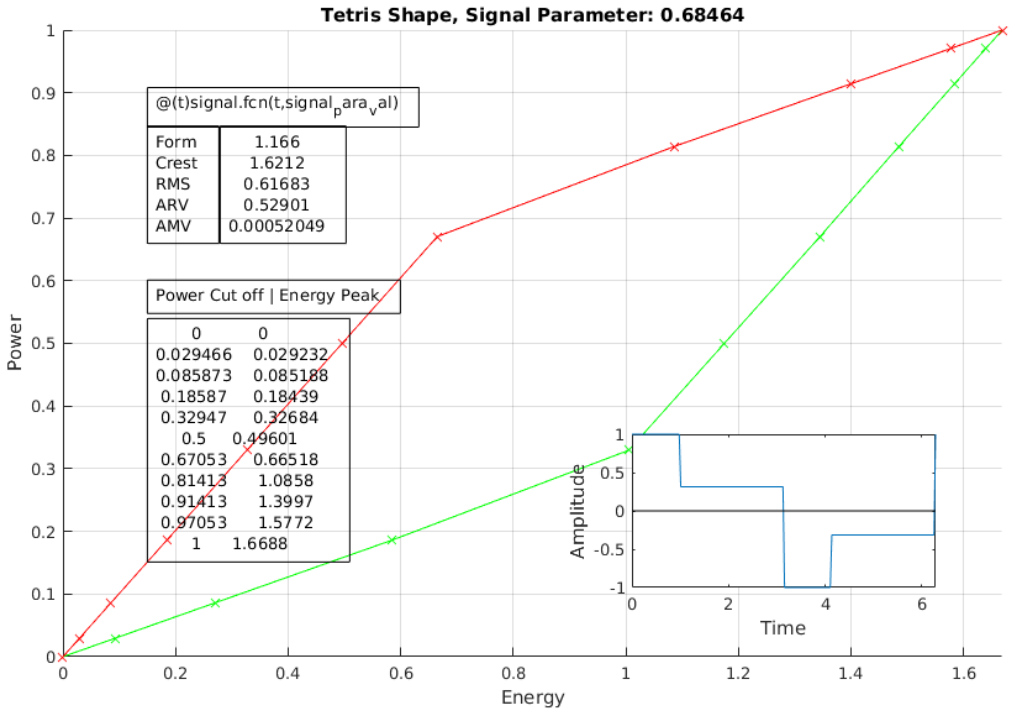
-



- Step-like, l-shaped, tetris-shaped, square, pwm functions




PWM, Signal Parameter: 0.83745
@(t)signal.fcn(t,signal_para_val)
Form 2.4927
Crest 2.4927
RMS 0.40118
ARV 0.16094
AMV -0.0007643
Power Cut off | Energy Peak
0 0
0.029466 0.015068
0.085873 0.043921
0.18587 0.095066
0.32947 0.1685
0.5 0.25572
0.67053 0.34294
0.81413 0.41638
0.91413 0.46752
0.97053 0.49637
1 0.51144
Power
Energy
Amplitude
Time

- 
Tetris Shape, Signal Parameter: 0.68464
@(t)signal.fcn(t,signal_para_val)
Form 1.166
Crest 1.6212
RMS 0.61683
ARV 0.52901
AMV 0.00052049
Power Cut off | Energy Peak
0 0
0.029466 0.029232
0.085873 0.085188
0.18587 0.18439
0.32947 0.32684
0.5 0.49601
0.67053 0.66518
0.81413 1.0858
0.91413 1.3997
0.97053 1.5772
1 1.6688
Power
Energy
Amplitude
Time

5 Data Fitting

5.1 Neccessary conditions

- Tested trail functions must fullfill: exact agreement at boundaries of leaf diagram (or transformed leaf diagram)
- (E,P) data was scaled to (1,1) and (0,0) at corners
- In best case: functions are not even defined outside this range

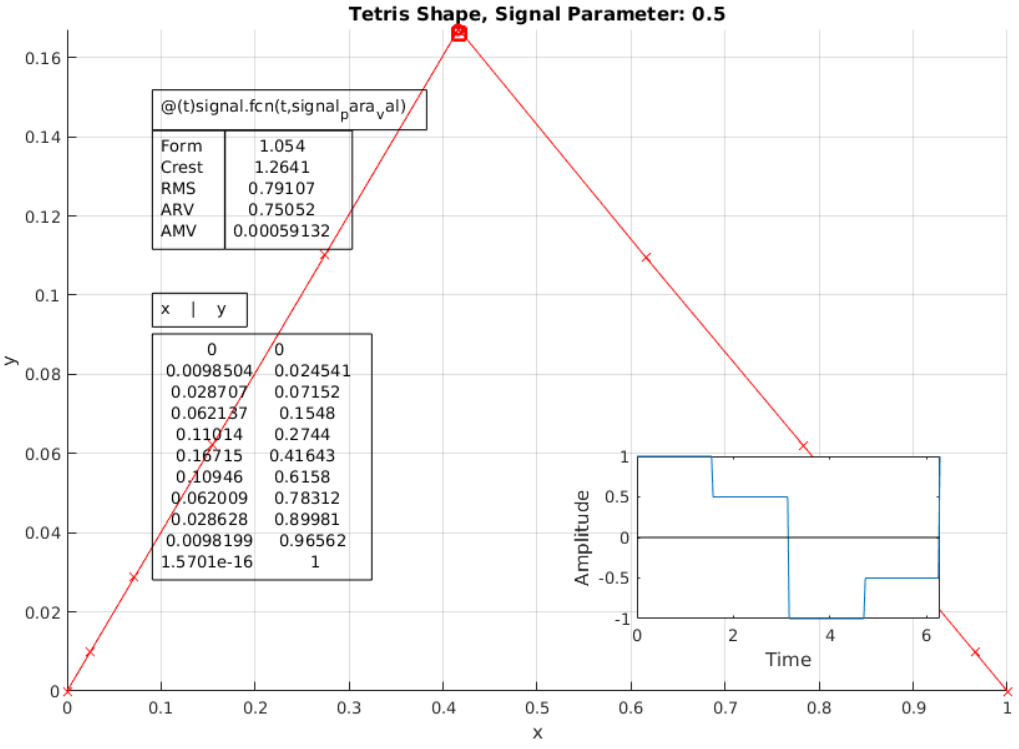
5.2 Eligible functions

- Trigonometric functions sin, cos, tan, asin, acos, atan
- Hyperbolic functions sinh, cosh, tanh and arcus fcns
- Exponential and logarithmic functions
- Polynomials, power and root functions

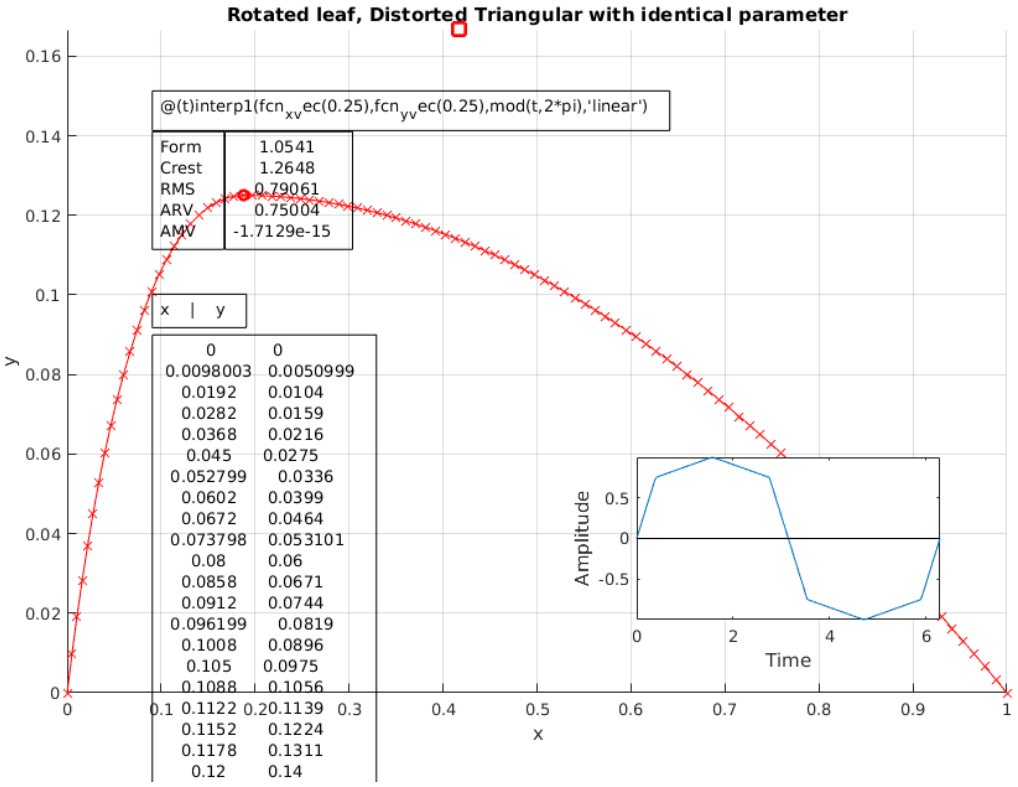
5.3 Fitting Attempts

- Untransformed coordinate system
  - Root Functions $\sqrt[n]{f(E,\pi)}$
  - Combined with Trigonometric $\sin^n(\frac{\pi}{2}E,\pi)$
  - Also satisfy limit F=1 (simple linear function) and F = infty (sqaure)
  - Polynomials do not fulfill boundary conditions in all circumstances
  - Within boundaries: non-removable deviations, function does not represent shape exactly
- 45 degree rotation, translation to mid, scale to (–1,1)
  - sin/cos shaped functions, sinh, cosh, stretched in between, nevertheless, no satisfying results
  - Limits: zero line if F/C = 1, Triangle when F/C = infty
- polar coordinates
  - last coordinate transformation was further transformed into polar coordinates
  - leaf ranges between -pi/2 and +pi/2
  - cosh-alike shape, but no formulation found to exactly meet data
  - Limits: for F/C = 1 cosh degenerates to 1 at boundaries and zero in between; for F/C = infty: 1 at boundaries and 0 deg, 0.71 at +-pi/4, cos-alike shape in between
- 45 degree rotation, bending curve approximation
  - Idea: shape looks after 45 deg rotation like a bending curve of a beam an asymmetric application of force

  - bending line is definied as two functions, left and right to application of force
  - Problem: peak of bending line is always between ca 0.4 to 0.6, independent of point of application of force, but the range of the leaf shape is larger – inadequate approximation
- analytical
  - observation: leaf degenerates to a diamond shape for l-shaped or step-like signals
  - idea: the maximum of this step can be derivated analytically and can be correlated analytically with Shape and crest factor
  - The following relationship can be found implicitly found: (C,F) |–> (E_peak, P_peak) |–> (x_max, y_max) |–> leaf shape which holds true for every signal with this distinct step
  - does not hold true for other signals, although results are of the same magnitude
- two signals with identical para but other leaf shape found:



-



-
- disproves theory that there is a simple relationship between (C,F) and leaf shape
- the first 3 approaches are not completely investigated and **may** be still adequate to describe the leaf shape, but a functional relationship was not found

6 Results

- The sum of e/p of two storages is always equal to e/p of the single storage
- the e/p ratio of each individual hybrid storage is for one higher, for the other one lower than the ratio of the single storage
- The spreading potential of the hybrid storage solution depends on the input signals
- Higher C, F values generally lead to more potential
- In its extremes, the leaf shape is a straight line or a square. Everything in between is possible.
- Base leaf and peak leaf a point symmetric and rotatable by 180 deg. around the mid point of the leaf (in normalized coordinates: around (0.5,0.5))
- The corresponding base/peak pairs can be found by rotation of a straight line around this mid point; a pair is a the two points of intersection
- The single functions of the leaf are strictly monotone
- Analytical formulation can be found for a class of signal shapes, but different classes have different shapes, while having identical signal parameters
- A sorted load profile should allow a functional relationship to generate the leaf shape

7 Open Questions, Not Analyzed

- Cascaded hybrid storages, leaf in leaf for more than two storages
- Thesis: Every Point/Pairs within leaf should be reachable, but this requires modified operation strategy. This strategy should be comparibly simple and dumb.
- The area within the curve could be a measurement for the spreading/hybridisation potential.
- Generation of leaf with a sorted load profile.
- Is leaf most practical visualisation or are there better representations
- Inter storage energy flow was not considered, proposed parameter
- Non symmetrical signals may make this energy flow neccessary
- Number of cycles of storages are not reduced with this operational strategy

8 Short Toolbox Description

- Function hybrid_leaf calls main and gathers complete calculation
  - call: result = hybrid_leaf(input_signal)
  - in: struct with
    - fcn: function handle of signal
    - period: period of signal
    - amplitude: amplitude of signal
  - out: struct with
    - single: struct with single storage parameters (energy, power)
    - hybrid_table: leaf shape with cut_off_power | energy base | energy peak | power base | power peak columns
    - transformed: as hybrid_table, but with rotated and scaled data
    - parameter: form, crest, rms, arv, amv
    - peak: (x,y) max in transformed data
    - theo_peak: theoretically calculated peak
- Visualize results with plot_leaf or plot_transformed
- Most samples in `sample/` executable w/o arguments

9 Development History/Git Log Summary

- Simple numerical calculation for single storage
- Simple numerical calculation for hybrid storage, based on single storage
- Simple plotting functionality
- First leaf investigation, failed fitting them w/o coord transformation in cli
- Bending Line Approximation (w/45 deg rotation), and polar transformation in cli
- Refactored sequential programming to modular functions
- Pretty Output w/additional info
- Parametric Study w/Triangular fcns
- Parametric Study for other functions: tetris, l-shape, distorted sin, pwm
- High resultion study
- Automated coord transformation + peak finding interpolated
- Study of diamond shaped leafs (l-shape input fcns)
- Simple automated processing script to analyze shape, crest functional behaviour
- Analytical calculation for l-shape

10 Project Folder Tree

```
.
|-- docs
|   |-- beginning.tex
|   |-- hybrid_leaf.md
|   |-- quickstart.md
|   |-- scientific
|   |-- scientific.md
|   |-- scientific.pdf
|   `-- scientific.tex
|-- hybrid_leaf.m
|-- LICENSE
|-- log160926
|-- project
|   |-- add_theo_peak.m
|   |-- auxiliary
|   |-- calc_hybrid_storage.m
|   |-- calc_single_storage.m
|   |-- coord_trans_result.m
|   |-- main.m
|   |-- plot_leaf.m
|   |-- plot_transformed.m
|   |-- signal_parameters.m
|   `-- transform_and_peak.m
|-- README.md
|-- REQUIREMENTS.md
|-- sample [17 entries exceeds filelimit, not opening dir]
|-- scihtml.html
|-- test
|   `-- test_main.m
|-- test_hybrid_leaf.m
`-- todo.md

6 directories, 24 files
```