

Locust tutorial workshop

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Overview of tutorial

- Brief intro to Locust
- Compiled examples:
 - Test signal.
 - Plane wave.
 - Transmitting antenna.
 - Electron radiating in free space.
 - Generating a Kassiopeia magnetic field map.
 - Free space detection with Project 8 hexbug config files.
 - Reconstructing electron signal with beam forming in Katydid.
 - Cluster jobs as simple example scripts.
- Extra slides: Parameter definitions and troubleshooting.

Note: While these examples require access to config files specific to Project 8, they do not contain any new Locust functionality.



What is Locust?

- Originally it was an RF receiver and digitizer simulation*.
- Next it was expanded to calculate radiative fields from moving electrons**.
- Now it can also model the response of an antenna to incident fields**.
- It is modular and flexible, and is compiled with the Kassiopeia*** particle tracking package.

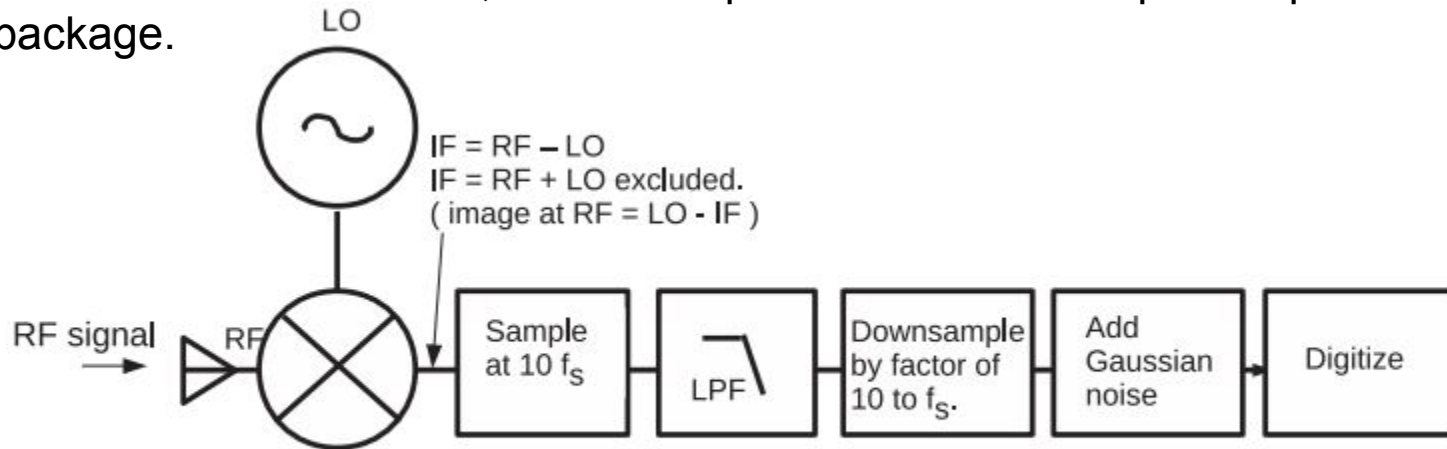


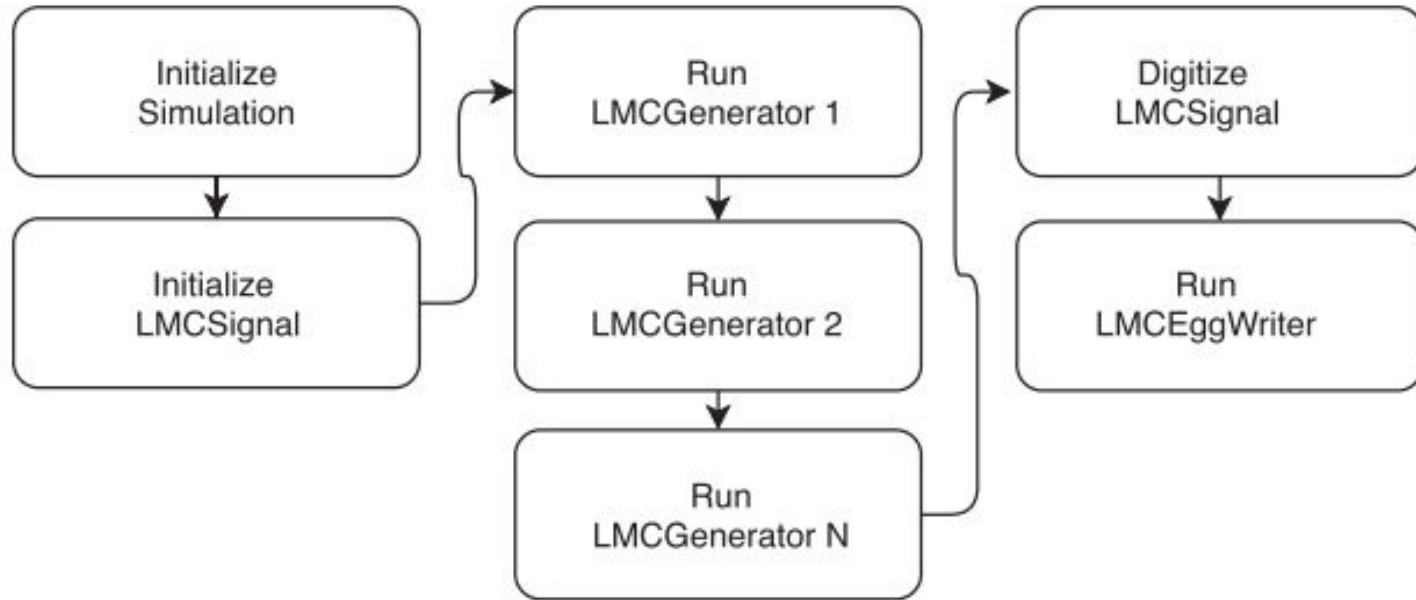
Figure 2. Block diagram of a receiver implemented algorithmically in Locust. Each of the square blocks represents one generator as in figure 1.

*Project 8 collaboration, New J. Phys. 21 (2019) 113051

**https://github.com/project8/locust_mc.git

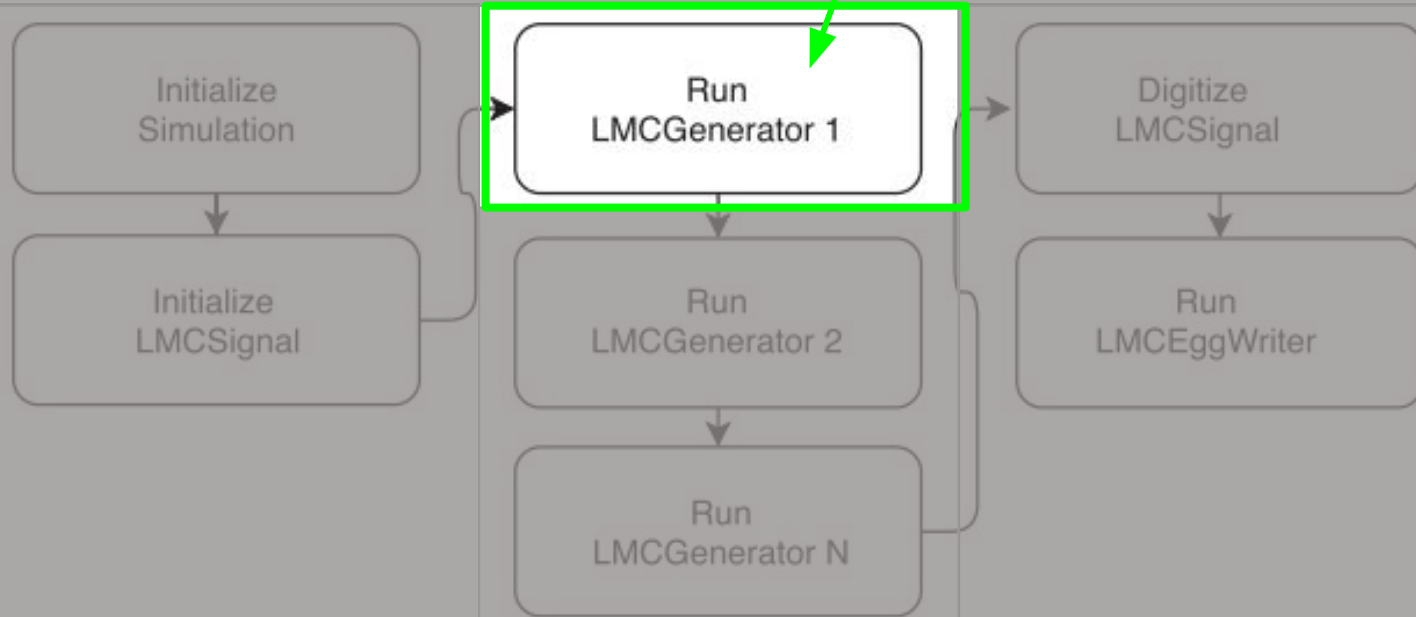
***Furse D et al 2017 New J. Phys. 19 053012

Locust work flow diagram

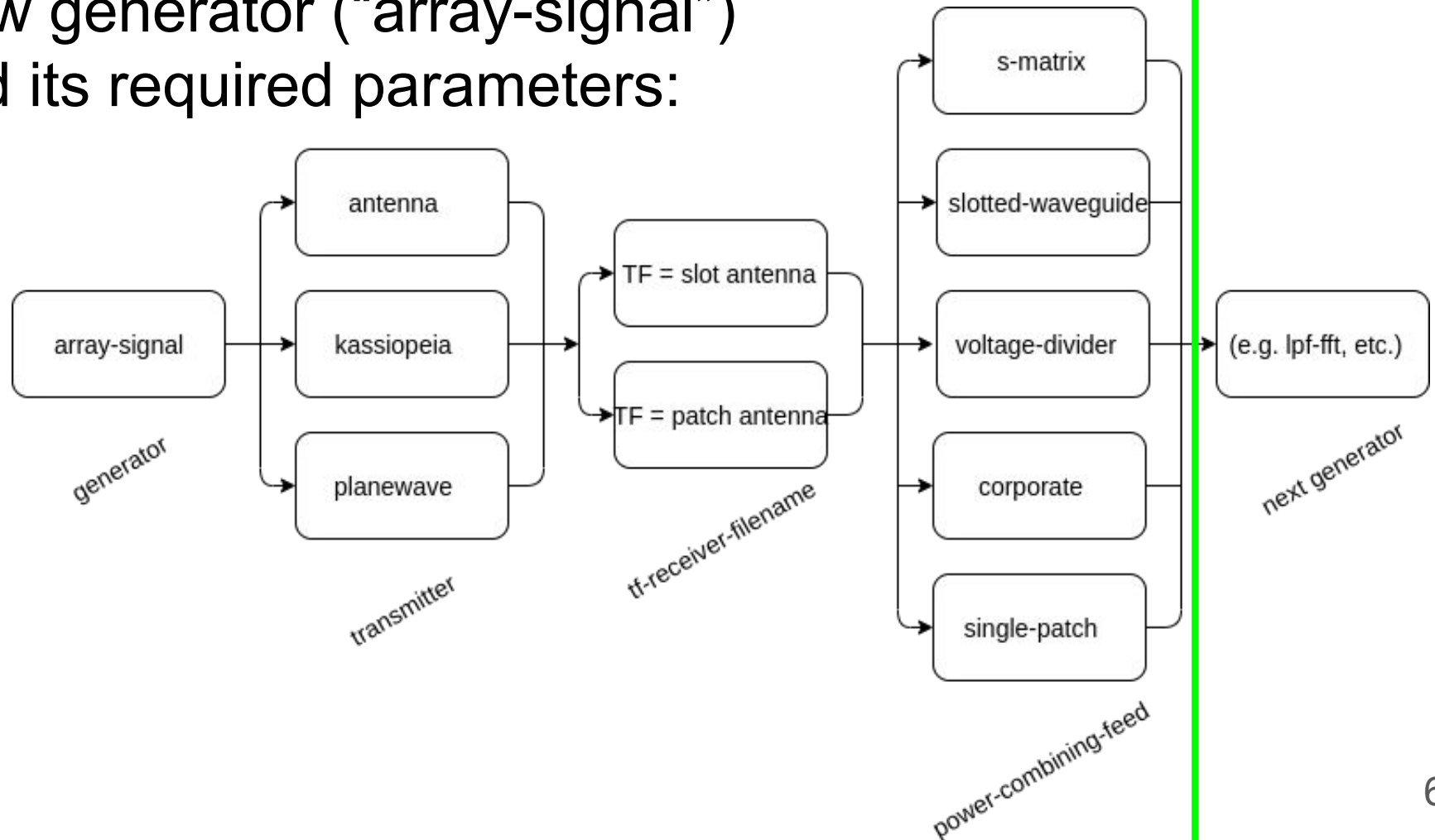


Locust work flow diagram

New functionality has been added here for antenna modeling



New generator (“array-signal”) and its required parameters:



Basic Locust json file: List of generators to be run, followed by parameter definitions

```
{
  "generators":
  [
    "test-signal",
    "lpf-fft",
    "decimate-signal",
    "digitizer"
  ],
  "test-signal":
  {
    "rf-frequency": 20.7e9,
    "lo-frequency": 20.65e9,
    "amplitude": 5.0e-8
  },
  "simulation":
  {
    "egg-filename": "/usr/local/p8/locust/v2.1.1/output/locust_mc.egg",
    "n-records": 1,
    "n-channels": 1,
    "record-size": 8192
  },
  "gaussian-noise":
  {
    "noise-floor-psd": 4.0e-22,
    "domain": "time"
  },
  "digitizer":
  {
    "v-range": 8.0e-6,
    "v-offset": -4.0e-6
  }
}
```

Generator 1: Selected by application.

Generators 2+: Receiver chain

Examples

First, some steps for setting up

Before we start the examples:

1. Install docker as in <https://docs.docker.com/get-docker>.
2. `sudo docker pull project8/p8compute`
3. `sudo docker pull project8/p8compute-jupyter`
4. Create a directory in your home directory, called ~/p8tutorial:
`mkdir ~/p8tutorial`
5. Start p8compute-jupyter and leave it open for the duration of the workshop:
`docker run -p 8888:8888 -v ~/p8tutorial:/tmp
project8/p8compute-jupyter`
6. Open a browser tab using one of the links provided in the resulting terminal output.

First, some steps for setting up (cont.)

7. In the ~/p8tutorial directory, clone the hexbug and locust-tutorial repos:

```
cd ~/p8tutorial
```

```
git clone git@github.com:project8/hexbug
```

```
git clone git@github.com:project8/locust-tutorial
```

8. cd into to ~/p8tutorial/locust-tutorial/scripts:

```
cd ~/p8tutorial/locust-tutorial/scripts
```

9. Open tutorialLocustscript.sh and tutorialKatydidscript.sh with a text editor. Check that the

Example #1: Locust test signal

- Drive 50 ohm antenna with a sinusoid in LMCTestSignalGenerator:
 - (uncomment the command below #Example 1 in tutorialLocustscript.sh, then):
`./tutorialLocustscript.sh`
 - (or interactively, in container):
`LocustSim config=/path/to/config/LocustTestSignal.json`
 - **Process egg file with** `./tutorialKatydidscript.sh`

"test-signal":

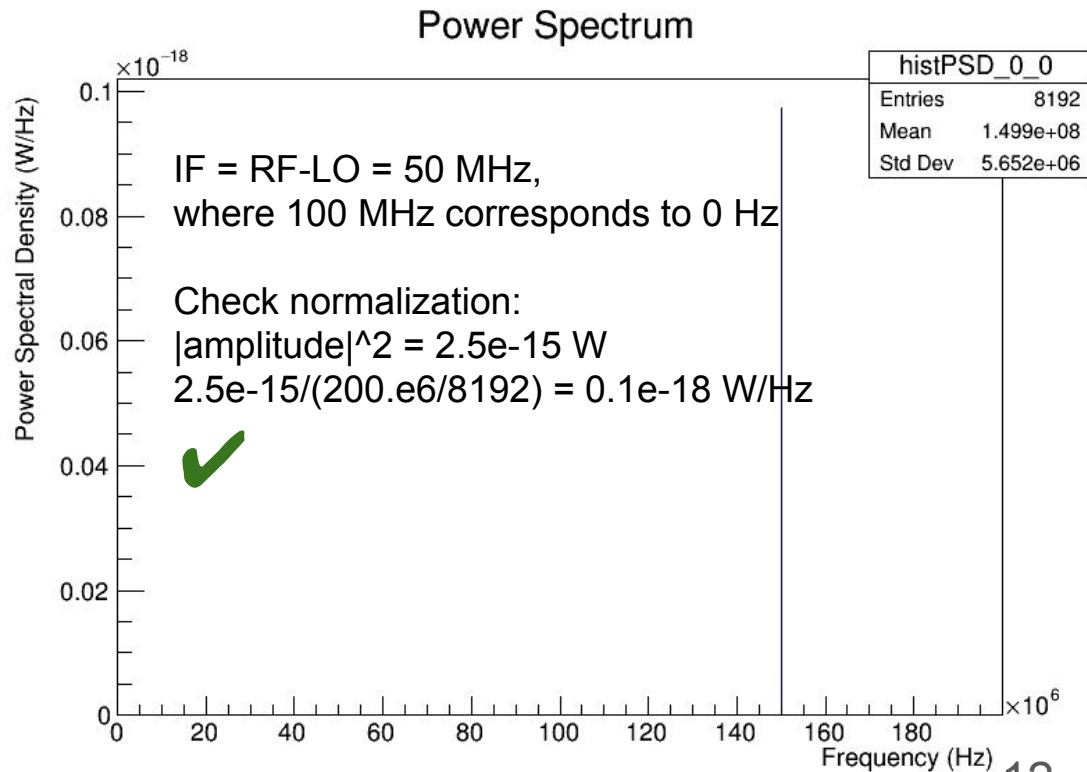
```
{  
  "rf-frequency": 20.7e9,  
  "lo-frequency": 20.65e9,  
  "amplitude": 5.0e-8  
}
```



This is in LocustTestSignal.json

Example #1: Locust test signal, cont.

- In the jupyter browser tab, navigate with single clicks to `/tmp/locust-tutorial/scripts/plotting/Plot PSD.ipynb`
- Click the ►►, then click “Restart and run all cells”.
- This plot should appear -> .



Example #2: Locust plane wave

- Drive 6 patches combined in a passive voltage combiner in LMCPlaneWaveSignalGenerator:
 - (uncomment the command below #Example 2 in tutorialLocustscript.sh, then):
`./tutorialLocustscript.sh`
 - (or interactively, in container):
`LocustSim config=/path/to/config/LocustPlaneWaveTemplate.json`
 - **Process egg file with** `./tutorialKatydidscript.sh`

"array-signal":

{

"transmitter": "planewave",

"transmitter-frequency": 25.9281e9,

"planewave-amplitude": 1.0e-8,

"AOI": 0.0, **verbose**

"voltage-check": **true**,

"lo-frequency": 25.8781e9,

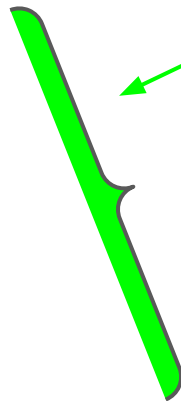
"nelements-per-strip": 6,

"element-spacing": 0.007753,

"power-combining-feed": "voltage-divider",

"tf-receiver-filename": "/usr/local/p8/locust/v2.1.1/data/PatchTFLocust.txt",

"tf-receiver-bin-width": 0.01e9



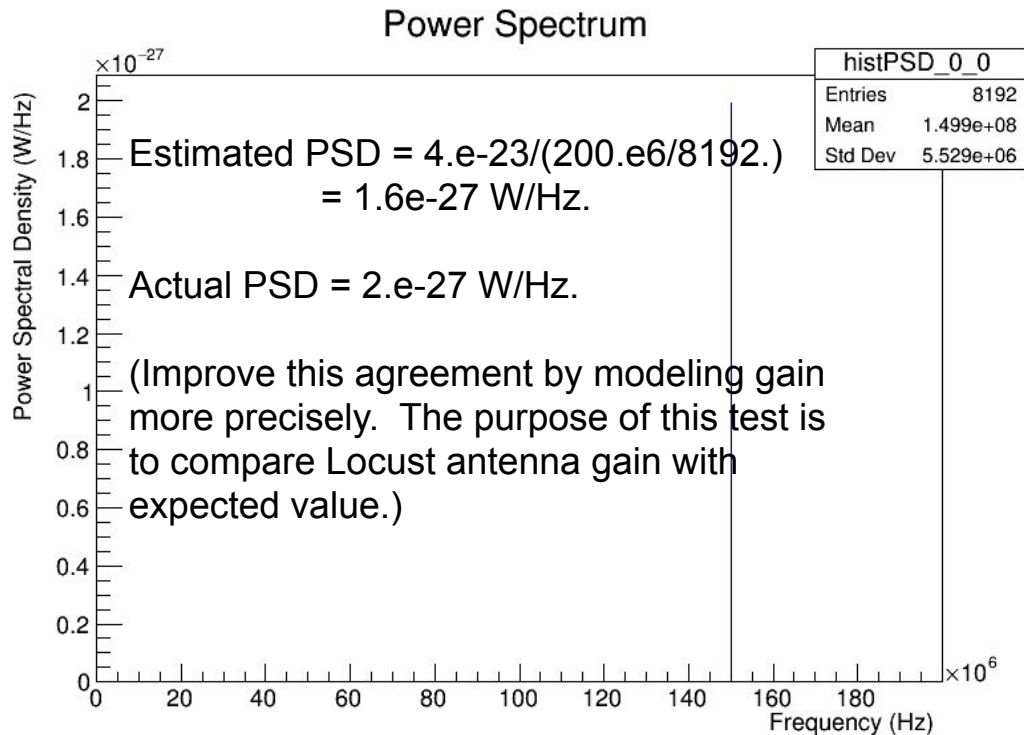
This is in

LocustPlaneWaveTemplate.json

**transfer
function**

Example #2: Locust plane wave, cont.

- In the jupyter browser tab, navigate to /tmp/locust-tutorial/scripts/plotting/Plot PSD.ipynb
- Click the ►►, then click “Restart and run all cells”. See this plot. ->
- Check calibration:
 - Estimate $G = 10$ dB for 6-patch voltage divider.
 - Effective aperture A_e for 6-patch voltage divider = $1.5e-4$ m².
 - Power S in plane wave: $c\epsilon_0|E|^2 = 2.7e-19$ W/m²; power incident on antenna strip $S \cdot A = 4.e-23$ W



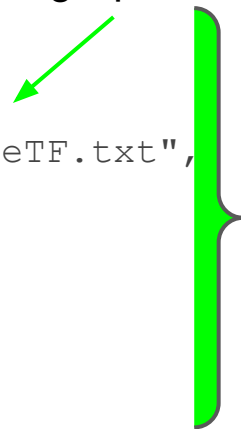
Example #3: Dipole antenna transmitter

- Drive single patch in LMCAntennaSignalGenerator:
 - (uncomment the command below #Example 3 in tutorialLocustscript.sh, then):
`./tutorialLocustscript.sh`
 - (or interactively, in container):
`LocustSim`
`config=/path/to/config/LocustMagDipoleAntennaTemplate.json`
 - **Process egg file with** `./tutorialKatydidscript.sh`

```
"array-signal":
```

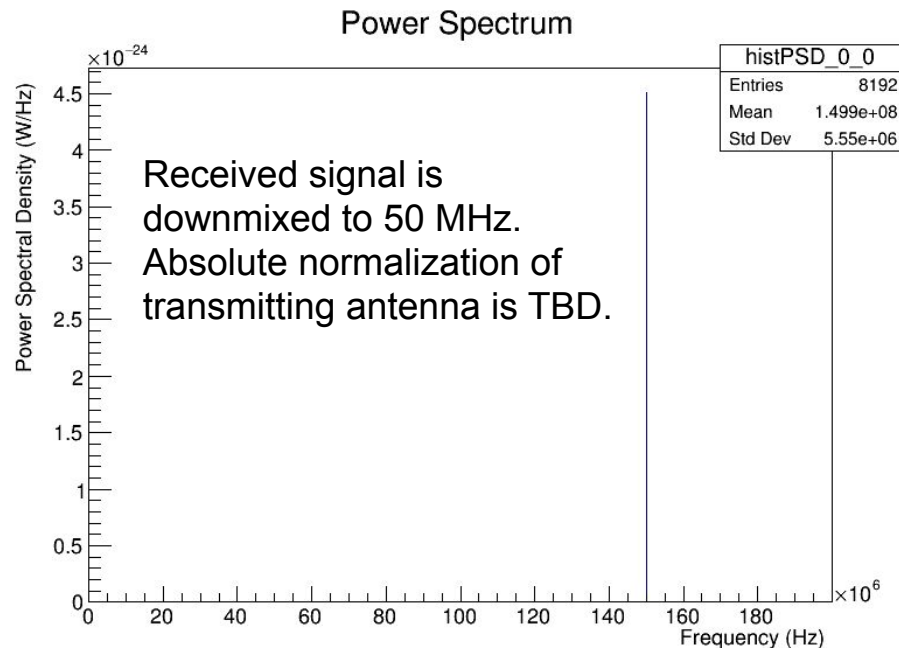
```
{  
  "transmitter": "antenna",  
  "transmitter-frequency": 25.9281e9,  
  "antenna-voltage-amplitude": 1.0,  
  "tf-transmitter-filename":  
"/usr/local/p8/locust/v2.1.2/data/UncoupledHalfWaveDipoleTF.txt",  
  "voltage-check": true,  
  "lo-frequency": 25.8781e9,  
  "array-radius": 0.05,  
  "nelements-per-strip": 1,  
  "power-combining-feed": "single-patch",  
  "tf-receiver-filename":
```

This is in
LocustMagDipoleAntennaTemplate.json



Example #3: Dipole antenna transmitter, cont.

- In the jupyter browser tab, navigate to `/tmp/locust-tutorial/scripts/plotting/PlotPSD.ipynb`
- Click the ►►, then click “Restart and run all cells”. See this plot. ->



Example #4: Locust-Kass electrons in free space

- Drive voltage divider with 3 sequential Kassiopeia electrons in LMCArraySignalGenerator:
 - (uncomment the command below #Example 4 in tutorialLocustscript.sh, then):
./tutorialLocustscript.sh
 - (or interactively, in container):
LocustSim config=/path/to/config/LocustFreeSpaceTemplate.json
 - Process egg file with ./tutorialKatydidscript.sh

```
"array-signal":  
  {  
    "transmitter": "kassiopeia",  
    "event-spacing-samples": 15000,  
    "lo-frequency": 25.8781e9, (fast, 10x) samples  
    "array-radius": 0.05,      between Kass  
    "nelements-per-strip": 6,  events.  
    "element-spacing": 0.007753,  
    "power-combining-feed": "voltage-divider",  
    "tf-receiver-filename": "/usr/local/p8/locust/v2.1.1//data/PatchTFLocust.txt",  
    "tf-receiver-bin-width": 0.01e9,  
    "Xml-filename":  
      "/usr/local/p8/locust/v2.1.1/config/ LocustKass_FreeSpace_Template.xml "  
  },
```

This is in LMCFreeSpaceTemplate.json.

Kassiopeia config file, next slide

Example #4: Locust-Kass free space electrons, cont.

<ks_simulation

name="project8_simulation"

run="1"

seed="[seed]"

events="3" 3 sequential e-'s will be generated

magnetic_field="field_electromagnet"

magnetic_field="field_magnetic_main"

space="space_world"

generator="[generator]"

"generator" defines e- starting kinematics.

trajectory="[trajectory]"

"trajectory" solves time-dependent motion.

space_navigator="nav_space"

surface_navigator="nav_surface"

writer="write_root"

add_static_run_modifier="run_pause"

Locust modifications

add_static_event_modifier="event_hold"

add_static_step_modifier="rad_extr"

/>

In LocustKass_FreeSpace_Template.xml,
<ks_simulation/> defines simulation with
parameters defined elsewhere in file.

Example #4: Locust-Kass free space electrons, cont.

Also in LocustKass_FreeSpace_Template.xml:

```
<ksterm_max_time name="term_max_time" time="1.0e-6"/>
```

electron max duration (sec)

```
<geometry>
```

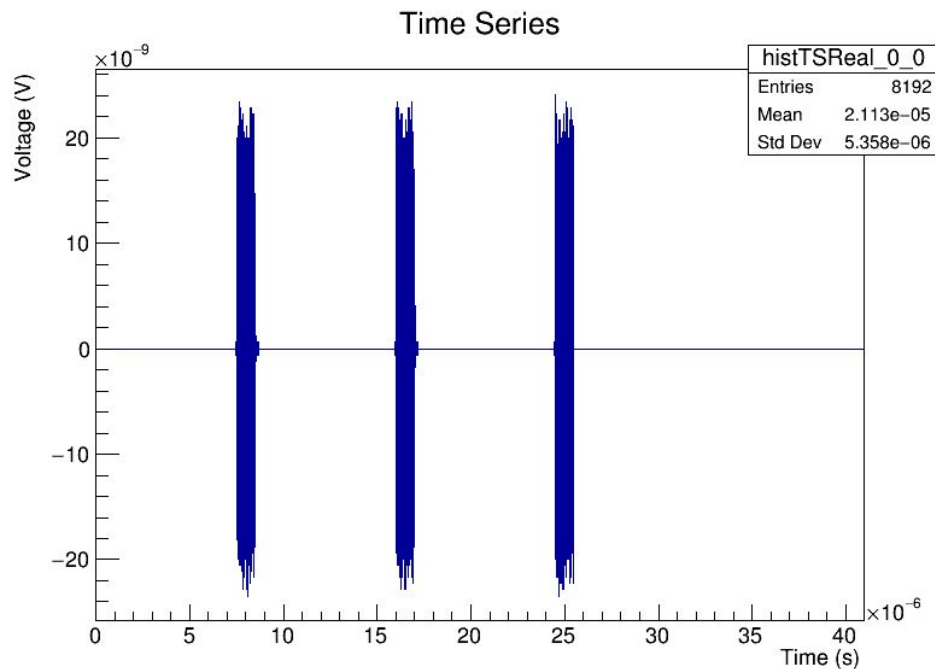
```
  <include name="[config_path]/FreeSpaceGeometry.xml"/>
```

```
</geometry>
```

Trap geometry file

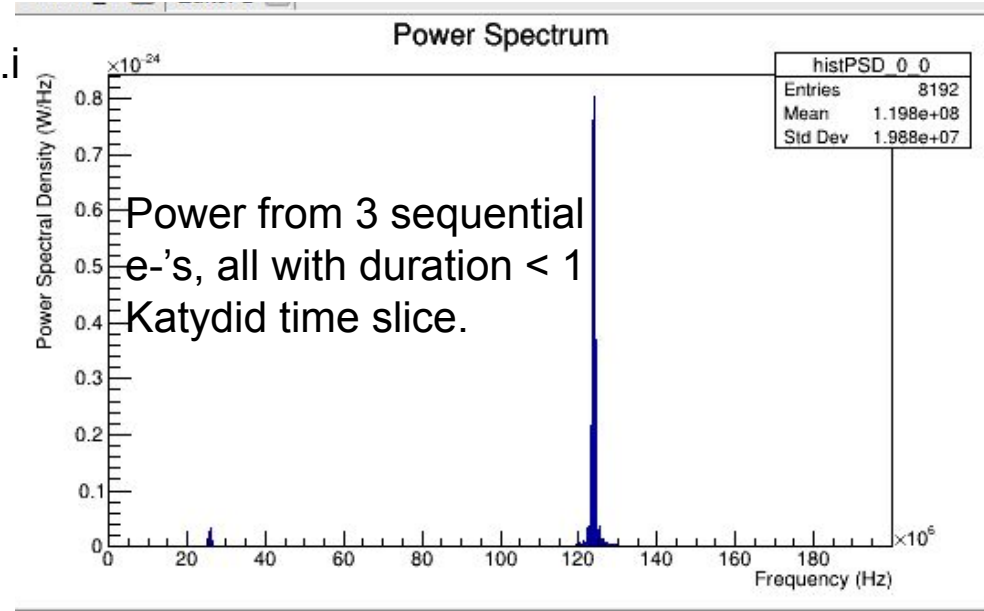
Example #4: Locust-Kass free space electrons, cont.

- In the jupyter browser tab, navigate to `/tmp/locust-tutorial/scripts/plotting/PlotTimeSeries.ipynb`
- Click the ►►, then click “Restart and run all cells”. See this plot. ->
- We see signals from 3 electrons spaced at 15000 fast samples (e.g. 2 GHz or 10x acq-rate), each with duration 1.e-6 s.



Example #4: Locust-Kass free space electrons, cont.

- In the jupyter browser tab, navigate to `/tmp/locust-tutorial/scripts/plotting/PlotPSD.ipynb`
- Click the ►►, then click “Restart and run all cells”. See this plot. ->
- Power from 3 identical $\theta=90^\circ$ electrons in one Katydid time slice. Carrier at 23 MHz; Sideband at -75 MHz.



Example #5: Generate Kassiopeia field map

- Without Locust, use Kassiopeia to measure B field values along field lines.
 - (uncomment the command below #Example 5 in tutorialLocustscript.sh, then):
`./tutorialLocustscript.sh`
 - (or interactively, in container):
`/path/to/LMCKassiopeia /path/to/config/JustKassFieldMap.xml`
 - Output is Root TTree file `~/p8tutorial/locust-tutorial/output/FieldLineSeed*.root`. Plot TTree variables e.g. `position_z` vs. `magnetic_field_z` for field map.

```
<external_define name="generator" value="gen_bfieldlines" />
                                     specialized generator
<geometry>
  <include name="[config_path]/FreeSpaceGeometry.xml"/>
                                     Trap geometry
</geometry>
```

Lines in
JustKassFieldMap.xml

Example #6A: hexbug config files

- Drive 5-slot slotted waveguide antenna with 3 sequential Kassiopeia electrons in LMCArraySignalGenerator:
 - (uncomment the command below #Example 6 in tutorialLocustscript.sh, then):
./tutorialLocustscript.sh
 - (or interactively, in container):
LocustSim config=/tmp/hexbug/Phase3/LocustPhase3Template.json
 - **Process egg file with ./tutorialKatydidscript.sh**

```
"array-signal":
```

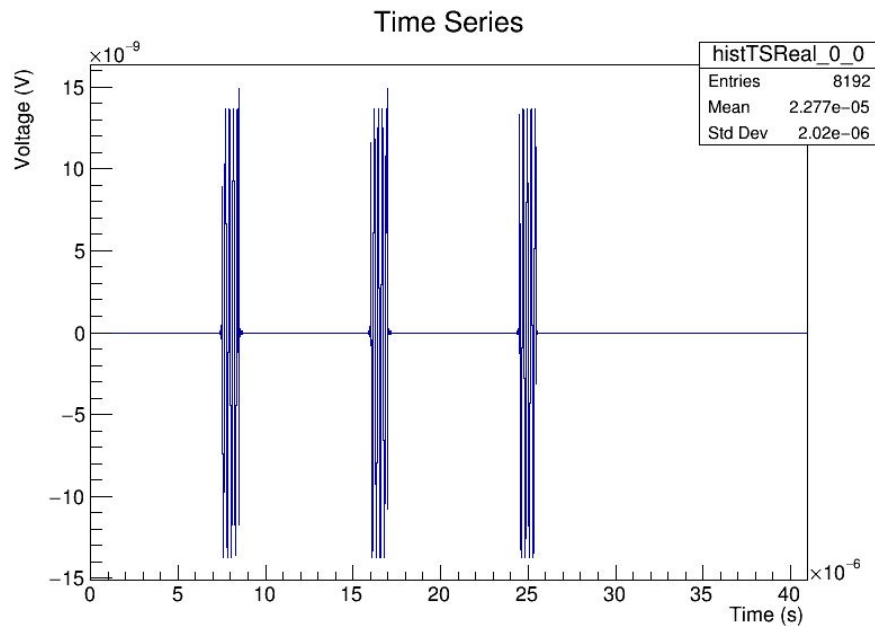
```
{  
  "transmitter": "kassiopeia",  
  "event-spacing-samples": 15000,  
  "lo-frequency": 25.8781e9,  
  "array-radius": 0.1,  
  "nelements-per-strip": 5,  
  "element-spacing": 0.007753,  
  "power-combining-feed": "slotted-waveguide",  
  "tf-receiver-filename":  
"/tmp/hexbug/Phase3/TransferFunctions/FiveSlotTF.txt",  
  "tf-receiver-bin-width": 0.01e9,  
  "xml-filename": "/tmp/hexbug/Phase3/LocustKassElectrons.xml"
```

Trap and transfer function are
P8-specific.



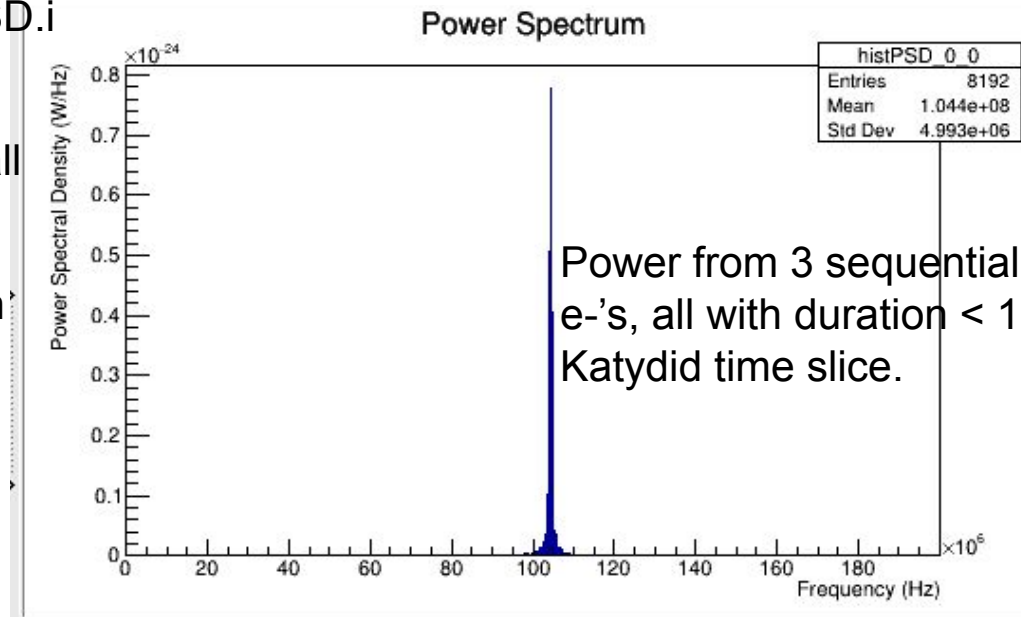
Example #6A: hexbug config files, cont.

- In the jupyter browser tab, navigate to `/tmp/locust-tutorial/scripts/plotting/PlotTime Series.ipynb`
- Click the ►►, then click “Restart and run all cells”. See this plot. ->
- We see signals from 3 electrons spaced at 15000 fast samples (e.g. 2 GHz or 10x acq-rate), each with duration 1.e-6 s.



Example #6A: hexbug config files, cont.

- In the jupyter browser tab, navigate to `/tmp/locust-tutorial/scripts/plotting/PlotPSD.ipynb`
- Click the ►►, then click “Restart and run all cells”. See this plot. ->
- Power from 3 identical $\theta=90^\circ$ electrons in one Katydid time slice. Carrier at 5 MHz.



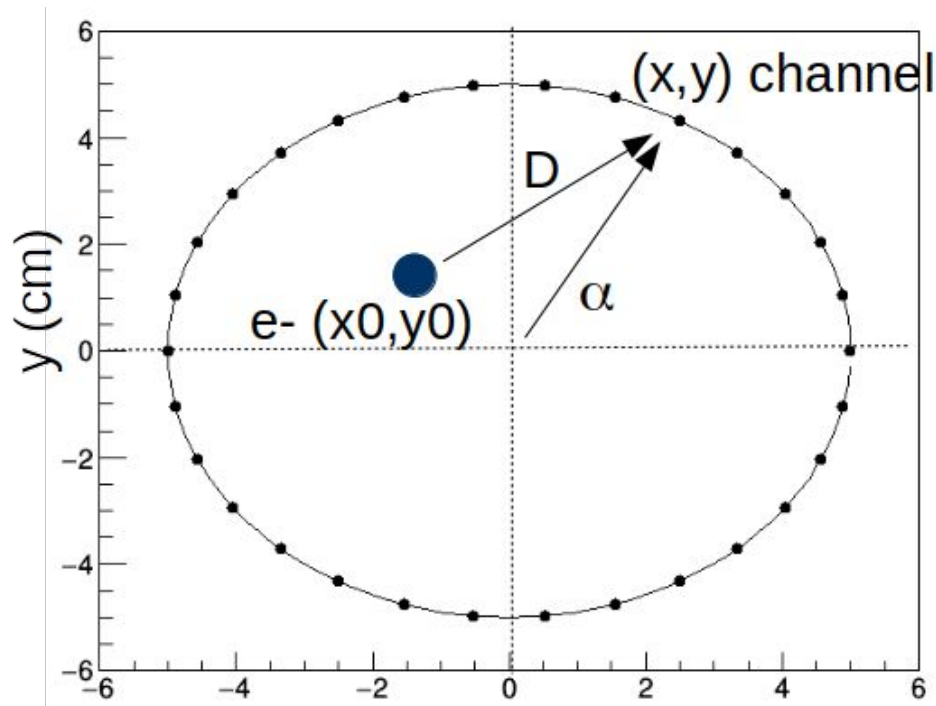
Example #6B: sim->analysis chain with hexbug configs

Let's do a slightly longer run, with 4 channels, and then reconstruct the signal in Katydid. The Locust run should take 10 minutes.


1. Open `~/p8tutorial/hexbug/Phase3/LocustPhase3Template.json` for editing.
 - a. Delete this: `"event-spacing-samples": 15000`, (this defaults to 150000, which makes the event start at the end of time slice #1 if slice size = 8192.
 - b. Change n-channels to 4, like this: `"n-channels": 4`
2. Open `~/p8tutorial/hexbug/Phase3/LocustKassElectrons.xml` for editing.
 - a. Increase max_time to 0.5e-4 s, like this: `"term_max_time" time="0.5e-4"/>`
 - b. Change n-events to 1, like this: `events="1"`
 - c. Change the pitch angle to 87°, also under “gen_uniform”:
`<theta_uniform value_min="87.0" value_max="87.0"/>`
3. In `tutorialKatydidscript.sh`, uncomment the 2nd Katydid command that starts like this:
`Katydid -c ${katydiddir}/config/ChannelAggregatorConfig.yaml ...`
4. Run the scripts: `./tutorialLocustscript.sh && ./tutorialKatydidscript.sh`

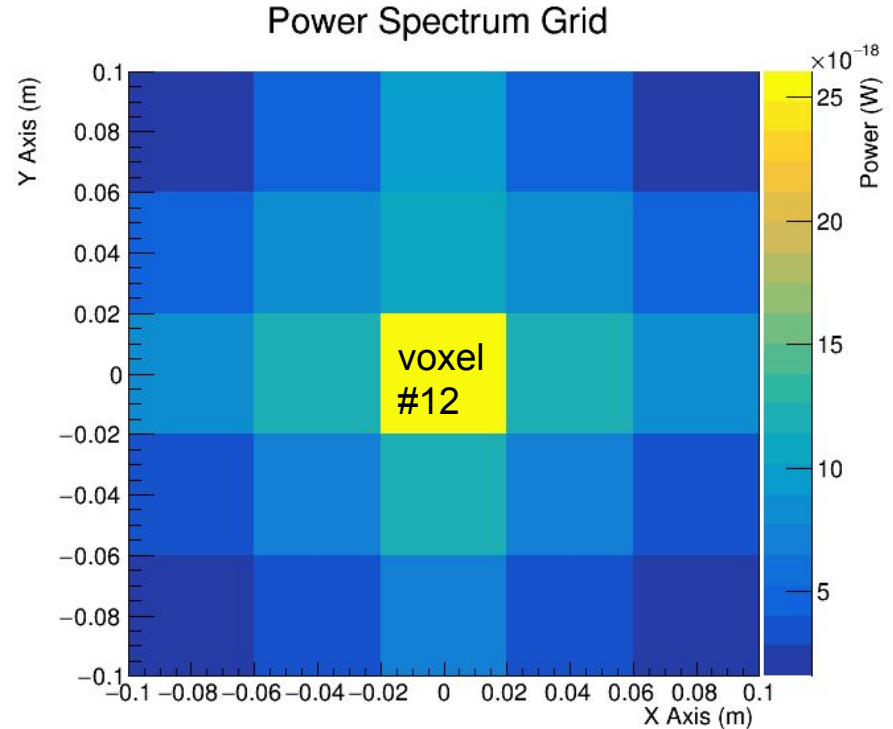
Beam forming signal extraction after Locust

- Steps to reconstruct signal:
 - Complex FFT in each channel.
 - Rotate voltage phase $\text{atan}(Q/I)$ in each channel for each grid voxel in xy .
 - Sum complex phase-sensitive voltages over all channels.
 - Convert voltage sum to PSD.
 - Grid voxels associated with high array power may have an e^- .
- A possible problem:
 - “High array power” can be caused by a powerful sideband at $f \neq f_{\text{cyc}}$.
 - This can complicate spectroscopy.



Example #6B: sim->analysis chain with hexbug, cont.

- In the jupyter browser tab, navigate to /tmp/locust-tutorial/scripts/plotting/PlotGrid.ipynb. Click the ►►, See this plot. ->
 - Highest power feature: Power_max = $26 \cdot 10^{-18}$ W.
-  **To infer absolute detected power, we have to infer ideal power combining between the e.g. N=4 channels, and we should scale Power_max by $1/N=1/4$. **.**
- (If simulating noise with signal, SNR will be correct with or without the above scaling.)

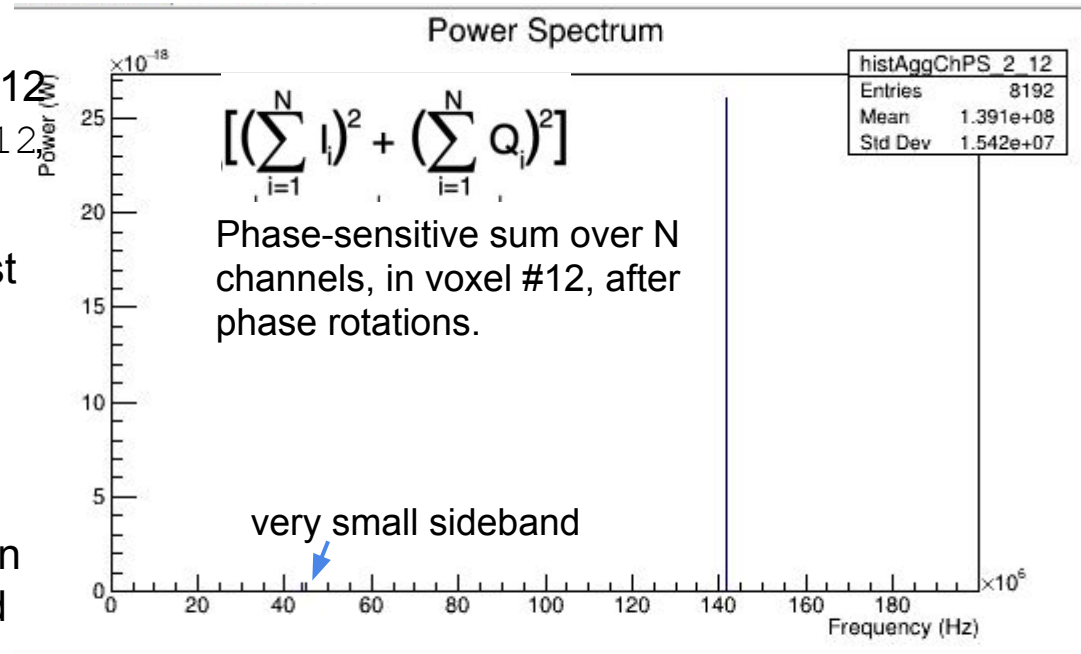


*M. Grando and M. Jones, <https://3.basecamp.com/3700981/buckets/3107037/uploads/2956124063>,

*N. Buzinsky, private conversations.

Example #6B: sim->analysis chain with hexbug cont.

- Each voxel in the grid corresponds to the maximum power in a frequency spectrum, after a set of N voltage phase rotations.
- In `PlotGrid.ipynb` we see pixel #12 in time slice 2 as `histAggChPS_2_12` here ->
- Line (carrier or sideband) with highest power defines voxel power in grid. Here the carrier is highest; reconstruction straightforward (w/o θ correction) ->
- If sideband powers were highest, then grid voxels would represent sideband powers -> potentially hard to find carrier, but with θ constrained.



Example #6C: Systematic effects (line broadening)

Now try moving the electron off axis:

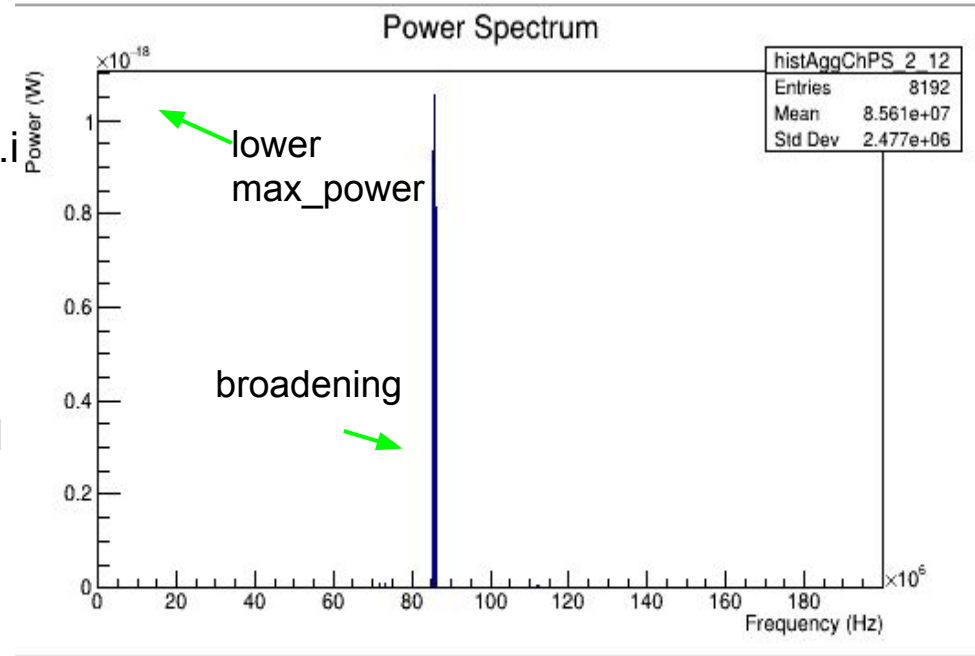
1. Open ~/p8tutorial/hexbug/Phase3/LocustKassElectrons.xml for editing. Move starting position to $(x,y) = (0.01, 0.01)$ m:

```
<x_uniform value_min="0.01" value_max="0.01"/>  
<y_uniform value_min="0.01" value_max="0.01"/>
```

2. Run the scripts: `./tutorialLocustscript.sh && ./tutorialKatydidscript.sh`

Example #6C: Systematic effects (line broadening, cont.)

- In the jupyter browser tab, navigate to /tmp/locust-tutorial/scripts/plotting/PlotGrid.ipynb. Click the ►►, See this plot. ->
- Notice the broadening over cyclotron orbit due to radial gradient in B.
- Also notice the peak power has decreased -> lost SNR. Try to avoid this problem.



Example #6D: Systematic effects (sidebands)

Now let's change to a different (non-harmonic) trap. (For a list of trap names and properties, see the hexbug README):

1. Open `~/p8tutorial/hexbug/Phase3/LocustKassElectrons.xml` for editing. Change starting position back to $(x,y) = (0,0)$:

```
<x_uniform value_min="0.0" value_max="0.0"/>
```

```
<y_uniform value_min="0.0" value_max="0.0"/>
```

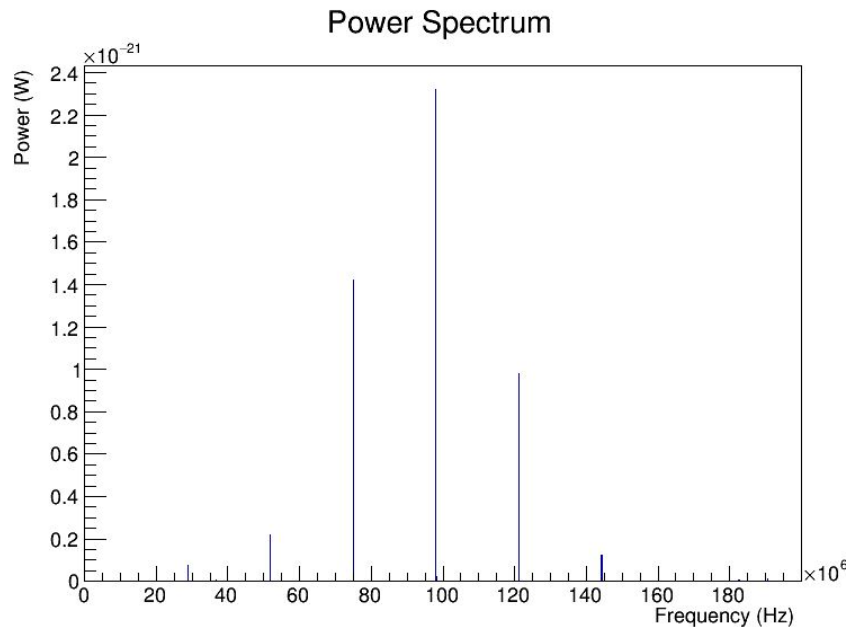
2. Edit the trap version to `V00_00_09`:

```
<include name="/tmp/hexbug/Phase3/Trap/FreeSpaceGeometry_V00_00_09.xml"/>
```

3. Run the scripts: `./tutorialLocustscript.sh && ./tutorialKatydidscript.sh`

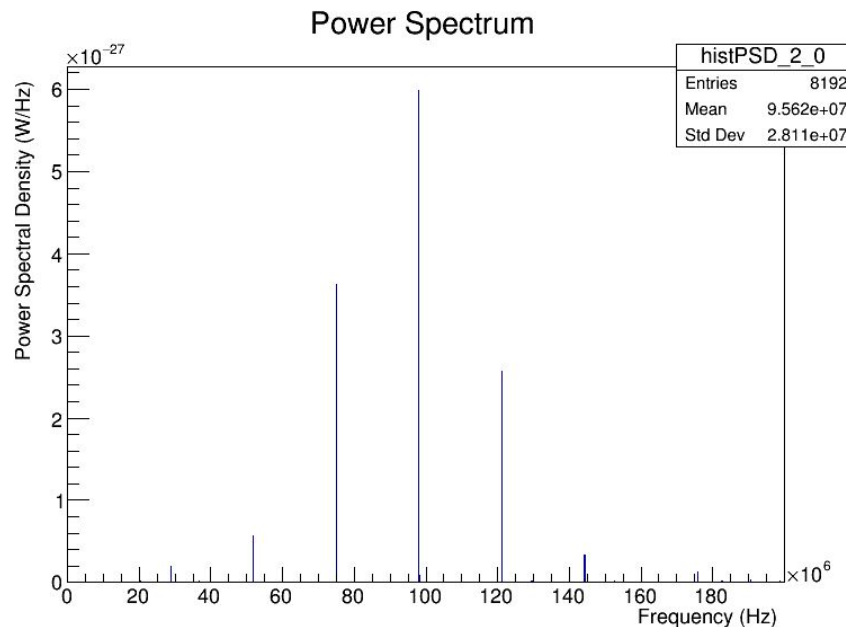
Example #6D: Systematic effects (sidebands, cont.)

- In the jupyter browser tab, navigate to `/tmp/locust-tutorial/scripts/plotting/PlotGrid.ipynb`. Click the ►►, See this plot. ->
- Sidebands are now present. From the plot alone it is not always obvious which feature is the carrier.
- Grid search will select feature with highest power, but it might not be at `f_cyc`, and it may not be obvious what to report for `e-energy`. Reconstruction is more complicated.



Example #6D: Systematic effects (sidebands, cont.)

- Single-channel sideband structure is usually very similar to that in whole array.
-> It is often faster to examine sidebands in just one channel.
- In the jupyter browser tab, navigate to /tmp/locust-tutorial/scripts/plotting/PlotPSD.ipynb. Choose time slice #2, channel #0 as in `dataHisto = histFile.Get("histPSD_2_0")`
Click the ►►, See this plot. ->
- Notice similarity to sideband pattern on previous slide.



Example 7A: Running a Locust job on pnnl cluster

- After following instructions here:

<https://discourse.project8.org/t/using-dirac/89>

Start the dirac client like this:

```
docker-compose run -v ~/p8tutorial:/tmp --rm p8-dirac-client
```

- In the container,

```
cd /tmp/locust-tutorial/scripts/pnnl/locust
```

```
dirac-wms-job-submit my_first_locust_job.jdl
```

- Follow instructions at

<https://discourse.project8.org/t/dirac-job-submission-basics/147>

- The output *.egg file will be in the output sandbox.

Example 7B: Processing Locust output on pnnl cluster

- After following instructions here:

<https://discourse.project8.org/t/using-dirac/89>

Start the dirac client like this:

```
docker-compose run -v ~/p8tutorial:/tmp --rm p8-dirac-client
```

- In the container,

```
cd /tmp/locust-tutorial/scripts/pnnl/katydid
```

```
dirac-wms-job-submit my_first_katydid_job.jdl
```

- Follow instructions at

<https://discourse.project8.org/t/dirac-job-submission-basics/147>

- The output *.root file(s) will be in the output sandbox.

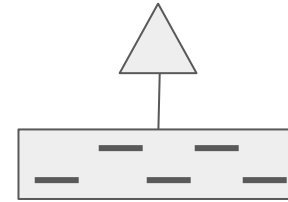
Example 8: Running p8compute in Singularity on Yale Grace cluster

- In `~/p8tutorial/locust-tutorial/scripts/yale/` are two scripts:
`locustsingularity.batch` **and** `katydidsingularity.batch` .
 - Interactive running:
 - Log onto compute node with 2 cores, e.g. `srun -c2 --time=03:00:00 --pty -p interactive bash`
 - Configure local paths for your I/O in the *.batch file. The `sifdir` path does not need to be edited.
 - Run scripts interactively as `./locustsingularity.batch` or `./katydidsingularity.batch` .
 - Batch job:
 - Configure paths in *.batch as above.
 - `sbatch locustsingularity.batch` or `sbatch katydidsingularity.batch` .
 - Documentation on running jobs on Yale clusters:
<https://docs.ycrc.yale.edu/clusters-at-yale/job-scheduling/>

Extra slides

Parameters for positioning array in “array-signal” generator

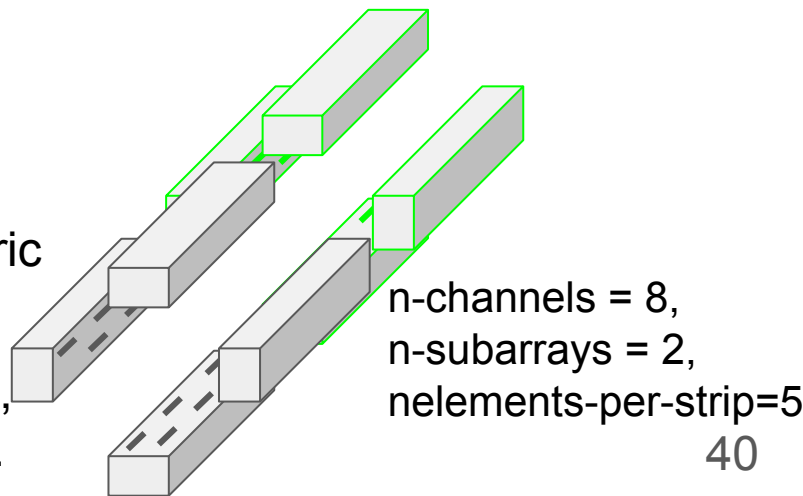
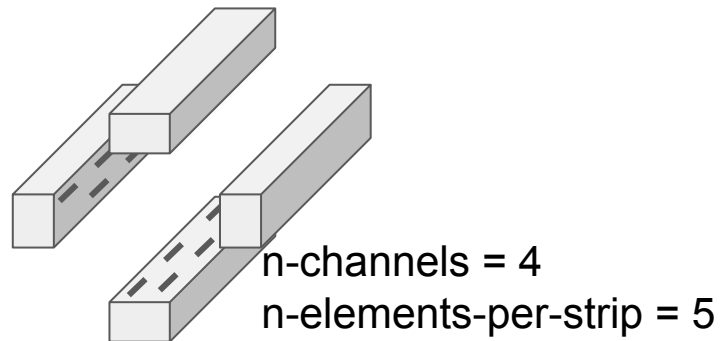
- “n-elements-per-strip”: Number of antenna elements (typically slots or patches) summed at the input to one amplifier.
- “array-radius”: Radius [m] of cylindrically-shaped antenna array.
- “element-spacing” : [m] spacing between elements. Determined for each slotted-waveguide transfer function.



n-elements-per-strip = 5

Parameters for positioning array in “array-signal” generator, cont.

- “n-channels”: Number of amplifiers in cylindrically-shaped array, spaced evenly around the radius of the cylinder.
- “n-subarrays”: Number of antenna rings.
- “zshift-array”: Longitudinal shift of entire antenna array relative to everything else (such as a trap, trapped electrons, or transmitting antenna). If not defined, then array is symmetric about $z=0$.
- Other parameters are listed in later slides here, and/or are defined in Locust classes on github.



Other parameters in “array-signal” generator

- “transmitter”: Select either kassiopeia, antenna, or planewave.
- “event-spacing-samples”: Number of fast-sampled (10x) digitizer samples preceding each electron event (if using kassiopeia). The default value is 150000, which allows an electron to start near the end of time slice #1 if Katydid slice-size = 8192 and Locust “acquisition-rate” is 200 MHz (default value).
- “voltage-check”: Print voltage values to terminal while the simulation is running. This is quite verbose and is used for quick debugging. A better way to check voltage values is to examine time series histograms in Katydid output.
- “lo-frequency”: Local oscillator frequency [GHz].

Other parameters in “array-signal” generator

- "tf-receiver-filename": Full path to transfer function file.
- "tf-receiver-bin-width": Resolution bandwidth [Hz] of transfer function.
- "xml-filename": Full path to Kassiopeia xml file containing standard Locust modifications.

Troubleshooting

- Histograms and time series are empty.
 - Digitizer range is too large.
 - Record length is too short (e.g. record ended before electron started).
 - “event-spacing-samples” has delayed the event start time(s) past the end of the record.
 - LO is tuned such that the signal is out of the window.
 - Katydid n-slices is too small and so the Locust signal was not processed.
 - Katydid was not run at all.
 - B field is higher/lower than expected, moving signal out of window.
- Unexpected high-power artifacts
 - Digitizer range is too small (or possibly too large).
 - Voltages can occasionally freeze at limit of digitizer range. To avoid, widen range. This is being investigated.
- Other
 - Switch on the verbose “voltage-check”: “true” flag to check for reasonable voltage values while simulation is running.
 - Look at the Katydid time series of voltages: check for clipping and quantization.

Other Root GUIs to try (1)

```
docker run -it --net=host --env="DISPLAY"  
--volume="$HOME/.Xauthority:/root/.Xauthority:rw" -v ~/p8temp:/tmp  
project8/p8compute
```

```
source /usr/local/p8/compute/v0.10.0/setup.shsource  
/usr/local/p8/compute/v0.10.0/setup.sh
```

```
root
```

```
new TBrowser()
```

Other Root GUIs to try (2)

```
docker run -it --rm -e DISPLAY=host.docker.internal:0 -v  
~/p8temp:/tmp project8/p8compute  
source /usr/local/p8/compute/v0.10.0/setup.sh  
root  
new TBrowser()
```

(The above required (on a Mac) first checking “Allow connections from network clients” in XQuartz security settings.)

Other Root GUIs to try (3)

Root's official docker container ([rootproject/root](#))