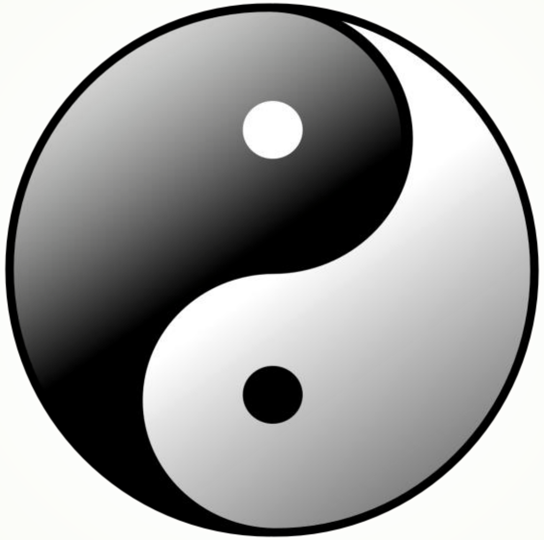
Algorithm for Measuring Efficacy of Lighting Arrays



Brought to you by Austin Rouse with LED Cultivation, Inc.

Algorithm for Measuring Efficacy of Lighting Arrays

Presenting a new algorithm developed for measuring the efficacy of lighting arrays. This method takes into account all three dimensions, whereas predecessors only calculated along the 2-Dimensional horizontal plane (X + Y).

Incorporating a 3rd Dimension, involves constructing a 3-Dimensional Cartesian Coordinate System Space, and a proper photometric uniformity mat within a CAD program, then creating a vertical line at the center of your CAD generated photometric uniformity mat, with a value representing the mounting distance of your fixture's placement. In this case, a 22" mounting distance was chosen. The vertical line within the 3-Dimensional Cartesian Coordinate System Space, serves as our Z-Axis, or, our 3rd Dimension.

A 5' x 5' photometric uniformity mat was used, with 73 total points. For this presentation, the focus is on a 4' x 4' space, meaning only 57 points are accounted for. Taking measurements using a quantum sensor at the center-point of each point on the mat, serves as our 2-Dimensional Base Point.

Creating a diagonal line from the 2-Dimensional Base Point, to the Origin of the 22" Z-Axis, serves as the measurement to be squared and formatted into the Inverse Square Law formula. Such will help us to find the Proportional Intensity between the 2-Dimensional Base Point, and the Origin of the 22" Z-Axis.

These are the defined variables which will be used to formulate the generation of Proportional Intensity measurements.

- $d1^2$ = Diagonal Measurement (Variable Numerator) [X + Y + Z-Axes]
- $d2^2$ = Mounting Distance (Constant Denominator - 22") [Z-Axis]
- i1 = Micromole Concentration (μmol $\mathbf{m^{-2}}$ $\mathbf{s}^{-1}$) At a 2-Dimensional Base-Point.
- * Solving for i2. – **Proportional Intensity**

Inverse Square Law Formula – Example Integrated Within Single Use-Case for this Practical Application

- Synergy Series: Ground Zero [**Elite**]
- ***Calculation for** (Point - **#37**)

- $\mathbf{i2} = \frac{\mathbf{d1^2}}{\mathbf{d2^2}} = \mathbf{i1} \rightarrow \mathbf{i2} = \frac{(39.125'')^2\ (\mathbf{d1^2})}{(22.000'')^2\ (\mathbf{d2^2})}\ (719\ \mu moles/m2/s)\ (\mathbf{i1})$

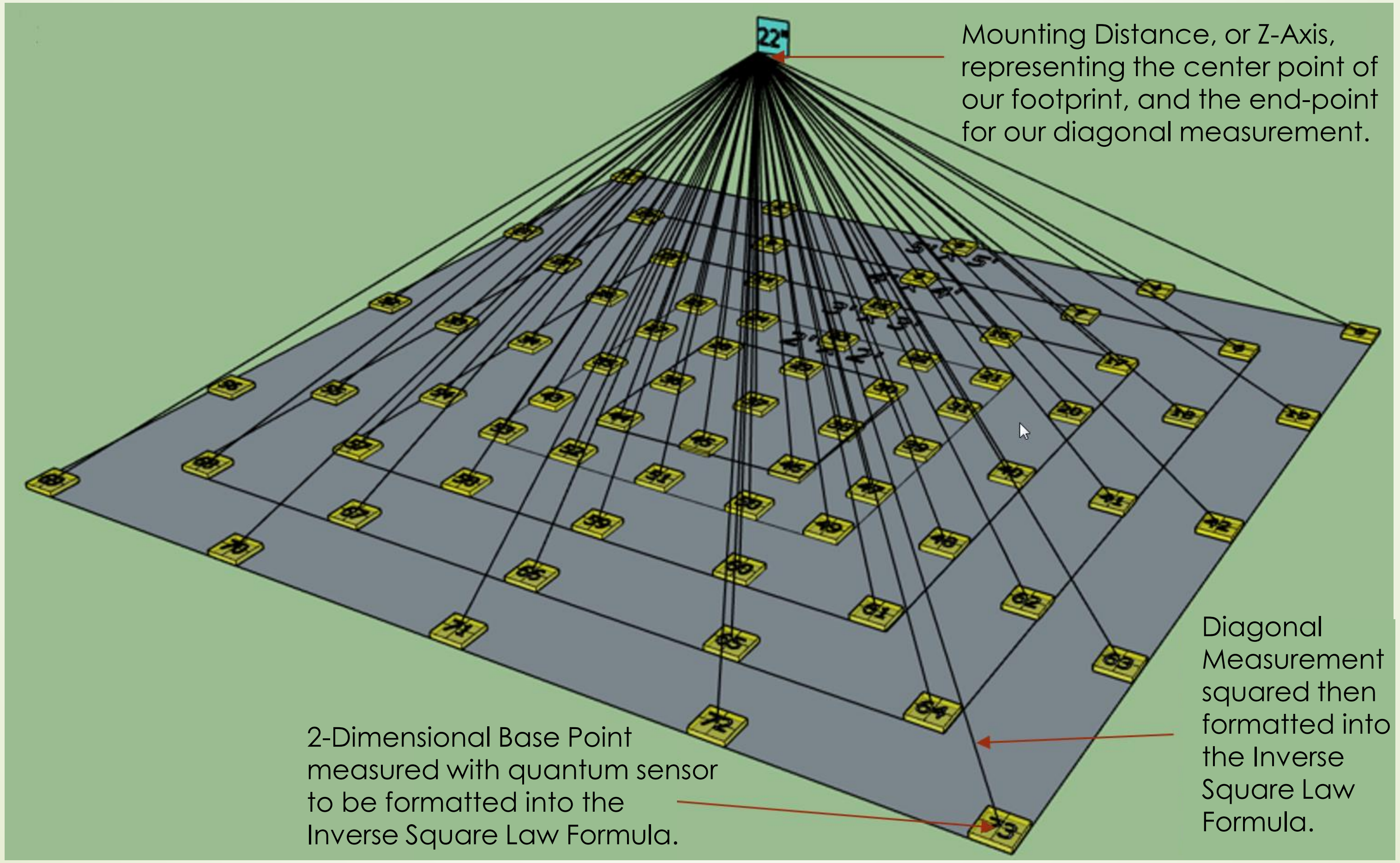
- $\mathbf{i2} = \frac{6.255''^2\ (\mathbf{d1})}{4.690''^2\ (\mathbf{d2})}\ (719\ \mu moles/m2/s)\ (\mathbf{i1})$

- $\mathbf{i2} = 1.333\ (719\ \mu moles/m2/s)\ (\mathbf{i1})$

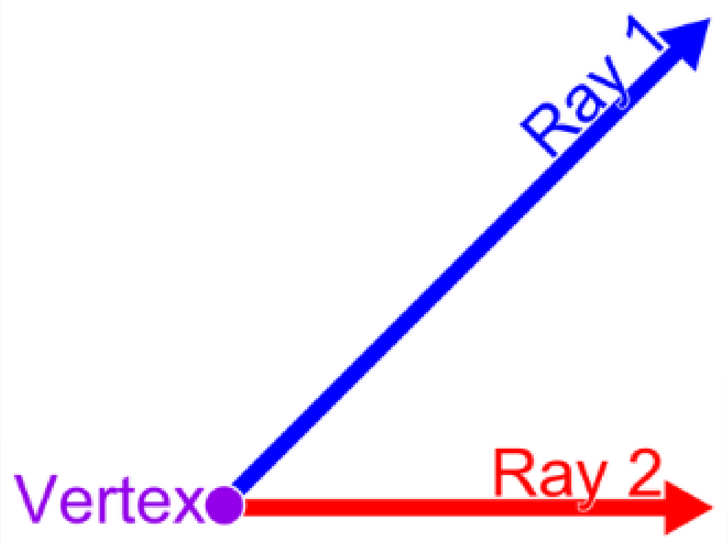
- **i2** = 958.427 *µmoles/m2/s*

  (The Proportional Intensity of light from the 2-Dimensional Base Point, to the Origin of the Z-Axis, through the diagonal measurement beginning at the 2-Dimensional Base Point, and ending at the Origin of the Z-Axis.)

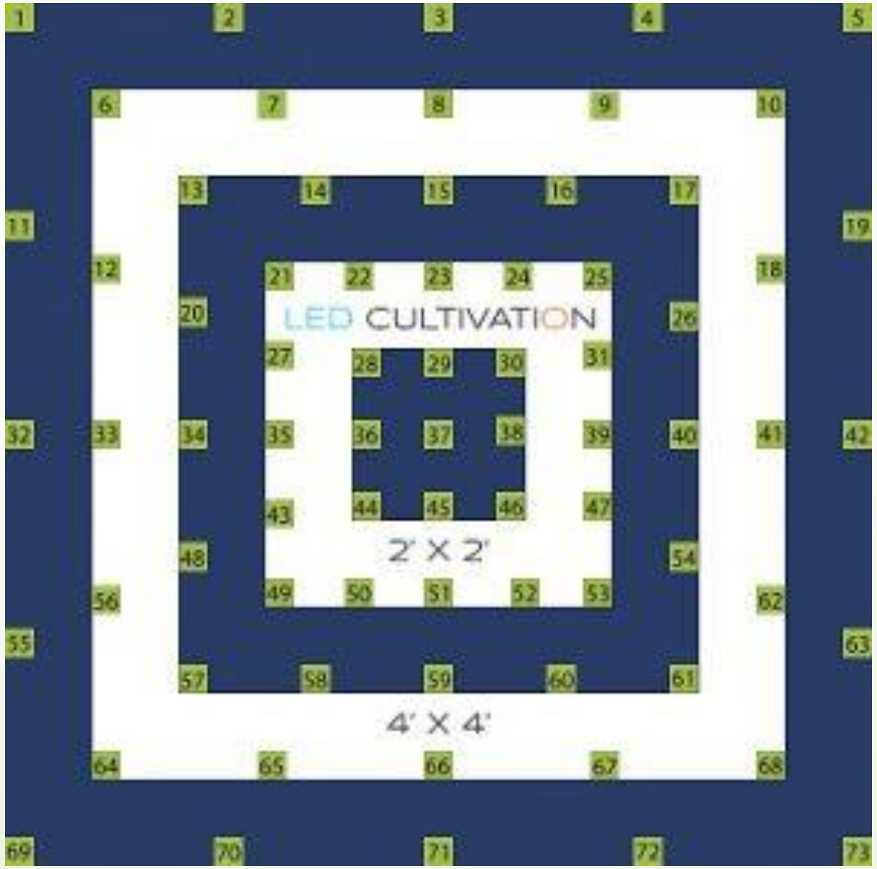
Visual Representation for 3-Dimensional Cartesian Coordinate System Space



Visual Representation for how a Diagonal Line Incorporates Dimensions: 1, 2, & 3



Representation for a Proper Photometric Uniformity Mat



Description for Practice of Algorithm

- Typically, attaining a value for Photosynthetic Photon Flux Density (**PPFD**) is merely done by taking quantum measurements of Photosynthetically Active Radiation (**PAR**) at points on a photometric uniformity mat, adding those measurements together, and then dividing the sum by the total measurements taken. This is rudimentary, and now ***obsolete*.**
- A more proper way to determine **PPFD**, is as follows:
- Still take quantum measurements on a proper photometric uniformity mat, and note those measurements as your 2-Dimensional Base Points. Then, construct a 3-Dimensional Cartesian Coordinate System Space, and a proper photometric uniformity mat, using a CAD program. Within this space, create a vertical line at the center-point of your photometric uniformity mat to represent the Z-Axis, or the mounting distance of your fixture. For this example, a Z-Axis, or mounting distance of 22", was chosen.
- Now, you are going to want to create a diagonal line from the center-point of your 2-Dimensional Base Point, to the origin of your Z-Axis. This will provide you with a line incorporating all three axes: X + Y + Z. You can use this line, and the measuring tool within your CAD program, to generate a measurement value for this diagonal line.
- **Now for the equation**:
- As you can see in *page #4*, the original diagonal measurement value is squared to form a new arrangement for the equation. This is why you must find the square root for each original measurement you take of your diagonal line, so that you can incorporate it within the next step of the equation. You will then be dividing the squared diagonal measurement (numerator), by your Z-Axis (constant-denominator), and now onto the final step.
- Take the quotient of dividing your diagonal measurement (numerator) by your Z-Axis (constant-denominator), and multiply that by the micromole concentration value (found through measuring the center-point of your 2-Dimensional Base Point). This will provide you with the *Proportional Intensity* between your 2-Dimensional Base Point and the 3-Dimensional Z-Axis (your mounting distance).
- As you could probably imagine, it is preferred that the Proportional Intensity between your 2-Deminsonal Base Point, and the Origin of your Z-Axis (3D Center-Point of Your Footprint), be lower rather than higher. The goal is to be as proportional as possible. Intensity implies increased proportion, or lesser uniformity. The goal is to have the best photometric uniformity possible. And the **PPFD** metric is intended to describe the photometric uniformity produced by the test subject.
- **This is now the new standard metric for defining the value of Photosynthetic Photon Flux Density**. The value is the Proportional Intensity between your 2-Dimensional Base Point & the origin of your 3-Dimensional Base Point (Z-Axis). The lower, the better. You could combine all of your Proportional Intensity values, and use the sum of these values for direct comparisons against competitors, as we did. ***Within our initial test using this new algorithm, we found that our array holds a more desired Proportional Intensity by 10.49%!***

What is the proper way to showcase the performance of lighting arrays?

- This is a multi-faceted process. Firstly, you need a proper photometric uniformity mat, as depicted in *page #7*. Second, you need to understand the process of determining the Proportional Intensity of the test subject, which is outlined within this document.
- As is depicted within *page #7*, the mat's squares (where you should take your 2-Dimensional Base Point Measurements), are merely numbered as 1-73, since the mat has a total of 73 points. For PAR Map representation, you would want those numbers to represent the measurements you take of your 2-Dimensional Base Points. This will allow you to generate a PAR Map; *the first element of your showcase*. This element is important, because it provides visual representation for how uniform your PAR spikes are, without a need for the more mathematical step of the process: **The 2nd element**.
- The 2nd element: **Proportional Intensity**
- The lower your Proportional Intensity, the better. The process by which you discover the Proportional Intensity of your test subject, is outlined in this presentation. This presentation also showcases its value in terms of comparing one fixture to another; you receive values for *a direct differential comparison in Proportional Intensity*!
- <u>The two facets by which one should showcase a fixture's performance are as such</u>:
- (1) Proper PAR Map, visually showcasing micromole concentration at 2-Dimensional Base Points.
- (2) Proportional Intensity values – Which can be divided by the number of values, similar to how the preceding process of defining Photosynthetic Photon Flux Density was conducted, to give you an ***Averaged Proportional Intensity***.
- ***Side Note**

  As you can see within this document, generating Proportional Intensity values is a great way to form a direct comparison against a competitor, in terms of photometric uniformity. Who ever scores lower, is the winner!

Excel Calculation Example of [Elite] VS. [HLG-550]

d2² (Constant)	Diagonal Measurements²	i2 = 6.255"² (d1) / 4.690"² (d2)	i2 * PAR Reading [Elite]	Elite PAR Readings	i2 * PAR Reading [HLG-550]	HLG-550 PAR Readings	Difference in Proportional Intensity
	4.690						
4' x 4 '							
10	6.254	1.333		421	512.0545842	384	-49.33859275
9	5.814	1.240	644.6226013	520	586.3586354	473	-58.26396588
8	5.617	1.198	670.6865672	560	676.6748401	565	5.988272921
7	5.809	1.239	682.4646055	551	645.306823	521	-37.15778252
6	6.244	1.331	617.7432836	464	513.8985075	386	-103.8447761
18	5.825	1.242	652.0522388	525	580.0159915	467	-72.03624733
41	5.640	1.203	662.6098081	551	627.7356077	522	-34.87420043
62	5.830	1.243	606.6183369	488	576.7846482	464	-29.8336887
64	6.249	1.332	556.9471215	418	426.3710021	320	-130.5761194
65	5.820	1.241	596.891258	481	593.1684435	478	-3.722814499
66	5.624	1.199	571.993177	477	643.9420043	537	71.94882729
67	5.820	1.241	578.2771855	466	567.108742	457	-11.1684435
68	6.255	1.334	546.8123667	410	426.7803838	320	-120.0319829
55	5.836	1.244	612.2200426	492	497.7398721	400	-114.4801706
33	5.646	1.204	635.6264392	528	632.0149254	525	-3.611513859
12	5.830	1.243	652.6119403	525	561.8678038	452	-90.74413646
3' x 3'							
13	5.700	1.215	633.1982942	521	559.0618337	460	-74.13646055
14	5.385	1.148	702.6908316	612	713.0245203	621	10.3336887
15	5.249	1.119	719.6390192	643	818.1277186	731	98.48869936
16	5.385	1.148	740.5810235	645	747.4701493	651	6.8891258
17	5.684	1.212	685.958209	566	643.5402985	531	-42.41791045
20	5.397	1.151	716.9149254	623	767.5477612	667	50.63283582
40	5.267	1.123	713.1226013	635	798.4727079	711	85.35010661
48	5.397	1.151	697.3522388	606	753.738806	655	56.38656716
61	5.690	1.213	626.021322	516	575.0660981	474	-50.95522388
60	5.390	1.149	656.2238806	571	704.4925373	613	48.26865672
59	5.262	1.122	638.396162	569	740.4946695	660	102.0985075
58	5.390	1.149	634.3880597	552	680.358209	592	45.97014925
57	5.700	1.215	629.5522388	518	565.1385928	465	-64.41364606
54	5.408	1.153	653.8029851	567	642.2720682	557	-11.53091684
34	5.280	1.126	683.3603412	607	718.2601279	638	34.89978678
26	5.402	1.152	683.0247335	593	650.7739872	565	-32.25074627
2' x 2'							
25	5.184	1.105	751.6247335	680	768.2046908	695	16.57995736
24	5.018	1.070	754.3049041	705	895.5364606	837	141.2315565
23	4.943	1.054	738.8151386	701	965.4132196	916	226.598081
22	5.012	1.069	763.0208955	714	939.3492537	879	176.3283582
21	5.172	1.103	762.0153518	691	864.5731343	784	102.5577825
31	5.024	1.071	745.5658849	696	955.5240938	892	209.958209
39	4.955	1.057	739.5522388	700	986.7739872	934	247.2217484
47	5.024	1.071	744.4946695	695	926.6012793	865	182.1066098
49	5.177	1.104	715.2869936	648	806.9055437	731	91.61855011
50	5.018	1.070	707.2277186	661	875.2076759	818	167.9799574
51	4.949	1.055	703.8343284	667	896.9402985	850	193.1059701
52	5.018	1.070	701.8780384	656	871.9978678	815	170.1198294
53	5.184	1.105	693.0422175	627	819.0498934	741	126.0076759
43	5.030	1.072	711.0639659	663	904.1130064	843	193.0490405
35	4.962	1.058	713.0891258	674	896.1223881	847	183.0332623
27	5.030	1.072	732.5138593	683	869.793177	811	137.2793177
1' x 1'							
28	4.847	1.033	732.7341151	709	997.303838	965	264.5697228
29	4.769	1.017	734.1616205	722	1039.214925	1022	305.0533049
30	4.847	1.033	739.9684435	716	1013.839446	981	273.8710021
38	4.775	1.018	710.6503198	698	1017.105544	999	306.4552239
46	4.853	1.035	726.3978678	702	966.4609808	934	240.063113
45	4.755	1.014	696.521322	687	975.3326226	962	278.8113006
44	4.853	1.035	722.2588486	698	931.2793177	900	209.0204691
36	4.775	1.018	715.7409382	703	1034.413646	1016	318.6727079
37	4.690	1.000	719	719	1026	1026	307

Total Difference in Proportional Intensity	Average Proportional Intensity	
4550.159	[Elite]	[HLG-550]
	681.378	761.206
	Percent Differene In Proportional Intensity	
	10.49 %	

These are calculations produced using an Excel Spreadsheet, to showcase the Proportional Intensity differences between our [Elite] & the [HLG-550].

This could be used to showcase that our photometric uniformity holds a Proportional Intensity improvement of 10.49% over the HLG-550.

It is commonly known that efficiency amongst variant diodes on the market is between 3-5%, between those such as the LM301B diodes incorporated within the HLG-550 & our combination of Samsung Strips / COB diodes incorporated within our designs.

Our uniformity doubles / triples the difference in diode efficiency, thus proving our arrays provide a higher degree of **Efficacy**.

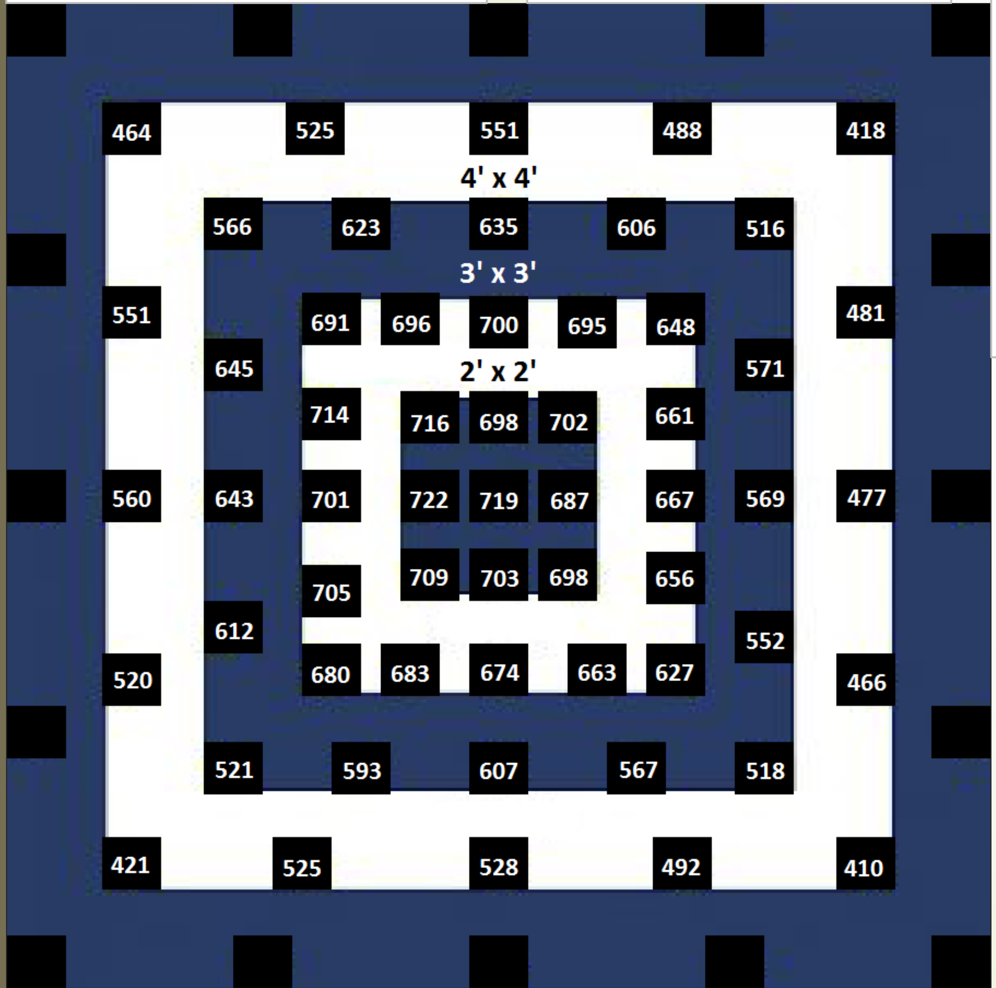
PAR Map Comparisons Between [Elite] and [HLG-550]

PAR Map for [Elite] @ 22" Mounting Distance

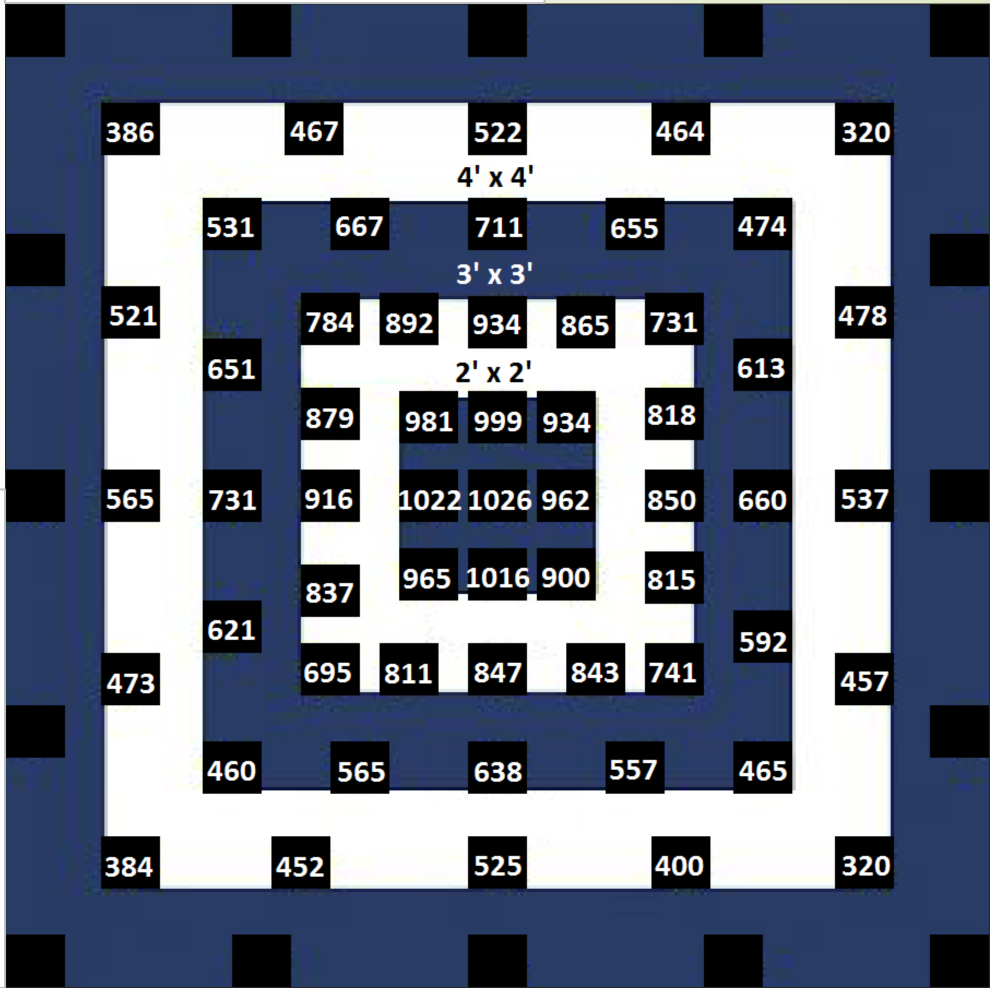
Dimmed from 100% to **43%** to match power draw of tested competitor.

Using our PWM dimming system, you can simply turn the knob on the linear taper rotary potentiometer included within our dimming system, to bring your maximum micromole concentration point to a desired level, while the uniformity provided by our proper configuration of diodes raises the rest of your PAR spikes to an appropriate degree.

☺



PAR Map for HLG-550 @ 22" Mounting Distance



Fixture has no dimming capability, so was ran at full power for the test, which we measured at 494 watts using a 'Kill A Watt Meter' - Which advertises an accuracy range of 0.2-2.0%.

We used our Pulse Width Modulation (**PWM**) dimming system to match the power draw of this fixture for a direct comparison.

Final Thoughts

- Visual perception is extremely important in terms of ascertaining whether or not something is good, or bad; or better, or worse. Through visually observing my [Elite] VS. the [HLG-550], I was annoyed to 'lose' the 'PPFD Test' – Or, the totaling of 2-Dimensional measurements, then dividing by the sum of said measurements to produce a final score.
- This drove me to create the new algorithm I have outlined here. I *knew* my fixture's performance was better. I just hadn't a way to properly quantify it yet. Many mathematicians will exclaim that, "*The proof is the hardest part*".
- I also knew Photosynthetic Photon Flux Density (**PPFD**), required, and deserved, a much more advanced process to accurately represent what this principle actually is. With PPFD, we're trying to understand the density of light, and how that density changes as it travels across a space. As a space is defined to be 3-Dimensional, it's no surprise that the preceding 2-Dimensional process has been succeeded by one which operates on a 3-Dimensional basis.
- LED Cultivation aims to be more than merely a company which sells grow lights. We aim to be a real scientific platform, with a community where we can all learn from one another, and improve upon processes such as defining Photosynthetic Photon Flux Density. I am proud to provide this for our community. We deserve it ☺

With Love,

Austin Rouse