Interim Report 1

Energy harvesting using 'flyback' pulses

Introduction:

This interim report lays out in detail the procedure, measurements and evidence, and an analysis of the results and uncertainties, arising from a set of experiments designed to confirm or refute prior claims expressed by the following hypothesis:

That high voltage or high intensity pulses delivered to a battery can result in a Coefficient of Performance (CoP) greater than 1 and that the whole electrical system can operate in an 'open' manner and harvest energy from the local environment.

A wide ranging schedule of experiments was designed to measure the effect on the battery charging process, and resulting CoP, when inductively generated HV pulses were applied directly to a 'Receiving' battery. The pulses were generated at varying frequencies by a set of solenoids in conjunction with a PWM module producing square waves with adjustable duty cycle.

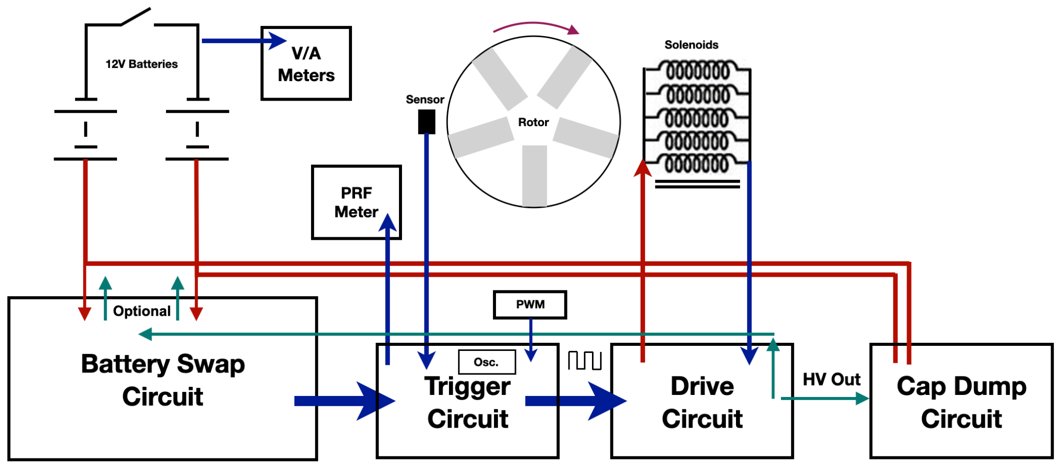

Fig 1: Functional Diagram

The elements of the generator system are shown in the functional diagram Fig 1:

A summary of the device's operation is as follows:
With a battery or, for testing purposes, a power supply providing power to the circuit, the set of 5 solenoids was energised when the rising edge of the square wave from a PWM oscillator switches on the main drive MOSFET. The magnetic fields in the coils build up to a maximum and, in keeping with Lenz's Law, results in an HV pulse which is earthed

through a diode to ground. On the falling edge of the square wave, the coils switch off and, again, generate a reverse polarity ‘flyback’ pulse as they oppose the collapse of the magnetic fields. This pulse, a little over 1,000V in this case, and with a pulse width of 40-50μs (FWHM) and dV/dt = 1.5E+08 V/s, appears at the Drain of the MOSFET and is directed to the receiving battery.

Alternatively, pulses can be directed to a bank of storage capacitors whereupon, at a set voltage, the capacitors will discharge into the receiving battery as a high current, high intensity pulse. However, experiments using this approach showed much less effect than using the HV pulses directly and so this report will focus on the latter.

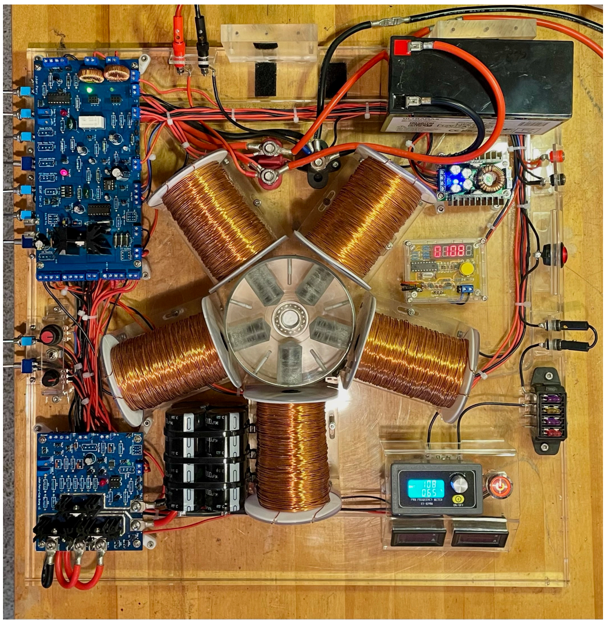

Fig 2: Generator Build

The peak flyback voltage has been measured using a custom built 10:1 potential divider and calibrated using transients generated by a signal generator. The peak pulse voltage has also been found to be limited by the ‘Avalanche breakdown’ rating of the MOSFET and so the innate peak voltage is even higher. Changing the MOSFET for one with a higher rating is planned for later experiments, although other factors such as the Source Drain resistance are substantially higher which will result in greater heat loss.

As an alternative to using the PWM module, switching the MOSFET can be done using a rotor driven by the energised coils in conjunction with a Hall sensor. This results in a fixed pulse repetition frequency, at max RPM, as each of the 5 sets of rotor magnets switches the solenoids on and off every rotation of the rotor. As such, at 3,000 RPM, the PRF will be 250Hz (3,000/60 x 5). Again, since the CoP values measured using the rotor switching were significantly lower than with the PWM, this report focuses on using the PWM method.

Using the battery swapper circuit, with a predetermined swap interval, the batteries can be automatically switched over so that the energy that has been expended to the circuit by the 'run' battery can be replenished when it becomes the 'receiving' battery. If a CoP> 1 is measured then the 'run' battery can also deliver some useful power to an external load. For the purposes of testing, this feature is switched off so that the effect of variations in individual battery properties was negated and a power supply used in place of the 'supply' battery and which also facilitated adjustment of the coil voltage in various test runs.

Experimental methodology:

Since the relative proportions of the energy entering the receiving battery from the generator pulses and the local environment are unknown, determining the CoP of this generator required an indirect approach and the following stages:

1. A measurement of the energy dissipated, in a controlled discharge of the 'receiving' battery, from a state of full, or near full charge

2. A measurement of the energy delivered by the 'run' battery to the generator in operation

3. The return of the 'receiving' battery to its original energy state and voltage by the generator in a measured time

4. The calculation of CoP as the ratio of '*energy returned to the receiving battery*' divided by the '*energy supplied to the generator by the run battery*'.

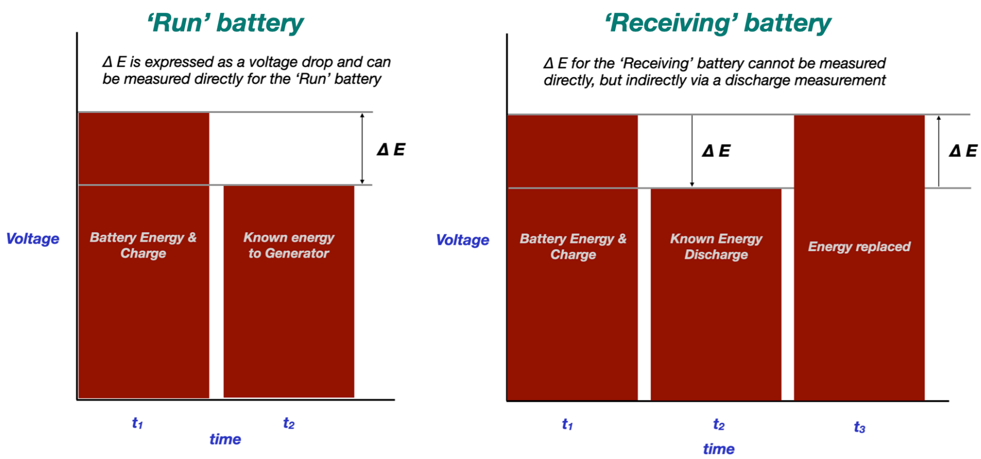

Fig 3: Measurement Process

This process is then repeated for different operational variables of the generator and is illustrated by Fig 3. Testing so far has involved the following variables of PRF, duty cycle, coil voltage, swap interval, number of batteries in series, battery capacity (Ah) and chemical format. Modifying the peak pulse HV and live load tests are yet to be completed.

A value of CoP>1 will mean that the device is drawing in (harvesting) additional energy from the local environment over and above the losses that the generator, with an estimated efficiency of 80-85% (yet to be measured), is encountering.

The equipment used in the experiments was:

- *Computerised Battery Analyser (CBA):(West Mountain CBA IV - 58250-1014)*
- *Recording Digital Multimeter (RDM): (Owon XDM1041 - 55,000 counts)*
- *Digital Multimeter (DVM): (Astro AI-WH5000A TRUE-RMS 6000 counts)*
- *Frequency counter (on board): 1-50MHz Crystal Oscillator Frequency Counter/Meter*
- *Stopwatch and timer: iPhone 12 and Apple Watch*

The key steps in the test procedure were:

1. Externally charge the ‘Receiving’ battery using a regular mains battery charger and, after at least a 1 hour period of stabilisation (often overnight), record the ‘start’ voltage using the CBA as part of the setup for the following ‘Discharge’ stage.

2. Using the ‘Discharge’ feature on the CBA, dissipate a specific amount of energy (Wh) from the ‘Receiving’ battery using a discharge current of 3,000mA. Record the discharge profile with the X axis as energy (Wh) expended. [*The nominal battery capacity is 7Ah so, discharging 1.0Ah (3,600 C) will result in approximately a 14% reduction in capacity and take about 20 mins at 3A*].

3. Rest the ‘Receiving’ battery for 10 mins and then record its voltage using the CBA

4. Having set the desired PRF value, run the generator and the CBA ‘Charge Monitor’ function simultaneously for a period of t + 60 min where t is a suitable run time to produce about 75% or more recharge to the ‘receiving’ battery.

5. The CBA monitored and recorded the voltage continuously and displayed it on a Vt graph as the charging monitor profile. However, the effect of the HV pulses being applied directly to the receiving battery, was to raise the voltage ‘artificially’, due to the ‘surface charge effect’, and mask the true value. In this event charge arrives too fast to migrate fully throughout the electrolyte, especially the gel form, and collects on the electrode surface.The obtain a realistic value the battery was left for a consistent 1 hour after the generator has been turned off so that charge can migrate and the battery chemistry and voltage can stabilise before being read.

6. During the charging process, record the average current and voltage supplied by the PSU (acting as the ‘Run’ battery) to the generator. For the current the RDM was inserted in to the feed from the PSU to the circuit. The average current $I_{(av)}$ was determined as the mean of a set of readings automatically recorded every 60s over the duration of the test and exported as an XLS file.

7. For the voltage, since a power supply was used, a DVM value taken on the PCB at the coil terminals is used as the supply voltage over the run duration.

8. This allowed calculation of the total energy in Joules supplied to the generator by the PSU during its incremental run time t min as:

   $E_{(Supplied)} = V_{(av)} \, . \, I_{(av)} \, . \, (t \times 60)$ J (*Equation 1)*

9. At the end of the run time, the generator was switched off but the CBA Charge Monitor function continued in order to record and display the receiving battery voltage during the stabilisation stage. After 1 hour, the CBA live voltage value was recorded as the final incremental battery voltage.

10. The energy delivered to the ‘Receiving’ battery after a single charging period was unknown since the battery’s voltage was not expected to return fully to its pre-discharge level and, even if it did, the true voltage is masked by the effect of the HV pulses on the battery. Instead, a plot of ‘Receiving battery voltage' vs $E_{(Supplied)}$, was plotted and extrapolated to give a reading of the energy supplied to return the battery to its original peak voltage of $V_{(pk)}$.

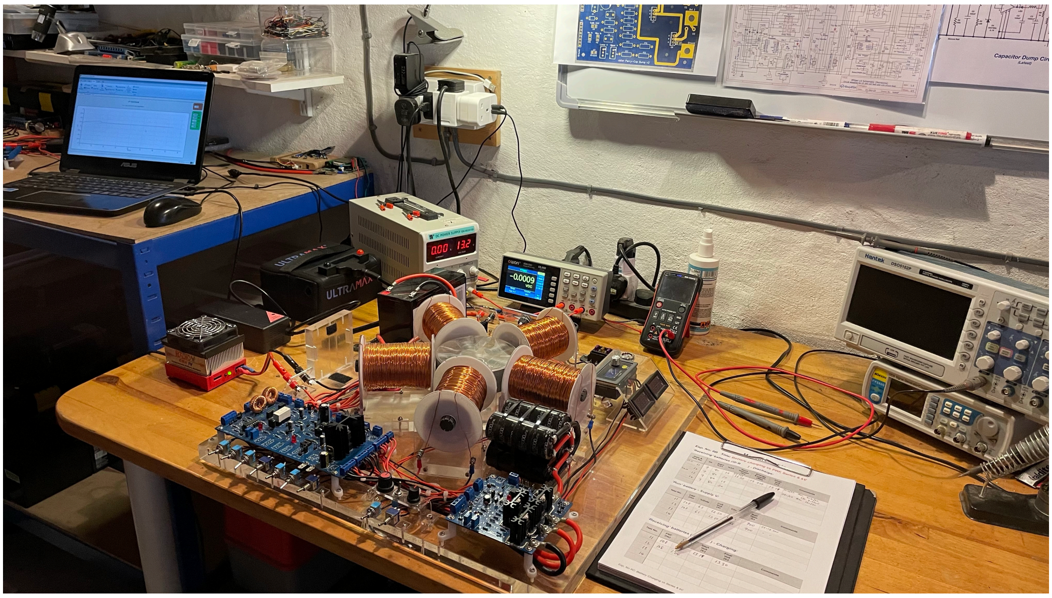

Fig 4: Measurement Setup

11. Determine the extrapolated value of $E_{(Supplied)}$ J as *Value 2*

12. The energy delivered to the receiving battery = ‘Energy Discharged’ J as *Value 3*

13. Calculate the Coefficient of Performance (CoP) as: *Value 3 / Value 2*
(Total energy supplied to ‘Receiving’ battery / Total energy supplied to generator)

14. Calculate the uncertainties using an appropriate statistical method.

15. Repeat with other variables and, where necessary, plot CoP as a function of the variable.

The general testing and measurement arrangement is shown in Fig 4 although different tests required different battery connections and configurations.

Data Recorded and Calculations:

The following worked example examines in detail the various stages of one particular test run, Test 4, using a 7Ah $LiFePO_4$ receiving battery and which produced the highest value of CoP in this particular set of experiments. It presents the recorded data alongside the calculations to derive the CoP value and its associated uncertainty. Taking each sequential stage in turn:

Mains Charging:

Mains charging was done using a standard charger and the battery allowed to stabilise before a reading was taken. This value serves as the reference voltage $V_{(pk)}$ for the subsequent return of the battery to a state of full charge after pulse charging and graphical extrapolation.

Controlled Discharge:

Next the controlled discharge was undertaken using a discharge current of 3,000mA. It was decided to dissipate 20% of the battery capacity (1.4Ah) and in Fig 6 below, the plot of V against t is shown, with the total Wh (energy) expended in a given time.

The value of 17.769 Wh equates to 63.97kJ (1 Wh = 3.6kJ) as shown in the accompanying spreadsheet entries in Table 1 below. The uncertainties in the values recorded will be addressed later.

At the end of the discharge stage the 'live value' of 13.07 (top right in Fig 6) showed the voltage starting to recover after the electronic load was switched off. This is to be expected as the voltage drop, due to the internal resistance of the battery, was no longer occurring. The important values are the energy expended in Wh (J) and also the stabilised final voltage measured after a 10 min rest period, in this case 13.22V. The discharge data was also made available as a CSV file and in CBA files that can be reloaded into the software for further analysis. Table 1 below shows the discharge values for a series of tests.

Fig 6: Controlled Discharge Results

Blue - data input *Red - Auto Fill/Calculations*

Receiving Battery (ID:B3) - Discharge

Test No.	Capacity (Ah)	Current (mA)	Start Voltage [1] (V_i)	Energy Discharge (Wh)	Energy Discharge (J) [2]	% Ah	Final Voltage [3] (V_f)	CBA Test ID	Screengrab File	Comments
1	7	3,000	13.53	17.751	63,904	20.0	13.23	181022_Discharge_1-1.bt2	181022-Discharge End 1	1 x $LiFePO_4$ - PRF Test
2	7	3,000	13.32	17.769	63,968	20.0	13.20	181022_Discharge_1-2.bt2	181022-Discharge End 2	1 x $LiFePO_4$ - PRF Test
3	7	3,000	13.33	17.780	64,008	20.0	13.22	191022_Discharge_1-1.bt2	191022-Discharge End 1	1 x $LiFePO_4$ - PRF Test
4	7	3,000	13.32	17.769	63,968	20.0	13.22	191022_Discharge_1-2.bt2	191022-Discharge End 2	1 x $LiFePO_4$ - Coil V Test
5	7	3,000	13.33	17.714	63,770	20.0	13.22	201022_Discharge_1-1.bt2	201022-Discharge End 1	1 x $LiFePO_4$ - Coil V Test
6	7	3,000	13.32	17.734	63,842	20.0	13.21	201022_Discharge_1-2.bt2	201022-Discharge End 2	1 x $LiFePO_4$ - Coil V Test
7	7	3,000	13.33	17.687	63,673	20.0	13.22	211022_Discharge_1-1.bt2	211022-Discharge End 1	1 x $LiFePO_4$ - Coil V Test

Table 1: Discharge Data

Pulse Charging:

Now that a known amount of energy has been dissipated from the receiving battery, with a starting voltage of 13.32V and a final voltage of 13.22V, in the next pulse charging stage, we monitor the changing voltage during pulse charging while also measuring factors to

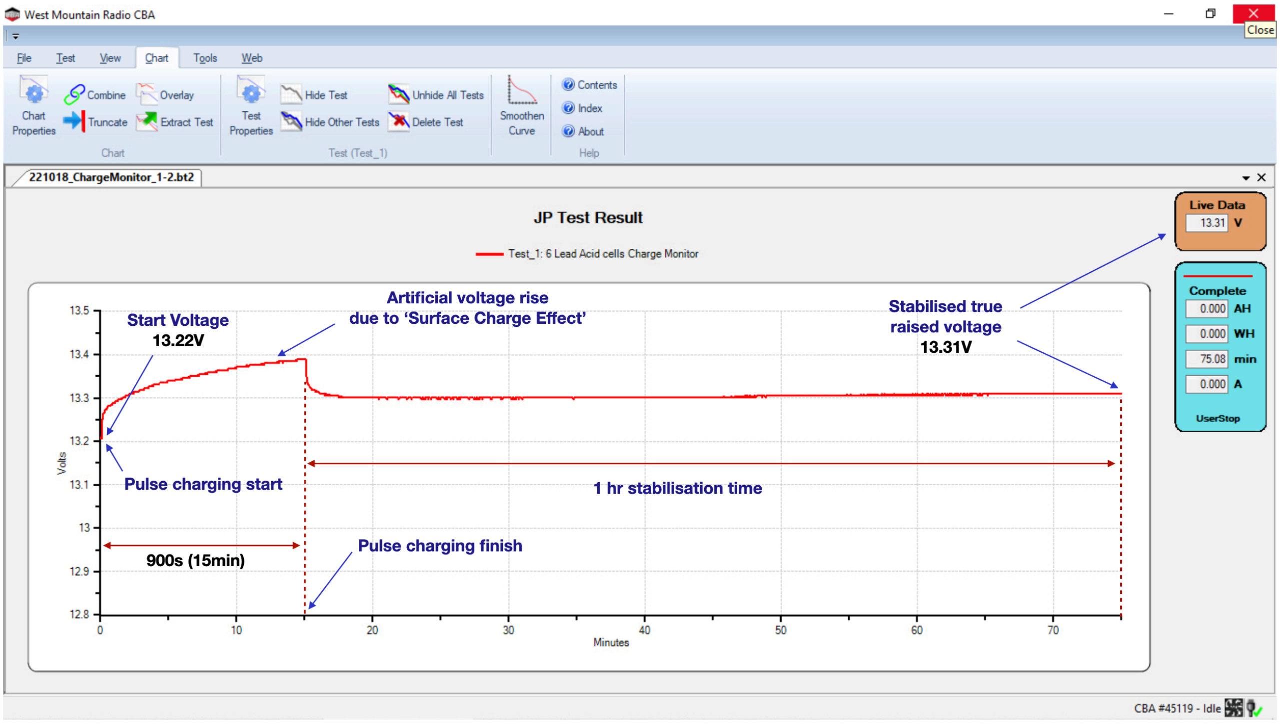

Fig 7: Charge Monitoring graph

calculate the energy delivered to the generator by the PSU in order for the receiving battery to be returned to a state approaching full charge.

However, as previously stated, using HV pulses directly on the receiving battery, rather than via the Capacitive Discharge circuit used in other experiments, resulted in the measured battery voltage being artificially raised for the duration of the generator 'run time', as is seen below in the charging monitor profile (Fig 7). This is due to the 'surface charge' effect at the electrodes and is the reason for the 1 hour stabilisation period to let the battery chemistry settle after its exposure to >1kV pulses.

In order to get around this 'artefact', a procedure was enacted whereby a partial recharge was undertaken, using an estimated run time, and the energy required to reach full charge was obtained by extrapolating a graph of 'Receiving battery voltage' vs 'Energy supplied'. This is shown further down.

	Receiving Battery (ID:B41) - Charging (Incremental)								
Test No.	Capacity (Ah)	HV (kV)	E Discharge (J)	$V_{(pk)}$ (V) [1]	Start Volt (V_i) [2]	Final Volt (V_f) [2]	dV (V)	CBA Test ID	Screengrab Files
1	7	1.04	63,904	13.53	13.23	13.31	0.08	181022_ChargeMonitor_1-1.bt2	181022-Charge Monitor End 1
2	7	1.04	63,968	13.32	13.20	13.31	0.11	181022_ChargeMonitor_1-2.bt2	181022-Charge Monitor End 2
3	7	1.04	64,008	13.33	13.22	13.31	0.09	191022_ChargeMonitor_1-1.bt2	191022-Charge Monitor End 1
4	7	1.04	63,968	13.32	13.22	13.31	0.09	191022_ChargeMonitor_1-2.bt2	191022-Charge Monitor End 2
5	7	1.04	63,770	13.33	13.22	13.30	0.08	201022_ChargeMonitor_1-1.bt2	201022-Charge Monitor End 1
6	7	1.04	63,842	13.32	13.21	13.30	0.09	201022_ChargeMonitor_1-2.bt2	201022-Charge Monitor End 2
7	7	1.04	63,673	13.33	13.22	13.31	0.09	211022_ChargeMonitor_1-1.bt2	211022-Charge Monitor End 1

Table 2: Charging data

During the pulse charging, the CBA's 'Charge Monitor' function was used to chart the receiving battery's voltage over time as it was exposed to the HV pulses from the generator. The recorded charging profile, shown in Fig 7 above, has been annotated with the key reference points including the 'Run' time duration, the 'artificially' elevated voltage during charging, the 1 hr stabilisation period and the start and stablised finish voltages. At the end of the stabilisation period we have a realistic value of the voltage rise after the assimilation of the pulsed charging. This data is assembled in Table 2 above.

In the pulse charging stage the energy to the generator is supplied by a power supply standing in for the the 'run' battery which made it easier to supply and determine a stable voltage. To calculate the total energy supplied to the generator, the average current supplied needs to be measured along with the supply voltage and the generator run time.

Current supplied:

The value of the current supplied to the generator by the run battery was provided from the mean of a series of current values automatically recorded every 60s by the RDM device and later exported. An example of the data is shown in Fig 8.

Test No.[1]	4	
Interval	**1m**	**1m**
Data Point	**I (A)**	**I (A)**
1	0.7954	0.7582
2	0.7813	0.7550
3	0.7736	0.7557
4	0.7691	0.7541
5	0.7635	0.7527
6	0.7608	0.7517
7	0.7612	0.7504
8	0.7593	
Mean:	**0.77**	
SD:	0.01	
Min	0.76	
Max	0.80	
Range	0.04	
Δ_I	0.02	
δ_I	0.02	
Notes	$\delta_I = \Delta_I/\mu$ *(Uncertainty / Average)*	

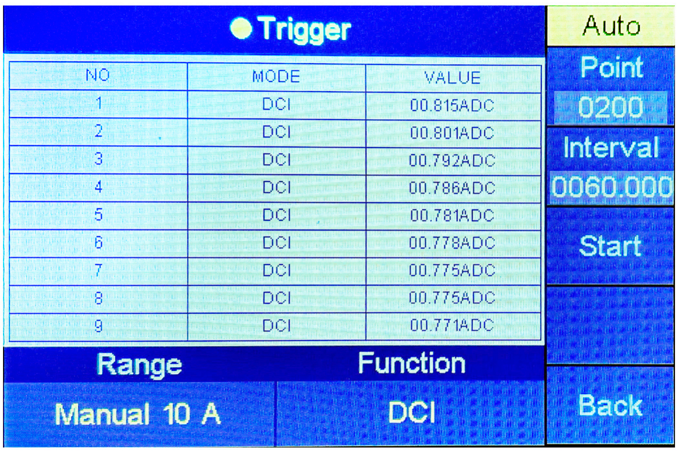

Fig 8: Exp 4 supply current data & sample RDM screen

The voltage supplied to the circuit, kept reasonably constant for the benefit of components, the adjustable voltage applied to the coils, the average total supply current and the run time (in seconds) were used to calculate the energy supplied by the run battery using an algorithm that incorporated the different circuit and coil voltages. This is simplified as:

$E_{(Supplied)} = V_{(av)} \,.\, I_{(av)} \,.\, t_{(Run)}$ J (*Equation 1)*

These are shown in Table 3 for a range of tests together with the data used in the calculations.

	Run Battery (PSU) - Supply									
Test No.	PRF (Hz)	%Duty	Supply V (V) [1]	Circuit Current (A) [2]	Circuit Power (W)	Coil V (V)	I_{av} (A) [3]	Run Time (s)	$E_{(Supplied)}$ (J) [4]	RDM Imaging/Export File
1	100	65	12.50	0.098	1.23	13.0	0.90	900	10,486	*181022-Current Table 1*
2	108	65	12.50	0.099	1.24	13.0	0.90	900	10,485	*181022-Current Table 2*
3	116	65	12.50	0.097	1.21	13.0	0.88	900	10,252	*191022-Current Table 1*
4	108	65	12.50	0.095	1.19	12.50	0.78	900	8,775	*191022-Current Table 2*
5	108	65	11.48	0.095	1.09	12.00	0.66	900	7,084	*201022-Current Table 1*
6	108	65	12.31	0.095	1.17	12.30	0.73	900	8,082	*201022-Current Table 2*
7	108	65	12.71	0.096	1.22	12.70	0.83	900	9,488	*211022-Current Table 1*

Table 3: Supply data

Calculating Total Energy Supplied:

As previously mentioned, the run time is any reasonable value which results in the substantial recharge of the battery. The energy delivered and voltage rise was then plotted on a graph to enable the energy supplied to the generator, for the receiving battery to reach the starting energy level at a voltage of $V_{(pk)}$, to be determined by extrapolation. A run time of 900s (15min) was found to be a good compromise for many tests, although some experiments were conducted with longer times.

In Fig 9 the blue plot line, with the thin black extension line overlaid, is the actual pulse charging undertaken and where a total of 8.78kJ was actually supplied by the PSU (see Table 3). The stabilised charging end voltage of 13.31V was extrapolated to the 'Discharge start voltage' of 13.32V (the reference value $V_{(pk)}$) to give an energy value for full charge of 9.70kJ.

For comparison, the graph of another test, using different variables, is shown in green.

The extrapolation process assumes that the stabilised voltage of the receiving battery is a linear function of the energy supplied to it by the generator. While this is not strictly true,

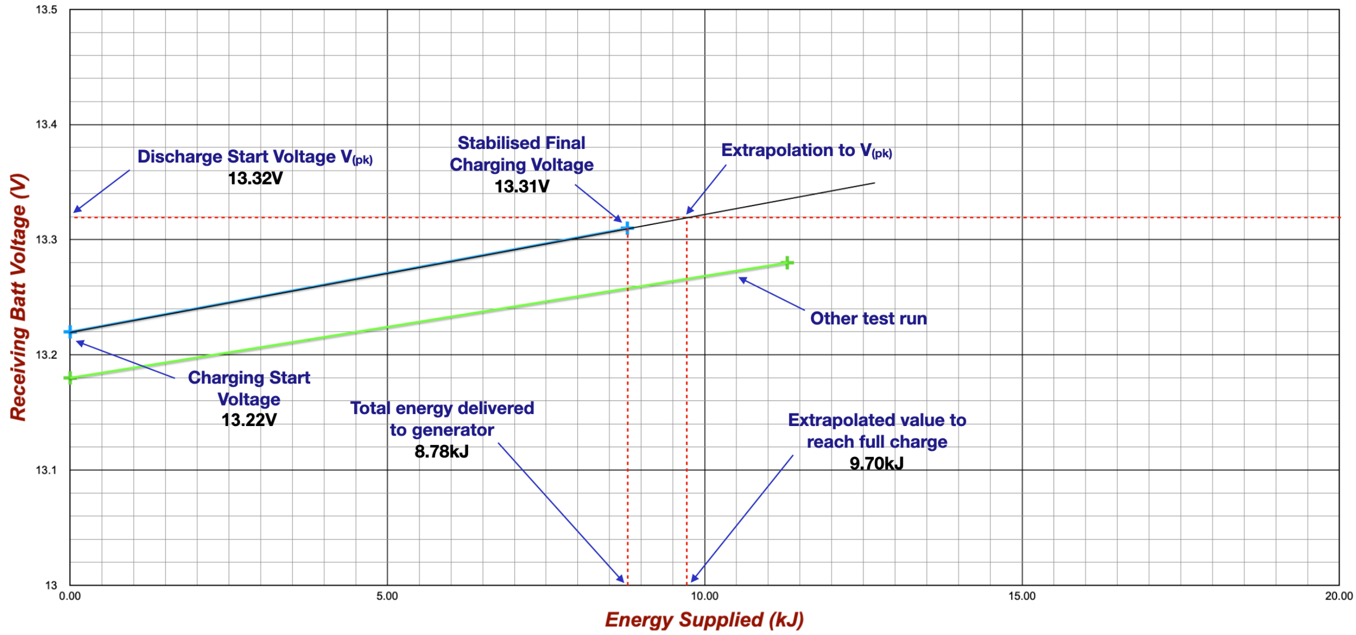

Fig 9: Receiving battery voltage vs Energy supplied

the consistent method of extrapolation used enabled CoP values to be obtained under a wide variety of operating conditions and on the basis that the assumption would constitute a systematic error that would be integrated into the load tests. The calculation of the uncertainties, incorporating most of the random and systematic errors, is discussed below.

CoP Calculations:

Now that we have values for both the energy returned to the receiving battery, to return it to the state of charge at the start of this particular test, and the energy supplied to the

	Receiving Battery - CoP & Uncertainties																
Test No.	**Capacity (Ah)**	**%Ah**	**HV (kV)**	**PRF (Hz)**	$E_{(Received)}$ kJ	Δ_{Er} (kJ)	δ_{Er}	$E_{(Supplied)}$ kJ [1]	δ_V V	δ_I A	δ_t s	δ_{Es}	Δ_{Es} J [2]	CoP	δ_{CoP}	Δ_{CoP}	**CoP ± Δ_{CoP}**
1	7	20.0	1.04	100	63.90	0.36	5.63E-03	39.50	8.00E-03	1.11E-02	5.56E-04	1.97E-02	777	**1.62**	2.53E-02	0.04	**1.62 ± 0.04**
2	7	20.0	1.04	108	63.97	0.36	5.63E-03	11.50	8.00E-03	1.11E-02	5.56E-04	1.97E-02	226	**5.56**	2.53E-02	0.14	**5.56 ± 0.14**
3	7	20.0	1.04	116	64.01	0.36	5.62E-03	12.50	8.00E-03	1.14E-02	5.56E-04	1.99E-02	249	**5.12**	2.55E-02	0.13	**5.12 ± 0.13**
4	7	20.0	1.04	108	63.97	0.36	5.63E-03	9.70	8.00E-03	1.28E-02	5.56E-04	2.14E-02	207	**6.59**	2.70E-02	0.18	**6.59 ± 0.18**
5	7	20.0	1.04	108	63.77	0.36	5.65E-03	9.60	8.71E-03	1.52E-02	5.56E-04	2.44E-02	234	**6.64**	3.01E-02	0.20	**6.64 ± 0.20**
6	7	20.0	1.04	108	63.84	0.36	5.64E-03	9.80	8.12E-03	1.37E-02	5.56E-04	2.24E-02	219	**6.51**	2.80E-02	0.18	**6.51 ± 0.18**
7	7	20.0	1.04	108	63.67	0.36	5.65E-03	11.50	7.87E-03	1.20E-02	5.56E-04	2.05E-02	235	**5.54**	2.61E-02	0.14	**5.54 ± 0.14**
8																	
Equations	$E_{(Supplied)} = V_{(av)} . I_{(av)} . t_{(Vpk)}$ J						$\delta_V = \Delta_v / V, \quad \delta_I = \Delta_I / I, \quad \delta_t = \Delta_t / t$			$\delta_{Es} = (\delta_V + \delta_I + \delta_t) = \Delta_{Es} / E_{(Supplied)}$				$\Delta_{Es} = (\delta_V + \delta_I + \delta_t) \times E_{(Supplied)}$ J			
Equations	$\delta_{Er} = \Delta_{Er} / E_{(Received)}$						**CoP =** $E_{(Received)} / E_{(Supplied)}$			$\delta_{CoP} = (\delta_{Er} + \delta_{Es})$				$\delta_{CoP} = \Delta_{CoP} / CoP \therefore \Delta_{CoP} = \delta_{CoP} \times CoP$ J			
Notes	[1] *Derived from extrapolation or interpolation of Graph 1 - 'Receiving' battery voltage vs '$E_{(Supplied)}$'*																
Notes	[2] *The uncertainty value Δ_{Es} used is the larger computational value rather than the graphical value of 100J derived from plotting and reading the graph of 'Receiving' battery voltage vs '$E_{(Supplied)}$'*																

Table 5: CoP derived values and uncertainties

generator in order to achieve that, the CoP can be derived as the quotient of the two values i.e. **CoP = $E_{(Received)}$ / $E_{(Supplied)}$.**

Table 5 displays the test data for a set of experiments and the data acquired for the specific test run is summarised below.

Test Run Data Summary:

1. The fully charged 7Ah Lithium Phosphate receiving battery was discharged from a voltage of 13.32V to 13.22V with 63.97kJ being expended through the electronic load.

2. The battery was then pulsed charged for 900s (15min), using a PWM frequency of 108Hz and 65% duty cycle and which raised its stabilised voltage from 13.22V to 13.31V.

3. In returning the receiving battery to a voltage of 13.31V, the run battery (PSU) supplied 8.78kJ of energy to the generator. This value was then extrapolated to give a value of 9.70kJ to return the receiving battery to its original full charge starting voltage ($V_{(pk)}$) of 13.32V. At that voltage the total energy returned to the battery, from whatever source, is the same as that discharged, i.e. 63.97kJ.

4. The CoP was calculated as 'Energy received' / 'Energy supplied' and therefore as 63.97 / 9.70 = 6.59. The uncertainties were calculated to give 6.59 ± 0.18 and therefore a CoP in the range 6.41 - 6.77.

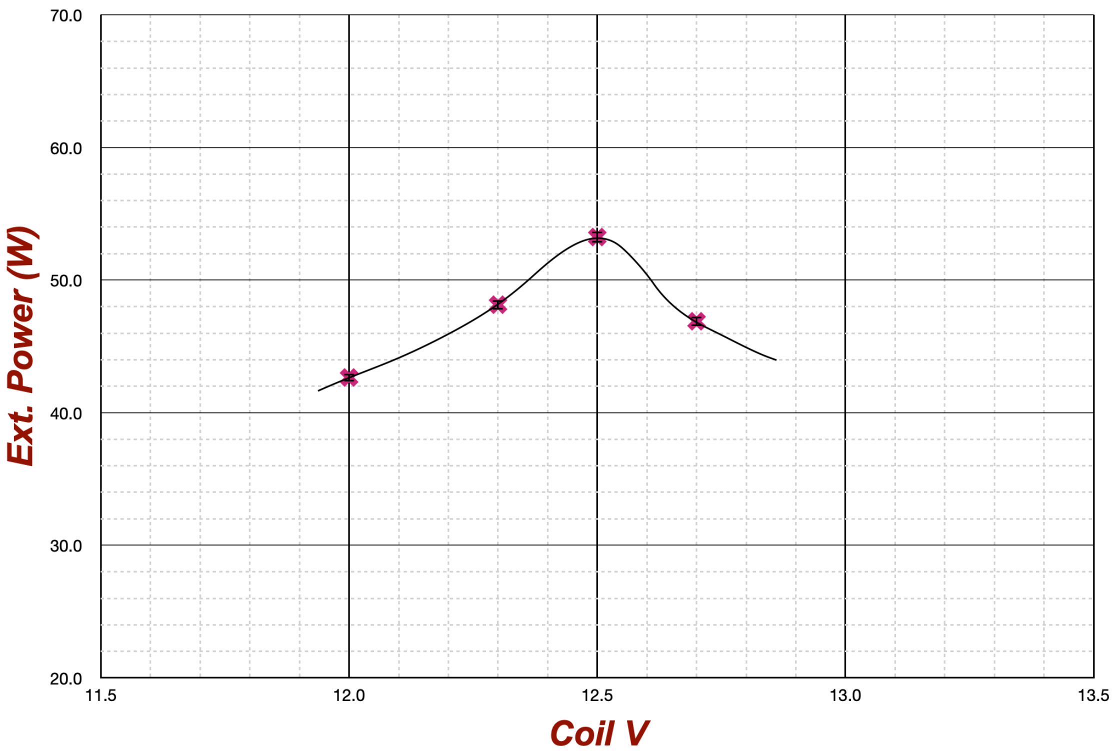

Fig 10: Plot of available external power vs Coil voltage

While it is useful to plot the CoP value against PRF and other variables to note trends, it is equally useful to derive a value for the available external power that can be drawn from the supply battery while not depleting either battery. This is done by calculating the difference between the energy supplied by the run battery to the generator and the total energy returned to the receiving battery. This value, divided by the time taken to reach full charge, provides a good indication of what the live power tests will deliver when they are completed.

Such tests will require the use of the battery swapper so that the energy delivered to the circuit and the external load by the run battery can be replaced when it becomes the receiving battery, a cycle repeating approximately every 15mins. The maximum load that can be supported will be that for which the both batteries never drop below a threshold voltage, indicating that energy harvesting is occurring to maintain their energy state.

A plot of several values is shown in Fig 10 above for a selection of coil voltages and indicates the optimum voltage to apply. Too low of voltage means that there is a significant energy barrier, or voltage 'hurdle', for the pulses to overcome to enter the battery easily, that will often be at a higher voltage, and therefore not enough response from the battery overall. Too high a voltage and energy is wasted unnecessarily, therefore increasing the energy supplied, reducing the CoP and the energy available for an external load.

Table 6 brings together the various calculated values, including theoretical calculations of the power available for an external load over the time taken for the battery to reach full charge. These predictions have yet to be confirmed by live load tests and will be addressed in a future report.

Test No	Capacity (Ah)	Coil V (V)	PRF (Hz)	%Duty	HV (kV)	Energy Returned to battery (kJ) [1]	Energy Supplied to Generator (kJ) [2]	CoP	Energy Available (kJ) [3]	Time Taken (min) [4]	Max Power available (W) [5]
1	7	13.0	100	65	1.04	63.90	39.50	1.62 ± 0.04	24.40	56.25	7.2
2	7	13.0	108	65	1.04	63.97	11.50	5.56 ± 0.14	52.47	16.36	53.4
3	7	13.0	116	65	1.04	64.01	12.50	5.12 ± 0.13	51.51	18.33	46.8
4	7	12.50	108	65	1.04	63.97	9.70	6.59 ± 0.18	54.27	16.67	54.3
5	7	12.00	108	65	1.04	63.77	9.60	6.64 ± 0.20	54.17	20.63	43.8
6	7	12.30	108	65	1.04	63.84	9.80	6.51 ± 0.18	54.04	18.33	49.1
7	7	12.70	108	65	1.04	63.67	11.50	5.54 ± 0.14	52.17	18.33	47.4
8	7	12.50	108	65	1.04	31.36	10.25	3.06 ± 0.10	21.11	17.14	20.5
Notes	[1] Equivalent to energy discharged from 'Receiving' battery							[2] Extrapolated from 'Run' battery data during charging process			
Notes	[3] Energy available from 'Run' battery for an external load when battery swapping enabled to maintain battery charge level. Calculated as 'Energy Returned to Batt.' (1) - 'Energy Supplied to Gen.' (2)										
Notes	[4] Time taken to replace discharged energy to 'Receiving' battery. Calculated from the proportion of the time taken to reach the final charging voltage compared to $V_{(pk)}$ and equals ((Run time + (Run time x ($V_{(pk)}$ - V_{final}) / (V_{final} - V_{start}))) / 60										
Notes	[5] Available power for an external load over the full recharge time. Calculated as Energy Available (3) / Time Taken (4)										

Table 6: Summary Table

Error (Uncertainty) Analysis:

No readings are complete without an analysis of the uncertainties involved in the measurement process. The one main assumption made, the linearity of the charging profile, was consistent throughout the testing process and will be integrated into the results of the forthcoming load tests.

From statistics theory, and using a simplified method of error propagation (cf partial derivatives method), the total relative uncertainty of a value derived from the multiplication of its component values i.e. $E_{(Supplied)} = V_{(av)} \cdot I_{(av)} \cdot t_{(Run)}$ J, is comprised of the sum of the individual relative uncertainties:

Rel. $U_{Es} = \delta_{Es} = \delta_V + \delta_I + \delta_t$

Also $\delta_{Es} = \Delta_{Es} / E_{(Supplied)} \therefore \Delta_{Es} = \delta_{Es} \times E_{(Supplied)} = (\delta_V + \delta_I + \delta_t) \times E_{(Supplied)}$

Although extrapolation has been used to determine the final value of the energy supplied, and a value of Δ_{Es} of 100J (0.1kJ) could have been used based on the uncertainty in reading the X axis value, since the computational value has been calculated at 207J, this larger value has been used in the calculation of the uncertainty.

δ_{Es} has been derived from the equipment specifications and calculated to be 2.14E-02.

$\therefore \Delta_{Es} =$ 2.14E-02 x 9,700 = 207J

For the energy discharged by the CBA, and subsequently returned to the receiving battery, the absolute uncertainty Δ_{Er} = 360J based on the device specifications and a more conservative value of the uncertainty in the measured energy dissipated of 0.1Wh (360J).

$E_{(Received)} = E_{(Discharged)}$ (direct measurement) J

Similarly the Rel. $U_{Er} = \delta_{Er} = \Delta_{Er} / E_{(Received)}$ = 360 / 63,970 = 5.63E-03

For the CoP, the total uncertainty of a value derived from the division of its component values i.e. CoP = $E_{(Received)} / E_{(Supplied)}$, is calculated by adding the component relative uncertainties such that:

$\Delta_{CoP} / CoP = \delta_{CoP} = (\delta_{Er} + \delta_{Es}) \therefore \Delta_{CoP} = (\delta_{Er} + \delta_{Es}) \times CoP$

$\therefore \Delta_{CoP} =$ (5.63E-03 + 2.14E-02) x 6.59 = (2.70E-02) x 6.59 = 0.18

The figures for the calculated uncertainties are shown in Tables 5 and 6 along with the values of CoP. So specifically for Test 4, the value of CoP is 6.58 ± 0.18 and so the actual value lies in the range 6.40 - 6.76.

Conclusions & Discussion:

In designing the various experiments, expectations were that the Coefficient of Performance for the generator, when applying its pulses directly to an AGM battery, would be in the range 0.95 - 1.10 and so serve almost as a control for the later work using the capacitive discharge system and which was expected to perform better.

The derived CoP values were much higher than expected when the system was optimised for best performance. The presence of peak responses, as illustrated for example in Fig 10, show that that are competing factors in the way the battery responds to the pulses and that there is a 'sweet spot' to be found for a particular configuration and the unique properties of the device.

For example, looking at the pulse repetition frequency (PRF), increasing the frequency results in less current draw from the 'run-supply' battery, reducing the operator energy input and therefore increasing the derived CoP value. However, the battery is unable to respond effectively to the pulses that are arriving too fast at the electrodes and so performance falls off. The optimum point has to be found to effect the best performance and balance of factors, and the same approach taken with all the other variables.

With battery capacity (Ah), the choice also reflects the ability of the battery to continuously supply a suitable current to both the circuit and the external load without internal damage arising from heat loss. This suggests that a physically larger 18Ah battery is better suited to the task compared to a 7Ah battery when required to deliver 10-15A over a period of up to 30 mins, even though there was little advantage from the measured CoP values alone.

Earlier experiments had shown that delivering high current pulses, of the order of 100A, to the battery using the 'Cap Dump' circuit, instead of the HV pulses being applied directly to the battery, was much less effective and this strongly suggests that it is dV/dt that is important for the phenomenon. It may be possible to increase the peak HV substantially beyond the current 1.5-2kV range by using an alternative approach, such as using a 'flyback' transformer, although is not yet known if there are qualitative differences between the respective pulses that could change the response at the pulse-chemistry interface.

Table 6 extended the reach of the investigation by calculating how much energy would theoretically be available for an external load but which would leave the batteries with no net deficit of charge or voltage when battery swapping is enabled. In this normal operational mode, this lets one battery provide the power for the generator, together with any external load, and then, when automatically switched over to become the receiving battery, recoup its loses over the next swapping interval. The maximum load that can be sustained in this way is to be explored as part of planned experiments using the optimum parameters determined by these earlier tests.

The peak value of CoP achieved in these experiments is significantly better than a domestic ground or air sourced heat pump, albeit at much lower power levels with this particular setup. However, the science of heat transfer from the environment is both familiar and well understood whereas the science involved in ‘far from equilibrium’ states, such as in high voltage transients, has been widely ignored by the mainstream scientific community, especially in the electronic and electromechanical domains. Indeed the term CoP has been almost exclusively applied in the context of heat transfer despite the fact that, as the simple unitless ratio of two energy values, it can be applied in any context where the energy being transferred is larger than that supplied by the operator alone, whatever the internal efficiency of the mechanism.

For the most part such transients are sought to be avoided as they contribute to electromagnetic interference (EMI) and for which many measures are undertaken to suppress or remove them to prevent damage to sensitive equipment or interfere with results. Perhaps because such transients and non-equilibrium conditions having been labeled as undesirable and problematic in our modern age, then this goes some way to explain why little attention has been given to them and their alternative impact on suitably engineered electrical systems, especially when seen in conjunction with more modern theories such as Quantum Electrodynamics (QED) and related areas.

While many important ideas and theories about less familiar properties of electricity, such as its apparent ‘inertial’ behaviour, have been forwarded by independent and competent researchers over many decades, it is still incumbent on the scientific community to investigate these phenomena more fully and update relevant theories. For example, with the ‘Laws of Thermodynamics’, despite evidence from the 1960s on negative entropy and ‘far from equilibrium’ states, suggesting that a revision is long overdue, they have remained essentially unchanged for the last two hundred years.

Further Work:

As an interim report, this document presents data so far obtained after extensive testing and there are still some pivotal tests to be completed, particularly with regard to power tests using external electronic and other non-inductive loads and the effect of raising the peak pulse voltage towards 2kV.

The curiosity driven investigation will continue to look at those areas highlighted above in an attempt to define those parameters that can be used by others to design a practical and effective implementation of the observed phenomena. Alternatives to the equipment used to generate pulses, such as flyback transformers, is one potentially fruitful area of research, with the prospect of providing much more powerful stimuli for the energy harvesting phenomenon.

Similarly, the work so far has indicated those parameters that have little or no value towards the output performance and which can be removed in a future design. These include the rotor switching system and the ‘cap dump’ circuit with it’s storage capacitors. Removing these elements, which were included for the comprehensive testing regime, would make for a much more compact device and be the basis of a ‘replication’ system for others to build and test.

The quantum vacuum is considered by the author to be a possible source of the energy influx, since the energy gain cannot be readily explained by conventional or classical theories. However, the current project is not suited to test that particular hypothesis so there is still ample opportunity to investigate the deep seated mechanisms further with their potential impact on current electromagnetic and quantum field theories. Also, the results of some preliminary results using super capacitors, strongly suggest that the battery’s electrochemistry is central to the phenomenon which raises valid questions regarding the role of chemical bonds, domain and boundary effects and thermodynamic asymmetry within the bulk of the system.

While mainstream scientific confirmation of what is occurring at a deeper level may be years away, there is nevertheless a range of working theories based on currently accepted science, and the longstanding work of other researchers. Some of these will be presented in the impending paper for publication along with the continued findings.

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