Monitoring AC Wall Voltage in the HEP Building

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Abstract

Monitoring possible external disturbances to Large-Area Picosecond Photodetector (LAPPD) production in HEP 321 is important because wall voltage fluctuations could possibly introduce shifts or sudden events in tile-production process parameters such as temperature or photocurrent. Indeed, the building power fluctuates as much as 4.1 V (3.2%) over the course of a single day, and shows interesting behaviors such as regular spikes at 12-h intervals, and quieting during weekends and holidays, during which standard deviation falls to a smooth $\pm$ 0.3 V from normally noisy $\pm$ 0.6 V during the week. Fortunately, plotting the wall voltage's correlation to the Kiethley and photocurrent measurements suggest that the fluctuations have not, as of yet, had significant impact.

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1 Wall Voltage Monitor

1.1 Equipment & Setup

Wall voltage monitor implementation involves an AC-to-AC "wall wart"[1], a full-wave rectifier, a low-pass filter, and a simple voltage divider to produce a varying DC signal readable via LabJack [2].

The "wall wart" is an AC-AC step-down transformer that takes an input of 0-120 V AC, 60 Hz up to 30 W. It outputs 0-12 V AC, 60 Hz with a maximum output power of 20 W. Full-wave rectification via four diodes, low-pass filtration with a time constant of 18 s ± 1 s, and stepping down the voltage through a voltage divider (values given in circuit diagram), produce a DC signal of at most 55 mA, which the LabJack samples every 4 seconds. A Raspberry Pi [3] converts this DC voltage according to our calibration equation:

$$V_{AC} = (0.1841 + V_{DC})/0.0283 \quad (1)$$

The choice of a time-constant of 18 s (leaving us with a cutoff frequency of roughly .008 Hz and period of 114s) was based primarily on the fact that the wall cycles at 60 Hz. Filtering out this single frequency meant cutting off at a significantly lower frequency, around $1/2\pi$. This initial calculation produces a time-constant of approximately 1 second. Further refinement to the current value was based on a desired precision of 0.1 V on a reading of 120 V. This dictates that

$$V_{max} * e^{(-f_{wall}/2\pi(RC))} = V_{max} - V_{err} \quad (2)$$

$$V_{max} * e^{(-f_{wall}/2\pi(RC))} = 120.0V - .1V \quad (3)$$

So

$$120V * e^{(60/2\pi(RC))} = 119.9V \quad (4)$$

Which gives a desired value

$$RC = 20s \quad (5)$$

The time constant in implementation is 18 s. This calculation was based on half-wave rectification, and so becomes more than sufficient for full-wave rectification, when f_{wall} is essentially doubled.

[1]MG Electronics Plug In Transformer model MGT 1220; MGT 1220 product information: http://www.mcmelectronics.com/product/MG-ELECTRONICS-MGT-1220-/82-1550

[2]LabJack U6 product information: https://labjack.com/products/u6

[3]Raspberry Pi 2 Model B, product information: https://www.raspberrypi.org/products/raspberry-pi-2-model-b/

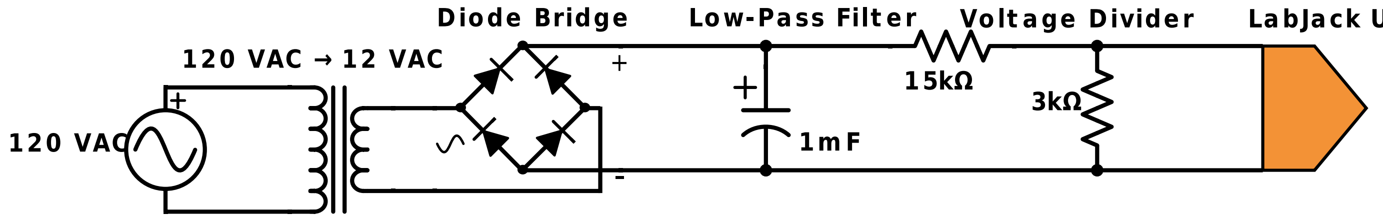

Figure 1: Wall Voltage Monitor Schematic. 120 VAC wall supply is initially stepped down to 12 VAC. It is then rectified by a diode bridge and low pass filtered to smooth the resulting DC signal. Finally, this DC signal passes through a voltage divider to reach a final value that the LabJack U6 can read. A Raspberry Pi converts this DC voltage to the corresponding AC voltage.

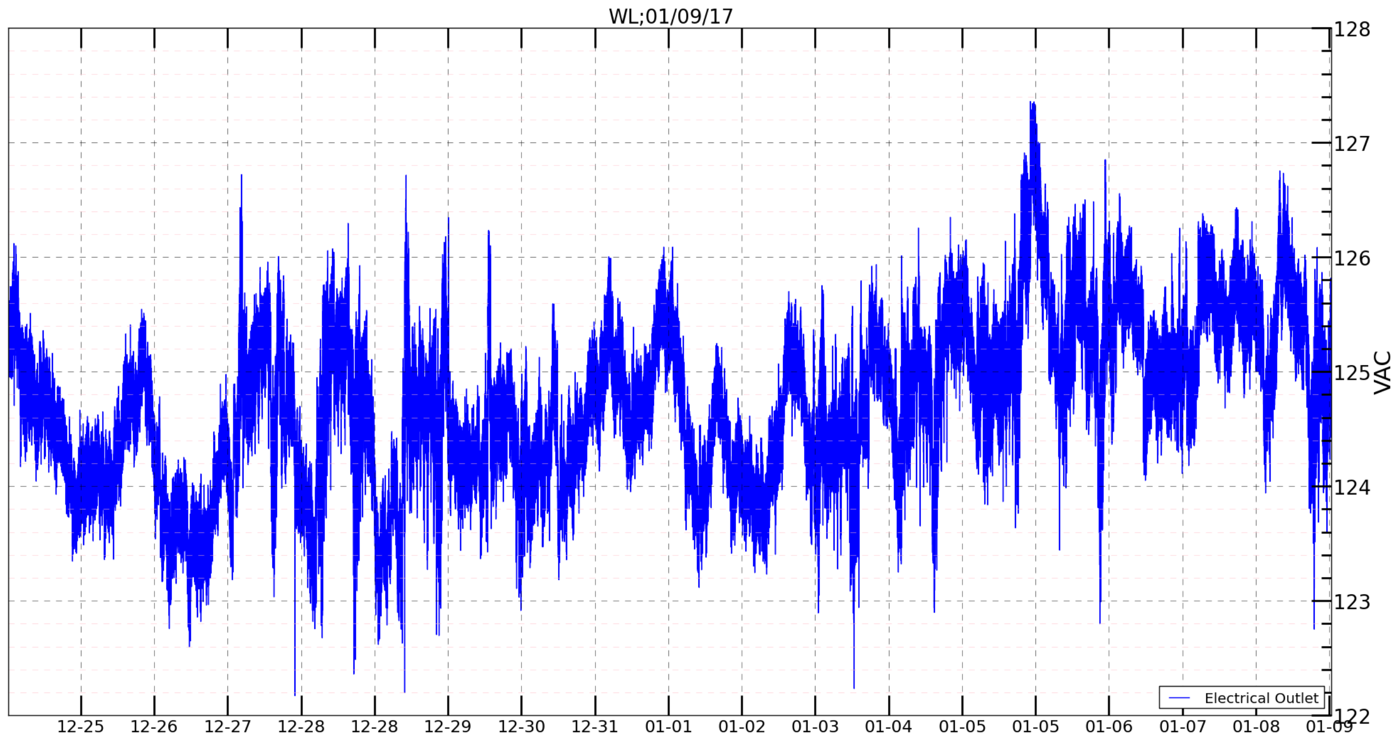

Figure 2: AC Wall Voltages over a 17-day period. The voltage fluctuates less over weekends (Dec. 10, 11, 17, 18, and Jan. 6, 7) and is even more stable on holidays (Dec. 24, 25, 31, and Jan. 1). This is visually evident in the figure and is also evident analytically; on weekends the standard deviation in wall voltage drops from the weekday 0.67 V to a mere 0.30 V. Less evident, however, is whether the signal exhibits periodicity. As found in Fig. 4, the AC voltage RMS is comprised of random noise over the intervals of interest (24 hours).

1.2 Weekday vs. Weekend Deviation

Fig. 2 plots the wall voltage over time. On weekends, such as Dec. 10-11, Dec. 17-18, Dec. 24-25, Dec. 31 - Jan. 1, and Jan. 6-7, the wall voltage quiets. During those intervals, the

Representative Day	Measurement	RMS	Standard Deviation
Weekday: Thursday, Dec. 14	Wall Voltage (V AC)	123.6	0.7
	Keithley (μA)	7.30	0.04
	Photocurrent (nA)	5	4
Weekday: Tuesday, Jan. 3	Wall Voltage (V AC)	124.9	0.5
	Keithley (μA)	7.30	0.02
	Photocurrent (nA)	6	5
Holiday Weekend: Saturday, Dec. 24	Wall Voltage (V AC)	125.1	0.3
	Keithley (μA)	7.83	0.02
	Photocurrent (nA)	0.314	0.003
Holiday Weekend: Sunday, Dec. 25	Wall Voltage (V AC)	124.2	0.3
	Keithley (μA)	7.622	0.008
	Photocurrent (nA)	0.312	0.003

Figure 3: Summary of data: Wall voltage fluctuates more during weekdays, when standard deviation $\sigma = 0.5$ to 0.7 V than during holiday weekend days, when standard deviation $\sigma = 0.3$ V.

standard deviation from the average RMS drops from the weekday 0.67 V to a mere 0.30 V. As notable on holiday weekends, in particular Dec. 24-25 and Dec. 31 - Jan. 1, the wall voltage quiets ($\sigma = 0.33$ V), rises to average 125.1 V over the course of Saturday, then falls to 124.2 V and quiets ($\sigma = 0.30$ V) over the following Sunday. These findings, reflections of the community's energy habits and the responses in the power supply, are summarized in Fig. 3.

1.3 Fast-Fourier Transform: Periodic Structure

Plots such as Fig. 2 seem to exhibit regular rises and falls based on superficial inspection. Fig. 4 shows the Fast-Fourier transform (FFT) of the 1000-bin dataset of wall voltage on Dec. 31, producing a plot of voltages in frequency space. While a periodic, discrete dataset would Fourier transform into a set of distinct points in frequency space, the FFT of the wall voltage over this 24-hour period is distinctly different. In frequency space, Dec. 31 data are clearly composed of a finite series of periodic functions, all conspiring to form a rough Dirac delta function centered at zero. This transform is the expected shape for the FFT of a discrete, non-periodic dataset.

Fig. 4 plots the absolute square of the complex-FFT amplitude against positive frequencies. The frequencies around zero – that is, slow oscillatory functions – are represented to an greater extent (two orders of magnitude greater), as expected, since the filtered signal is nearly constant. Meanwhile, higher frequencies are evenly and less present. The constancy of the distribution of frequencies away from zero reveals no periodic structure, but rather suggests that the wall voltage RMS is random noise.

The length of a bin, in Hertz, in frequency space is

$$\Delta f = (f_b/N) \tag{6}$$

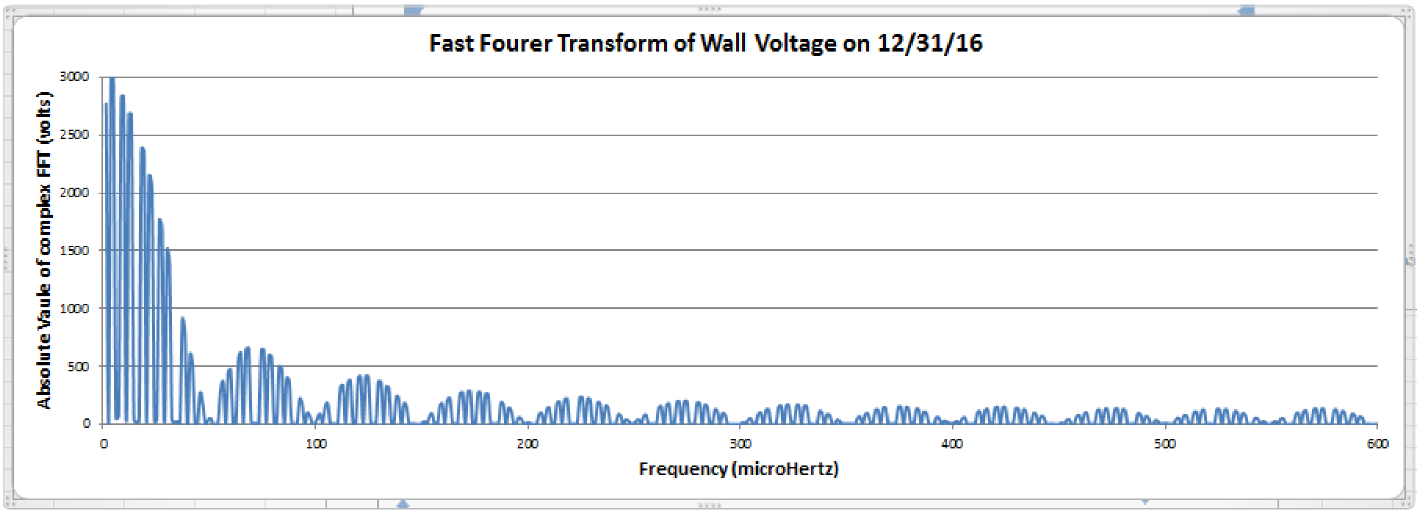

Figure 4: To identify any periodic structure in the wall voltage over the course of a 24-hour period, the 1000-bin wall voltage data set underwent a Fast-Fourier transform, producing the above plot in frequency space. A discrete, non-periodic dataset in time-space is expected to manifest as a finite sum of sine waves in frequency-space. Our transform shows this behavior in the plot above, where the absolute square of the complex-FFT amplitudes for positive frequencies are shown. Moreover, the frequencies around zero are highly represented, while other frequencies are evenly and less present. This low frequency representation reflects the expected transform of the constant, filtered reading. The constant distribution reveals no periodic structure, but rather random noise.

where f_s is the binning frequency (1000 bins / 24 hours), N is the number of bins (1000). This yields

$$\Delta f = 1.2 \mu Hz \tag{7}$$

which means that the 500 positive-frequency bins span the frequency-space interval of 0 to 5.8 mHz. This upper limit on frequency confirms the minimum period allowed in a dataset in which points are 86 seconds apart. A minimum of (2n+1) points are required to specify n periods, which means that our minimum measurable period is 172 s. This corresponds to a maximum frequency of 5.8 μHz which agrees with our conversion calculation of the bins' units into Hertz.

In addition, a lack of periodic structure helps verify that the readable signal is properly filtered. Given the finite sampling rate of the LabJack (measurement every 4 seconds), periodicity would suggest remnant alternating current. Fortunately, lack of periodicity suggests that the circuit detailed above has suppressed alternating behavior sufficiently.

1.4 Time-Derivative Correlation with Project Measurements

Of particular interest to the LAPPD project is whether these disturbances in wall voltage affect measurements. Sensitive measurements such as the Keithley [4], photocurrent, temperature, and pressure measurements can potentially receive manipulation from fluctuating building voltages. Finding correlation would suggest that the wall voltage affect measurements, since it is far less likely that measurement instruments draw enough current to illicit responses in the wall voltage. The search for such influence involved plotting the time-derivatives from these measurements

[4] The Keithley is a measurement of the current across all the MCPs in the Margherita.

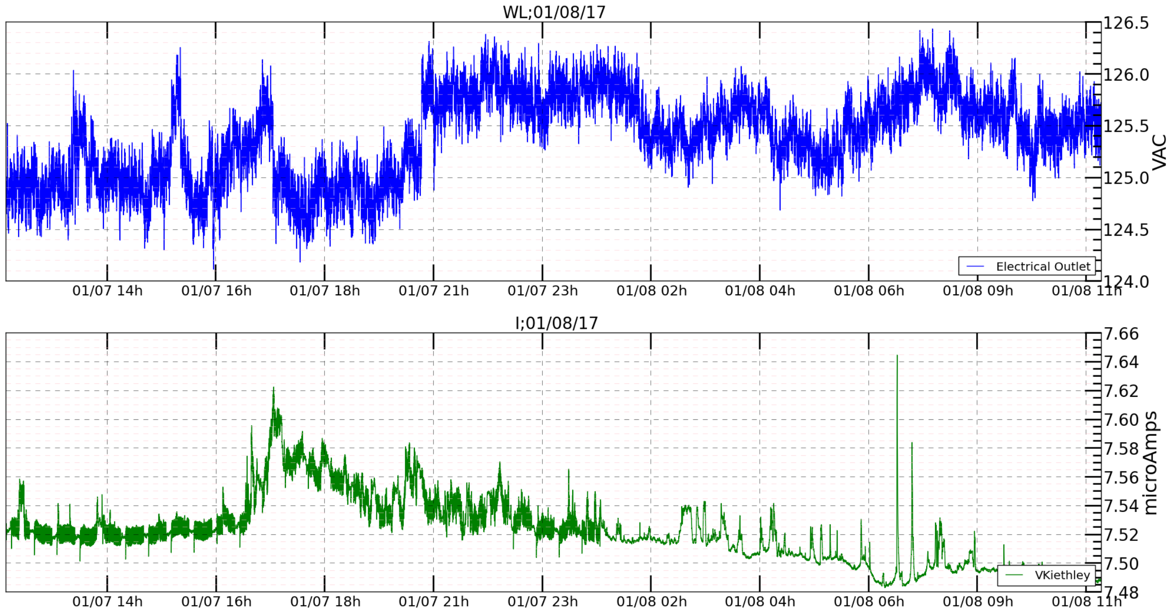

Figure 5: The Keithley is a measurement of the current across all the MCPs in the Margherita. This figure juxtaposes Wall Voltage RMS with Keithley measurements. Although it is impossible to account for other factors, the two measurements exhibit independence and no strong correlation (Fig 6). Kiethley, thus, has historically displayed independence of its power supply.

against wall voltage time-derivatives and searching for correlation. This approach shows that if there is correlation in in the first derivative, then there is correlation in the zeroth derivative, and if there is no correlation in the first derivative there is no correlation in the zeroth derivative. However, that such a correlation exists on a local scale is unlikely. Fig. 5 gives a visual representation of some sample data. Fig. 6, Fig. 7, and Fig. 8 show insignificant correlation of the wall voltage time-derivative to the time-derivatives of Kiethley, photocurrent, and temperature, respectively.

1.5 Conclusions

Fortunately, no measurable correlation has yet been found between the wall voltage and either Keithley, temperature, or photocurrent measurements. If anything, the cumulative activity of the building has more of an effect on the wall voltage than the wall voltage has on lab measurements; a clear distinction emerges between workdays (σ = 0.6 V) and off-days (σ = 0.3 V). In addition, Fast-Fourier transforms reveal a lack of periodicity in the wall voltage RMS. Thus, the wall voltage is virtually entirely composed random noise, despite its periodic appearance in Fig. 2.

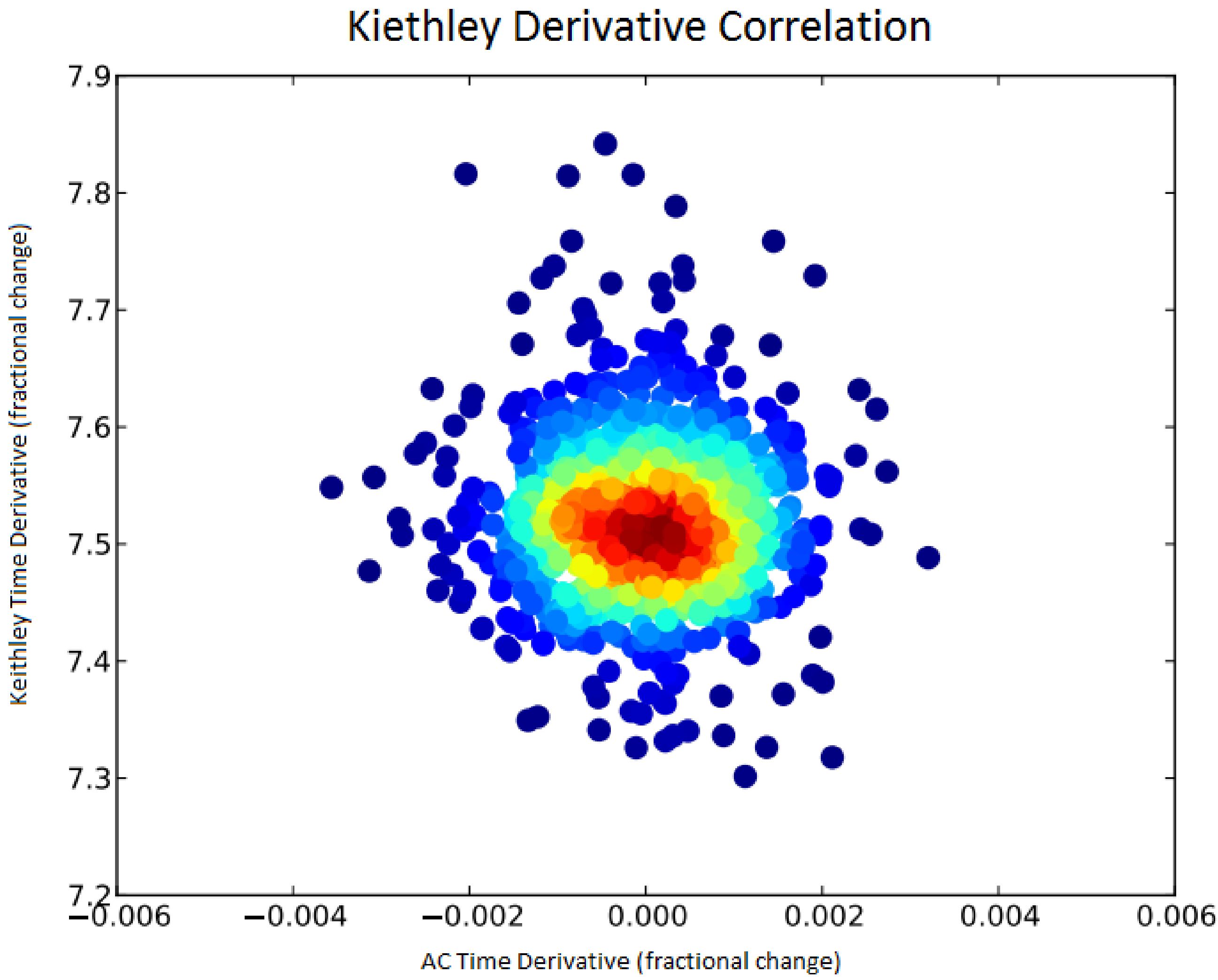

Figure 6: Kiethley, a measurement of current across the Microchannel Plates in the Margherita photodetector, is expected to remain independent of wall voltage. Any correlation between the time derivatives would imply correlation in the values themselves (the reverse is not necessary). AC wall voltages and Keithley currents over Dec 31, 2016 were averaged into 1000 bins. The time derivative of the nth bin was estimated as the percent change from the nth to the (n+1)th bin. The above density plot confirms the lack of correlation between the two sets of time-derivatives.

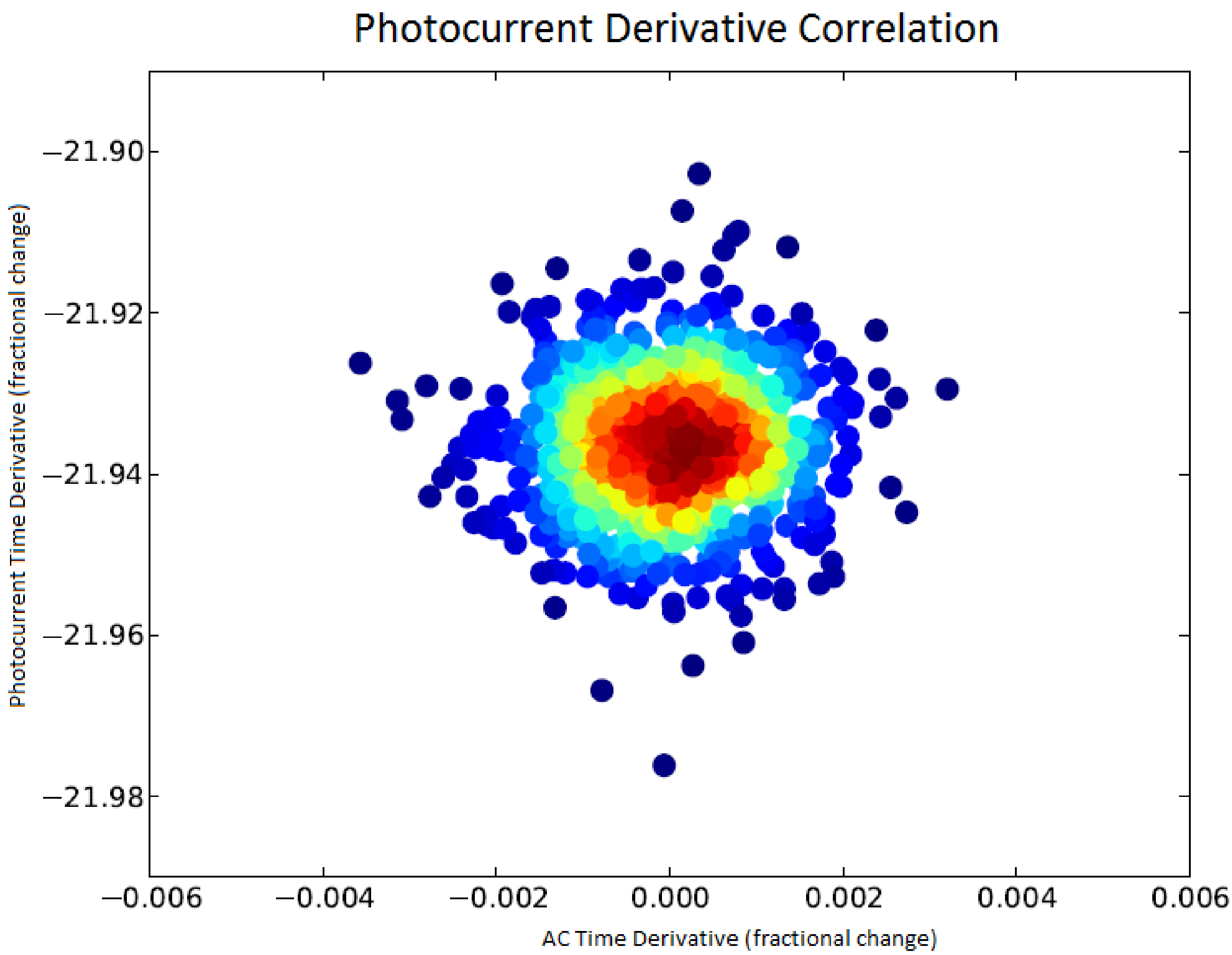

Figure 7: Plots the derivative of wall voltage measurements against the natural log-scaled time-derivatives of photocurrent measurements on December 31st 2016. These measurements were averaged into a 1000 bins. Any correlation between the time derivatives would imply correlation in the values themselves, but the reverse is not necessary.The graph shows that-with exception of a few outliers-there is a large density of points centered around the origin. This in turn implies that there is no correlation between the first derivative in the ac wall voltage and photocurrent, which implies no correlation between the ac wall voltage and photocurrent.

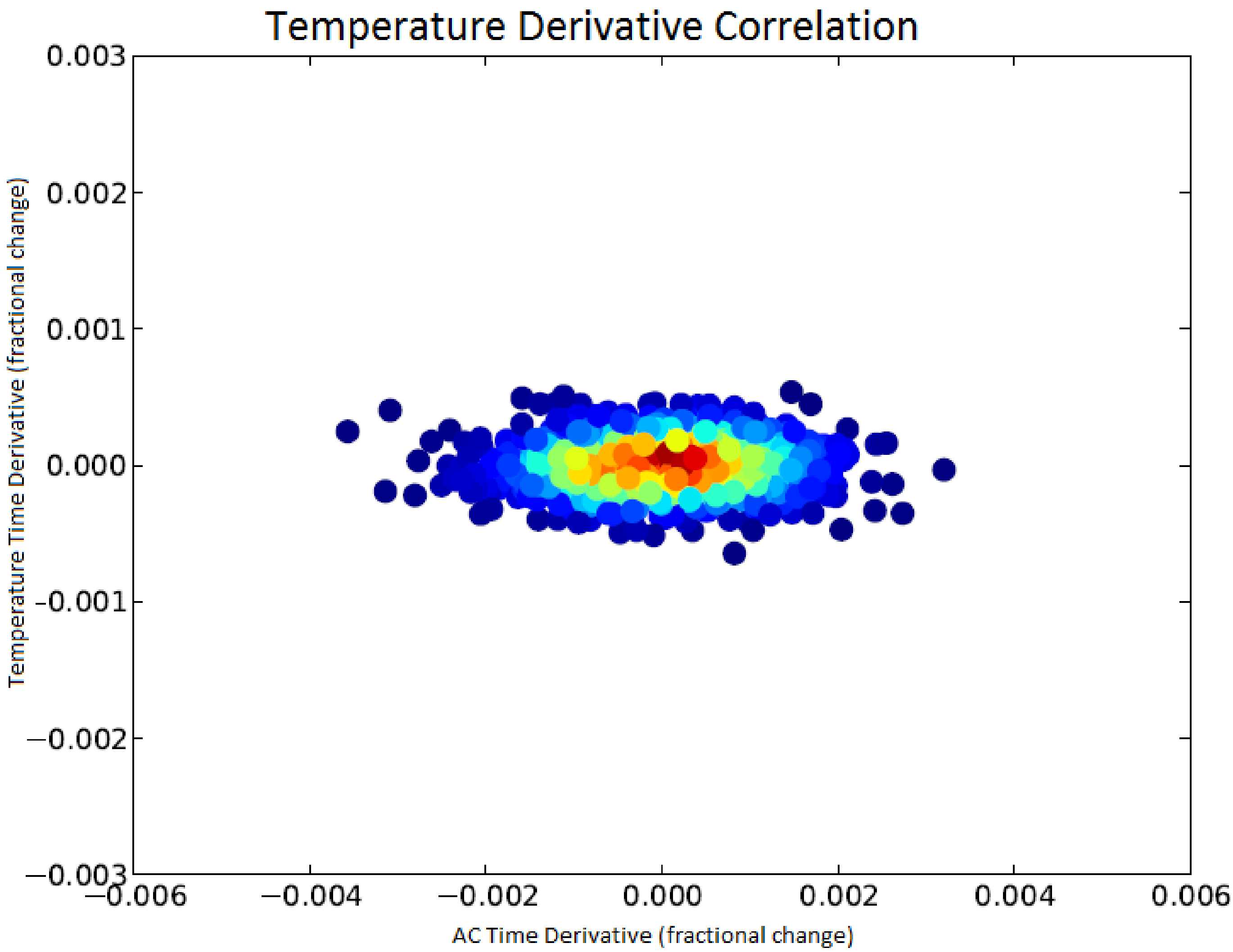

Figure 8: Plots the derivative with respect to time of the temperature measurements vs. time-derivative of wall-voltage on December 31st 2016. These measurements were averaged into a 1000 bins. The graph shows that-with exception of a few outliers-there is a large density of points centered around the origin. This in turn implies that there is no correlation between the first derivative in the wall voltage and temperature, which implies no correlation between the ac wall voltage and temperature.