Plant Modulation Schema

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Introduction:

Plants appear to have the equivalent of an autonomic nervous system that is present and detectable at all times. To date there have been invasive plant electromyograph measurements noting the plant's reaction to an external stimulus. Researchers also believe that this autonomic activity is based on the use of glutamate to speed reactions. Others feel that plants may have a central nervous system but no brain. However, what is the function of a "brain"? Could a brain be described as the coordination of processes for living, reproduction and growth?

Using a non-invasive sensor, electromagnetic signals have been detected emanating from plants. The complexity of the modulated signals detected within a plant, in this case mainly a Money Plant, are far beyond simple signal structures that would seem to imply a coordinating entity or a brain.

This paper will study the signals detected by the plant sensor.

Test Setup:

Figure 1 shows the test setup used for this experiment. Two plant sensors are used for this measurement so as to measure two points simultaneously. In this case one sensor monitors a leaf and the other the trunk. For information purposes only, up to 6 sensors can be used and the measurements, are made sequentially instead of simultaneously, can be taken at arbitrary time intervals. These measurements were taken at 15 minute intervals. The sensors only need to make proximal physical contact with the surface to be measured. At each time interval the plant sensor measurements are recorded, the ambient conditions such as temperature, humidity, ambient light as well as near infra-red are also measured.

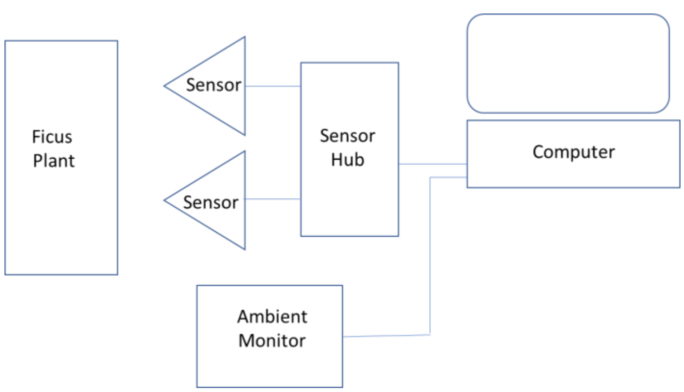

Figure 1 Test Setup

Waveforms:

Figure 2 shows 6 traces. The top two traces are 25 millisecond [ms] Time Domain captures. The Amplitude units are arbitrary and linear. The measurements were made with a 12 Bit analog to digital converter at a sample rate of approximately 0.75 MegaSamples per Second. The second set of two traces are a differentiation, or Delta trace, of the Time Domain shown in the upper two traces. The first trace in the set of two is the leaf and the second trace is the trunk. The last row of traces are a Sub-Carrier plot of both waveforms and a Fourier Transform Frequency Domain plot of the two Time Domain traces shown in Figure 2. The Sub-Carrier plot is the resultant of subtracting the Delta plot from the original data captured by the sensor in the uppermost row. The x-axis of the Fourier plots, shown in the bottom right, represents frequency from 0 Hertz [Hz] to 500 kiloHertz [kHz]. The y-axis is the normalized linear amplitude and the units are arbitrary. The reason the data is normalized to the maximum value is so that the results can be compared with other data captures, since the relative frequency distribution is more important than the actual amplitude.

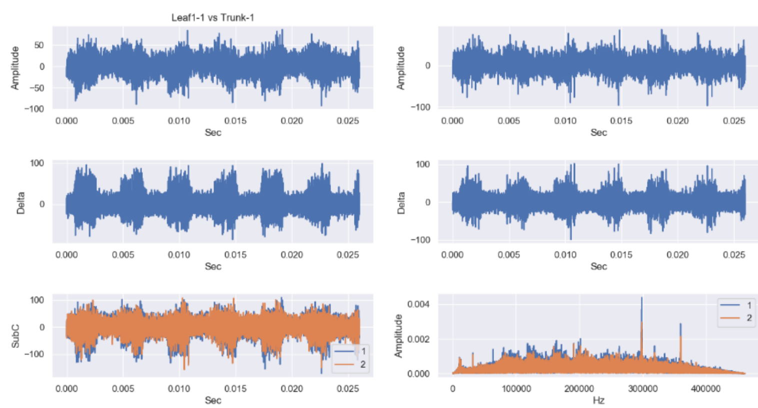

Figure 2 Full Time Sweep

While the uppermost traces do show a periodic structure with respect to time, the Delta traces show a consistent periodicity to the envelope of the signal. Even though it is not immediately obvious in the Time Domain trace; there are clusters where specific activity is greater in amplitude and areas which appear to have less amplitude. This portion of the analysis will concentrate mostly on the Fourier and Delta plots.

Figure 3 shows the second cluster seen in the Delta plot of Figure 2. The Leaf measurement is shown on the left and the trunk measurement is shown on the right. The first row is the time domain and the second row is the Delta. The spectrum of the time domain traces are richer in spectral content but here only the Delta will be analyzed for simplicity. The lower right trace is the frequency domain plot of the Delta plots and the lower left plot is the Sub-Carrier time domain plots Note the level of activity observed in the Frequency Domain plot in the lower right-hand corner; its significance will be elaborated upon next.

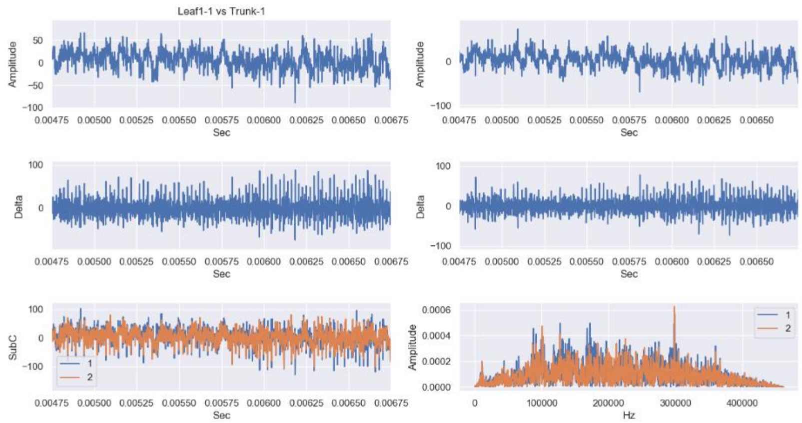

Figure 3 Second Data cluster

Figure 4 is a zoomed in section of cluster two. The frequency domain plot in the lower right-hand corner appears to be less active spectrally. The reason for this is that the integration time is less since 40 microseconds was arbitrarily chosen as the window time. This window time will be used to demonstrate ways that these waveforms can be used in various waveform analyses.

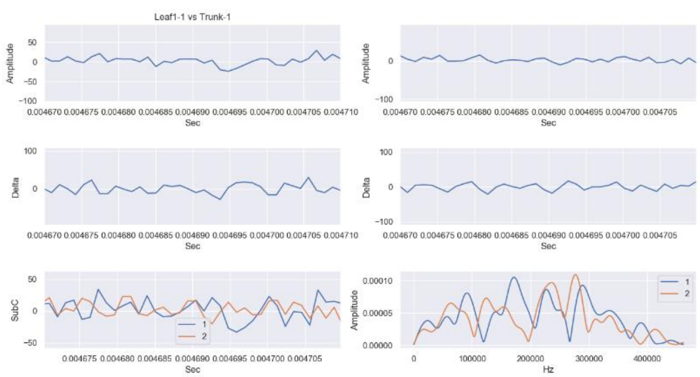

Figure 4 Zoomed in Section of Cluster 2

It may be that the plants communicate and carry out biologic processes with more than chemical reactions but with complex frequency structures and not the simple data structures that are familiar to us such as the use of discrete levels of 1's and 0's. In the paper "**Resonance electroconformational coupling: a proposed mechanism for energy and signal transductions by membrane proteins**" by T Y Tsong, et al state:

"Recent experiments show that membrane ATPases are capable of absorbing free energy from an applied oscillating electric field and converting it to chemical bond energy of ATP or chemical potential energy of concentration gradients. Presumably these enzymes would also respond to endogenous transmembrane electric fields of similar intensity and waveform. A mechanism is proposed in which energy coupling is achieved via Coulombic interaction of an electric field and the conformational equilibria of an ATPase. Analysis indicates that only an oscillating or fluctuating electric field can be used by an enzyme to drive a chemical reaction away from equilibrium. In vivo, the stationary transmembrane potential of a cell must be modulated to become "locally" oscillatory if it is to derive energy and signal transduction processes."[1]

It may be that these membrane ATPases are reacting to these signals and it may further be possible that the Sub-Carrier signal may delineate each electromagnetic message structure.

It appears that there is some complex messaging being carried out within the plant. The purpose of this paper is not to get into the similarities between the messages found within the leaf versus the trunk although that is possible. The purpose here is to delve deeper into the possible applications that may be derived from the activity found in the frequency domain data.

Comparing Similar Plants:

Observing how plants react to various stimuli in real time can allow a view into how a plant reacts to watering schedules, fertilizer, light exposure, temperature and possibly heritage. Data has been captured under various conditions and the results, to date, has been very promising. A brief glimpse into some of these observations will now be presented.

Plant Reactions:

If two identical plants are exposed to the same environment and observed simultaneously when both receive the same stimulus it is assumed that their reactions should be the same. Taking two plants that are dissimilar in a known way, it should be possible to deduce how much that dissimilarity affects their responses to a given identical stimulus.

Determining Similarity:

The first experiment was to take some cannibus sativa plants and determine how they respond to ambient conditions. There was nothing special done to affect the plants and multiple measurements were made over time for comparison purposes. The baseline plant was named Blockberry and its detected signal was compared to every other plant in the matrix of available plants of which there were 9.

Figure 5, Figure 6 and Figure 7 show the degree of matching from the least to the most. From these examples it appears that their desired qualities could be compared and tabulated. Then, with enough testing, the data could be correlated with the data contained within the graphs below to gain a basis to trend the data against desired qualities.

Even though most of the data sets seem to correlate with one another, it is the Spectral plots that seem to be the great differentiators. From the data it appears that looking for degree of matching should be a relatively straightforward process.

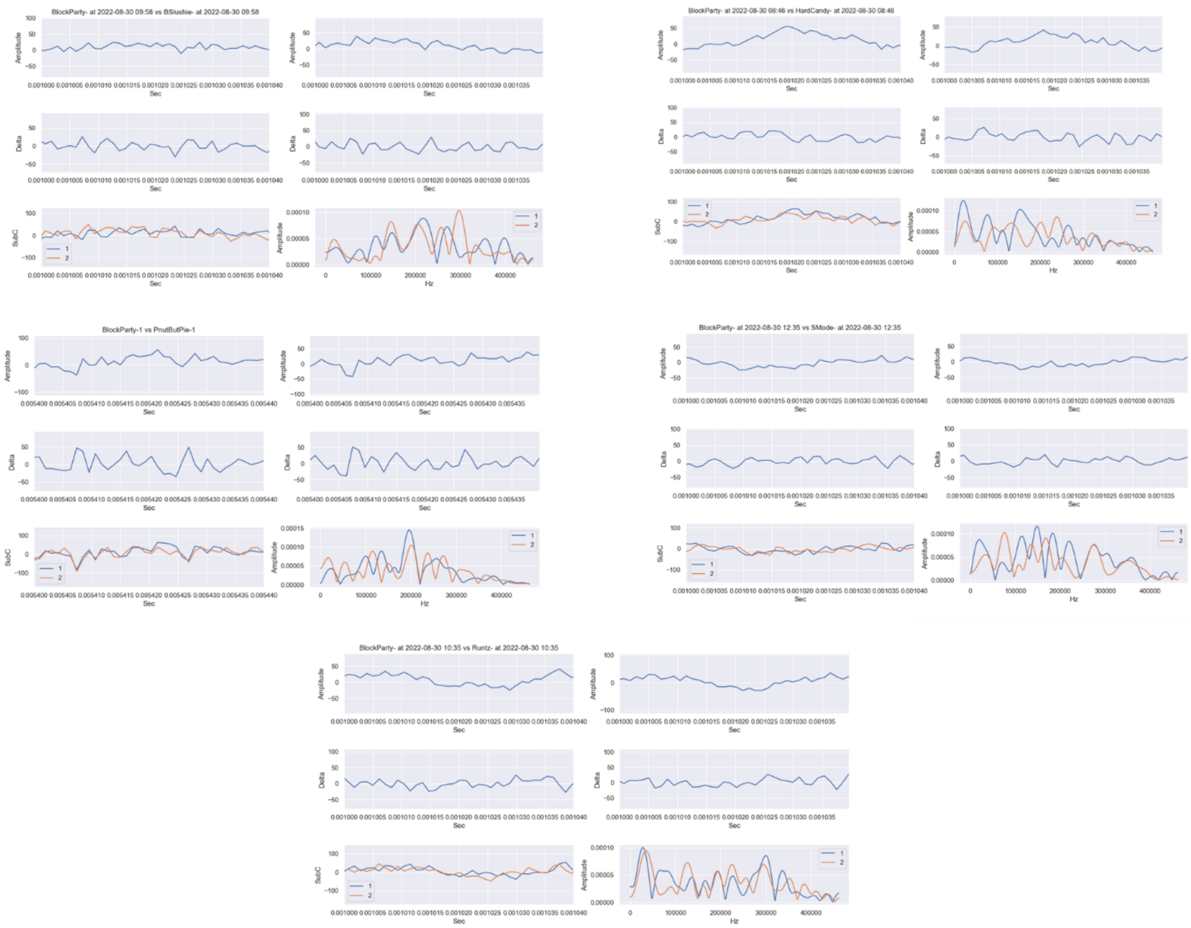

Figure 5 No Apparent Match

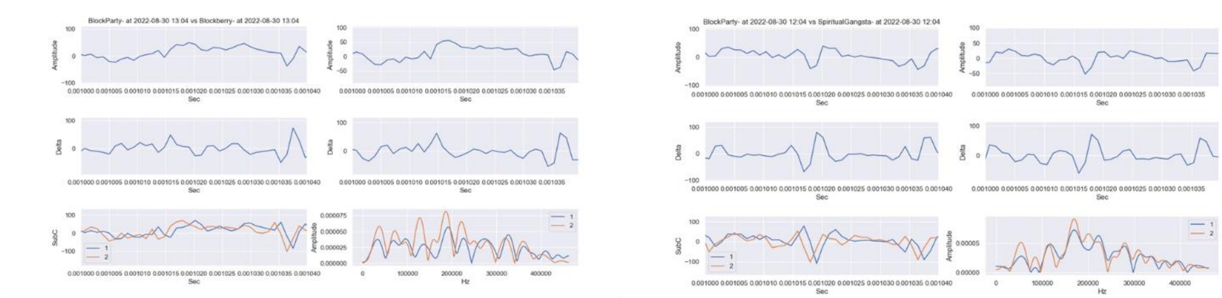

Figure 6 Slight Match

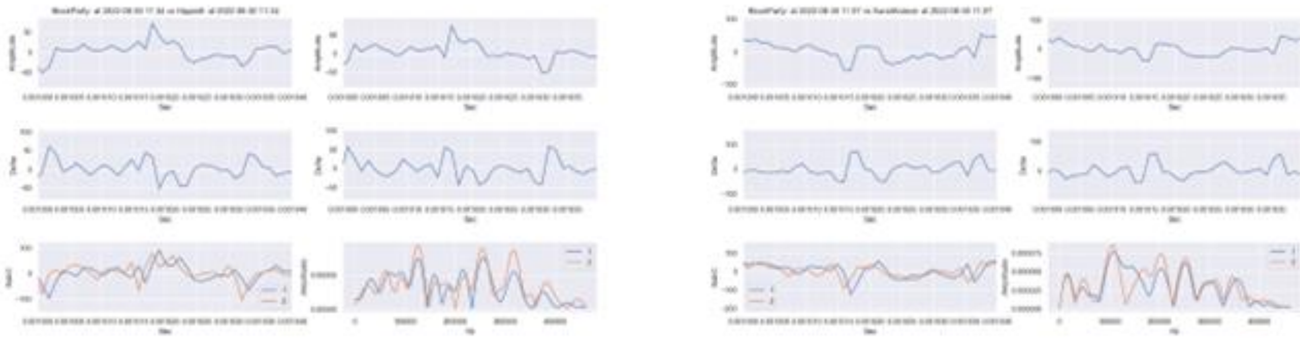

Figure 7 Close Match

Plant reaction to Watering – Pepper Plant:

Pepper Plants, in a greenhouse located in the desert, were watered on a periodic basis. For this experiment water was removed from 4/12/2022 at 11 AM which corresponds to measurement 917 and watering was resumed at 4/14/2022 at 11:20 AM which corresponds to measurement 1103. The measurements were taken at intervals 15 minutes apart. The measurements are also time stamped. The following figures will show samplings of the data taken to show the possible utility of the measurements for determining the overall health and/or stress level of a plant at a given time under certain known conditions.

Figure 8 shows a Pepper Plant measured before the water is removed and when the plant is in a fair amount of distress because it had not been watered for two days in an arid environment. It can be readily observed that the time domain signal level peak to peak level for the measurement just before the watering is resumed is twice the amplitude of the case on the left and also the plant seems to be in some sort of distress since the waveform has changed drastically.

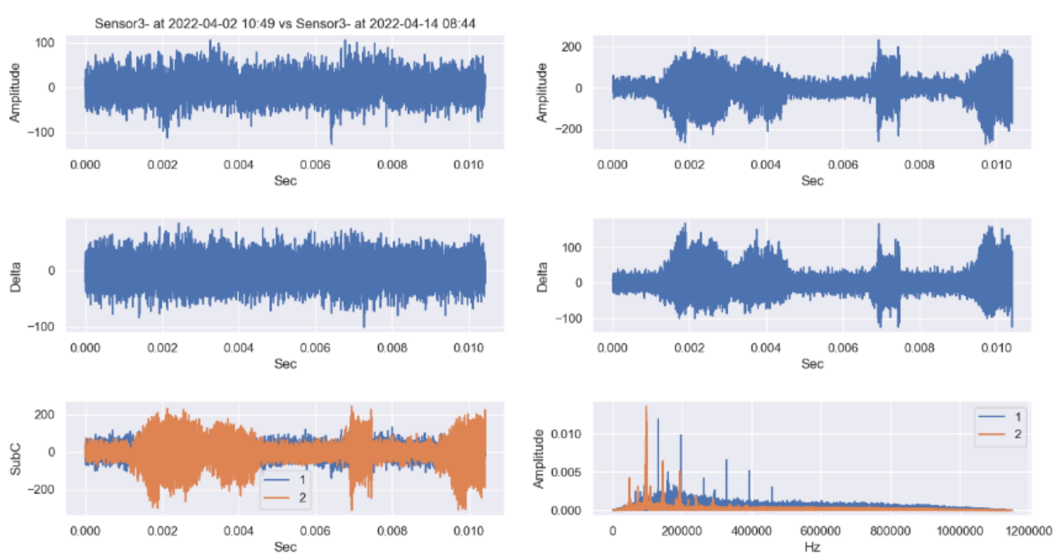

Figure 8 Pepper Plant before water is removed and just before watering is resumed

Figure 9 is the Sub-Carrier response at the beginning of the experiment and just before watering is resumed. What stands out here is that the Sub-Carrier response just before watering is resumed is much lower than at the beginning of the experiment. Perhaps going to a wideband view and finding out if there is another frequency range that is dominating the power consumption percentage would be helpful in understanding this result.

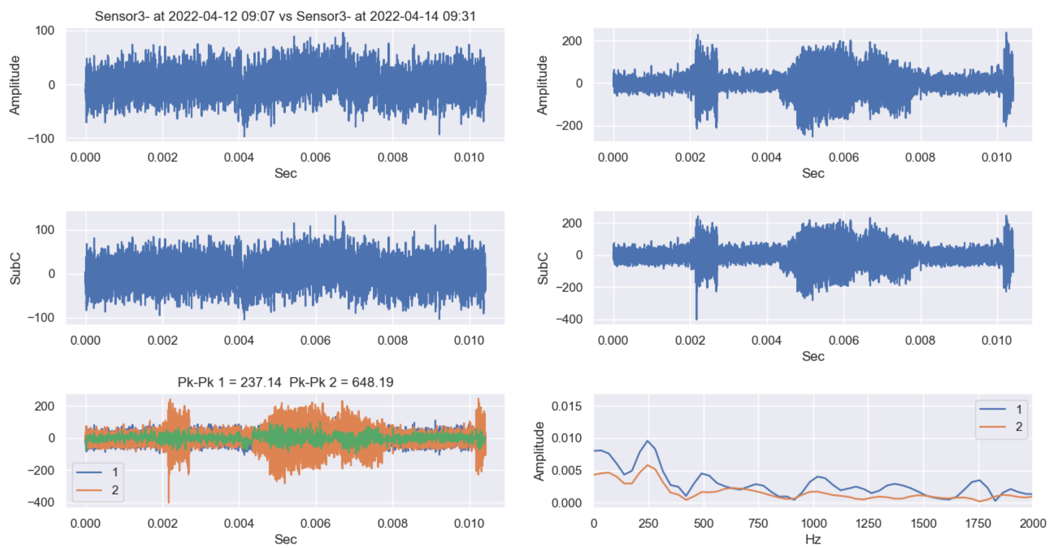

Figure 9 Sub-Carrier before water is removed and just before watering is resumed

Figure 10 shows the area of the spectrum which is dominating the normalized band energy. As can be observed, the spectrum around 97 kHz is dominant for the time just before watering resumed and was basically noise before the water was removed. This helps to explain the phenomena of having the Zero Frequency value appear lower and therefore implying less stress.

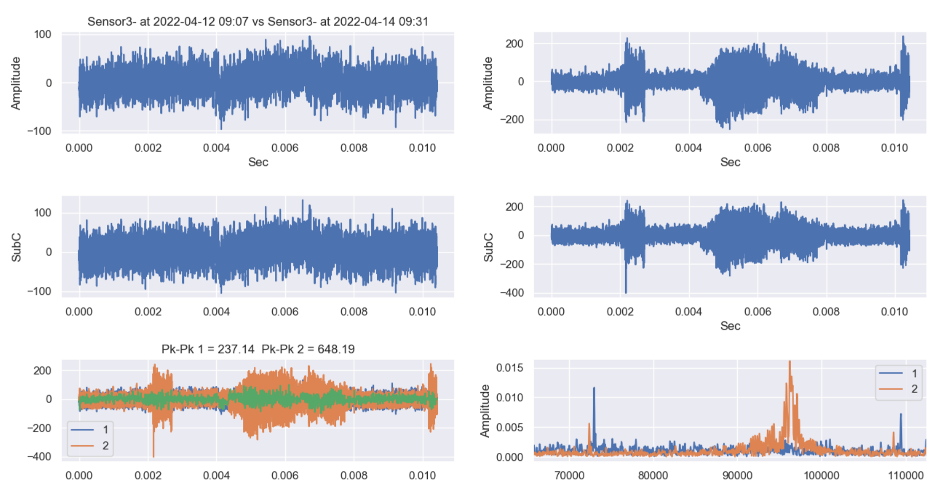

Figure 10 Sub-Carrier band area that dominates energy consumption

Returning to the Delta analysis, Figure 11 shows a smaller time window of 40 microseconds which results a less cluttered view of the spectrum. It can be readily observed that at around 98 kHz there are two peaks; the blue line is before the water is turned off and the brown trace is just before watering has resumed. The difference in amplitudes is approximately a factor of 2. Therefore it appears safe to assume that the higher the amplitude, which corresponds to a higher spectral density at that frequency, the higher the level of plant distress. Apparently the same can be said of the Sub-Carriers shown in the lower lefthand corner of the figure with a higher peak to peak amplitude.

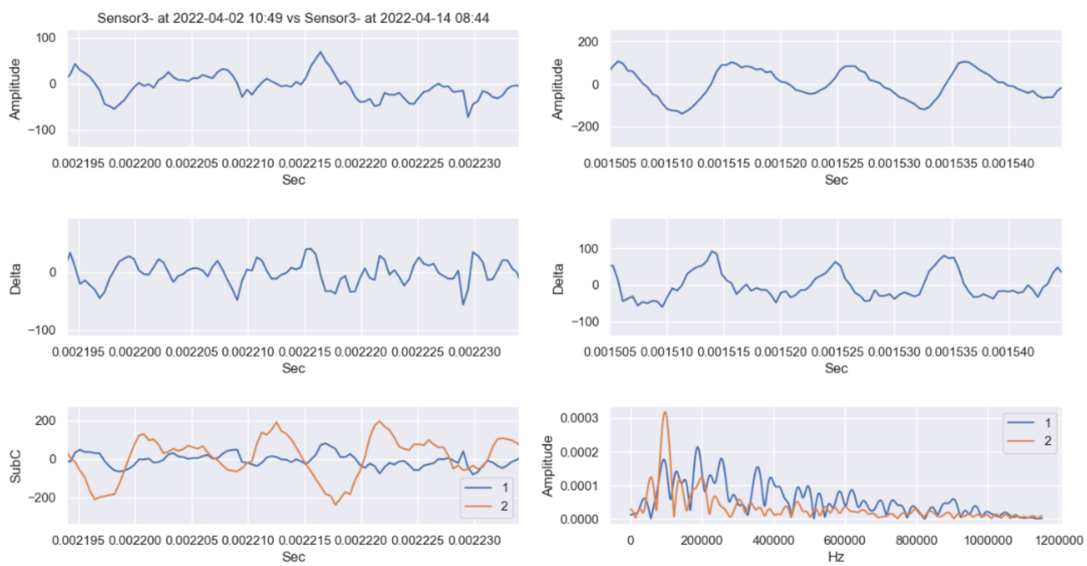

Figure 11 40 microsecond view

Figure 12 shows the Sub-Carrier status of the plant at the beginning and at the end of the experiment. It appears that the waveforms from the beginning of the experiment, on the left, and at the end of the experiment, on the right, are once again similar in nature. However the spacing between the two vertical lines in the graph on the left is much less than those on the right.

Figure 13 also shows the Sub-Carrier at the beginning and at the end of the experiment. The Sub-Carrier peak to peak value has decreased by about 10 percent. The interesting area to examine is the frequency domain plot shown in the lower righthand corner. Apparently the Zero Frequency value has risen. It is proposed that this may have something to do with the amount of stress the plant is currently under. The other spectral points may be related to the plant type. It may be noted that the Sub-Carrier peak to peak values for Figure 12 and Figure 13 differ by about 10 percent. This value does seem to fluctuate over time and the degree of difference has yet to be qualified as to importance.

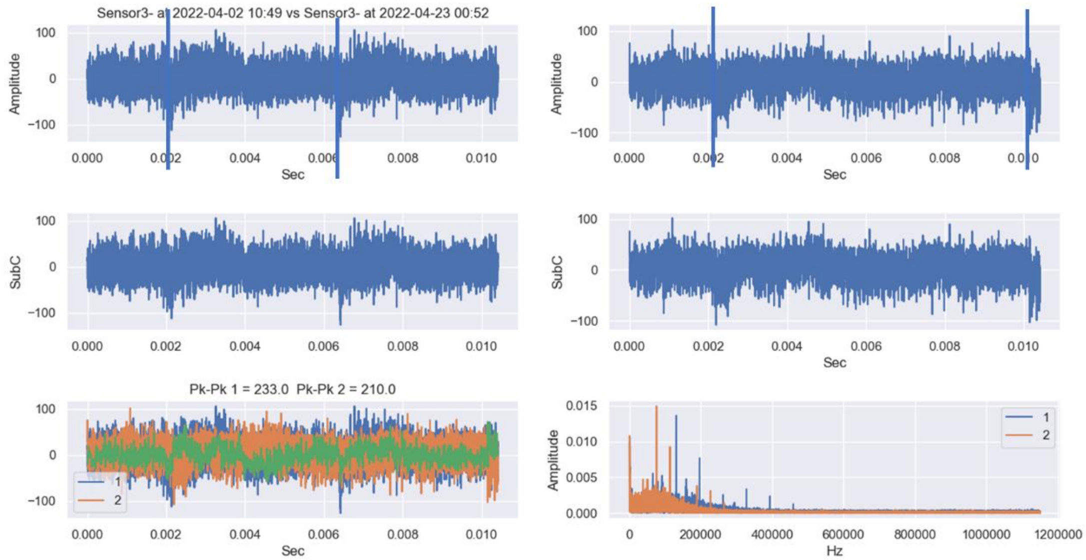

Figure 12 Just before experiment was stopped

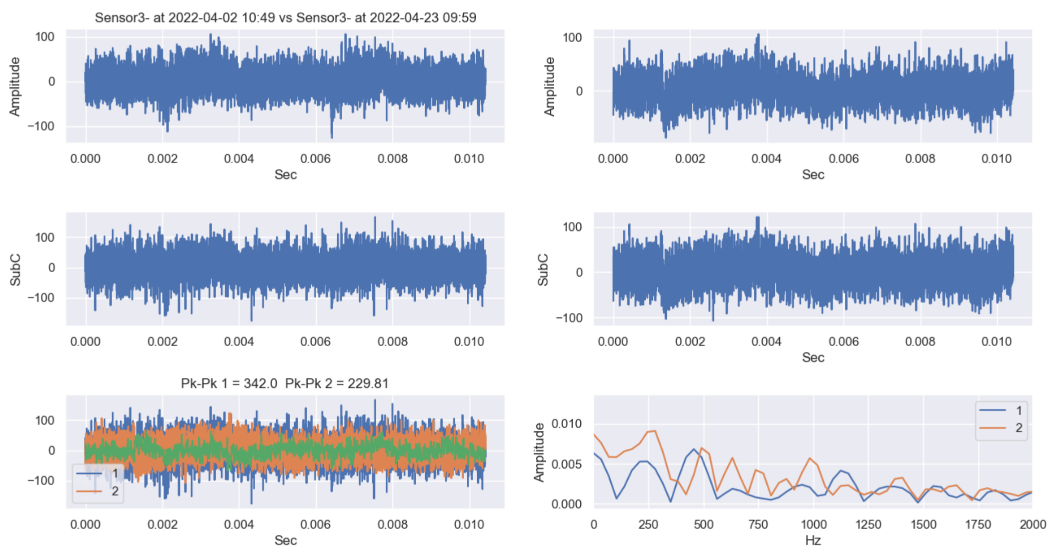

Figure 13 Sub-Carrier response at beginning and end of experiment

Figure 14 shows the Delta performance and that the 98 kHz amplitudes are now similar in amplitude but from 200 kHz to 300kHz the signal level corresponding to the end of the experiment is greatly diminished. The Sub-Carrier chart in the lower lefthand corner of Figure 14 shows that the Sub-Carriers seem to be at about the same or peak to peak levels. This may or may not mean that since watering has resumed the approximately same amplitudes the stress level has decreased significantly from that shown in Figure 10 where the peak to peak amplitude under stress was around a factor of 3 more than the before case.

Figure 14 Zoomed in 40 microsecond window

It appears that the detected waveform can represent various states of plant distress and extreme distress can even show a difference in the basic waveform. It might be that the plant may go into a self-protect mode and shutdown various plant functions to increase its chance of survival.

Plant reaction to Watering – Peppermint Plants:

Three Peppermint Plants were purchased at the same time, they were placed in a room in a fairly well controlled environment in Southern California in November of 2022. They were watered at the same time and the amount of water was recorded as well as the time of day. One plant was watered more than the Normal plant and one received no water until its leaves withered and then it received water. Later in the experiment plant food was added to see what effect it might have on the plants. Only More and None received plant food while Normal did not. The measurements were taken at intervals 15 minutes apart. As can be seen from the table below, the plants may have not been optimally watered. However relative amounts of water were recorded. The More plant grew due to the excess water and that is why it was flooded at measurement 749. The More plant had water visible at the surface of the dirt in the planter and so the amount of added water was noted.

Measurement Number	Date	Time	MORE[TBsp]	NORMAL[TBsp]	NONE[TBsp]	
	11/11/2022	13:46	2	2	2	
	11/13/2022	9:05	4	2	0	
	11/14/2022	9:30	4	2	0	
	11/15/2022	7:50	4	2	0	
295	11/16/2022	16:35	4	2	0	Both Normal and None wilted
	11/17/2022	7:14	4	2	0	
451	11/18/2022	8:55	4	2	2	Bringing None back up
	11/19/2022	6:40	4	2	2	
	11/20/2022	5:10	4	2	2	
719	11/21/2022	6:35	10	2	3	Flooding More and increasing None recovery
	11/22/2022	5:35	5	2	2	
	11/23/2022	5:36	5	2	2	
997	11/24/2022	6:55	5	2	2	
1095	11/25/2022	8:30	5	2	2	Added plant food to More and None
1207	11/26/2022	13:44	5	2	2	Had to put Normal Sensor back on plant
1277	11/27/2022	7:55	6	3	2	Normal looks wilted
	11/28/2022	7:27	5	3	2	
	11/29/2022	12:00	6	3	2	
	11/30/2022	16:40	6	3	2	
1649	12/1/2022	8:35	6	4	2	Starting to see wilting on Normal
	12/2/2022	16:35:00	6	4	2	
	12/3/2022	19:25:00	6	3	2	

Figure 15 Table of watering times and conditions

Figure 16 shows the initial measurements of the three Peppermint plants, Normal, None and More. For this measurement we will be concentrating on the Sub-Carrier measurement. We will compare their peak to peak measurements, zero frequency amplitude level as well as comparing their relative spectra as the metrics to be used for this experiment. As can be seen, by inspecting the figure below, the Normal and More plants seem to be almost identical in their Sub-Carrier spectral characteristics, shown in the square outlined area. However their peak to peak analog levels are different. Comparing these results to the Normal to None plant characteristics it appears the opposite is true. Looking at left set of graphs shown in Figure 16, we can see that within the square outlined region the None value is higher . In addition the triangular and circular regions are higher for the None case as well. Attempts will be made, within this paper, to address these phenomena. Now we will be referring to the Figure 15 to compare the waveforms at different stages of the experiment. Please note that Figure 16 does not have the correct time/date formatting. This is because the time stamp feature was added the day after the experiment started on November 11, 2022. This did not change the physical configuration of the experiment but the capture software was modified to add the timestamp capability.

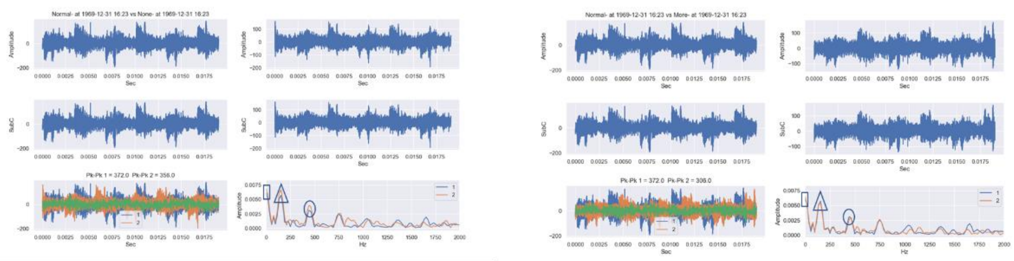

Figure 16 Initial Peppermint Plant Measurements

On November 16th, the Normal and None plants appeared to show some wilting. One on one comparisons will be examined between initial and present condition. Observing Figure 17 there are some very interesting observations that can be made. For the Normal case, shown on the right, the peak to peak amplitudes seem to track fairly well and the zero frequency amplitudes, shown in the square, are fairly close. The zero frequency amplitude for the initial case is slightly lower than for the wilted case. Note that the blue lines represent the initial measurement taken on November 11th and the tan lines represent the measurement taken on November 16th. The Normal and None cases have about the same difference in amplitude at 750 Hz, shown in the circles,. For the None case 750 Hz is the only frequency which seems to show any real difference.

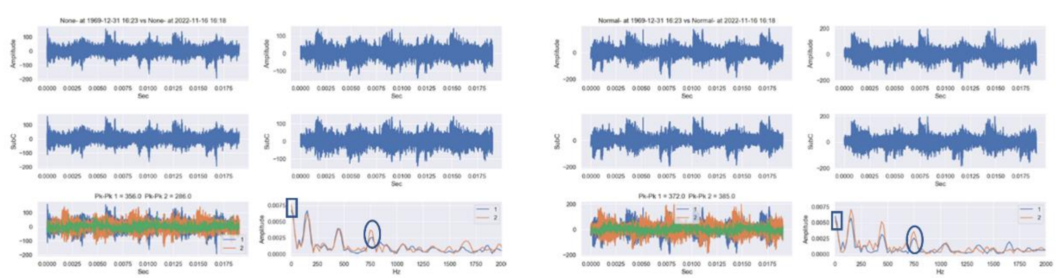

Figure 17 Normal and None show first signs of wilting

Figure 18 shows two examples of wilting for the None case. Here it appears that the measurement 451, taken on November 18th, case shows less overall spectral amplitude than the measurement 295 case, taken on November 16th. Looking at the top row, of time domain captures, it can be seen that measurement taken on the 16th, on the right, appears to be noisier than that of the 11th, on the left. In addition, at the Zero Frequency, shown in the square, it appears that the level has slightly decreased over time. This may imply that the plant has adapted to this condition and is possibly showing less stress.   There is also a triangular outline shown in Figure 18. This is mentioned for completeness but no possible characteristic has been assigned to this frequency. Referring back to Figure 17 it can be observed that for the None case, on the left, the None initial time domain and Delta waveforms, shown in the upper two rows on the left, appears to be less noisy as well. It appears that the signal integrity does diminish as the plant is starved for water. The spectral content displayed is limited to 2000 Hz so that we can see the close in performance of the waveform better. In Figure 19 we can see the part of the spectrum where the extra noisy energy resides. The blue lines represent the measurement taken on November 16th and the tan lines represent the measurement taken on November 18th. The signal power is being diverted to the higher frequencies that are not visible in Figure 18 which makes the time domain plot appear noisy. This should help explain the same phenomena seen in Figure 16 when multiple spectral peaks decline in amplitude.

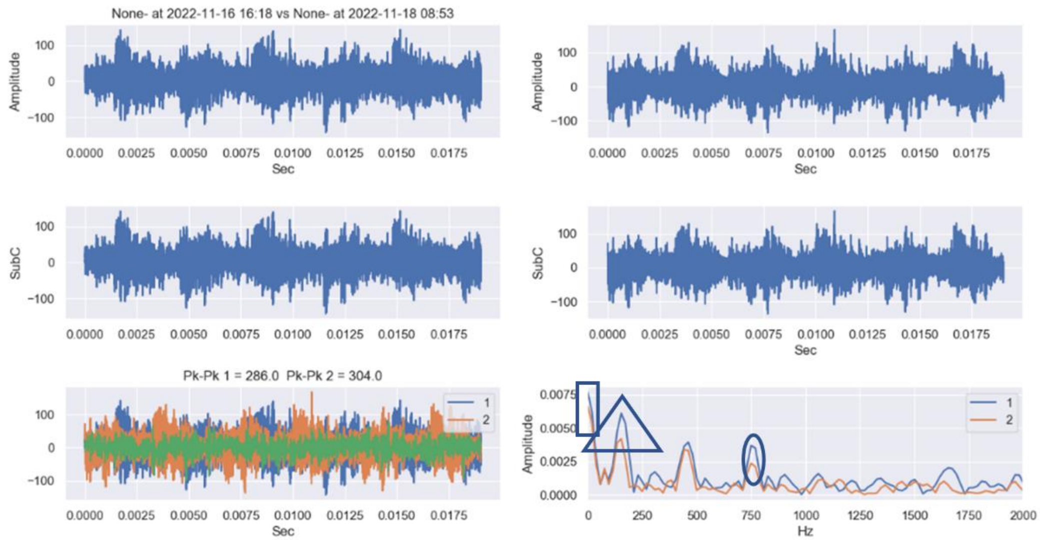

Figure 18 Comparison of 295 and 451 wilting for None case

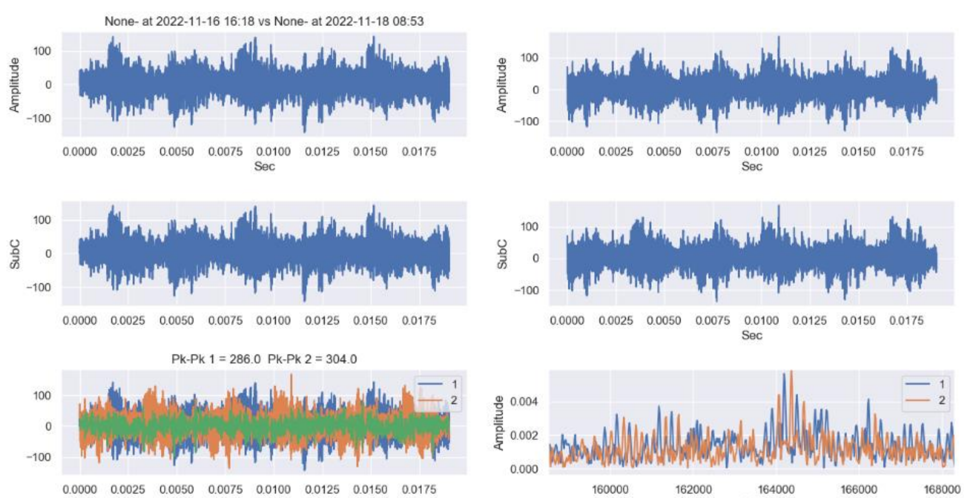

Figure 19 Selected Wide Bandwidth of 295-451

It appears that during the wilting process we can see that the signal integrity may diminish and at 750 Hz for the Sub-Carrier, for the Peppermint Plants measured, there seems to be more sensitivity to wilting regardless of watering.

For completeness, the plant which received more water than necessary, More, will be compared to its initial condition. Examining Figure 20 we see nothing special at 750 Hz since there is no wilting observed on More. The peak to peak value of the Sub-Carrier has decreased a bit and the zero frequency amplitude has increased relative to the initial value.

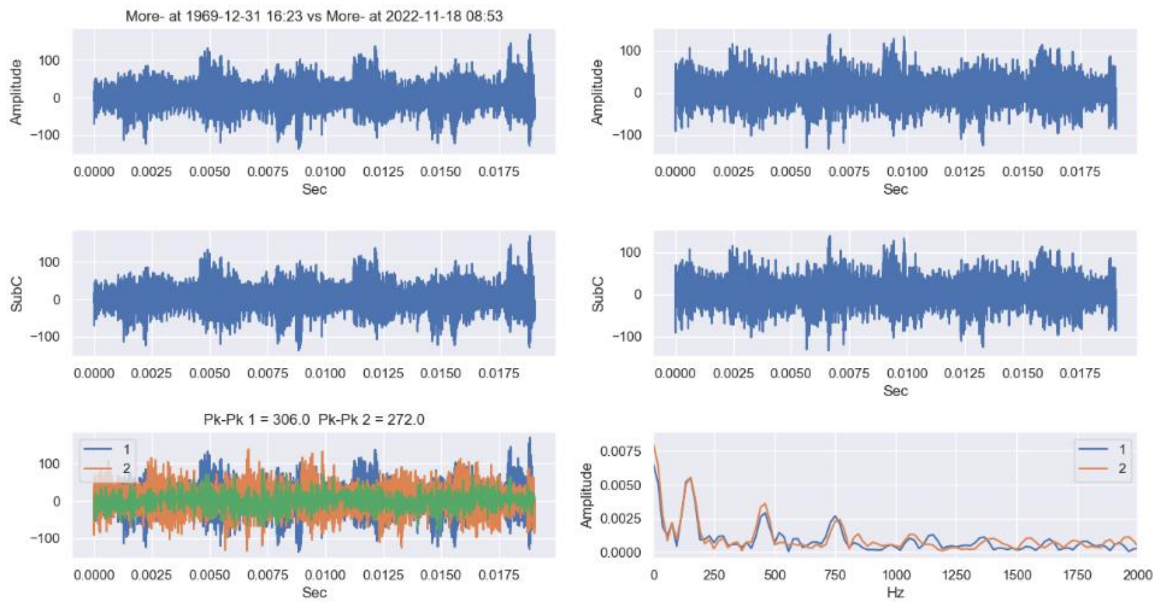

Figure 20 More compared to initial after 7 days

After 7 days into the measurement it was decided to try and bring back None by watering it. By its appearance the plant never really recovered but it would be interesting to compare its signal characteristics. After 7 days of watering the signal characteristics have not improved much.

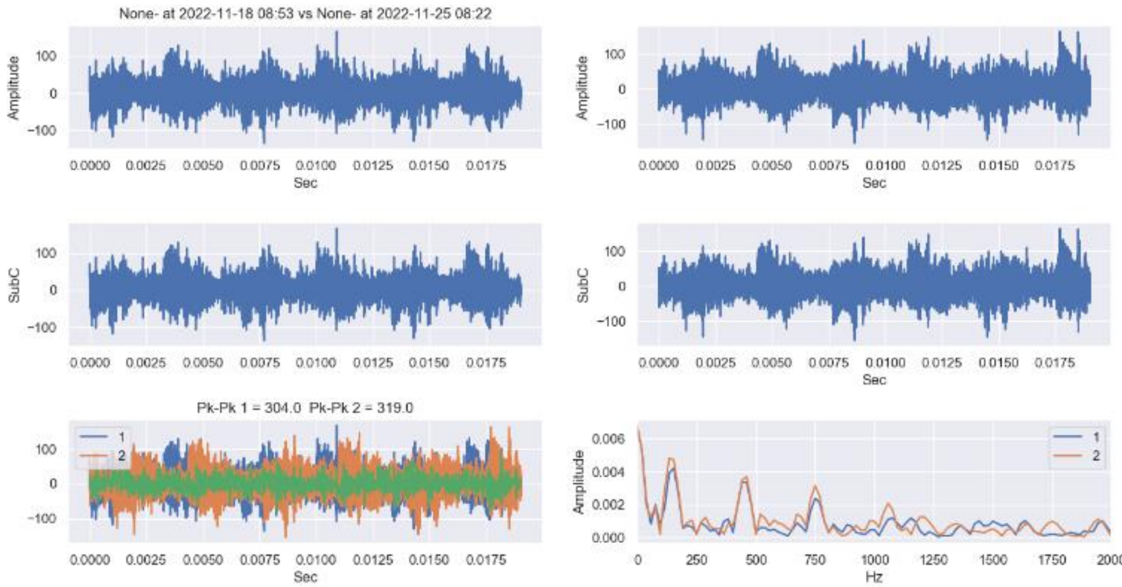

Figure 21 None after 7 days of watering

Effects of adding Plant Food:

On November 25th plant food was added to More and None to see if any changes in signal to be detected. Physically no improvement was observed in None and More grew appreciably. Signals on the day the plant food was added will be compared to measurements taken on December 1st.

The first instance to look at is More. As seen in Figure 22, there were incredible changes noticed in the signal detected from the plant. Overall detected signal amplitude nearly doubled. This was also realized in the peak to peak value of the Sub-Carrier. The most notable change was in the zero frequency amplitude, surrounded by the square. The level detected, 6 days after the plant food was added, decreased significantly which could mean the plant is very satisfied with its environment since it had shown significant growth. The 750 Hz component, which is in the second circled region seems to be at approximately the same level. The first circled region, around 500 Hz, has seen an increase in amplitude. It is unknown at this time if this is related to growth.

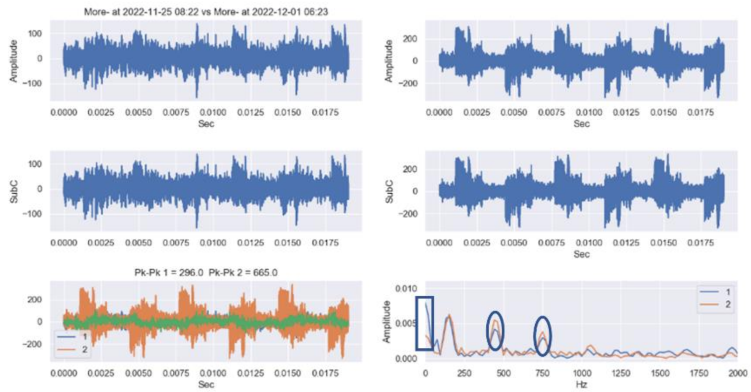

Figure 22 More after adding Plant Food

Figure 23 shows the results for None before and during the addition of the plant food. Just as with the More case peak to peak amplitude as well as the overall detected amplitude increased around 100 percent. The zero frequency amplitude, shown in the square, decreased a bit but not nearly as dramatically as the More case. There was no change in the amplitudes at 500 Hz and 750 Hz. Some change was noticed around 175 Hz but it is unknown what caused this change at this time.

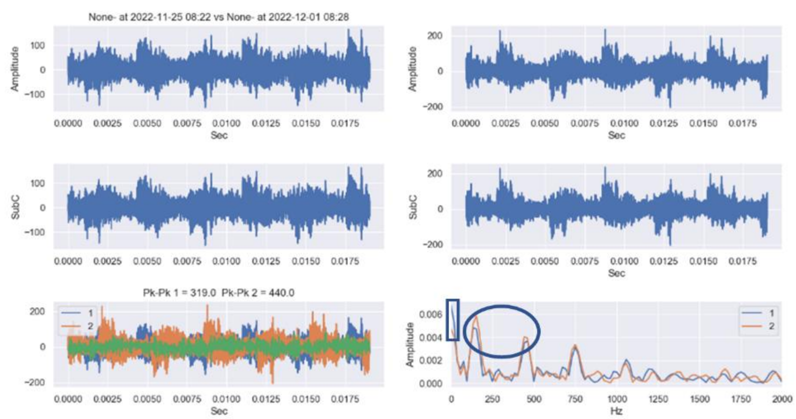

Figure 23 None after adding Plant Food

Figure 24 also shows a dramatic increase in peak to peak amplitude but more like 60 per cent instead of 100 percent. It appears that there was an overall amplitude increase in all plants regardless of adding additional nutrients. The zero frequency amplitude dropped as well. The drop in zero frequency amplitude is comparable to that witnessed in the None case.

It appears that the main area of interest in this portion of the plant food experiment may be the zero frequency amplitude level. It is possible that the plant's overall well being may, in some way, be related to the zero frequency amplitude level.

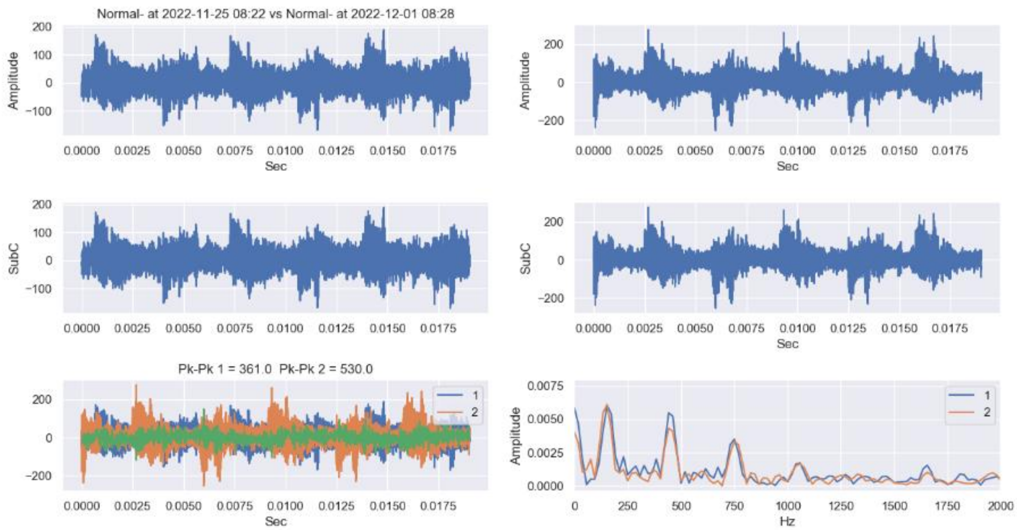

Figure 24 Normal without benefit of Plant Food

Conclusion:

It appears that signals detected from a plant may one day be capable of determining a plant's overall well-being. By changing the plant's environment it may be possible to optimize performance of certain characteristics. Plants can be compared to one another to determine it they behave the same way to a controlled stimulus.

By making periodic measurements in a controlled situation it is possible to determine characteristic metrics that can be followed over time and compared, on a measurement number basis on the x-axis, to other metric parameters to determine possible correlations.

References:

1. Tsong TY, Liu DS, Chauvin F, Astumian RD. Resonance electroconformational coupling: a proposed mechanism for energy and signal transductions by membrane proteins. Biosci Rep. 1989 Feb;9(1):13-26. doi: 10.1007/BF01117508. PMID: 2655737.