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W-Waves and Plant Communication

Abstract

Plants have been found to communicate directly with each other. An ax chop to one tree has been detected in a neighboring tree for example. The basis of this communication has been hypothesized to be W-wave signals.

Introduction

There is much recent research that suggests plants are able to communicate. Under stress, such as from insect attack, plants are hypothesized to emit chemical substances, pheromones, that, it is hypothesized, stimulate the surrounding plants to prepare to resist a similar attack (Rhoades 1985).

Earlier we reported the discovery of W-waves in plants (Wagner 1988a,b). Evidence for their existence consisted of measured electrical patterns, recorded oscillations, excitation behavior, and reflection phenomena. Measured electrical patterns appeared to indicate that standing waves are always present in plants and have something to do with their physiology. Recorded oscillations demonstrated another feature that one would expect to find if waves were present. Other evidence indicated that the observed waves were not electromagnetic but they interacted weakly with charge so it was possible to observe some of their effects with ordinary electrical measurement equipment. We found that one could disturb the apparent standing wave pattern in a tree at different locations and detect oscillatory behavior coming from two probes elsewhere in the tree. This would be typical behavior for disturbing a standing wave pattern anywhere. Using pulse reflections we found the velocity of the waves in the tree. The evidence all pointed to the existence of waves in plants.

We hypothesized that if insect damage caused trees to communicate maybe damage with an ax or nail would cause the tree to send an immediate message to the surrounding trees. The evidence given here seems to indicate that this is the case. We already knew that such mechanical trauma produced changes in the standing wave pattern in the damaged tree itself. We theorized that the W-waves involved could also propagate through space or ground to adjacent trees (Wagner 1988a, 1989f). The purpose of this paper is to further discuss the evidence that suggests that W-waves are involved in this communication between plants.

Materials and Methods

Live Tree Samples

Much of the methodology is described elsewhere (Wagner 1988b, 1989h).

To determine if a live tree responded to stress damage to a neighboring tree we placed probes in a "transmitting tree" and in one or more "receiving trees." Every lead was grounded coaxial cable. Pairs of probes in receiving trees were spaced at varying distances to optimize the signal strength of the received signals. Trees with relatively few and smaller lower branches seemed to work best. Since we are dealing with wave phenomena that setup differently in each tree it is difficult to determine ahead of time the appropriate placement of contacts or exactly where one should chop to produce an optimum pulse. It was often effective to place the lower of the two probes on receiving trees just a few centimeters above the ground. Probes on transmitting trees usually used the standard two probe spacing (Wagner 1988b). Next the transmitting tree was chopped, struck with the sharp edge of a woodcutter's ax, near its base one to three times and the resultant signal simultaneously recorded from both the transmitting and receiving trees. Where two receiving trees were used, only the signals from the receiving trees were recorded because a two channel strip chart recorder was available at the time. Each channel was electrically isolated from the other one. A dry cell operated offset adjustable preamplifier was used in each channel. Attempts were made to minimize unnecessary disturbances to all plants near and involved in the experiments since any kind of damage seemed to increase the electrical noise output levels of the trees involved in the experiments.

To obtain velocities of disturbances traveling between trees we used three trees. Table 1 shows results for both two-tree and three-tree experiments. Since W-wave disturbances seem to travel at approximately 1 m/sec in plant material (Wagner 1988a,b; 1989h), the processing time (the time the wave takes to spread within the sending and receiving trees before passing sensory probes) may vary with tree height and position of probes. To reduce the possible variation to effects of processing time, we reasoned that the use of two receiving trees of near equal heights with equally spaced probes and using the difference in arrival times of the transmitted signals would eliminate the possible delay variables (assuming the receiving tree delays are equal). When using three trees, one was chosen as a transmitting tree and the others as receiving trees. Following a chop into the transmitting tree a sharp rise (here termed a "pulse" for descriptive convenience) appeared in the output voltage first in the transmitting tree then in the receiving trees. The pulse arrival times were used, together with the difference in distances from the transmitting tree, to calculate the velocity of W-waves traveling between trees. Communication data were taken spanning more than a year in time, with variations in methods, to assure that the observed phenomena are real. Measurements were taken in trees at about 460 m above sea level.

Capacitor Sensors

To directly record W-waves, capacitors were used (Wagner 1989a,c,j). In preliminary results, capacitors connected to high impedance voltmeters have been observed to produce comparatively large fluctuating voltages. We attribute these fluctuations to W-waves in space (e.g. a 2 microfarad capacitor has been observed to produce as large as ± 50 mv fluctuations (unpublished observation)). We reasoned then that large volume capacitors would present a large cross section to W-waves. Thus we used them to monitor W-waves traveling in air between trees. Signals from these were analyzed on a Schlumberger model 1201 FFT low frequency spectrum analyzer. A differential input setting was used on the analyzer to minimize common mode signals. Two sensor capacitors were made of Celotex, a foam type insulating material comprised of foam separating foil layers by 3.81 cm (1.5 in). One of the sensors was 96.5 cm x 50.8 cm (#1), and the other was 243.8 cm x 25.4 cm (#2). The capacitors were placed flat on level platforms, 1.52 m above the ground, made of two inch PVC pipe attached (by ropes) to trees in clumps of predominantly white fir (*Abies concolor*) (#1) and in madrone (*Arbutus menziesii*) (#2). Many precautions, to minimize noise, were followed when using the spectrum analyzer (see Wagner 1989h).

Salt Solution Saturated Tree Sections

To demonstrate that W-waves arise from external sources and that these waves are not peculiar to living organisms we used sections of trees filled with salt solution for communication experiments. Salt solution filled samples were prepared by placing 2.4 meter (or less) sections of freshly debarked live trees into 10 cm (4.0 inch) diameter PVC pipe filled with saturated salt solution. Then the end was capped. The container was then laid on its side for at least a month to allow the wood to absorb the salt solution. Salt solution filled samples were removed from the PVC pipe and tested on a wooden table in the laboratory.

Results

Live Tree Transmissions

Figure 1 shows the response of two ponderosa pines to three ax chops in quick succession (within 5 seconds) to the base of the transmitting tree. The two trees were about 13.7 m apart and both were approximately 28 cm in diameter at the base, and 9 m high. To assure a large amplitude transmitted pulse three ax chops were delivered. Further, not every chop gives a good response because it cannot be known ahead of time where exactly to strike the tree for maximum response because of the differences in the wave structure within different trees. Delivering more ax chops instead of one often makes the leading edge and other portions of the damage curve more complex than that for just one chop. For example, there are extra bumps after the start of the sharp rise in Figure 1. In Table 1 are shown some other results of 8 experiments. One chop or more was followed by a response in a nearby tree. In the earliest two cases (Table 1) we tested pairs of madrones. The damage curves

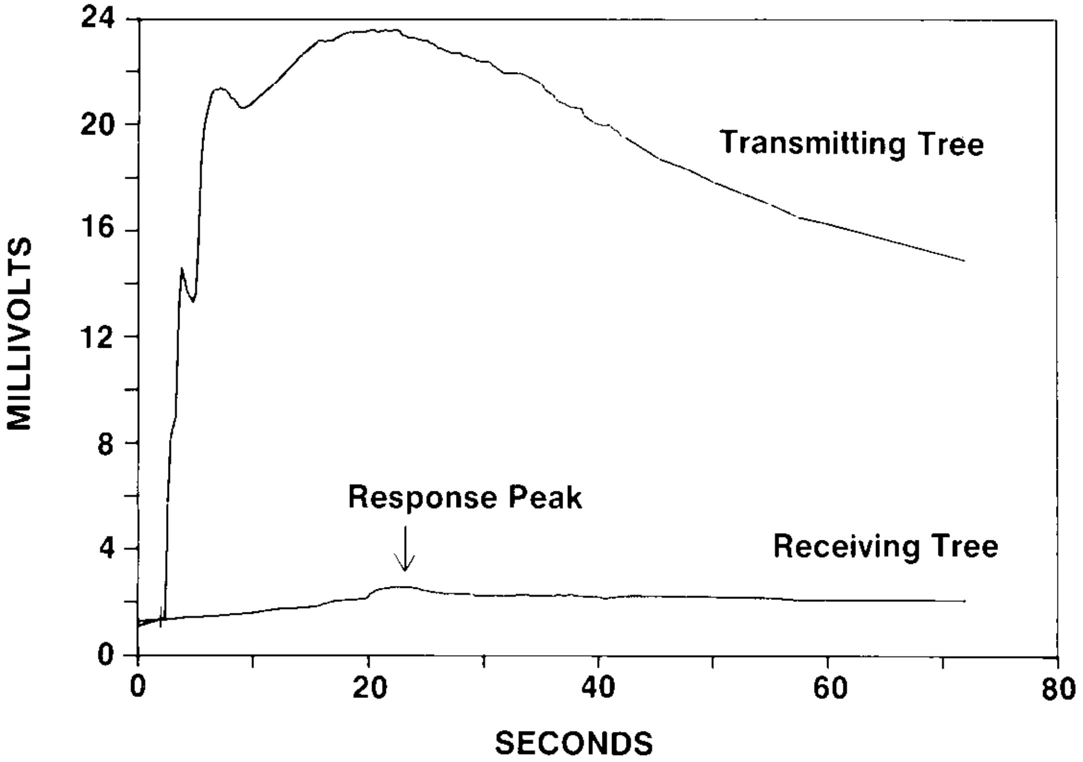

Figure 1. Transmitting and receiving tree responses to ax chops to the base of the transmitting tree. The higher curve is what has been previously designated a damage curve from chopping into the base of a tree The lower curve represents the output of a receiving tree 13.7 m away. Note the rather small but sharp rise at about 20 seconds which is the beginning of the receiving tree response. The first chop occurred where the line crosses the curves just before the sharp rise.

are small in amplitude and the receiver responses close to 0.1 mv with receiver probe spacings of 1.5 m. These first results were enough to encourage further testing but we used larger receiver probe spacings (up to 7 m) with apparently somewhat larger amplitudes resulting. Due to the delays mentioned previously we did not use these initial experiments to determine a velocity for W-waves between trees but they still demonstrate that there is communication. The first 4 entries of Table 1 are typified by Figure 1. In Figure 1 the first chop occurred approximately at the time the small line crosses the two curves just before the sharp rise of the damage curve. The two curves are synchronized in time because the data from the strip chart recording (where the pens are displaced along the recording paper to prevent collision) was transferred point by point to a computer program which then replotted the curves. At about 20 seconds there is a sharp rise (in some cases a dip, apparently depending on the wave pattern) in the receiving tree response indicating that the receiving tree has received data from the transmitting tree. From there the receiving tree response usually flattens (or begins oscillations or pulsations). In the meantime the damage curve from the transmitting tree is decaying rapidly.

It is difficult to obtain a second set of good data from trees in the vicinity immediately after finishing an experiment, where chopping is involved due to the noise (oscillations and changing voltages coming from probes) generated in the chopped and nearby trees. We usually attempted to obtain immediate second sets of data but often without success. The noisy condition persists for a few hours and then tests can be resumed.

Figure 2 shows the response of two receiving trees taken from a strip chart recording.

TABLE 1. These are results from some of the experiments done here relative to plant communication.

Date Temp.	Trans/Rec. Separation (m)	Ampl. Trans. (mv)	Ampl. Rec. (mv)	Delay (secs)	Vel. (m/sec)	Comments
3/18/88* 19°C	28.6	12.5	0.3	13	N/A	p. pine
3/17/88* 23°C	13.7	23.5	0.5	18	N/A	Figure 1
3/8/88* 17°C	2.1	10.0	0.1	3.6	N/A	First (madrone)
3/9/88* 7°C	4.9	2.0	0.1	10	N/A	madrone
3/31/88** 16°C	14.0 34.4	N/A	0.3 0.2	4.2	4.9	Figure 2 pine
4/1/88** 24°C	17.6 35.4	N/A	0.3 0.1	3.6	4.9	ash trans.
4/1/88** 25°C	7.3 33.2	N/A	0.1 0.1	5.6	4.6	ash trans.
4/5/88**	5.2 31.7	N/A	0.2 0.1	5.3	5.0	pine temp. not rec.

* The results from chopping at the base of a transmitting tree and one receiving tree.

** Data from sets of three trees where only the receiving trees were monitored while the transmitting tree was chopped. In the last four sets the delay is the time between the pulses received from the two receiving trees. The velocity of W-waves between trees is calculated by dividing the difference in distances from the transmitting tree by this delay. The species of trees used in these experiments were ponderosa pine (*Pinus ponderosa*), Oregon ash (*Fraxinus latifolia*), and madrone (*Arbutus menziesii*). The time for these experiments was between 0900 and 1700 hours. See the text.

These curves are illustrative of the second set of four entries of Table 1. Using 20.4 m for the difference in distance of the receiving trees from the transmitting tree and dividing by 4.2 seconds (the time between the sharp rises of Figure 2) gives 4.9 m/sec for the W-wave velocity between trees in this case. See Table 1 for other results. The average velocity obtained from the values in the table is 4.9 cm/sec for W-waves traveling between trees. The same procedure was used for the three last entries for determining the velocity of W-waves between trees.

Much additional data were taken to be sure of the communication result. Some of the additional data had relatively large receiving tree amplitudes some of which are: 0.6, 0.6, 0.3, 0.2, 0.8, and 0.4 mv. The corresponding distances of separation between receiving and transmitting trees were near 15.2, 13.1, 20.4, 21.6, 13.0, and 13.7 m respectively. These data were from ponderosa pine pairs.

Capacitor Signals

The very existence of apparent plant spectra from the large area capacitor sensors in the vicinity of trees seem to indicate that W-waves travel in air rather than through the earth alone since these sensors are in air with no direct connection to trees. These sensors when connected to the 1201 usually showed a 1.6 Hz series of harmonics plus some other peaks (Figure 3) that apparently are plant related since they seem to show only in the vicinity of a relatively high concentration of live plants and may indicate a constant communication between plants. They are found with much more detail when the spectrum analyzer is connected directly to plants (Wagner 1988a; 1989b,d,e,g,h,i,j). The data here may indicate some kind of W-wave resonance phenomena in plants.

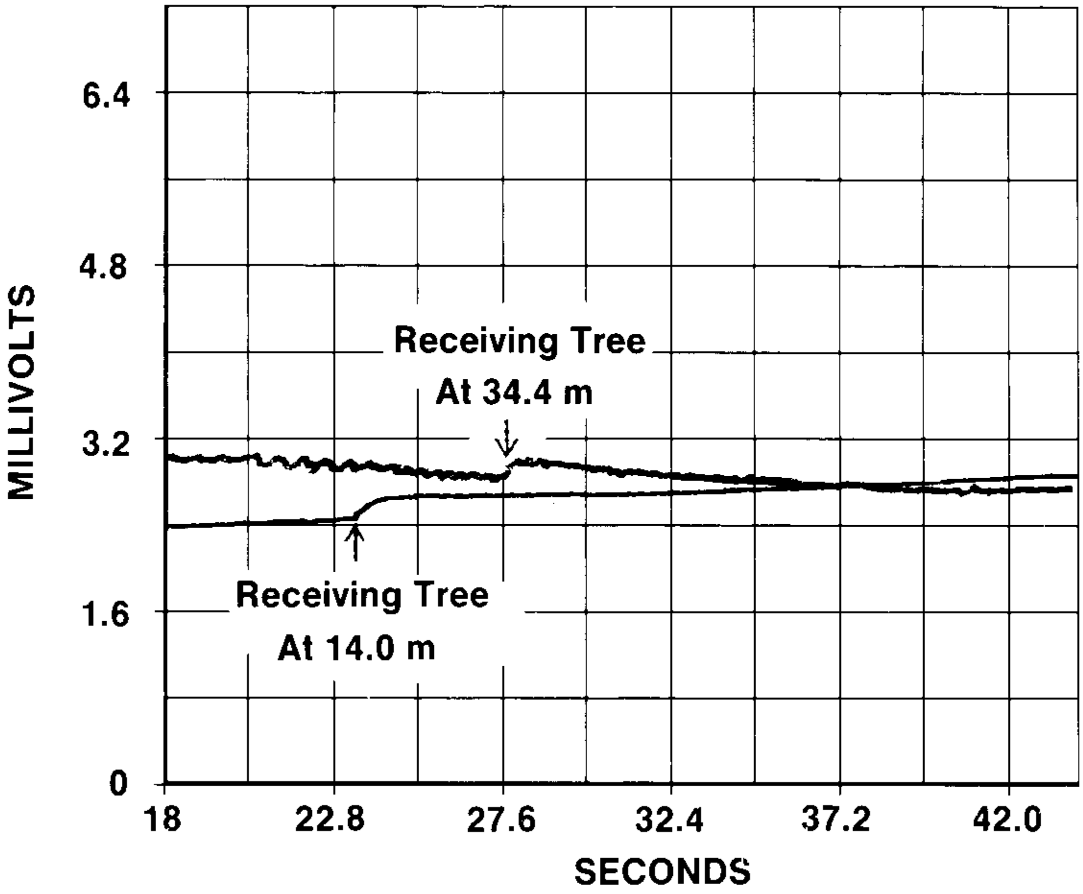

Figure 2. Curves of a strip chart recording of the response of two receiving trees to a woodcutters ax chop to a transmitting tree. The time on the abscissa is the approximate time from the ax chop. All three trees were ponderosa pine (*Pinus ponderosa*) near 10 m in height. See the text for more discussion and Table 1 for more data.

Salt Solution Filled Tree Sections

Attempts have been made to demonstrate communication between salt solution filled tree sections. So far the results have been ambiguous due to noise. This might be expected since wave patterns observed in salt solution filled tree sections have smaller amplitudes (compare Figure 4 with pattern data of Wagner 1988b). Also signals that are transmitted along salt solution filled tree sections appear to be weaker than comparable signals in trees (compare, for example, Figure 5 with Figure 1 the top curve). Thus probably transmitted signals would also be weaker.

Discussion

Characteristics of W-waves

W-waves seem to be distinct from electromagnetic waves. Some of the apparent characteristics of W-waves are as follows:

(1) W-waves appear to travel very slowly; at about 96 cm/sec in live plants (Wagner 1988a; 1989h,c) and here we find that they seem to travel at about 4.9 m/sec in air (the range was 4.6-5.0 m/sec). This is not characteristic of electromagnetic waves which travel at about 3.0 x 10^8 m/sec.

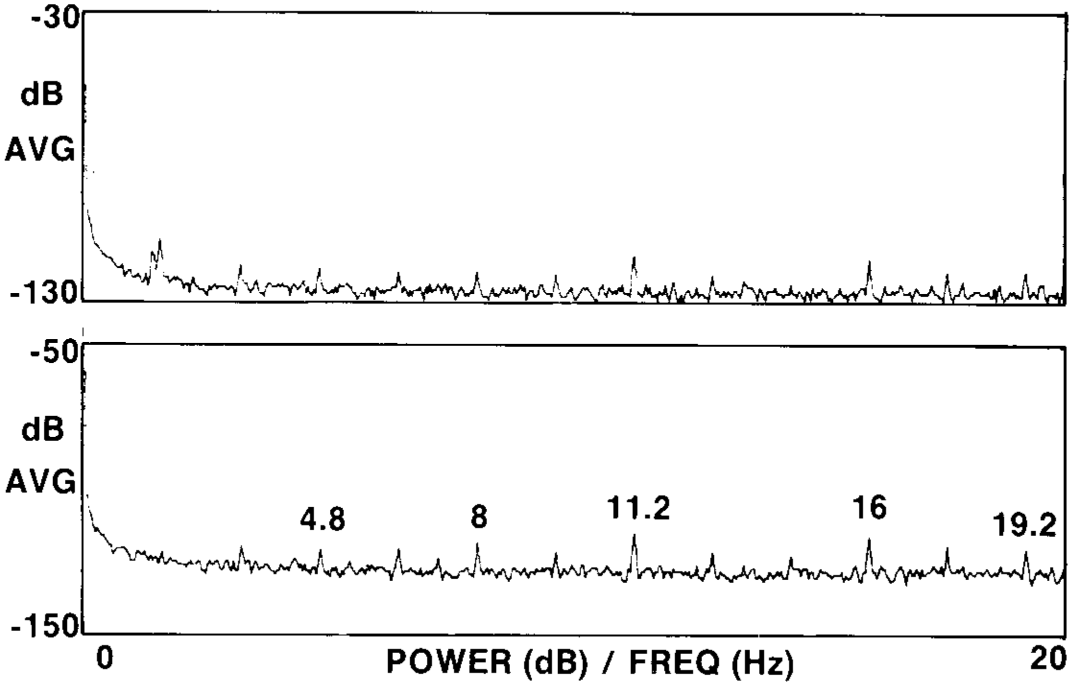

Figure 3. Typical spectra from the two different capacitor sensors that were used. The upper spectrum was from #1 and the lower from #2 (see the text). Some of the major peaks are marked with frequency (Hz). Other peaks can be identified by the fact that major peaks are spaced by 1.6 Hz. These spectra are present most of the time when the sensors are near plants, apparently indicating a W-wave field in the space near plants.

(2) A W-wave disturbance typically seems to produce a semipermanent displacement of charge (e.g. damage curve (Wagner 1988b) and Figures 1, 2, and 5 as indicated by the voltage changes) with a relatively slow decay of this displacement back to equilibrium. A typical electromagnetic pulse, however, is a quick change in voltage with a quick return to the original value. The W-wave behavior may be analogous to a light pulse falling on a semiconductor which produces excess minority carriers and then these slowly recombine with majority carriers in an exponential manner.

(3) W-waves appear to interact weakly with charge so that it takes appreciable time to build up charge (Wagner 1988b).

(4) A spectrum analyzer shows that characteristic W-wave frequencies often appear to combine (heterodyne; see e.g. Halliday et al. 1970 pp. 332-334) to form sum and difference frequencies with the frequency (f) of a small ac voltage applied with two probes along a plant stem (Figure 6). For example if f_1 is a proper (as yet we don't know what determines which W-wave frequencies will combine with the ac signal) W-wave frequency then $f+f_1$ will appear in the spectrum as well as $f-f_1$. The analyzed signal is monitored from additional probes placed between the probes furnishing the ac voltage. The observed sum and difference frequencies appear to provide dramatic evidence for the existence of W-waves because their amplitudes are so large (can be millivolts) and the frequencies obtained (f_1) match those obtained from ordinary spectra as well as those obtained from plant spacings (Wagner 1988a; 1989b,g,h).

(5) W-waves seem to be a factor in the spacing of plant structures as the spacings when converted to frequency appear to match frequencies measured on the spectrum analzyer (Wagner 1989b,c,g,h). This appears to demonstrate standing wave action within a conducting medium where electromagnetic waves would quickly decay.

(6) W-waves seem to come from an external source since the set of frequencies obtained seems to be the same from every source. Concern that

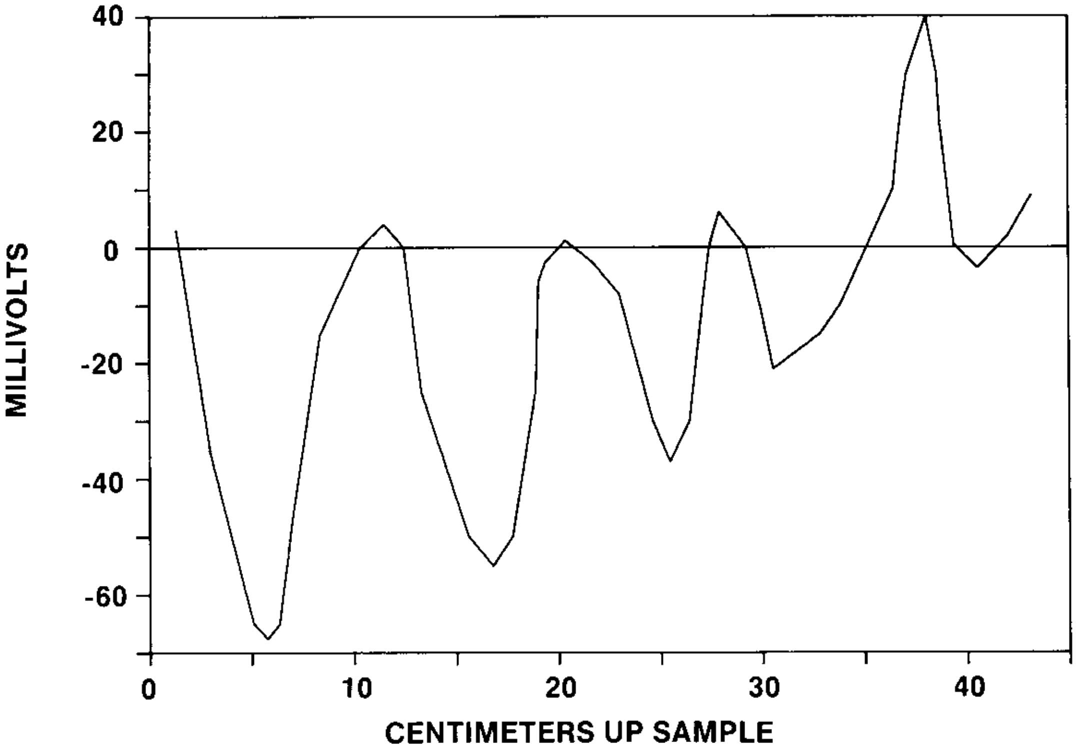

Figure 4. Wave pattern taken from a portion of a salt solution filled section from willow (*Salix* sp.). It was 3.5 cm in diameter at the base and 94 cm long. Probes were spaced at 1.25 cm. The amplitudes of peaks are considerably smaller than amplitudes usually obtained from live trees.

the spectra might be induced by external noise are addressed by noting that the spectra are nearly identical from experiments conducted on trees in different locations. Tests also indicate that they don't come from the equipment (Wagner 1989h). Thus W-waves (or whatever produces their frequencies in W-wave sensors such as plants, salt solution filled tree sections, and capacitor sensors) appear to be matter penetrating. For example they appear to travel in plants and highly conducting salt filled samples, and their spectra appear coming from either plants or salt solution filled samples located in metal shields (Figure 7; Wagner 1989d,e,i,j). Also we obtained characteristic spectra from a potted lemon tree located more than 100 m underground in a mine shaft (Figure 8). Such matter penetrating behavior is not characteristic of electromagnetic waves. The matter penetrating quality correlates with the fact that other plant phenomena appear to work anywhere on and in the earth (e.g. Salisbury et al. 1969 pp. 550-552).

Most of the above characteristics and others (see Wagner 1988b) are not typical of electromagnetic behavior and thus we believe that W-waves are a real and separate entity but they do seem to interact with charge and electromagnetic waves in a manner which is not completely understood at this time. The curves in Figures 1 and 2 look typical of W-wave behavior with, for example, their buildup and decay characteristics and the small velocities obtained and thus we associate the observed communication behavior with W-waves.

Live Tree Transmissions

Figure 1 shows considerable time delay between the initial response from the transmitting tree and the overt response of the receiving tree (at about 20 seconds). This time lag is apparently larger than just the transmission time perhaps due to the low velocity (approx. 1 m/sec) of W-waves in the transmitting and receiving trees. Ambiguity is present due to the time it took to make three

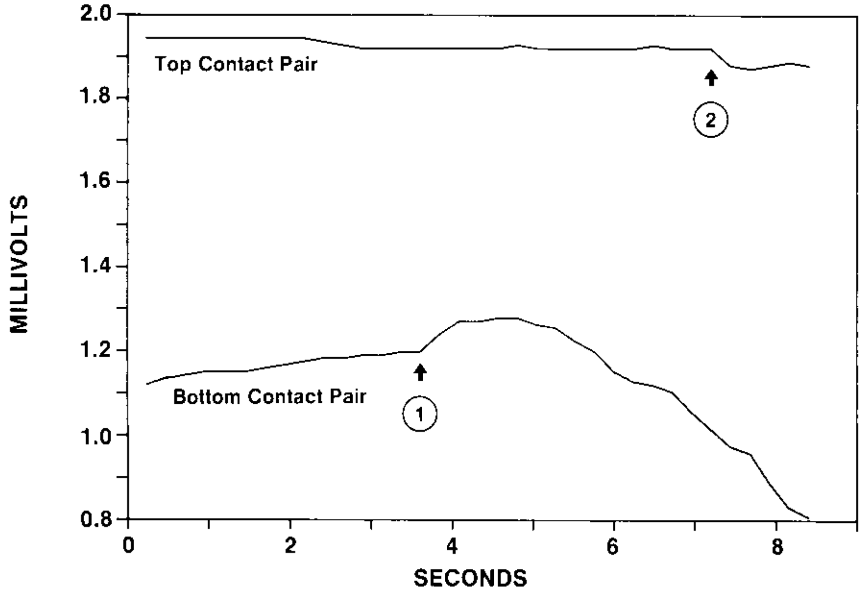

Figure 5. Results from a nail pushed quickly into the base of a salt solution filled tree section (Douglas fir (*Pseudotsuga menziesii*)). This sample was 7.5 cm in diameter at the base. A pair of probes spaced at 2.5 cm were placed along the sample at 30 cm from the base. Another pair of probes (spaced at 2.5 cm) were placed along the section at 3.75 cm from the top. The distance between the centers of the pairs of probes was 263.75 cm which when divided by 3.5 sec (the time between signal arrivals) gives about 75 cm/sec for the velocity in this case. ① is the beginning of the response from the bottom contact pair and ② is the beginning of the response from the top contact pair.

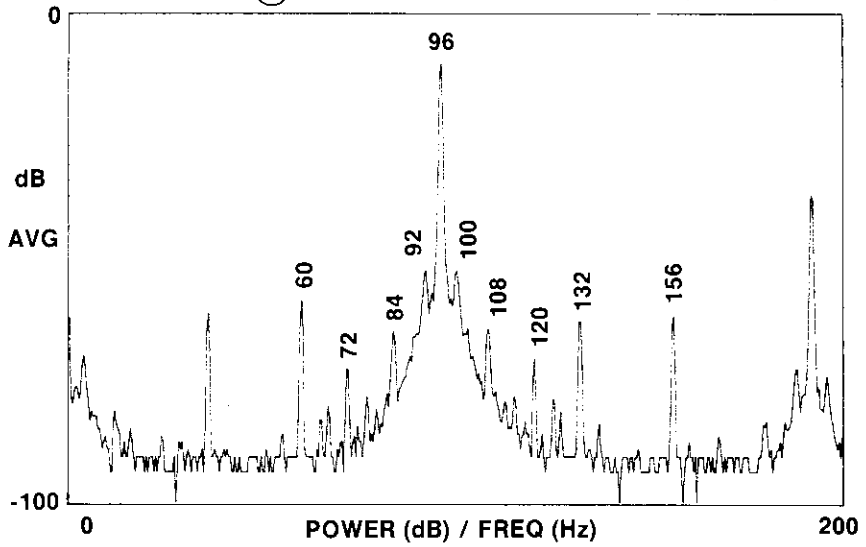

Figure 6. A sum and difference frequency spectrum (see the text) resulting from applying a small ac signal (96 Hz) along the stalk of a begonia plant (*Begonia* sp). The current source electrodes were 45 cm apart with 65 mv applied through a 50,000 ohm resistor. The electrodes with leads going to the spectrum analyzer were 3.5 cm apart along the stalk between the source electrodes. The first two peaks that are symmetrical about the 96 Hz peak were at 92 Hz and 100 Hz or at ±4 Hz away from the 96 Hz peak. The next easily readable peaks are at ±12, ±16.8, ±19.2, ±21.6, ±24, ±28.8, ±30.8, ±36, ±40.8, and ±60 Hz and so on away from the 96 Hz peak. Three of the frequencies represented here (19.2, 24, and 28.8 Hz) are integral multiples (harmonics) of 1.6 Hz while the others appear to be harmonics of a subharmonic of 1.6 Hz which here is 0.16 Hz (except for 30.8 Hz where it is 0.08 Hz). To the far right one sees the second harmonic of 96 Hz or 192 Hz.

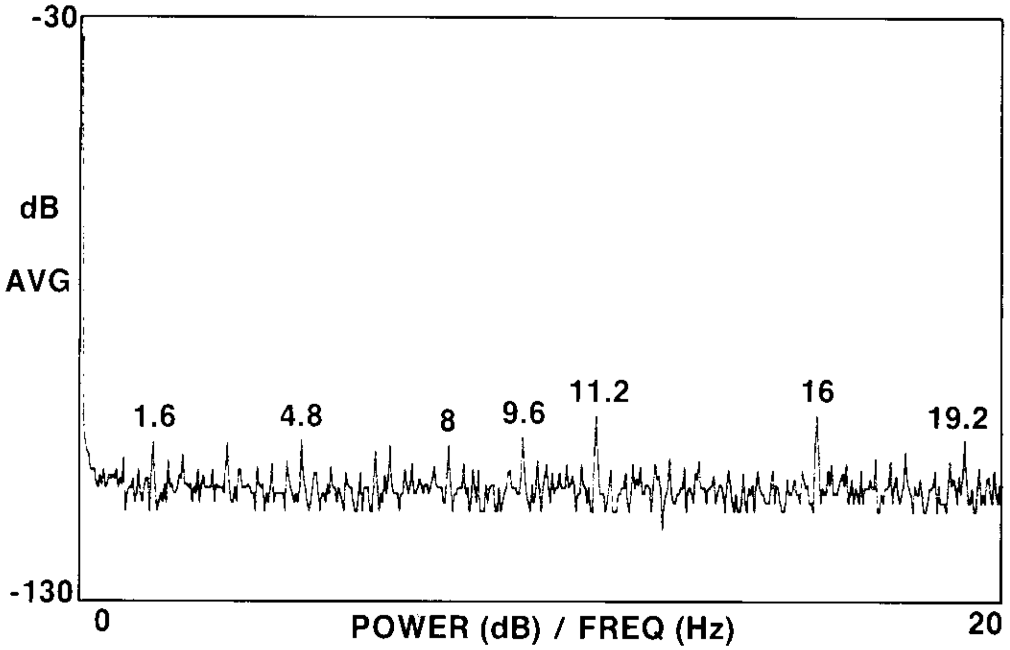

Figure 7. A spectrum from probes in a salt solution filled tree section (hazelnut, *Corylus* sp.) in an aluminum box. The spectrum is typical of spectra obtained from plants and solution filled tree sections outside the box. The 0.32 spaced peaks (for a 20 Hz baseband) are still present with the generally larger amplitude 1.6 Hz harmonics some of which are labelled.

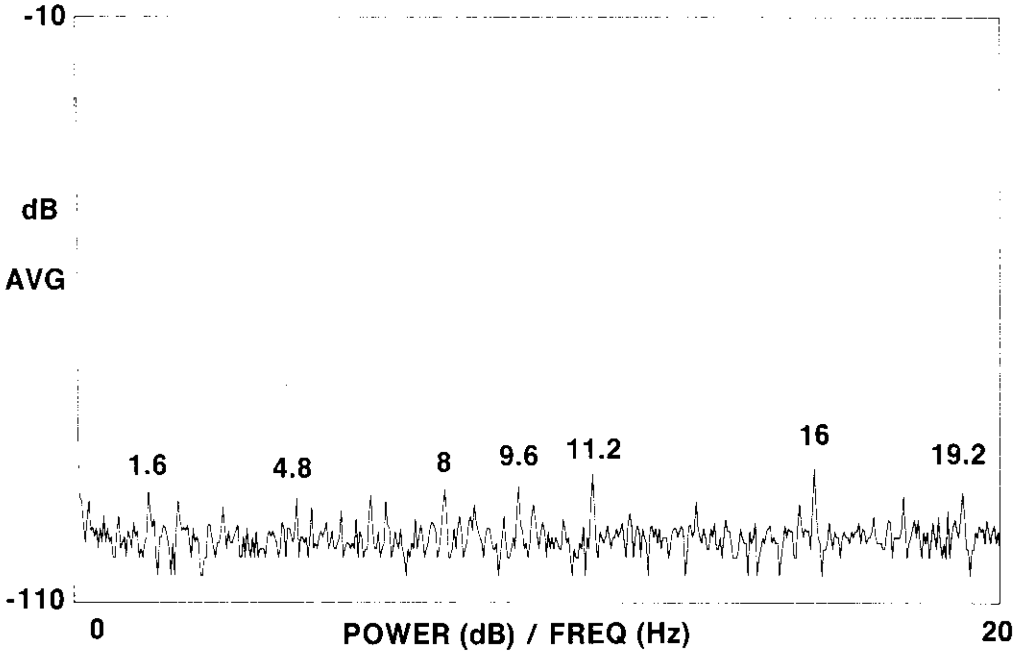

Figure 8. A spectrum taken from probes on a potted lemon (*Citrus Limon* sp.) tree 100 m underground in a mine shaft. The spectrum is similar to that obtained above ground from other plants and salt solution filled tree sections. It appears so far that W-wave phenomena are unaffected by shielding.

chops (less than 5 seconds). The received response (lower curve at about 20 seconds) is considerably smaller than the transmitting tree response but it is still quite appreciable when it is considered that W-wave effects are basically hard to detect due to the lack of good sensors and a lack of complete knowledge of the wave characteristics of a particular tree. The rises resulting from the reception of chop information usually had amplitudes of from 0.1 mv to 0.8 mv. The rise in the receiving tree curve preceding the received signal is a normal positive drift which often occurs on initial placement of probes. The top curve is the damage curve of Wagner 1988b. We see no apparent reflection blip because the results of several chops often obscure later curve structure but there are some roughness in the region where the reflection blip would be expected.

A processing time is likely required by receiving and transmitting trees. We attempted to reduce this effect by testing pairs of trees with presumably similar processing times to obtain velocities for signals traveling between trees. Of course, this may or may not be true because processing times may depend on signal strength, tree structure differences, etc. However, generally we obtained a velocity for signal travel between trees which was between 4.6 m/sec and 5.0 m/sec as the air (or ground) velocity (Table 1). The magnitude of the velocity would seemingly exclude tree root connections since the velocity in roots would probably be similar to that in the body of the plant. The between tree speed measured here is approximately five times the *in situ* velocity (96 cm/sec) (Wagner 1989h). The radical difference between the *in situ* velocity and this velocity suggests that an air velocity was measured rather than a velocity through earth since salt filled sample tests give an even lower velocity for more dense materials. For example we found velocities of near 70 cm/sec by pushing in a nail at the base of fresh salt solution filled tree sections using time of flight measurement techniques (Figure 5). The velocity for W-waves obtained from Figure 5 is 75 cm/sec but an earlier test on the same sample (24 hours earlier) gave a velocity of 66 cm/sec and when the sample was pulled from solution the apparent velocity was 62 cm/sec. The loss of salt and water as the sample dried appeared to increase the W-wave velocity.

Conclusions and Observations

The data here suggest that plants communicate in a much more fundamental way than just by means of aerosols (Rhoades 1985). The data also suggest that this communication involves W-waves.

Still there is the challenge of developing a better transducer for these waves. These waves don't interact with anything very much and thus a really superior sensor might be difficult to construct. Trees and other plants with salt solution filled samples and capacitors seem to provide the best detectors so far.

Acknowledgments

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