# Integrating plant electrophysiology, plant signalling and art

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**Abstract**

This paper gives a brief overview of plant electrophysiology and its history, looks at recent research and controversial new developments such as "plant neurobiology" and discusses how these findings can be integrated with sonic and visual art. It also looks at the potential to create multidisciplinary work that advances both science and art.

**Keywords**

Action potential, sound installation, mycorrhizal network, plant signalling, multichannel audio, art, plant behaviour, plant neurobiology, plant learning

## Plant electrophysiology – an introduction and brief history

The first suggestion that there was electrical activity in plants was in 1783 with Betholons' article "*De l'electricite des vegetaux*"[1]shortly after Luigi Galvani discovered that the twitching of dismembered frogs' legs was the result of an electrical signalling system in animals. Plant electrophysiology was further explored in 1873by Charles Darwin and electro physiologist Dr. Burdon Sanderson. The first plant to be investigated was, unsurprisingly, *DionaeaMus-cipula* (The Venus fly trap) when Sanderson released his pioneering paper on electrical activity in the plant[2] whilst working with Darwin[3].

There are two main ways of measuring electrical signals in plants(known as action potentials or APs and variation potentials or VPs)[4]. The first is extracellular, which takes measurements from outside the cells, and the second is intracellular, which requires one electrode inside the cell vacuole and one outside the cell wall. The first extracellular reading was taken in 1873 by electro physiologist Burden-Sanderson[5] and the first intracellular recording was made in the 1930s by Umrath et al[6]. For art installations it is easier to use extracellular readings using standard electrodes (Agcl, graphite, etc.) and data acquisition devices. Intracellular recordings require a high level of specialist knowledge and bulky expensive equipment such as micro manipulators which are more problematic for use in art installations.

The next significant research into this area was conducted by Indian scientist Sir Jagadish Chandra Bose. Bose was the first scientist to seriously propose that electric signalling in plants used APs with a nervous system similar to that of animals[7]. He proposed that fibres in the phloem of a plant fulfilled the same purpose as the nervous system in animals in transporting these electrical signals around the plant[8]. Despite Bose having been a well-respected early pioneer of radio, his presentations on plants were received with barely concealed ridicule at the royal society in London; however many of them would eventually be proved correct. His ideas that plants responded to wounding with electrical signals would be demonstrated over 70 years later by Willdon et al[9]who showed electrical signals were involved in the inhibition of proteinase as a result of burning the plant[10].

### The not so secret life of plants and telepathic yoghurt

In the 1960s a lot more research in this area would be conducted, though the maverick nature of some of the research would put off many serious scientists from researching this area for many years. One popular documentary (and book) that investigated the relationship between plants and sound, amongst other things, was “The Secret Life of Plants“ released in 1973 by Peter Tompkins and Christopher Bird[11]. Many of the included experiments are viewed as poorly controlled and the contents of “The Secret Life of Plants” has now been written off as largely pseudo-science by most biologists. Among the experiments conducted was one which tested the effect of music on plants. Aside from the fact that the experiments were not properly controlled, little thought was given as to why plants would respond to human music let alone the occidental “well-tempered scale”, nor why such a response would allow an evolutionarily advantage. The legacy of this era can be seen even to this day with many artists attempting to convert plant electrical signals into sound using midi instruments and the equal-tempered scale. In reality it is far more likely that plants would respond to sounds found in nature (e.g. insects that might be predators). The documentary included a report by the CIA’s chief polygraph technician Cleve Baxter who claimed that polygraph tests indicated that plants responded not just to wounding, light and temperature but even to human thought. Many of these claims were refuted by the scientific community in papers such as “The Not So Secret Life of Plants” by Galston and Clifford[12]. Baxter caused further controversy by claiming that all life, even the microorganisms found in yoghurt, were in possession of a kind of telepathy, causing nearly the entire scientific community and associated funding bodies to shun the entire field for many years. Despite the fact that his work has been comprehensively discredited, many artists still look to Baxter’s work as a source of inspiration and as a basis for technical guidance, ignoring more recent research that has a more solid scientific basis and almost equally astonishing implications. However it should be noted the using devices that measure conductivity on the surface of leaves may still produce tangible insights into plant physiology in response to external stimuli such as carbon dioxide[13]

### The renaissance of plant electrophysiology

Despite this stigma, several good studies were conducted during this lull of interest, and recently research in this area has been blooming. APs in plants have now become more accepted into the scientific mainstream and are beginning to find new applications in agriculture which use plants as biosensors to monitor environmental conditions[14][15]. Although plant action potentials are generally much slower than those found in animals (usually in the order of mm/s),claims of much faster APs have been made including one in soya of 30m/s[16] - which is comparable with animals.

Since the days of Darwin and Bose much more has been understood about plant action potentials. It has been found that these tiny electrical signals propagate through the phloem due to the opening and closing of voltage gated ion channels across the cell membrane[17]and may propagate through the plasmodesma of cell walls via the apoplastic pathway. However, unlike animal nerves, the depolarisation of these APs is effected by the release of negative chloride ions instead of the uptake of positive sodium ions[18].

These signals are difficult to measure for those coming from an artistic background or even a scientific background in a different field. Things are made even more difficult today due to an increase in background electrical noise from gadgets and today's ubiquitous electrical technology, despite the filtering of mains electrical frequencies (50/60hz) and use of a faraday cage. A useful paper for artists interested in measuring these signals is "Instrumentation for Measuring Bioelectrical Signals in Plants" by Lee Karlsson[19]. This gives a good overview on how to measure action potentials in plants and includes detailed circuit diagrams as well as information on electrode type and placement.

**Recent research that demonstrates that plants respond to sound**

Recently there has been renewed interest in the field of plants and sound[20] though most experiments have been looking at growth patterns[21,22,23]and gene expression in response to sound[24]. Perhaps the most astonishing recent study is one which suggests that maize roots generated, and respond to, sound[25]. When researchers tested the sound on other maize seedlings they found the roots grew towards the sound[26]. There is also a suggestion that the clicking noises produced are a kind of communication rather than just the random noises produced by the movement of water in the stem. Monica Gagliano, who made the discovery, encourages more research in the field in her article "Green Symphonies: a call for studies on acoustic communication in plants"[27].Amplifying tiny acoustic emissions from plants such as those suggested by Gagliano represents another avenue of exploration for soundart installations that does not involve electrophysiology.

Although many experiments have shown that electronic signalling in plants is common in response to a range of stimuli, such as light[28,29], pollination[30], physical movement[31,32,33,34], temperature[35], insects[36], and wounding[37,38], to date no properly controlled experiments that the author is aware of have been conducted which test plant APs in response to sound. However it is quite possible that they do – especially in tropical plants and especially above 3khz which is the region of the audio spectrum occupied by tropical bird and insect noise. This also presents interesting possibilities for sound installations, especially if AP responses in plants can be used to control sound equipment.

**Plant neurobiology**

Plant neurobiology is a recent term to describe a new field of plant science. It has caused some controversy with flurries of papers and counter papers arguing for[39,40]and against[41] the validity of the term. Eventually proponents agreed the term should be used as a metaphor in order to avoid anthropomorphising the processes involved[42]. However, arguing about the validity of the term may seem petty in the light of recent research and many scientists now agree that plants are much more able to compute complex responses in the environment than previously thought[43].Although there are still concerns about anthropomorphism, many scientists in the field now agree that plants can no longer be considered "'automata'-like organisms" with many studies suggesting that they can learn, remember and communicate like many other organisms[44,45]. To many artists and indigenous people this may seem obvious, but for scientists to find evidence of this flies in the face of a deep rooted cultural prejudice in the West that dates back to the time of Aristotle[46].

## The revival of the "root brain"

Plants have some of the same neurotransmitters found in humans, although their function is not clear[47]; while controversial, it has been claimed they have something similar to a synapses[48,49]. They have also been shown to have coordinated movement including "swarm like behaviour"[50] as well as various forms of memory[51]. Perhaps most interesting of all is the revival of Darwin's "root brain" hypotheses[52] which postulates that plants' root systems are a kind of neural net with most activity being found in the transition zone of the root apex. Similar research into the mycelium of fungi exhibit action potentials, some spontaneously arising without external stimuli[53] . Even more recent advances have shown that plant roots are able to differentiate self from non self [54] and plants can even recognise their kin[55] .

Even if some of this research turns out to be mistaken, there is already more than enough good cutting edge material for artists to engage with on many levels. Plant action potentials are involved with many of these processes, and action potentials can be converted into sound or light.

## Very recent research and unexplored areas

Plant learning and behaviour is another area only recently being explored. Recent research has shown that *Mimosa* plants have both long and short term memory and are able to learn which external stimuli are real threats and which are not, even when the stimuli are very similar[56]. The paper also showsthat light hungry plants learn faster so as to waste less energy.

Action potentials have been detected both in the root systems of plants[57] and the mycelia of fungi[58]. Recent research has shown that plants and trees are able to communicate rapidly across the mycorrhizal network[59,60,61] and some research has been conducted on electrical activity in the myzcorrhizal network[62]. Another paper shows "action potentials in fungal mycelia signalling the availability of nutrients at the tips of hyphal chords"[63]. However, despite this tantalising data, to the author's knowledge no research has been done on whether action potentials can cross from the root systems of plants to the mycelia and back to the roots of other trees via the Arbuscular mycorrhizal network and most scientists still believe this to be a form of chemical signalling. Although this seems disconcertingly like the script of the film 'Avatar', it should be borne in mind that several ideas from the film came about as the result of consultations with biologists. Converting these electrical potentials into light and multichannel sound installations by amplifying them and feeding them into a computer program in situ presents exciting opportunities to bridge the gap between science and art.  Audio visual installations that make tangible these hitherto unseen aspects of complex electrical plant activity, have the potential to engage the public and alter the way they perceive the biosphere of which they form a part; they would also allow scientists to see how signals propagate in natural habitats in an audio-visual way that would be hard to replicate in the laboratory. Some steps by artists in this direction have already been made[64].

## Summary

A synergy of visual and sonic art and plant electrophysiology, and signalling in general, presents multiple possibilities and avenues of exploration and is a relatively unexplored area. Audio visual art may lead to an alternative, immediate and intuitive method of understanding plant bio-electrics and the bisophere beyond the mere sonification or visualisation of data. Artists must take care that they are reading real and relevant data as spectacular displays of pseudoscience may impress the public but do little to reveal the true processes latent in the biosphere. Wherever possible, artists should try and work alongside scientists who have a profound knowledge of how to acquire the data they wish to work with.

The challenge is to create something that fulfils aesthetic and imaginative goals of the artist and yet at the same time maintains rigorous scientific method.

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