AUG 2023 – NO. 6

BAVARIAN JOURNAL OF APPLIED SCIENCES®

Resonant Low-Frequency Electromagnetic Biostimulation of *Lepidium sativum* Short: ELF-EMF Beats

Jens Ebbecke[*]

https://doi.org/10.25929/5mna-3d22

ABSTRACT

Low-frequency electromagnetic waves were applied to *Lepidium sativum* (garden cress) in order to alter their germination and seedling properties. Two different methods were used to generate the electromagnetic signals. Either a 1.8 GHz carrier signal was multiplied with an extremely low frequency signal (between 1 Hz and 200 Hz) – also called amplitude modulation – or, as the second method, a beat signal of two high-frequency electromagnetic waves with very similar frequencies was created. The generated amplitude modulated signals were sent to an antenna for emission of the waves to free space. In close vicinity to the antenna, seeds of garden cress were placed in a moist environment. The seeds were exposed to the electromagnetic waves initially for 20 minutes and subsequently every 24 hours for 20 minutes. After 100 hours, the length of the cress plants was measured. Within the measurement accuracy, a retarded growth was detected at extremely low frequencies of 50Hz. The growth inhibition was more pronounced with the beat signal than with the amplitude modulation. This method of beat signals opens up new possibilities to alter biological systems and more advanced topics than the germination and seedling of garden cress will be explored in future work.

Lepidium sativum *(Gartenkresse) wurde mit niederfrequenten elektromagnetischen Wellen bestrahlt, um ihre Keimung und ihr initiales Wachstum zu beeinflussen. Zwei verschiedene Methoden zur Generierung der niederfrequenten elektromagnetischen Signale wurde verwendet. Zum einen wurde ein 1,8 GHz Trägersignal generiert, welches mit einem extrem niederfrequenten Signal (zwischen 1 Hz und 200 Hz) multipliziert wurde – zumeist als Amplitudenmodulation bezeichnet. Zum anderen wurde eine Schwebung erzeugt durch die Überlagerung zweier hochfrequenter Wellen mit sehr ähnlichen Frequenzen. Diese Signale wurden mittels einer Antenne in eine abgestrahlte elektromagnetische Welle umgewandelt. In der Nähe der Antenne wurden Samen der Gartenkresse in einer feuchten Umgebung platziert. Die Samen wurden initial 20 Minuten bestrahlt und anschließend alle 24 Stunden für 20 Minuten. Nach 100 Stunden Keimung und Wachstum wurde die Länge der Kresse bestimmt. Im Rahmen der Versuchsgenauigkeit wurde ein verringertes Wachstum für eine Frequenz von 50 Hz ermittelt. Hierbei war die Wachstumsverringerung bei Verwendung der Schwebung größer als bei Verwendung der Amplitudenmodulation. Somit eröffnet die Methode der elektromagnetischen Schwebung neue Möglichkeiten, biologische Systeme zu beeinflussen und bedeutsamere Themen als die Keimung und das Wachstum von Gartenkresse werden in zukünftigen Arbeiten untersucht.*

KEYWORDS

Biostimulation, garden cress, ELF-EMF, beat, amplitude modulation

Biostimulation, Gartenkresse, ELF-EMF, Schwebung, Amplitudenmodulation

---

[*] Faculty of Electrical Engineering and Media Technology at the Deggendorf Institute of Technology

1. Introduction

Biostimulation with extremely low-frequency electromagnetic fields (ELF-EMF) is an emerging area for alternative medical treatment [1–3] and for biotechnological applications [4–5]. One way of explaining the effect of the ELF-EMF on living organisms is the concept of forced oscillation. Many processes in biological materials are based on electrical signals of ion transport or are mediated by electric fields within an organism with function-dependent frequency. If an external electromagnetic stimulus is applied with a frequency similar to the eigenfrequency of the process, a resonantly forced biostimulation occurs. Dependent on the process which is affected, this electromagnetic biostimulation can have positive or negative effects on the organism.

Different concepts for electromagnetic biostimulation exist in literature. The most common method is the generation of ELF-EMF by magnetic coils. The research field can be divided into three groups: human brain stimulation (mostly named “transcranial magnetic stimulation” [6]) and human body treatment in general, second the alteration of the growth of bacteria [7,8] and third, changing the germination and seedling of plants [4,9–11]. For the research related to effects on plants, the initial stage of germination and seedling of the plants have been focused on and both, the increased and decreased growth of plants under ELF-EMF radiation generated by magnetic coils have been reported [9]. Mechanisms behind these effects are not fully understood to date but one hypothesis is that the activation of ions and the polarization of dipoles in living cells might be influenced [9].

Another method for the creation of ELF-EMF is the generation of an amplitude modulated electromagnetic wave. One functionality of modern high-frequency signal generators is to create an extremely low-frequency signal envelope of a high-frequency carrier signal named amplitude modulation. These amplitude modulated RF signals were used to increase the calcium-ion efflux from brain tissue [11], to change the ornithine decarboxylase activity [12] and for the growth inhibition of bacteria [13–14] by inducing morphological changes in the bacteria.

In addition to the amplitude modulated electromagnetic wave method we also used an electromagnetic beat signal for the generation of ELF-EMF. A similar extremely low-frequency envelope of a high-frequency electromagnetic wave can be created by superimposing two high-frequency signals with almost the same frequency. The resulting beat signal has nearly the same ELF-EMF envelope as for the amplitude modulated one. To our knowledge, no experimental investigations of the effect of electromagnetic beat waves on living organisms has been published so far.

Here, we present an experimental work of electromagnetic biostimulation using a newly developed technique of electromagnetic beats in order to alter the germination and seedling of plants. Garden cress seeds (*Lepidium sativum*) are popular crop species and are commercially cultivated across the world. Garden cress has been chosen due to their fast germination and short seedling time.

2. Theory of amplitude modulation and beat generation

Amplitude modulation is a well-known technique in radio and information technology. A high-frequency electromagnetic signal (carrier signal) is multiplied with a low frequency signal where usually the information is transmitted by. This can be mathematically described as:

equation of electric field (as scalar) of carrier signal:

$$E_C(t) = A_C \cdot \cos(\omega_c t) \qquad (1)$$

with A_C the amplitude of the electric field and ω_C the frequency of the carrier signal; and equation of electric field (as scalar) of modulation signal:

$$E_M(t) = A_M \cdot \cos(\omega_M t) \qquad (2)$$

with A_M the amplitude of the electric field and ω_M the frequency of the carrier signal.

For amplitude modulation the modulation signal is added with a DC component (which is set here to 1) and both are multiplied with the carrier signal:

$E_{AM}(t) = [E_M(t) + 1] \cdot E_C(t) = A_M \cdot \cos(\omega_M t) \cdot A_C \cdot \cos(\omega_c t) + A_C \cdot \cos(\omega_c t)$ **(3)**

rearranged: $\frac{E_{AM}(t) - A_C \cdot \cos(\omega_c t)}{A_M \cdot A_C} = \cos(\omega_C t) \cdot \cos(\omega_M t)$ **(4)**

now using the trigonometric identity (i): $\cos(\alpha) \cdot \cos(\beta) = \frac{1}{2}\cos(\alpha + \beta) + \frac{1}{2}\cos(\alpha - \beta)$

gives:

$\frac{E_{AM}(t) - A_C \cdot \cos(\omega_c t)}{A_M \cdot A_C} = \frac{1}{2}\cos(\omega_C t + \omega_M t) + \frac{1}{2}\cos(\omega_C t - \omega_M t)$ **(5)**

rear.: $E_{AM}(t) = A_M \cdot A_C \cdot \left[\frac{1}{2}\cos(\omega_C t + \omega_M t) + \frac{1}{2}\cos(\omega_C t - \omega_M t)\right] + A_C \cdot \cos(\omega_c t)$ **(6)**

rearranged: $E_{AM}(t) = A_C \cdot \left[\frac{A_M}{2}\cos(\omega_C t + \omega_M t) + \frac{A_M}{2}\cos(\omega_C t - \omega_M t) + \cos(\omega_c t)\right]$ **(7)**

rearranged: $E_{AM}(t) = A_C \cdot \left[\frac{A_M}{2}\cos(\{\omega_C - \omega_M\}t) + \cos(\omega_c t) + \frac{A_M}{2}\cos(\{\omega_C + \omega_M\}t)\right]$ **(8)**

equation (8) shows that the resulted amplitude modulation consists of the lower sideband $\frac{A_M}{2}\cos(\{\omega_C - \omega_M\}t)$, the carrier signal $\cos(\omega_c t)$ and upper sideband $\frac{A_M}{2}\cos(\{\omega_C + \omega_M\}t)$.

A similar modulation of the amplitude can be achieved by superimposing two closely spaced electromagnetic waves of same amplitude often referred to as a beat signal. Mathematically, a beat signal can be described by:

equation of electric field (as scalar) of the first signal: $E_1(t) = A \cdot \cos(\omega_1 t)$ **(9)**

and equation of electric field (as scalar) of the second signal: $E_2(t) = A \cdot \cos(\omega_2 t)$ **(10)**

if both signals are superimposed we get: $E_1(t) + E_2(t) = A \cdot [\cos(\omega_1 t) + \cos(\omega_2 t)]$ **(11)**

rearranged: $\frac{E_1(t) + E_2(t)}{A} = \frac{E_{beat}(t)}{A} = \cos(\omega_1 t) + \cos(\omega_2 t)$ **(12)**

We here use the trigonometric identity (ii): $\cos(\alpha) + \cos(\beta) = 2\cos\left(\frac{\alpha+\beta}{2}\right) \cdot \cos\left(\frac{\alpha-\beta}{2}\right)$:

$E_{beat}(t) = 2 \cdot A \cdot \cos\left(\left\{\frac{\omega_1 + \omega_2}{2}\right\} \cdot t\right) \cdot \cos\left(\left\{\frac{\omega_1 - \omega_2}{2}\right\} \cdot t\right)$ **(13).**

If $E_1(t)$ and $E_2(t)$ are very similar frequencies then this beating signal consist of a high-frequency part (like the carrier signal) multiplied with a low-frequency part – the envelope. The difference of the amplitude modulated signal is that a constant part (here „1“) is added to the low-frequency signal – see equation (3) – which results in three frequency contributions: the carrier frequency and two sidelobes. Without this constant part the amplitude modulated signal would be identical with the beat signal.

3. Experimental setup

For generation of the amplitude modulated signal, a signal generator Siglent SSG3000X and a helical antenna from Taoglas (TG.22.0111, 824 MHz-2.17 GHz) were used. A carrier frequency of 1.8 GHz and 15 dBm was chosen because it provided the highest signal amplitude using the helical antenna (verified with a spectrum analyzer Siglent SSA3021X and two TG.22.0111). For generating the beat signal, two signal generators were used: a Siglent SSG3000X and a Rohde&Schwarz HM8135. Both signals with amplitude of 15 dBm were superimposed by using an inverted HF beam splitter and then the same helical antenna was used. The resulted signals are presented in Figures 1 a) to d).

In Figure 1 a), the frequency spectrum of a 100% amplitude modulated 1.8 GHz carrier signal with 50 Hz modulation signal is presented. The center of the scale is at 1.8 GHz with 500 Hz span. Clearly, the frequency spacing of 50 Hz between the carrier signal and the sidelobes can be seen. The y-scale is in logarithmic dB scale. The signal generator Siglent SSG3000X also uses higher order sidebands for the amplitude modulation, but already the 2nd order sideband has -15 dB less amplitude. In Figure 1 c), the corresponding envelope of the amplitude modulated signal of a) is presented which was measured with a Rohde&Schwarz RTM3004 oscilloscope. For this measurement, two helical antennas (TG.22.0111) were used which were placed at the same distance as the antenna-seeds distance of the later described measurements in order to get values for the field strength of the

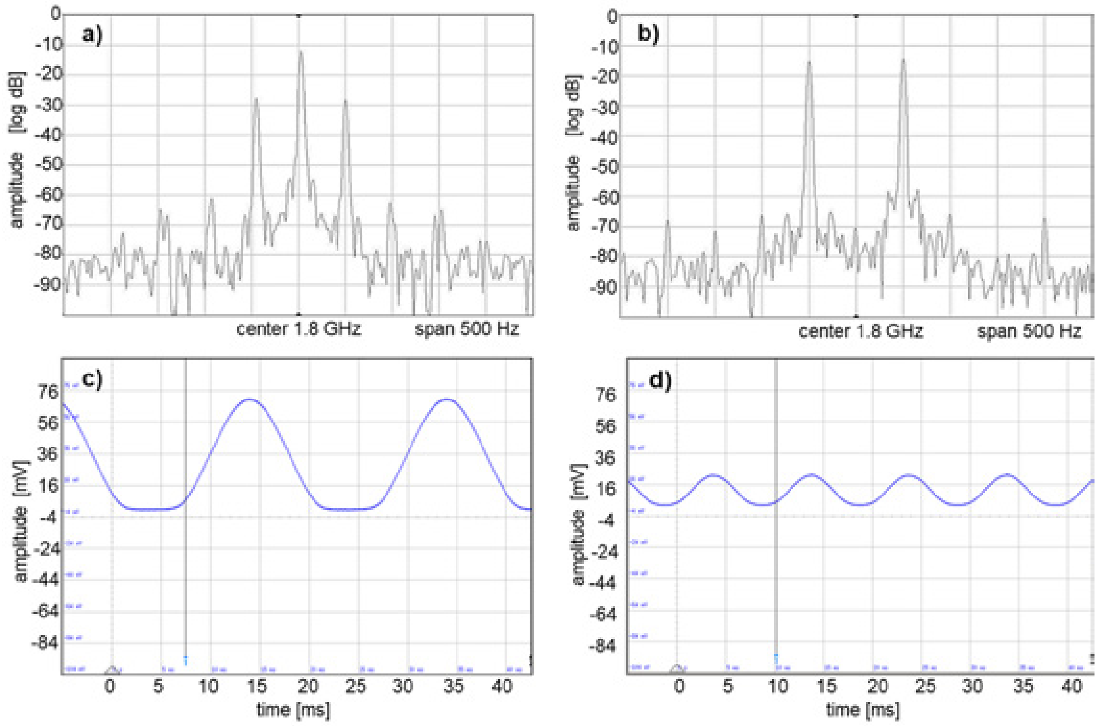

Figure 1: a) Frequency spectrum of the amplitude modulated signal in frequency space with main frequency signal and side lobes. b) Frequency spectrum of the beat signal in frequency space showing that two frequencies of same amplitude are applied. c) Resulting envelope signal of the amplitude modulated signal measured with an oscilloscope with periodicity of 20 ms. d) Resulting envelope signal of the beat signal measured with an oscilloscope with periodicity of 10 ms

applied ELF-EMFs. The maximum amplitude of the amplitude modulated signal in c) is 68 mV. The amplitude loss by detection of the signal with the second helical antenna needs to be taken in account, which is a factor of two different amplitudes as a first order assumption. Therefore, an amplitude of roughly 136 mV of the electric field can be approximated which is acting on the garden cress seeds. The measured periodicity in time in Figure 1c) is 20 ms which correlates well with the ELF-EMF of 50 Hz.

In Figure 1 c), the frequency spectrum of the beat signal is shown. The center of the scale is at 1.8 GHz with 500 Hz span. According to equation (13) a frequency difference of 100 Hz was set at the two signal generators in order to create a beat envelope of 50 Hz. In Figure 1 d) the corresponding envelope measured in the time domain is presented. A periodicity of 10 ms was detected instead of the expected 20 ms which means that the envelope of the created beat signal has a 100 Hz periodicity. The only reasonable explanation is that the inverted HF beam splitter is not leading to a superposition of the HF signals but to a multiplication, which means to equation (3) without the constant factor 1. Still an ELF-EMF can be created by the beating method, but the frequency difference between the two signal generators was needed to be adjusted for the experiments. The detected amplitude of the beat signal by using two helical antennas was approximately 22 mV (see Figure 1 d) which is only one third of the amplitude of the amplitude modulated one. This smaller amplitude is caused by combining the two high-frequency signals from two different signal generators using the inverted HF splitter. The experiments were done in ambient conditions, at constant room temperature and under natural day light. Five to six petri dishes, each with ten garden cress seeds were used in one experimental cycle. The seeds of garden cress were placed onto layers of tissues in a petri dish, as visualized in Figure 2 a). In total, six experimental cycles were conducted. In order to minimize external effects, the petri dishes were kept next to each other and as closely as possible, except for the time when the non-reference ones were treated with the ELF-EMF. A reference petri dish (one for each experimental cycle), where no ELF-EMF was applied, was used for each experimental cycle. The average length of the garden cress was similar for all six reference petri dishes from which it can be concluded that the external conditions were similar for all petri dishes.

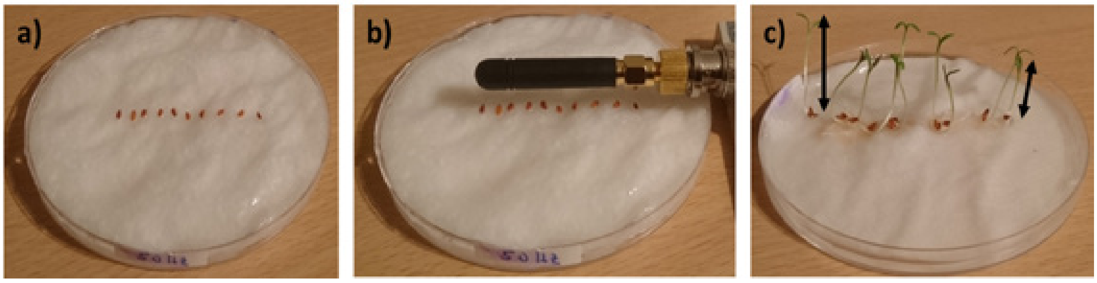

Figure 2: a) For each experiment, ten seeds of garden cress were placed next to each other onto water-soaked tissue layers. b) The helical antenna was placed directly above the cress seeds for applying the electromagnetic waves. c) After 100 h of germination and seedling the length of the cress seeds was measured.

The helical antenna was placed directly above the seeds (see Figure 2 b). Just before the start of the experiment, the seeds were soaked with water and then ELF-EMFs were applied for 20 minutes. This ELF-EMF treatment was repeated every 24 hours and after 100 hours the lengths of garden cress seeds were measured (Fig. 2 c). The seeds were kept wet with 12 ml of water each day.

4. Result

As described in the previous chapter, for each experimental cycle one petri dish with seeds was not exposed to ELF-EMFs, serving as references. For four experimental cycles, an amplitude modulated RF signal was used and the different modulation frequencies are listed in the left row of the left part of Table 1. The modulation frequency was set between 1 Hz and 200 Hz. Several modulation frequencies were repeated in the replicated experimental cycles in order to increase the confidence level of the results. In addition, a carrier signal of 1.8 GHz without amplitude modulation was used in the first experimental cycle, resulting in seedling lengths similar to the unexposed references. The carrier signal experimental is placed at the bottom of the left part of Table 1 and is named “$1.8{\cdot}10^8$”.

The length of the seedlings was measured and the average length for each frequency is listed in the middle row of the table. In the right row, an experimental error is listed. Besides an inaccuracy of length measurement, the error also indicates the measure of how far a set of numbers is spread out from their average value, the variance. Not all cress seedlings in one petri dish have exactly the same length after 100 hours of growth and in order to take the spread into account, the variance was calculated and added to the length measurement inaccuracy.
The average lengths of six references are between 20.6 mm and 26.6 mm. If a shorter or longer average length of the seedling is obtained for certain ELF-EMFs, then these results are worth a more detailed discussion.

The right part of Table 1 presents the ELF-EMF values and results of the two experimental cycles where the ELF-EMF was generated by a beat. Here, the reference and in addition the 50 Hz and 100 Hz ELF-EMF were repeated in order to improve significance and validity of the results. For most ELF-EM frequencies, the results are located within the spread of the references. The only frequency region which shows a significantly different length is around 50 Hz modulation frequency.

This shorter seedling length at 50 Hz is obtained for all experimental cycles and also for both electromagnetic field modulation methods. For the amplitude modulation technique, the length at 50 Hz ELF-EMF is not much shorter than those of the references and could be explained within the measurement error. But for the experiments with the beat signal the resulted average lengths at 50 Hz are below 18 mm and for one cycle even below 15 mm, both outside the reference band.

For the amplitude modulation method, one experiment was done at 50 Hz with a factor 10 lower intensity (5 dBm instead of 15 dBm) and is referred to in Table 1 as “50**”. Interestingly, the resulted length of 19.5 mm lies between the reference band and the results at 50 Hz full EMF intensity which provides a first information regarding amplitude dependency.

5. Discussion

This experimental study reveals a retarded growth of garden cress seeds when exposed to an ELF-EMF of 50Hz, either created by the amplitude modulation method or created by a

Amplitude modulation		
frequency [Hz]	**length [mm]**	**error [mm]**
Ref	21.6	2.6
Ref	26.6	1.5
Ref	20.6	2.7
Ref	24.4	2.4
1	20.5	2.7
1	24.3	2.7
4	22.8	2.6
7	22.2	3.0
10	22.9	2.5
10	23.2	3.1
10	21.4	2.9
25	23.2	2.2
30	20.9	2.3
50	18.0	2.3
50	19.4	3.0
50	18.6	2.4
50	18.1	2.0
50**	19.5	2.3
70	25.5	2.6
90	21.0	2.4
200	23.1	2.4
$1.8 \cdot 10^9$	25.8	2.4

Beat		
frequency [Hz]	**length [mm]**	**error [mm]**
Ref	23.6	2.2
Ref	23.0	2.4
20	22.9	2.3
40	20.1	2.1
50	17.7	2.2
50	14.9	2.4
60	22.9	2.8
100	19.7	2.6
100	23.3	2.2
150	19.4	2.0
200	19.1	2.3

Table 1: Results of the germination and seedling experiments with garden cress under the influence of ELF-EMFs. In the left part of Table 1, the results with an amplitude modulated signal are presented and in the right part the results where a beat signal was applied.

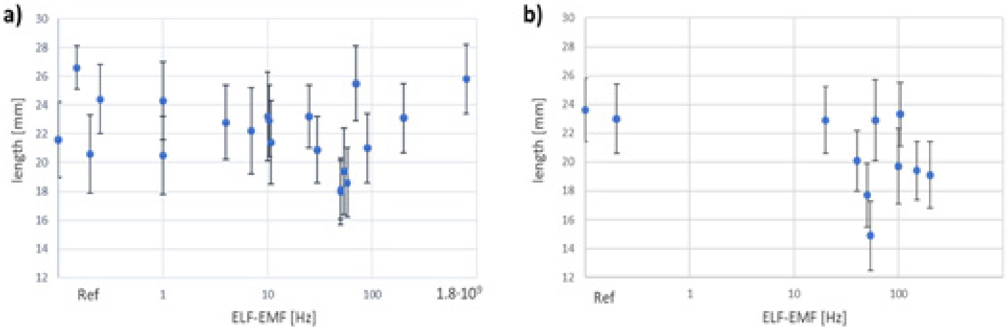

Figure 3: Numbers of Table 1 visualized by graphs: a) the obtained average lengths with using an amplitude modulated signal, and b) the length of the garden cress seedling for an applied beat signal.

beat process. The retarded growth was found to be more pronounced for the beat signal method which has a smaller signal amplitude as presented in Figures 1 c) and d). Both envelopes of the resulting electromagnetic signals are very similar in shape (see Figure 1). Therefore, one can conclude that the growth distinction might be caused by the difference in the frequency domain. Figure 1 a) shows that the amplitude modulated signal by one signal generator consists of the carrier frequency (in this experiment 1.8 GHz) and side lobes caused by the multiplication of the carrier signal with the modulation signal (50 Hz in Figure 1a). Therefore, the first order side lobes are at 1.799 999 950 GHz and 1.800 000 050 GHz. Whereas Figure 1 b) presents that the beat signal consists of only two frequency contributions (1.799 999 950 GHz and 1.800 000 050 GHz in Fig. 1 b) which have the same amplitude in order to create a beat signal.

As introduced in the beginning, one way of explaining the effect of the ELF-EMF on living organism is the concept of forced oscillation. For the resonant case, the frequency of the driving force needs to be similar to the eigenfrequency of the biological system. When an RF signal is used as a carrier signal, this RF frequency itself is too high for the creation of a resonant condition. Therefore, a low-frequency signal is added, either by using an amplitude modulation method or by creating a beat signal. In the case of the amplitude modulation, this low-frequency signal is the difference between the carrier signal and the side lobes (see Figure 1 a). There are at least three frequencies involved: the carrier signal, the lower side lobe und the upper side lobe. The frequency difference between these three signals is +50 Hz and -50 Hz for Figure 1 a). In the case of the beat signal, there are only two signals of equal amplitude involved as depicted in Figure 1 b). There exists a more defined frequency difference between two signals. This clearer definition of a frequency difference might lead to a better forced oscillation in the plants than in the case of an amplitude modulation. But this assumption needs to be proved in future work.

Both an increase and decrease of the germination and seedling properties of plants under the influence of ELF magnetic fields have been reported [8,9]. Especially in [8], the strongest decrease of seedlings was found for 50 Hz ELF magnetic field treatment. It was assumed that this change of growth might result from the excitation of Ca^{2+} ions. This is an explanation which often is used to explain results obtained with ELF-EMFs (see Reference [15] and references therein). Calcium is an essential structural, metabolic and signalling element in plants and it is involved in many cellular processes such as cell proliferation. It is transported in Ca^{2+}-permeable ion channels. These voltage-gated channels are normally closed, but they open in response to a transmembrane voltage pulse. Therefore, the influence of an ELF-EMF on the Ca^{2+} membrane channels might be a stimulation of the Ca^{2+} transport across the membrane channels and thus altering the growth characteristic of the plants. Due to the fact that we only detect a retarded growth for exactly one modulation frequency, one can conclude that this ELF-EMF of 50 Hz resonantly stimulates the calcium transport by a forced oscillation.

There exist many papers about the influence of 50 Hz, respectively 60 Hz electromagnetic fields on the healthiness of humans and other living creatures because this is the frequency of our power lines (see for example [16–19]). According to Maxwell's equation, every current is generating a magnetic field and therefore the currents in our power lines are also creating small magnetic fields of 50 Hz, respectively 60 Hz frequency. But following the explanation using forced oscillations by ELF-EMF, we think that it is a pure random coincidence that here the garden cress seeds are showing the strongest effect also at 50 Hz ELF-EMF. Because it cannot be assumed that the cells and calcium channels in garden cress seeds have the same eigenfrequencies as human body cells and therefore there should be no correlation between these two topics.

6. Conclusion

In conclusion, we have introduced a new method of creating an ELF-EMF by superimposing two GHz electromagnetic waves of very similar frequencies. This beating concept if of course not new in general and it is applied in many different technical applications but to our knowledge, it has not been used yet for the creation of ELF-EMFs. These ELF-EMFs created by a beating process and additionally by using a standard amplitude modulation technique were used to alter the germination and seedling behavior of garden cress seeds. A retarded growth for an ELF-EMF of 50 Hz was found. This frequency seems to resonantly influence the growth of the plant because it is the only frequency where a retarded growth was detected. Hereby, the beating signal has shown an even bigger effect than the amplitude modulated signal which opens up new possibilities for influencing the proliferation of bacteria or even human body cells, which will be addressed in future work.

7. Acknowledgements

We thank Werner Bogner and Peter Breitschopf for the help with the RF equipment.

References

1] Markov, Marko S. (2007): Expanding use of pulsed electromagnetic field therapies. In: Electromagn. Biol. Med. 26 (3), S. 257–274. https://www.tandfonline.com/doi/abs/10.1080/15368370701580806

[2] Consales, Claudia; Merla, Caterina; Marino, Carmela; Benassi, Barbara (2012): Electromagnetic fields, oxidative stress and neurodegeneration. In: International Journal of Cell Biology 2012, S. 1-16. https://www.hindawi.com/journals/ijcb/2012/683897/

[3] D'Angelo, C.; Costantini, E.; Kamal, M., A.; Realea, M (2015): Experimental model for ELF-EMF exposure: Concern for human health. In: Saudi Journal of Biological Sciences 22 (1), S. 75–84. https://www.sciencedirect.com/science/article/pii/S1319562X14000795

[4] Nair, R. M.; Leelapriya, T.; Dhilip, K. S.; Boddepalli, V. N.; Ledesma, D. R. (2018): Beneficial effects of Extremely Low Frequency (ELF) Sinusoidal Magnetic Field (SMF) exposure on mineral and protein content of mungbean seeds and sprouts. In: Indian Journal of Agricultural Research 52 (2), S. 126-132. https://www.indianjournals.com/ijor.aspx?target=ijor:ijar2&volume=52&issue=2&article=004

[5] Rekena, Alina; Didrihsone, Elina; Vegere, Kristine (2019): The role of magnetic field in the biopharmaceutical production: Current perspectives. In: Biotechnology Reports 22, S. 1-7. https://www.sciencedirect.com/science/article/pii/S2215017X18303072

[6] Hallett, M. (2000): Transcranial magnetic stimulation and the human brain. In: Nature 406, S. 147–150. https://www.nature.com/articles/35018000

[7] Cellini, Luigina; Grande, Rosella; Di Campli, Emanuela; Di Bartolomeo, Soraya; Di Guilio, Mara; Robuffo, Iole; Trubiani, Oriana; Mariggio, Maria A. (2008): Bacterial Response to the Exposure of 50 Hz Electromagnetic Fields. In: Bioelectromagnetics 29, S. 302-311. https://onlinelibrary.wiley.com/doi/abs/10.1002/bem.20391

[8] Obermeier, Andreas; Mati, Florian, Dominik; Friess, Wolfgang; Stemberger, Axel (2009): Growth Inhibition of Staphylococcus aureus Induced by Low-Frequency Electric and Electromagnetic Fields. In: Bioelectromagnetics 30, S. 270-279. https://onlinelibrary.wiley.com/doi/abs/10.1002/bem.20479

[9] Huang, Hsin-Hsiung; Wang, Show-Ran (2008): The Effects of Inverter Magnetic Fields on Early Seed Germination of Mung Beans. In: Bioelectromagnetics 29, S. 649-657. https://onlinelibrary.wiley.com/doi/abs/10.1002/bem.20432

[10] Shabrangi, Azita; Majd, Ahmad (2009): Comparing Effects of Electromagnetic Fields (60 Hz) on Seed Germination and Seedling Development in Monocotyledons and Dicotyledons. In: PIERS Proceedings 18-21, S. 704-709.

[11] Blackman, C. F.; Benane, S. G.; Elder, J. A.; House, D. E., Lampe, J. A.; Faulk, J. M (1980): Induction of Calcium-Ion Efflux From Brain Tissue by Radiofrequency Radiation: Effect of Sample Number and Modulation Frequency on the Power-Density Window. In: Bioelectromagnetics 1, S. 35-43. https://onlinelibrary.wiley.com/doi/abs/10.1002/bem.2250010104?casa_token=0K0J_sRxqdoAAAAA:eRNdfeHLp5gz4IEjnk4aeUPSNadIz3MR_GQouSrWUYchVGz8xM1YMr2f_nGHERXA1paOmDd5t9pZng

[12] Litovitz, T. A.; Krause, D.; Penafiel, Miguel; Elson, Edward C.; Mullins, J. M. (1993): The Role of Coherence Time in the Effect of Microwaves on Ornithine Decarboxylase Activity. In: Bioelectromagnetics 14, S. 395-403. https://onlinelibrary.wiley.com/doi/abs/10.1002/bem.2250140502?casa_token=smD8fTysWfQAAAAA:u0ajKZ-YQ9rZ8cRsoXMxGz2Q8VT9cPh7cd85vteQqaX-Tj9F19qcgO_qeRG8PnSYqdfb5xuGMM-I3w

[13] Fadel, M. A.; Mohamed, Z. A.; Abdel-Lateef, M. A.; Hosny, A. A. (2018): Effect of Extremely Low Frequency of Electromagnetic Fields on Some Toxic Species of Cyan Bacteria. In: International Journal of New Horizons in Physics 5 (1), S. 5-10. https://www.naturalspublishing.com/Article.asp?ArtcID=13987

[14] Mohamed, Zakaria; Fadel, Ali; Abdel-Lateef, Medahat; Hosny, Asmaa (2020): Growth inhibition of the toxic cyanobacterium Cylindrospermopsis raciborskii by extremely low-frequency electromagnetic fields. In: Acta Botanica Croatica 79 (2), S. 193–200. https://hrcak.srce.hr/clanak/349648

[15] Funk, Richard H. W.; Monsees, Thomas; Özkucur, Nurdan (2009): Electromagnetic effects – From cell biology to medicine. In: Progress in Histochemistry and Cytochemistry 43, S. 177–264. https://www.sciencedirect.com/science/article/abs/pii/S0079633608000375

[16] Masoudi-Khoram, Nastaran; Abdolmaleki, Parviz (2021): Effects of repeated exposure to 50 Hz electromagnetic field on breast cancer cells. In: Electromagnetic Biology and Medicine 41, issue 1, S. 44-51. https://www.tandfonline.com/doi/abs/10.1080/15368378.2021.1995872

[17] Wolf, Federica I.; Torsello, Angela; Tedesco, Beatrice; Fasanella, Silvia; Boninsegna, Alma; D'Ascenzo, Marcello; Grassi, Claudio; Azzena, Gian Battista; Cittadini, Achille (2005): 50-Hz extremely low frequency electromagnetic fields enhance cell proliferation and DNA damage: possible involvement of a redox mechanism. In: Biochimica et Biophysica Acta (BBA) - Molecular Cell Research 1743, issues 1-2, S. 120 -129. https://www.sciencedirect.com/science/article/pii/S0167488904002228

[18] Tokalov, Sergey V.; Gutzeit, Herwig O. (2004): Weak electromagnetic fields (50 Hz) elicit a stress response in human cells. In: Environmental Research 94, issue 2, S. 145 – 151. https://www.sciencedirect.com/science/article/abs/pii/S0013935103000884

[19] Trimmel, Michael; Schweiger, Elke (1998): Effects of an ELF (50 Hz, 1 mT) electromagnetic field (EMF) on concentration in visual attention, perception and memory including effects of EMF sensitivity. In: Toxicology Letters 96-97, S. 377 – 382. https://www.sciencedirect.com/science/article/pii/S0378427498000964?casa_token=3kwyEU-35K18AAAAA:33vh5OsT38UsV8IEo_Buv4YZEn-hHyacRO1K72tCk2_DomTWAQxTbsjzH7_kcOwyl-Zw5R_UR5OQ

Jens Ebbecke

Jens Ebbecke received his doctorate at the TU Braunschweig and his habilitation at the University of Augsburg on the subject of „Semiconductor Nanostructure Acoustodynamics". Since 2022, he has been professor of "Optical Metrology and Optical Sensors" at the DIT and scientific head of the research group "Optical Sensor and Quantum Optics" at the TC Teisnach Sensor Technology. His further interests are in the field of low-frequency stimulation of biological processes.

Jens Ebbecke promovierte an der TU Braunschweig und wurde an der Universität Augsburg zum Thema „Semiconductor Nanostructure Acoustodynamics" habilitiert. Seit 2022 ist er Professor für „Optische Mess- und Sensortechnik" an der THD und wissenschaftlicher Leiter der Forschungsgruppe „Optische Sensortechnik und Quantenoptik" am Technologie Campus Teisnach Sensorik. Weitere Interessen sind die niederfrequente Stimulation von biologischen Prozessen.

Kontakt / *Contact*
✉ **jens.ebbecke@th-deg.de**