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# Microwave treatment against the attack of wood boring in timber structures

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**Abstract.** Timber is a sustainable building material that can be damaged by several biological agents, like insect activity, fungal decay and more. This is one of the most common problems in historical buildings. This paper gives an overview of microwave (MW) technologies, which have been used in wood boring insect control. Electromagnetic waves penetrate throughout the entire volume of treated material, causing water in wood and wood boring insects infesting wood to heat up simultaneously. The rise of temperature is the main effect used in MW pest control. A microwave wood boring insect neutralisation device herein is introduced. This paper looks at the long-distance microwave irradiation and radiation energy distribution of the irradiated surface. Tests for evaluation of wood pest elimination by MW radiation are specified and discussed.

**Key words:** wood boring insect, pest control, microwave technology, dielectric heating.

## INTRODUCTION

One of the main factors that reduce the durability of timber structures is biological activity, most commonly a variety of fungus that digests wood, causing it to rot, and the insects that bore into wood. According to the taxonomic rank, insects that damage wood constructions in buildings belong to the following orders – Coleoptera, Hymenoptera, Lepidoptera, and Isoptera. Fortunately the last ones named are not present in Estonia. The constructions are not damaged by the adult insects, which lay eggs on timber surfaces, but instead by the larvae who hatch from the eggs and are attracted to the starches and sugars contained within the timber. Depending upon the species, larvae can spend up to 12 years within the timber boring tunnels inside, up and down the grain.

Therefore destroying the insect in its early life cycle extends the life span of wooden buildings or objects.

Different mechanical, chemical, biological and physical methods are used to exterminate biological organisms in timber structures. Physical methods are preferred in the EU, because they are effective and environment-friendly. They can be classified according to the technique used: irradiation (including use of UV-, X-ray or gamma-ray radiation and radioactive compounds), freezing, heating and microwave treatment.

The principle of the last two described techniques is based on the thermal treatment of timber, resulting in temperature rise of the structure. Studies indicate that different pest species have different capacities to survive high temperatures, but generally it is about 55 °C (Leary, 2002; Andreuccetti et al., 1994; Diaferia et al., www.emitech.it). The international standard ISPM 15 (ISPM No. 15, 2009), which regulates the phytosanitary measures that reduce the risk of pest introduction and spread via wood packaging materials, states that during the heat treatment the material must be heated in accordance with a specific time–temperature schedule that achieves a minimum temperature of 56 °C for a minimum duration of 30 continuous minutes throughout the entire profile.

Microwave treatment provides an accurate control of the temperature inside the timber structure. Microwaves are radio waves with wavelengths ranging from 1 mm to 1 m and with an oscillating frequency between 0.3 GHz to 300 GHz. Different MW technologies against wood pests have been investigated during the last 50 years (Whitney et al., 1961; Nelson & Kantack, 1966; Ponomaryova et al., 2010).

Using the direct effect of MW in pest control is a complicated task. It depends on the characteristics of the biological lifeform: geometric dimensions, coefficient of heat conductivity, heat endurance and the sensitivity of its nervous system. Since the geometric dimensions of pests are small (diameter 0.5–10 mm and length 1–35 mm) it requires a high field intensity (units V m–1) to get better results in insect mortality. It is stated that 100% insect mortality is reached at exposures of 1–30 seconds and the field intensity of 2000 kV m–1 (Ponomaryova et al., 2010).

## MICROWAVE TREATMENT METHODS ASPECTS

Using the thermal effect of MW is a more simplified approach in pest control. Microwave irradiation on timber starts to heat it up from inside, as a result pests can be neutralised deep inside the structure without damaging the outer layers. The temperature has to be over 55 °C in a given period of time (Nelson & Charity, 1972; Nelson, 1981; Rashkovan et al., 2003). Because the energy is absorbed throughout the entire volume of material the losses to the surrounding environment are significantly lower compared to other methods. Heating water with microwaves can provide about 15% lower energy consumption than heating water with heaters based on electrical resistance.

The power scale of MW devices, used in pest control in a residential building is between 0.7–1.2 kW. Magnetron equipped with a guided antenna (horn) is mounted directly against the surface (wood) which will be heated. Mainly two or more magnetrons in parallel are used. During the treatment they will be moved after every 5–12 min. For large surfaces, like buildings, this method is extremely time-consuming.

The temperature rise time constant of wood damaging insect larvae depends linearly on the size of the insect. Larvae with a radius of 0.5–1.5 mm have a time constant $\tau$ = 22.4–68.3 s. For example the time constant of H. Bajalus larvae in a high-frequency field varies from 1–2 minutes. The time needed for the larvae to obtain a steady state temperature in a high-frequency field is equal to twice the value of its time constant $t = 2\tau$ = 2–4 min (Andreuccetti et al., 1994).

Practical examples of wood pest control in a residential building are described on many company websites and in papers (Steinbach, 2006; Steinbach, 2008; Company MBL Solutions; Company Kohler-Automation; Company Wavelengthemts). Mostly frequencies that are intended for scientific and medical apparatus are used: 40.660–40.700 MHz, 433.050–434.709 MHz, 2,400–2,500 MHz, 5,725–5,825 MHz. In the United States a frequency of 915 MHz is often used.

**Figure 1.** Example of wood microwave treatment (Company MBL Solutions).

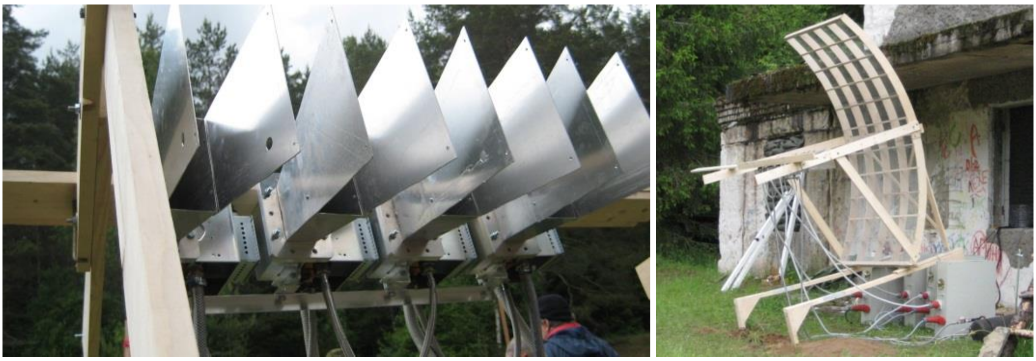
The selected MW frequency range defines the electromagnetic field penetration depth into wood. This depth is measured as the distance between the surface and a point inside the wood, where the MW power has reduced e times (e = 2.718) compared to the power on the surface of wood. Lower frequencies penetrate deeper into material and vice versa. Because MW can pass wood at low frequencies more easily, there is a risk of leaking radiation. This means that special attention should be paid to protection of the environment and living organisms. On the other hand using higher frequency ranges (5,725–5,875 MHz) the penetration depth is not sufficient for pest control in the centre of timber structures. This frequency range is appropriate for treating outer layers of wood or plank materials. In addition to frequency ranges, the wood's physical and dielectric properties affect the penetration depth. Higher density and moisture content reduce the penetration depth. Temperature of the material has an opposite effect: MW with the same frequency penetrates deeper into frozen wood than into wood at room temperature.

For the best thermal-effect the electromagnetic field strength vector E must coincide with the wood grain direction and the direct axis of the insect. Practically it is not possible to control the placement of the insect in the wood and it is not always possible to know the direction of grains in wooden structures. Therefore it is advisable to use a circularly polarised electromagnetic field. To prevent overheating of wooden objects, the temperature must be monitored in real-time. Overheating can affect the mechanical properties of the structure (strength, hardness, etc.). Because of the high field intensity inside the processed object, online temperature monitoring inside the material can be done only with fibre-optic measuring techniques. The surface temperature can be monitored with a thermographic camera.

## FOCUSING THE ELECTROMAGNETIC FIELD

The high-frequency electric field strength E, V $m^{-1}$ is directly dependent on the output power of a high-frequency generator, characteristics of the antenna and the distance of treatment (the area of radiation). Existing solutions have not taken into account the effect of reflecting radiation to the radiation source. A high-frequency energy separator (circulator) must be positioned between the radiation source (magnetron) and antenna (guide). Not using the separator results in decrease of magnetron / radiation source lifetime because of the reflecting radiation.

Existing solutions use direct wood treatment, where the radiation source is placed in direct contact with the wood surface or a few centimetres away. This ensures that most of the microwave energy reaches the target area. There is also a possibility to direct the radiation onto the target area from a distance. For example, one solution for this has been tested in Tallinn University of Technology. In this case the field produced by small-scale radiation sources can be focused on one target area. This is done by using a series of antennas in a row (similar to MW wood treatment) and using a parabolic cylinder mirror. This way the electromagnetic field is concentrated on a target area at a specified distance (for example 6 m). An opportunity for wooden objects treatment from a distance allows reduction of time for the set-up. Tests with four 3 kW magnetrons used as radiation sources (total radiation power of 12 kW) and a parabolic mirror to focus the source have been presented in Fig. 2.



a) b)

**Figure 2.** 12 kW MW focused radiator: a) radiator row with four sources b) system with parabolic cylinder mirror. Radiation sources are positioned on the centre axis of the parabola.

Tests carried out with a field absorbing fabric, which was radiated from a distance of 6 m using a parabolic mirror antenna (Strandberg et al., 2002). A maximum temperature of 47 °C was recorded on the surface of the fabric with windy conditions. Fig. 3 presents the thermographic image of electromagnetic radiation effect on the fabric.

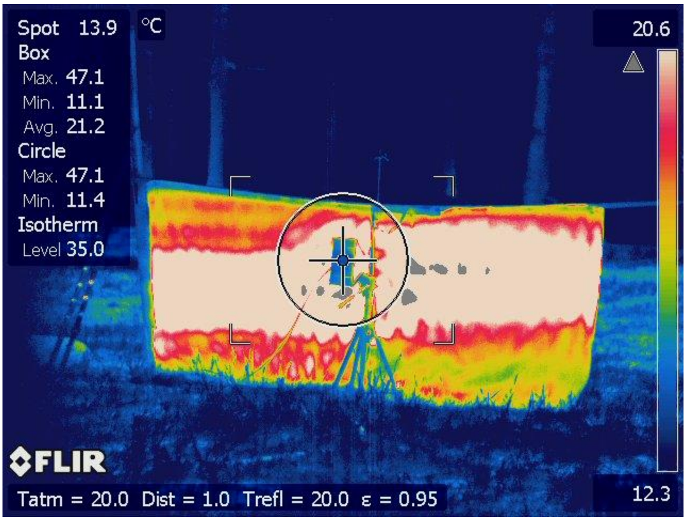



**Figure 3.** Radiation flux conversion to heat on an electromagnetic field absorbing fabric.

Fig. 4 describes the electromagnetic field power distribution on the fabric. The power was measured with a polarised antenna M3-56 with a frequency range of 0…236 GHz and power range 1 mW…30 W. The amplification factor of the antenna was 10 dB at 2.4 GHz.

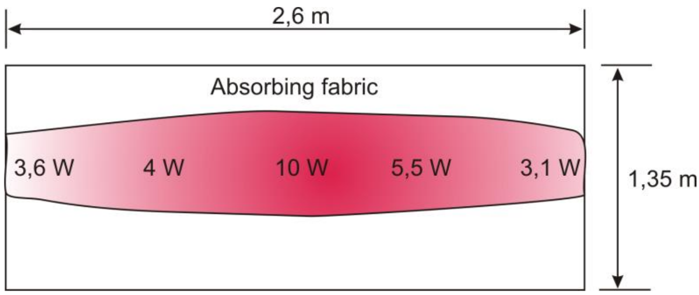



**Figure 4.** Power distribution on an electromagnetic field absorbing fabric.

## RESEARCH OF THE MW PEST TREATMENT

The main shortcoming of this equipment is the limited size of the processing area. It is not possible to treat entire buildings and timber structures without disassembling them. Another problem is the short life span of the equipment due to the reflection of radiation.

In Tallinn University of Technology, research plans have been laid out for the research of more effective MW treatment methods. Within the research two test devices would be used.

For the initial tests on radiation patches, a set of typical MW wood treatment equipment (see also Fig. 1) comprised of a low-output power source, radiation source, and horn antenna would be used (Fig. 5, a). The power of emitters is approximately 1 kW (usually 700 W), and it allows only short-range treatment. In addition, the area to be treated is very limited, in practice only to the horn antenna dimensions.

The more powerful and remote processing equipment presumes a more complex device (Fig. 5, a) in regard to the transmission of radiation and the path for forming the radiation patch. In order to achieve a larger area for the radiation patch, a higher powered source of radiation is needed. MW focusing solution would be used for the second device providing the ability to create a concentrated radiation patch with high energy density and dimensions at specific distances (ranges from 6–7 m).

One of the key problems is the life span and reliability of the equipment. In order to ensure a long life span, the effects of reflected radiation must be eliminated. Another important aspect is to ensure fire and health safety during the course of the work (Järvik et al., 2010). The research is expected to uncover more advanced methods and test equipment for the neutralisation of insects in culturally valuable historical wooden structures and modern timber buildings. In the future, it will be possible to use this equipment for the treating of wood used in buildings, as well as for the treating of wooden freight pallets, fabric, agricultural products, etc.

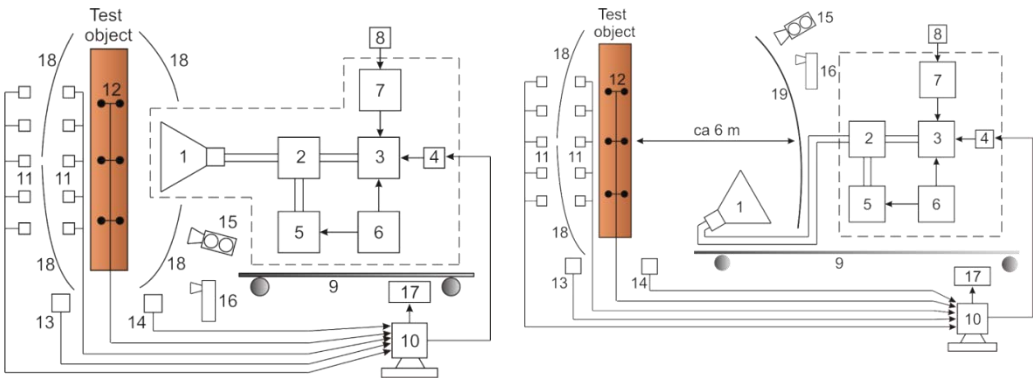



**Figure 5.** a) Block diagram of the wood boring insects neutraliser working at short distances. b) Wood boring insects neutraliser working at long distances. The apparatus consists of an 1 – antenna, 2 – circulator (reflected radiation separator), 3 – the radiation source (magnetron), 4 – the control system, 5 – load for reflected radiation, 6 – water cooling closed system, 7 – the power source, 8 – the power supply (generator, network), 9 – radiator's mobile support base, 10 – the host computer, 11 – radiation detectors, 12 – temperature sensors, 13 – smoke detectors, 14 – humidity sensors, 15 – the thermal camera, 16 – firefighting equipment, 17 – the alarm, 18 – electromagnetic shielding, 19 – parabolic antenna.

## CONCLUSIONS

Microwave treatment for wood pest control using microwaves is not yet widely used, but has high potential. The current state of knowledge is not possible to destroy insect pests directly using weak electromagnetic radiation. Rather the microwave radiation is used to heat up the wood, where pests are residing, with more efficiency and precision. In all stages of a wood pest's lifecycle the lethal temperature threshold is 55 °C, in which case they expire.

In Europe it has been reported in use for building construction treatment in Germany and for chamber treatment in Italy. Research is planned to be carried out in Tallinn University of Technology to further develop methods to use the directed electromagnetic field for treatment of timber structures against wood pests from distances. Experiments show that focusing the electromagnetic field may be able to neutralise the wood insect at distances.

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