DESIGN OF RECTANGULAR SHAPED SLOT PLANAR APPLICATOR

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Abstract

This paper deals with the design construction and evaluation of the slot planar applicator of the square type. In fact composition of four applicators of this type is used for heating a large area under treatment. Matrix composition of applicators has total dimensions of 106mm x 106mm and operates at 434MHz. From the measurement of impedance matching and final evaluation on agarose phantom using thermo-camera we can say that applicator is suitable for use in clinical practice.

1. Microwave hyperthermia in general

Term "microwave hyperthermia" [1] is used for artificial heating of biological tissue with microwave energy. The increase of temperature is caused by dissipation of electromagnetic energy in tissue, which behaves as a dielectric. The electromagnetic field causes polarization of the molecules and changes their rotation in the direction of electric vector of intensity field *E*. So if we let alternate current power to take effect on the molecule its field would lead to the alternating polarization from one direction to another. With increasing frequency, the molecule loses its ability to track the rapid changes, the effective dielectric constant decreases, loss angle increases and the energy field is converted to heat. Designated frequencies ISM (industrial, scientific, medical) for microwave applications are 435 MHz, 915 MHz and 2450 MHz. There is no practical use for frequencies above or under the higher resp. lower limit. As higher frequencies have very limited penetration and lower frequencies despite their deep penetration are very difficult to focus their power. Penetration is usually determined by equivalent penetration depth that is depth in which intensity of electromagnetic field decreases to cca 37 % as of surface value.

What is the main purpose of heating biological tissue? One reason for doing this is to accelerate body's natural healing processes or to augment conventional cancer therapy. It was observed already by ancient physicians, that increased temperature in tissue induces and speed up healing process, as we can read on prescriptions by Hippocrates of Cos. It's known, that increased temperature induces better blood perfusion in heated tissue which causes better oxygenation and flushes waste products of metabolism out of the heated tissue. If we intentionally heat healthy tissue, we just increase its cellular metabolism to point, when even tremendously increased blood flow can't cool down cells, and temperature in tissue reaches point, where cellular proteins are damaged. Without proteins and enzymes cell dies. We profit from this in cancer thermotherapy, when thanks to cancer poor and chaotic blood supply stream can't cool down effectively cancer cells, while surrounding healthy tissue is easily cooled and remains undamaged. Sole hyperthermia is used rarely, as tissue cells by time develop certain resistance to heat. So the main potential is in combination with conventional cancer therapy to reach better results in treatment. [2]

Limit for this form of therapy is water content in target tissue, as microwave is especially absorbed in water molecules. So primarily high-water content tissue like muscles are heated at most and we can poorly heat another structures like tendons or bones. This is both limitation but also advantage, as we can target quite precisely for example cancerous tissue against surrounding layers, due to its vast blood vessel interaction and thus very high water level content.

2. Applicators for microwave hyperthermia

Microwave antennas for biomedical use, are usually called applicators. We can use both planar antennas and waveguides. Both types have different limitations and advantages, so it's up to physician and biomedical engineer to decide which use in certain situations. The main differences are in energy transfer efficiency and versatility.

3. Waveguide applicators

Basically we can describe waveguide applicator [3] as conductive tube with any shape of cross-section. Main advantage of this type of applicator is in fact, that it allows highest broadband power transfer and also has lowest loss of electromagnetic energy among all kinds of applicators.

Electromagnetic field is by the format of tube shaped to mods. Heat profile in treated tissue depends on used mod. Every mod has its critical frequency. For excitation of chosen mod in waveguide, we have to use higher than its critical frequency. On the contrary when we use lower than critical frequency, the transmitted energy is exponentially dampened through the waveguide, these mods are called evanescent. Common shapes of waveguides are rectangle and cylinder. Thickness of waveguide tube material has to be at least quintuple as its effective penetration depth.

$$k_{c,mn} = \sqrt{\left(\frac{m\pi}{2}\right)^2 + \left(\frac{n\pi}{2}\right)^2}.$$

Constant of cross-section of rectangle waveguide for mod TE_{mn} can be calculated as where a is longer side of waveguide, b is shorter side and m,n are indexes of mod.

4. Planar applicators

Planar applicators [4] are versatile group of different shaped antennas realized as printed circuit board, so they are cheap to manufacture and could be even made of elastic materials. Most common shapes of such applicators are Archimedean double spiral and rectangle slot applicators. This type of applicator can be used both superficially and also intracavitary, as it can be realized as quite tiny spot antennas. Despite its lower transmission, compared to waveguides, is planar applicator with its flexibility and easy adhering to treated areas considerable choice.

Spiral applicator behaves as broadband antenna and is more resistant to dependence of working frequency on permittivity than slot applicator. On the other hand, slot applicator as a resonant structure allow us transfer more electromagnetic energy to target tissue Wavelength of this applicators can be calculated

$$\lambda = \frac{c}{f\sqrt{\varepsilon_{eff}}},$$

where c is speed of light, f is frequency and ε_{eff} is effective permittivity. We consider value of ε_{eff} higher than relative permittivity of used dielectric and lower than relative permittivity of treated tissue.

5. Design and evaluation of applicator

To ensure optimal heat distribution in treated area we decided to design composition of four square slot applicators. To allow applicator operate in unshielded room, we chose operational frequency 434 MHz. To ensure maximum energy transfer to treated tissue, we had to find optimal impedance matching between applicator itself and treated tissue, so minimum of radiated energy is reflected back to antenna aperture. To design and simulate optimal solution for our applicator, we used CST MICROWAVE STUDIO 2011 software suite. This software is capable of entering variables as dimension parameters of individual geometric primitives and that allows easy modification of model parameters. After modeling geometry of applicator and stating its material dielectric parameters, we for it defined power source type “edge source” producing transversal electromagnetic wave. Simulations showed up, that no parasitic mode is transmitted in our antenna solution. Main goal of simulations was to find ideal impedance match between applicator and biological tissue (agarose model) with given parameters - permittivity $\varepsilon_r = 54$ an conductivity $\sigma = 0{,}8$ S/m. Agarose model was in simulation from applicator separated by water bolus of thickness t = 30 mm, as it would be separated in any biomedical application to prevent creating hotspots and to improve impedance matching of applicator and biological tissue. On figure 1 is shown final impedance matching that we reached.

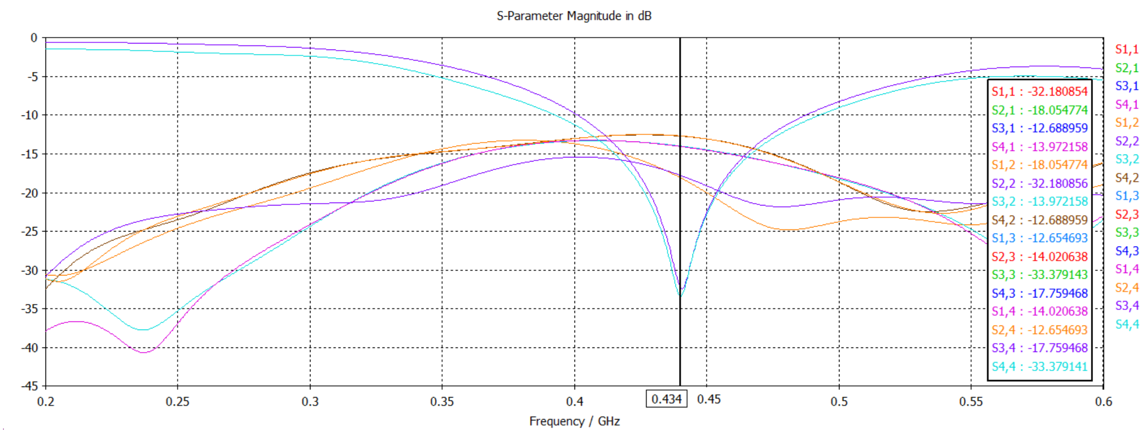


Figure 1: Impedance matching of the composition of four slot applicators all S-parameters (S_{11}, S_{22}, S_{33} and S_{44} were less than -30dB).

After finding an optimal solution for impedance matching for this applicator we ran couple of simulations to evaluate the filed distribution. Field distribution can be found on the figure 2, which is showing SAR distribution in all three cutting planes, from sagittal, frontal to transversal respectively.

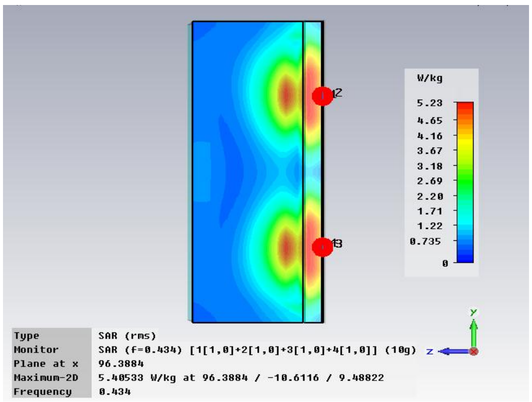


Figure 2a: SAR distribution of composition of four applicators in sagittal cut plane.

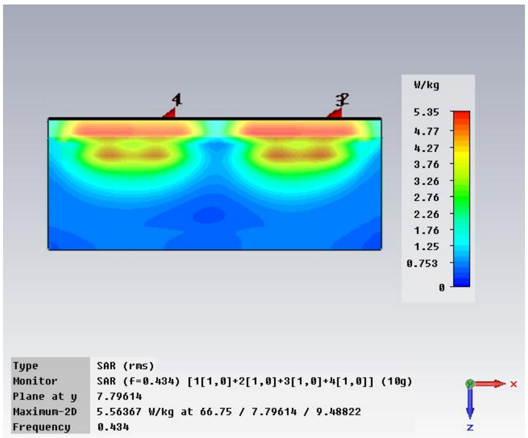


Figure 2b: SAR distribution of composition of four applicators in frontal cut plane.

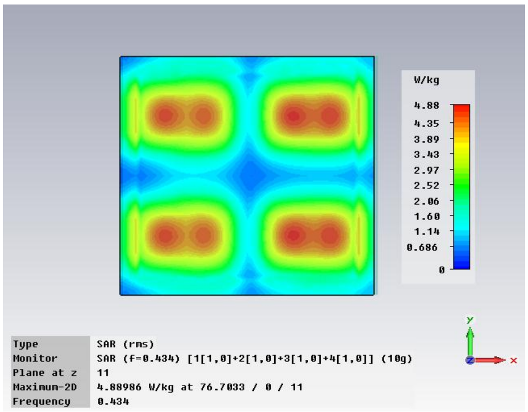


Figure 2c: SAR distribution of composition of four applicators in transversal cut plane.

After optimal design was found whole structure was realized and its properties evaluated on agarose model. Agarose phantom was chosen for its close nature like a high-water content biological structures, such as muscles. To ensure optimal dielectric properties, 3g of salt (NaCl) was added to 1.25l agarose phantom. Heat profile in model was observed with thermo-camera FLIR P25 figure 3. Power delivered to applicator was 50 W and time of exposure model was 2 minutes.

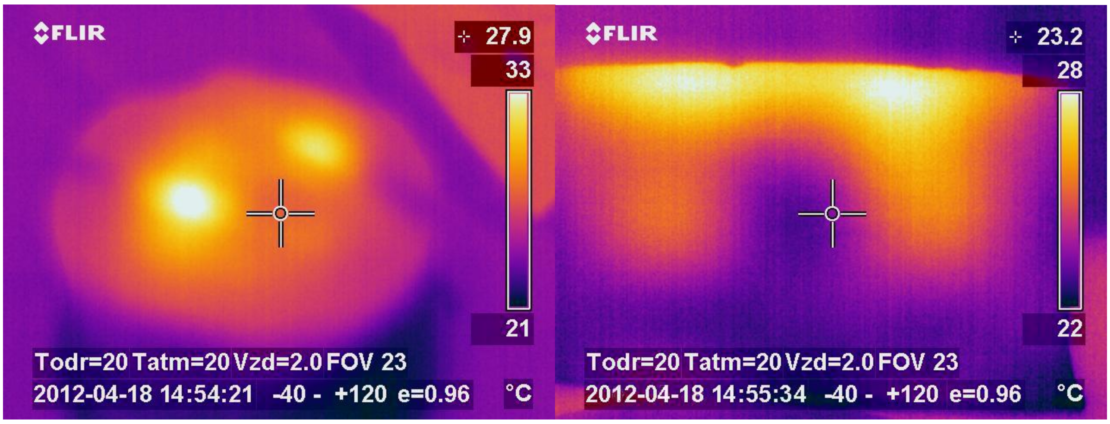
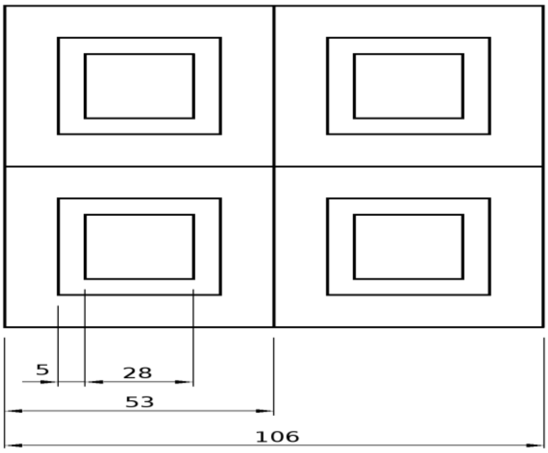


Figure 3: Transversal view of irradiated agar phantom (left) Sagittal view of irradiated agar phantom (right).

As resonant structure this type of applicator is strongly dependent on good impedance matching to prevent creating hotspots and to ensure maximum energy is radiated from applicator aperture to target tissue, which was successful. For final design of the applicator see figure 4.



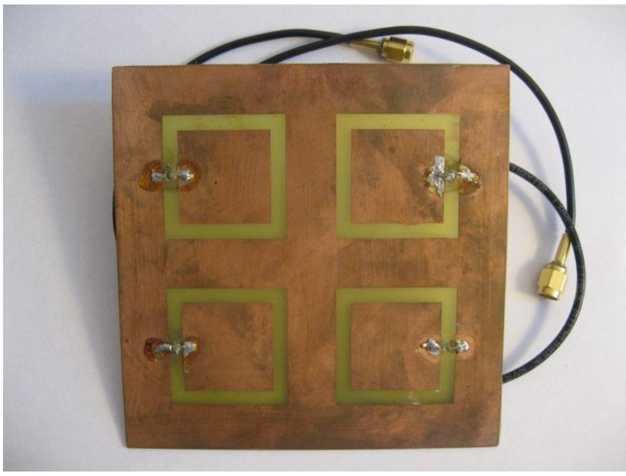


Figure 4: Composition of four rectangular shaped slot planar applicators scheme (left) final designed model (right).

6. Results

Our applicator is suitable for superficial use in hyperthermia treatment. Limit for this form of therapy is water content in target tissue, as microwave is especially absorbed in water molecules. So primarily high-water content tissue like muscles are heated at most and we can poorly heat another structures like tendons or bones. This is both limitation but also advantage, as we can target quite precisely for example cancerous tissue against surrounding layers, due to its vast blood vessel interaction and thus very high water level content.

References

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