# Solutions for High Density Antenna Arrays for the 2020 Hyperthermia System

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## INTRODUCTION

Characteristic for patients undergoing hyperthermia is that tumors are locally advanced, i.e. the tumors are usually large and the disease may have spread to lymph nodes nearby. In general the target to be treated is substantial (10-30 cm in longest dimension) or, alternatively, multiple tumor locations distributed over a large volume must be treated. In addition, following the earlier successes in tumor sites like the pelvic and head and neck region, adjuvant hyperthermia is also considered for new tumor indications like ovarian cancer, where the whole abdomen needs to be heated. Heating of these large volumes to a prescribed dose level is a challenge as the state-of-the-art technology for loco-regional deep hyperthermia exploits frequencies in the range of 70-120 MHz for heating a centrally located tumor. Moreover, clinical studies demonstrate that a direct relation exists between the probability of clinical success and the thermal dose delivered to the treatment volume. Avoiding “hot spots” in regular tissue enables achieving a higher thermal dose in the target region by delivering more energy in that region. In summary, a strong need exists for equipment that enables both more target-specific and more homogeneous energy delivery.

From the above, it is clear that a strong need exists for a new generation of hyperthermia equipment. The hyperthermia system of 2020 will be multi-functional, with the ability to adequately heat the above described target volumes. The operating frequencies will be between 250 and 400 MHz, and the reduced penetration associated with the higher-frequency waves is counteracted by exploiting wave interference from a sufficiently large number of antennas configured in multiple, longitudinal rings around the body or in a large (e.g. >40 element) planar array. The system will be designed to operate as a broadband or multi-frequency system, to allow simultaneous focusing of heat in multiple targets. Depending upon tumor size and shape, the different foci can be used, in a single treatment, either as independent operating foci for heating multiple targets, or in a patchwork setting to create a large continuous high quality energy distribution.

Using a large number of antennas requires new algorithms for planning, monitoring and high-precision control of the energy and temperature distributions. These algorithms have to account for the complex interactions between the different domains involved (electrical, biological, mechanical) and have to be capable of responding adequately to disturbance factors (movement, changing medium parameters, electrical distortions) as well as to patient complaints during treatments.

## HARDWARE AND SOFTWARE REQUIREMENTS

To realize the hyperthermia system of 2020, extensive research is required to integrate complex hardware, modeling of energy and temperature distribution, monitoring devices for temperature and electrical field sensing and adaptive and self-learning control algorithms. The most important requirements are:

**Hardware**

- Broadband and MR-compatible antennas, to operate the system inside an MR for non-invasive temperature measurement.

- Ability to create multiple independent foci.
- Phase and amplitude control for 40-50 individual antennas.
- Robust high-power, broadband amplifiers, one per antenna.
- On-line E-field and/or temperature sensors that provide input for the control loops.

**Software**

- Advanced hyperthermia treatment modeling software.
- Pre-treatment planning and decision making.
- Independent, adaptive control of the various heating targets.
- Use of the E-field or temperature feedback signals for accurate setting of all antennas.
- Self learning for early warning of potential hot spots and adequate counter measures.

## ANTENNA DESIGN

In our first antenna work [1], we investigated the performance and MR compatibility of a printed antenna design that has high potential for "high frequency" (>300MHz) and "many antenna" (>20) phased-array applicators, to facilitate local "target conformal" heating. Experiments emulating the clinical situation with a prototype designed for the 433 MHz ISM band show excellent matching properties with a magnitude of $S_{11}$ less than -15 dB over a 7.2% bandwidth. In addition, the mutual coupling between array elements is below the specified -23 dB level. Lastly, the image distortion due to the antenna in an MR scanner proved to be negligible. Hence, this work paves the way for investigating array designs for a number of applications where precise heating of the target is required, e.g. the head and neck region.

## ANTENNA MODELING AND TREATMENT PLANNING & MONITORING

Designing and operating new generation of hyperthermia equipment requires a new approach to modeling the electromagnetic behavior of such a system. We propose to use the local behavior of the individual antenna elements as a starting point. Using characteristic basis functions [2] or eigenfunctions [3] for such elements, either on their own or embedded in a small subarray, we can characterize their mutual coupling by considering linear combinations of a few well chosen field distributions per element. When we compare hyperthermia with astronomy, radar or telecommunications, for which our modular (diakoptic) approach was originally developed, we observe a fundamental difference in the loading of the antenna due to presence of the patient. The presence of a large dielectric load significantly enhances the mutual coupling between the elements, and makes it dependent on the electromagnetic properties of the individual patient. Therefore, we propose to characterize the interaction between the antenna system and the patient with the aid of an equivalence principle or a spectral decomposition. Last but not least, we need to account for the coupling between the antenna and its feed structure, which will probably consist of steered individual networks containing advanced amplifiers. One advantage of such a modular approach is that it may lead to an alternative for the MR for treatment monitoring and control, by exploiting the unique connection between the predicted electromagnetic fields inside and outside the patient.

## REFERENCES

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