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MTEnergy technology in medical applications

Abstract

MTEnergy is an advanced RF/MW measurement technology that enables simultaneous, real-time monitoring of multiple coherent signals without disturbing therapeutic processes. In medical applications, it enhances hyperthermia (HT) and microwave ablation (MWA) by improving patient alignment, supporting adaptive treatment planning, and enabling novel techniques for non-invasive, real-time temperature monitoring. These capabilities contribute to greater precision, safety, and effectiveness of RF/MW-based cancer therapies. By integrating MTEnergy, next-generation oncology systems can become more adaptable and clinically impactful.

Introduction

MTEnergy is an innovative measurement technology that enables novel characterization and control features in RF/MW energy generators, systems, and applications. It provides a mechanism for simultaneous measurement of the parameters of individual signals in multichannel, coherent RF/MW energy systems, without disturbing the system operation.

The technology is based on multi-tone (MT) RF signals, which resolve ambiguities when characterizing concurrent coherent signals generated by multiple sources. Each MT signal consists of a single large-level (LL) tone, phase-coherent with the other LL signals in the system, and several small-level (SL) tones at source-specific frequencies. The LL and SL tones are correlated through defined mathematical functions. After sampling and measuring the SL tones, the parameters of the belonging LL tones can be accurately estimated.

MTEnergy is a versatile tool that delivers functionality, performance, and cost benefits across the RF/MW energy supply chain—supporting suppliers of RF/MW devices, system OEMs, and end-users. In the medical field, it holds particular promise for enhancing RF/MW-based cancer therapies, especially in hyperthermia (HT) and microwave ablation (MWA).

MTEnergy in Hyperthermia systems

State-of-the-art non-invasive RF/MW radiative hyperthermia systems may use dozens of RF/MW power emitters, arranged in 2D or 3D arrays to converge energy on targeted regions of the patient's body. The parameters - frequency, phase, and amplitude, of each emitter's signal can be independently controlled, enabling dynamic steering and alingment of the heating pattern.

The steering parameters, required to accomplish the alignment, are calculated within a treatment planning procedure, which involves several steps:

1. **Model creation** – MRI or CT scans are used to generate a 3D model of the treated body part.
2. **Segmentation** – Tissues are identified, and their electrical, thermal, and physiological properties are assigned.

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3. **Simulation** – The segmented model, positioned within the RF applicator setup (antenna array, water bolus, etc.), is analyzed using multi-physics 3D simulation to calculate the optimal RF parameters for chosen thermal treatment.

Current systems guide treatment using feedback methods such as patient complains, MR thermometry, and fiber-optic sensors. MTEnergy can complement or even replace some of these approaches by enabling simultaneous measurement of multiple signals transmitted and received by the emitters, as shown of Fig.1.

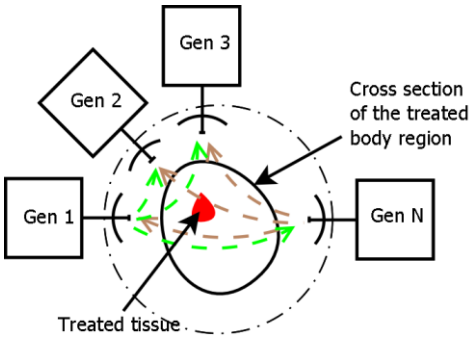

Fig.1. A simplistic depiction of HT system with a semi-circumferential 2D antenna array, illustrating a set of RF signals, which can be concurrently measured with MTEnergy-enabled generators.

Let's assume that all generators are MTEnergy-enabled, thus capable of producing MT signals, and sampling and analyzing both its own transmitted and reflected signal, and the signals received from the other generators. Providing that the generators processes the MT signals synchronously, the HT system obtains the functions of a real-time N-port vector analyzer, which measures the full S-parameters matrix of the applicator.

The obtained S-parameters, or the parameters of the directly measured RF signals, can be compared with the respective ones, which have been priorly calculated in the treatment planning. Detected deviations could point to nonconforming patient's body position or movement, or to deficiencies in the model, used in the simulation.

The detrimental effects, caused by a nonconforming position, can be compensated in real time by adapting the treatment plan. The required adjustments of the steering parameters could be determined either by a trained physician, or algorithmically estimated. It seems, that both scenarios would benefit form certain "extension" of the planning procedure. That procedure should precompute additional treatment plans and parameters sets with some probable deviating positions of the model in the simulation setup.

Another possibility is, that the detected discrepances might be caused by inaccuracies of the used model. That case would require adjustment of the model, taking into account the measured parameters.

In the context of HT therapy, MTEnergy technology could be applied in some less comprehensive ways.

For instance, measuring only limited subset of the full S-parameters matrix would likely provide sufficient input for detecting a nonconforming body position and adjusting the treatment plan.

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Along the same line, one could assume, that a set of scalar S-parameters might be sufficient to serve the same purposes. This approach seems attractive, because it would relax the clocks synchronization requirements, at a cost of higher computational efforts.

As shown on Fig.2, depicting a sketch of a HT system in the context of H&N treatment, an interesting implementation option would be to detach the receiver function from the generators, and implement it in the collar unit. The receiver(s) could reuse some of the transmitting antennae, as presented on the sketch, or use other dedicated receive-only probes.

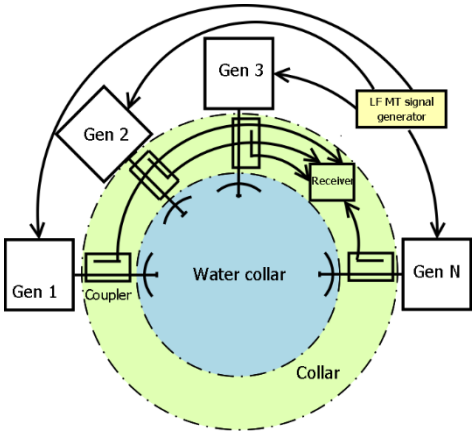

Fig.2. A sketch of H&N HT system with separated receiver and LF MT signal generator.

Furter, the MT signals could be produced in a dedicated low-frequency (LF) MT signal generator, which provides reference signals to all RF generators. The LF signals could be phase-aligned MT or CW waveforms, ensuring that the RF generators will deliver signals with the planed parameters, regardless of the actually employed reference signal. Therefore, the RF generators could use sequentially a single MT pattern, and yet, all applied RF signals could be analyzed.

MTEnergy in microwave ablation applications

The state-of-the-art non-invasive MWA systems apply different techniques to increase the size and adjust and the shape of the treatment zone in order to simultaneously assure that the malignant tissue is completely ablated, yet not overheated, and that the nearby healthy tissues suffer no thermal injury.
Key techniques include:

- Selecting and adjusting MW frequency, power, and duration
- Choosing the number and position of applicators
- Optimizing antenna type and directivity
- Performing multiple ablations when needed

An emerging approach uses a number of applicators as a steerable phased antenna array. This approach enables dynamic control of the treated area without repositioning applicators inside the body. By adjusting the phase and the power applied to the individual probes, a fixed applicator geometry can generate treatment zones of different sizes, shapes, and positions.
For instance, Fig.3. shows few, of virtually endless number of, possibilities to position and shape the EM field pattern of a 4-applicators array.

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In general, the MWA treatments can apply planning procedures, guiding and evaluating techniques similar to the ones used in HT treatments. However, MWA treatments differ in some specific characteristics: spatially localized deployment of the RF energy and higher treatment temperature of the ablated tissue. These specifics enable the use of other monitoring options, based on measuring the dielectric properties of the tissues in the ablation zone.

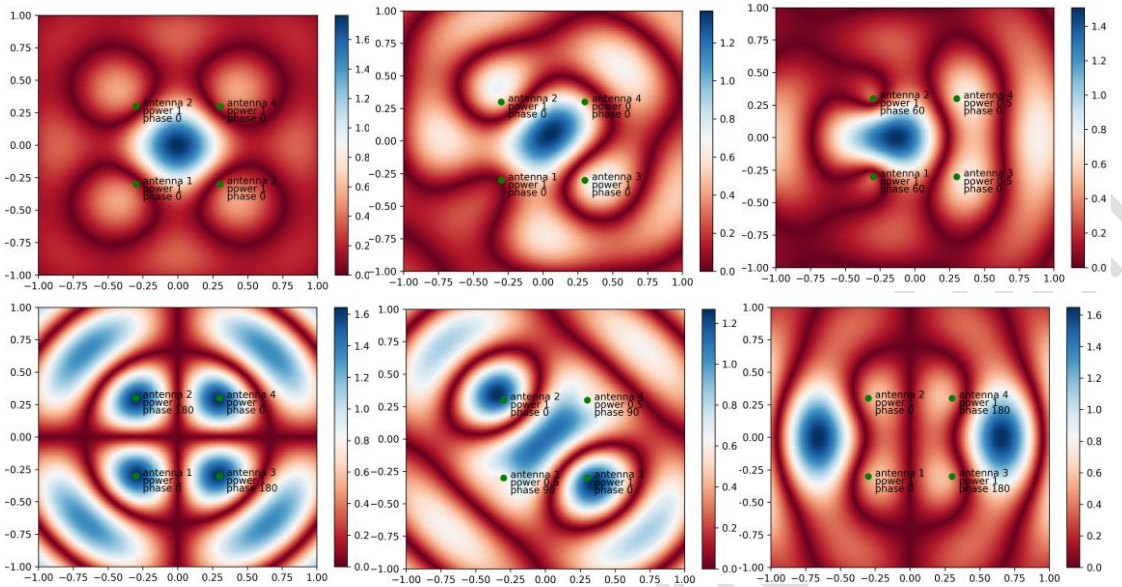

Fig.3. Course approximation of different E-field distribution patterns, generated by 4 omnidirectional emitters array with pitch of 0.6 wavelengths. The E-field patterns are calculated as a superposition of sine waves, propagating in uniform medium (no nearfield effects taken into consideration).

MTEnergy technology enables enhanced monitoring and control functions in the MWA systems using antenna array:

- **Applicator alignment verification** – As discussed in the context of HT applications, comparing measured signal parameters with planned values can reveal misalignment in the positioning of the applicators vs the targeted body zone.
- **Applicator misalignment compensation** – As recent studies suggest, malignant and healthy tissues considerably differ in dielectric properties. Therefore, the measured signals' and S-parameters are indicative for the tumor position and for the extent of an eventual misalignment.

  For instance, assuming that the tumor possesses higher dielectric constant then the heathy tissue, the signals transmitted between Ch1 and Ch2 on Fig4.B will experience larger phase shift comparing to the same signals on Fig4.A. The opposite phase shift difference will be observed for the signals propagating between Ch3 and Ch4.

  The measured signal parameters, in combination with the tumor model, makes possible to estimate the actual tumor's position in the applicator, and to adopt the treatment plan.
- **Real-time temperature estimation based on dielectric property monitoring** – MTEnergy technology enables continuous monitoring of the dielectric properties of the tissues, in which the applicators are immersed. By using temperature-dependent dielectric models of the ablated tissue is possible to estimate the temperature in the ablation zone. And, since

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the tissues dielectric properties can be measured between any pair of probes, the construction of the evolving temperature map (SAR pattern) is also possible.

This feature allows real-time temperature monitoring, ensuring both therapeutic effectiveness and safety—without use of other invasive sensors.

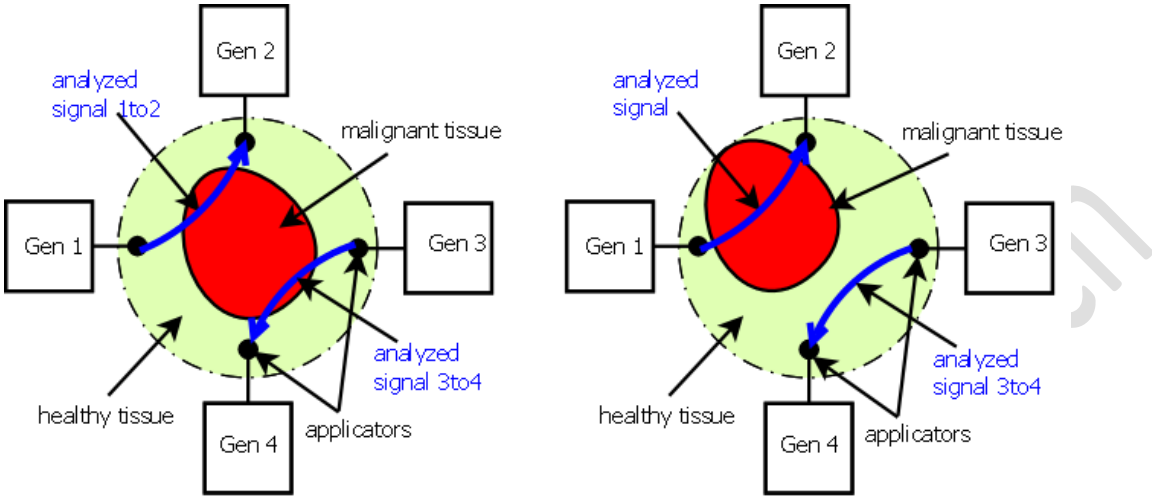

Fig.4. 2D sketch of 4-channel applicators array used in MWA treatment illustrating a correct and misaligned applicator positions. Due to tumor's higher dielectric constant, in the misaligned applicator's the signal 2to1 encounters larger phase shift, while the signal 3to4 - a snaller one.

Conclusion

MTEnergy's unique ability to measure parameters of multiple coherent signals unlocks new monitoring and control features for multichannel RF/MW medical applications. It enables improvements in:

- Patient alignment in HT and MWA procedures
- Enhanced models for treatment planning
- Online temperature monitoring without additional invasive probes
- Real-time safety and effectiveness control during ablation

By integrating MTEnergy, next-generation hyperthermia and ablation systems can become safer, more precise, and more adaptable—paving the way for broader adoption in clinical oncology.

A comprehensive report of MTEnergy technology is available on Andivatech website.

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