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Comparison of Simulated and Robotically Mapped RF Fields in 64 and 128 MHz Medical Implant Test Systems

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INTRODUCTION

Standards, regulatory agencies, and customers rely on testing and measurement to demonstrate compliance.

Robotic mapping of RF exposure in device test platforms is of great value within an ISO 17025-compliant test facility for both verification and validation processes (V&V)[1-2].

Establishing and evaluating consistence between measured and simulated fields is critical when either is used as part of a medical device testing procedure[2].

In this study, we demonstrates a procedure for the use of a semi-automated robotic positioning system to map electromagnetic fields within RF exposure systems and quantitatively compare the results against simulation of those same systems.

PURPOSE

The aim of this study was two fold:

1. Demonstrate a procedure for using a custom built, semi-automated robotic positioning system to map EM field within and around RF exposure systems.
2. Quantitatively compare the results against detailed simulations of those same systems.

METHODS

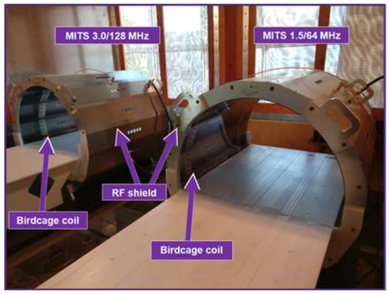
Exposure System

Measurements were performed on two different transmit-only body RF birdcage Medical Implant Test Systems (MITS, Figure 1) 1.5 T and 3.0 T[3], corresponding to frequencies of 64 and 128 MHz, respectively[3].

Parameters	MITS 1.5	MITS 3.0
Pulse type:	sinc2π	sinc2π
Duty cycle [%]:	40	40
Pulse rep. rate [kHz]:	1.0	1.0
Polarization [°]:	270	90
Frequency [MHz]:	63.8	127.7
Power [dBm]:	50	50
Whole-body SAR [W/kg]:	~0.4	~0.3
$B_{1,rms}$ [μT]:	~1.6	~0.9

Figure 1 (right): MITS 1.5/64 MHz (right) and 3.0/128 MHz (left) bench top exposure systems[3].

Table 1 (left): MITS sequence parameters (Software v1.12.10[3]).



METHODS

Field Probes

Field measurements were obtained independently with either a calibrated E-field (EX3DV4) or H-field (H3DV7) RMS probe integrated into an EASY4MRI standalone data acquisition system[3].

Figure 2: Standalone EASY4MRI data acquisition system with field probes[3].

Robotic Mapping

A 3-axis stepper motor driven gantry robotic field mapping system built in-house was used to gather data.

A LabVIEW program was designed to integrate and control data collection with the robotic system.

Data collection was taken at points in the unloaded MITS bore at constant spatial increments (3.0 cm) along all directions in an area of XYZ=42 × 21 × 42 cm (limit=50 cm^3).

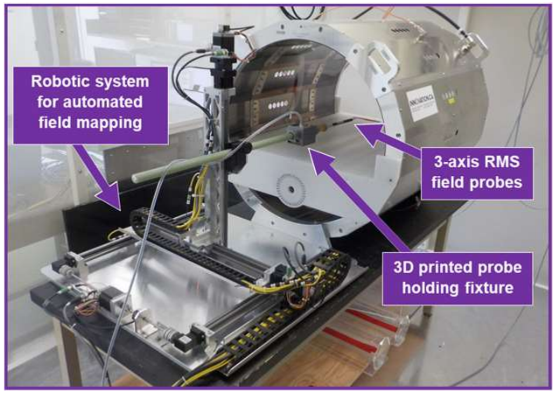


Figure 3: xMR semi-automated robotic system with EASY4 probe in MITS 3.0.

Computer Simulations

Finite difference time domain (FDTD) computations were carried out using EMPro 3D EM simulation software[4].

The models were based on the coil geometry using 48 generic ports with sinusoidal excitation at corresponding frequencies.

The phase of the signal feeding the source was equal to its azimuthal position and the ports at the same azimuthal position in the two rings were 180° out of phase.

Simulated field values were scaled to values from an independent reference H-field probe fixed below the table.

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METHODS

Analysis

All data was linearly interpolated onto a 1 mm grid and the measured data was compared to simulated data using a linear regression model and the difference between data sets was calculated by[2]:

$$Diff = \sqrt{\frac{\sum_{n=1}^{N}(M_n - S_n)^2}{\sum_{n=1}^{N}(S_n)^2}}$$

n – measured location index for N distinct locations.
S – normalized simulated target value at each location n.
M – normalized measured value at each location n.

Validation acceptance criteria: Calculated difference metrics need to be within the combined uncertainties of the target value simulation, the RF field source, and the measurements[2].

Combined uncertainty budget for measurements was determined from calibration certificates and manufacturer.

RESULTS

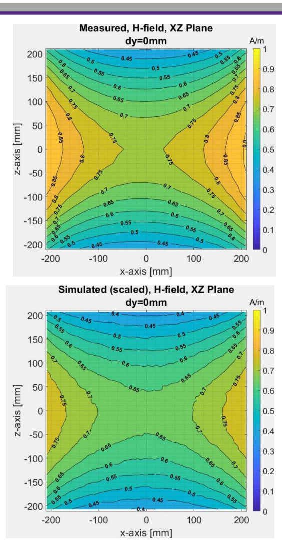

Figure 4 (left): Representative MITS 3.0 2D planes for XZ-axis showing data collected at the geometric coil isocenter in air (Z-axis = 0). Measured (top) and scaled simulated (bottom) total vector magnitude H-field RMS values.

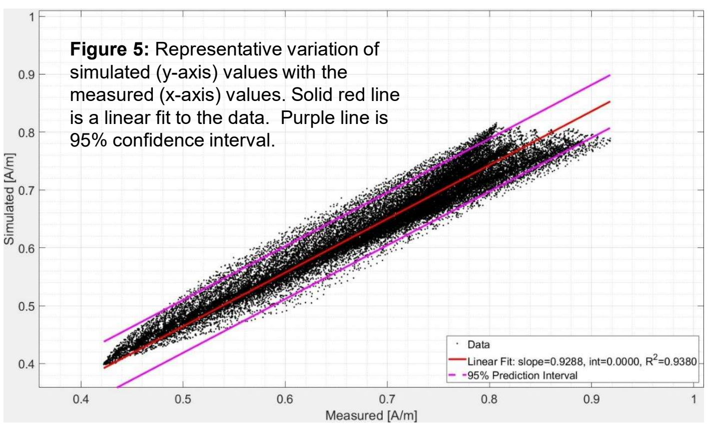

Figure 5: Representative variation of simulated (y-axis) values with the measured (x-axis) values. Solid red line is a linear fit to the data. Purple line is 95% confidence interval.

RESULTS

Table 2: Summarized results for scaled field data using reference H-field probe.

MITS	Field	Est. Unc.	Pct. Diff.	R^2-value	Validation Check
1.5 T (64 MHz)	H-field	23.1%	1.9%	0.93	PASS
1.5 T (64 MHz)	E-field	23.1%	11.4%	0.98	PASS
3.0 T (128 MHz)	H-field	23.1%	4.9%	0.93	PASS
3.0 T (128 MHz)	E-field	23.1%	13.6%	0.94	PASS

DISCUSSION AND CONCLUSION

Percent difference values (1.9 to 13.6%) for simulated vs. measured data show good agreement and meet the acceptance criteria according to ISO 10974 requirements[2].

R-squared values ranged from 0.93 to 0.98, showing strong relationship between the linear model and plotted values.

Physical coils are difficult to model because they rely on detailed geometric information[5] and are based on the assumption that RF coils function as azimuthal transmission lines at all frequencies of interest[6].

Future work will (1) utilize lumped element models to accurately compute all coupling effects within the birdcage[6], (2) investigate the effect of correcting the correlation with a rigid body transform, (3) optimize the workflow, and (4) compare mapped SAR values within an ASTM phantom[7].

In this work, we have presented a protocol and results showing that a semi-automated robotic system can effectively operate within the complicated EM environment of the RF exposure platforms with good agreement between simulated and measured results.

ACKNOWLEDGEMENTS

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[1] ISO/IEC 17025:(2005-2017). [2] ISO/TS 10974:2018. [3] (ZMT/Speag, Zurich, Switzerland). [4] (Keysight, CA, USA). [5] Liu Y. (2013) BME, 12(12). [6] Ibrahim T.S. (2001) PMB, 46. [7] ASTM F2182-11a.