Uncertainty determination for SAR Zoom scan parameters 5pts×5pts×9pts(16mm×16mm×32mm), res:4mm×4mm×4mm in comparison to recommended P1528 SAR Zoom Scan parameters of 7pts×7pts×7pts(30mm×30mm×30mm, res: 5mm×5mm×5mm

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Purpose:

To determine the uncertainty budget introduced in using a smaller measurement volume than one recommended by the IEEE P1528 SAR standard.

Background:

Zoom scan parameters for the determination of the Peak 1 gram Spatial average SAR is recommended at comprising 1.5 times the cube side in each direction. In the case of the 1 gram SAR, this would mean a zoom scan volume of 30mmx30mmx30mm which represents 27 times the averaging volume used. In the majority of SAR systems, this zoom scan volume is usually divided up into a measurement grid employing 7x7x7 measurement points which results in a grid resolution of 5mm and some 343 measurement points.

For low frequency applications where the E-Field gradients are gradual, this resolution is adequate to fully characterize the field contours adequately. At the higher frequency bands such as the 2.45GHz and especially the 5GHz bands, the field gradients are much steeper and the hot spots more concentrated as would be expected since the penetration depths are much shorter. Maintaining the same 5mm grid resolutions in these frequency bands is not optimal to obtaining a sufficient number of data points to fully characterize the hot spot volume with reasonable spatial precision. Decreasing the grid resolution to 4mm would mean an increase in measurement points to 512 measurement points. The following table illustrates the penalties for increasing the spatial accuracy by reducing the grid resolution.

Grid Resolution (mm)	Measurement Matrix	Number of points 30mmx30mmx30mm	Increase in Zoom Scan Duration multiplier
5	7x7x7	343	1.0
4	9x9x9	729	2.1
3	11x11x11	1331	3.9
2	13x13x13	2197	6.4
1	15x15x15	3375	9.8

Table 1

From the above table, the zoom scan duration in reducing the grid resolution by 1mm represents a doubling of the number of measurement points for the specified scan volume. This directly translates into doubling up the measurement times. Currently, the zoom scan time for a 7x7x7 measurement matrix is between 20 to 30 minutes depending on the SAR system used.

Most hand held devices to be tested for SAR are battery operated and are normally not designed to transmit continuously for long periods of time without significant power droop, overheating or experiencing other non-linear effects. It is therefore imperative to try and complete the zoom scans in as short a time interval as possible. A reasonable zoom scan time is under 30 minutes as longer durations may result in overstress of the device-under-test beyond its normal operating parameters.

Uncertainty Analysis

With this in mind, a zoom scan volume reduction can be done provided it can be shown that the uncertainty in determining the peak spatial 1g average SAR, introduced in this approach, is within acceptable limits. For the 2.45GHz band, in order to maintain the zoom scan times down below 30 minutes using a reduced grid resolution of 4mm would require a zoom volume reduction to 16mmx16mmxx32mm requiring 229 measurement points. In order to determine the uncertainty of the zoom volume scan reduction, the evaluation test function specified in the P1528 standard will be used in the post processing algorithm to determine the sensitivities of the reduced volume scan. The evaluation function given is:

$$f(x,y,z) := A \cdot e^{\frac{-z}{2a}} \cdot \left(\cos\left(\frac{\pi \cdot \sqrt{x1^2 + y1^2}}{2 \cdot 5a} \right) \right) \qquad \text{E1.}$$

where x1 = x + d mm and y1 = y + d mm
d - Offset value used to shift the function off center
a - decay factor

The target value for a=20 is given as SARref = 0.881 W/Kg accurate to 0.01% and this can be used to evaluate the post processing algorithms.

To investigate the uncertainty of the reduced volume scan on the post-processing algorithm used, 7 simulations are run for the reduced scan volume with the test function offset by increasing increments of 0.5mm. These are compared to 7 additional simulations using the recommended zoom scan volume carried out using the same test function and incremental offsets.

A = 1.0 [W/Kg] : arbitrary amplitude constant

a = 20 [mm] : decay factor

d : lateral shift of the SAR distribution [mm]

L_z = 16.0 : side length of the zoom scan cube

L_c = 10.0 : cube side length

$|d| \leq (L_z - L_c) / 2 = 3.0$

L_h = 10.0 : height of the zoom scan volume

z_d = 2.0 : measurement point closest to the inner surface

Zoom scan volume is centered at $(0, 0, L_h / 2 + z_d) = (0, 0, 7.0)$

$SAR_{Tolerance}$ [%] = $100 \times | (SAR_{eval} - SAR_{ref}) / SAR_{ref} |$

SARref = 0.881 W/Kg

Spec - $5_{pts} \times 5_{pts} \times 9_{pts}$ ($16_{mm} \times 16_{mm} \times 32_{mm}$, res: $4_{mm} \times 4_{mm} \times 4_{mm}$)		
Function Offset d [mm]	SAR_{eval} [W/Kg] $(f_1)_{1g}$	$SAR_{Tolerance}$ [%] $SAR_{to}(f_1)$
3.0	0.878	0.374
2.5	0.878	0.378
2.0	0.877	0.451
1.5	0.878	0.378
1.0	0.878	0.374
0.5	0.878	0.367
0.0	0.878	0.386
Spec - $7_{pts} \times 7_{pts} \times 7_{pts}$ ($30_{mm} \times 30_{mm} \times 30_{mm}$, res: $5_{mm} \times 5_{mm} \times 5_{mm}$)		
Function Offset d [mm]	SAR_{eval} [W/Kg] $(f_1)_{1g}$	$SAR_{Tolerance}$ [%] $SAR_{to}(f_1)$
3.0	0.875	0.664
2.5	0.875	0.692
2.0	0.875	0.664
1.5	0.875	0.641
1.0	0.876	0.558
0.5	0.877	0.462
0.0	0.877	0.468

Table 2

From the above table, it can be determined that the deviation is less than 0.7% from the target value provided in the IEEE P1528 standard for both the recommended zoom scan volume as well as the reduced zoom scan volume.

To determine the sensitivity of the zoom volume scan reduction over the P1528 recommended volume specified, the measurements are compared directly an it can be seen from the table below that the sensitivity in the post processing algorithm is less than 0.5%.

Function offset d [mm]	Recommended Scan Volume SAReval [W/Kg]	Reduced Scan Volume SAReval [W/Kg]	Sensitivity of reduced volume scan
3	0.875	0.878	-0.292%
2.5	0.875	0.878	-0.316%
2	0.875	0.877	-0.215%
1.5	0.875	0.878	-0.265%
1	0.876	0.878	-0.185%
0.5	0.877	0.878	-0.095%
0	0.877	0.878	-0.082%

Table 3

Conclusion

A reduction in the grid spacing and the zoom scan volume is a viable approach to optimizing the scan parameters of SAR system to take into account the density of the electric fields and the measurement times associated with the zoom scans. Further work needs to be performed to categorize how far the optimization can go without significantly affecting the overall measurement uncertainty budget for the post-processing algorithm which in most SAR systems, is below 3%.

References:

1. IEEE P1528/D1.2, April 21, 2003 – Recommended practice for determining the peak spatial-average SAR in the human head from wireless communications devices: Measurement techniques