SAR COMPLIANCE TESTING OF PROXIM CORPORATION MODEL 8455 (FCC ID# IMK-8455) CARDBUS CARD INSERTED INTO A LAPTOP COMPUTER

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I. Introduction

The U.S. Federal Communications Commission (FCC) has adopted limits of human exposure to RF emissions from mobile and portable devices that are regulated by the FCC [1]. The FCC has also issued Supplement C (Edition 97-01) to OET Bulletin 65 [2] and a more recent version of the same [3] defining both the measurement and the computational procedures that should be followed for evaluating compliance of mobile and portable devices with FCC limits for human exposure to radiofrequency emissions.

We have used the measurement procedure for SAR compliance testing of the Proxim Corporation wireless CardBus card (FCC ID: IMK-8455) inserted into a laptop computer. A photograph of the unit with the CardBus card inserted into the laptop computer is given in Fig. 1. A picture of the Proxim Model 8455 CardBus card placed on the laptop is given in Fig. 2. The Proxim Model 8455 wireless CardBus card operates with a nominal conducted RF power output of 21 dBm (126 mW) for the frequency band 5.18-5.825 GHz.

For SAR measurements, two configurations of the wireless PC relative to the experimental phantom have been used:

a. Since the wireless PC may possibly be placed on a user's lap where the RF antennas would be the closest to the body, a planar phantom model with inside dimensions 12" × 16.5" (30.5 × 41.9 cm) and a base thickness of 2.0 ± 0.2 mm (recommended in [3]) was used for SAR measurements and the wireless PC cards mounted in a portable computer (as in Fig. 1) pressed against the bottom of this phantom (see Fig. 3).
b. For a bystander, the "end-on" SAR value is obtained for the PC and the card edge at 90° to the flat phantom with a spacing of 2.5 cm (see Fig. 4).

II. Experimental Measurements of SAR Distribution

As aforementioned, the measurements of the SAR distributions for the Proxim Corporation Model 8455 wireless CardBus Card inserted into a laptop computer (as in Fig. 1), both for the "above-lap" and "end-on" positions, were done with a planar rectangular box phantom made of acrylic of inside dimensions 12" × 16.5" (30.5 × 41.9 cm) shown in Figs. 3 and 4 for "above-lap" and "end-on" positions, respectively. This box phantom of external dimensions 13" × 17.5" (33 × 44.5 cm) is filled with a tissue-simulant fluid up to a depth of 15 cm. As recommended in [3], the base thickness of the box phantom is 2.0 ± 0.2 mm (0.079"). As seen in Figs. 3 and 4, a 1" thick Styrofoam block is used under the base, except for the region of the wireless laptop to prevent bending of the 2 mm thin base. Also for the SAR testing for the "end-on" position, a separation of 1" (2.5 cm) from the end of the PC card to the bottom of the planar phantom is used.

The tissue-simulant fluid uses a composition developed at the University of Utah which consists of 68.0% water, 31.0% sugar and 1% HEC. For this composition, we have measured the dielectric properties using a Hewlett Packard (HP) Model 85070B Dielectric Probe in conjunction with HP Model 8720C Network Analyzer (50 MHz-20 GHz). The measured dielectric properties at a mid band frequency of 5.30 GHz are as follows: $\varepsilon_r = 48.5 \pm 1.7$ and $\sigma = 5.40 \pm 0.08$ S/m. From the FCC Supplement C [3], we obtain the desired dielectric properties to simulate the body tissue at 5.30 GHz to be $\varepsilon_r = 48.9$ and $\sigma = 5.42$ S/m. Thus, the measured properties for the body-simulant fluid are close to the desired values.

III. Calibration of the E-Field Probe

As in some previously reported SAR measurements at 6 GHz [4], we have calibrated the Narda Model 8021 Miniature Broadband Electric Field Probe of tip diameter 4 mm (0.4 to 10 GHz) using a rectangular waveguide WR 159 that was filled with this body-simulant fluid at 5.30 GHz. By comparing the electric fields expected in the tissue from the analytical expressions of the waveguide theory, we obtain a calibration factor of 2.98 (mW/kg)/μV. This is considerably

larger than calibration factors of 0.39 and 0.565 (mW/kg)/μV previously reported for the same probe at 835 MHz and 1900 MHz, respectively [5]. This is to be expected since the sensitivity of the diodes used for the Narda Model 8021 Miniature Broadband Electric Field Probe of tip diameter 4 mm is likely to diminish with frequency.

IV. The Measured SAR Distributions

The SAR distributions were determined using the automated SAR measurement system developed at the University of Utah [5]. As described in [5], this SAR measurement system has been validated using a number of wireless telephones at 835 and 1900 MHz, respectively.

The highest SAR region for each of the measurement frequencies (5.18, 5.32, 5.745, and 5.825 GHz) was identified in the first instance by using a coarser sampling with a step size of 8.0 mm over three overlapping areas for a total scan area of 8.0 × 9.6 cm. After identifying the region of the highest SAR, the SAR distribution was measured with a resolution of 2 mm in order to obtain the peak 1 cm^3 or 1-g SAR. As given in [5], the SAR measurements are performed at 4, 6, 8, 10, 12 mm height from the bottom surface of the body-simulant fluid. The SARs thus measured were extrapolated to obtain values at 1, 3, 5, 7 and 9 mm height and used to obtain 1-g SARs. The uncertainty analysis of the University of Utah SAR measurement system is given in Appendix A. The combined standard uncertainty is ± 8.3%.

The SAR distributions measured for transmit frequencies of 5.18, 5.32, 5.745, and 5.845 GHz are given in Tables 1-4 for the "above-lap" position and in Tables 5-8 for the "end-on" position, respectively. The peak 1-g SARs are summarized in Table 9. For the measurements in Tables 1-4, the separation between the Proxim Model 8455 wireless CardBus card and the bottom of the experimental phantom is on the order of 1 cm. For the "end-on" position, the separation between the card edge at 90° to the bottom of the flat phantom is 2.5 cm and the SAR distributions at the various frequencies are given in Tables 5-8. From Table 9, it may be noted that all of the measured 1-g SARs are less than the FCC96-326 Guideline of 1.6 W/kg.

V. Comparison of the Data With FCC 96-326 Guidelines

According to the FCC 96-326 Guideline [1], the peak SAR for any 1-g of tissue should not exceed 1.6W/kg. For the maximum conducted power condition of 21 dBm (126mW), the Proxim Corporation Model 8455 wireless CardBus card has been measured to give peak 1-g SARs of 0.25 to 0.98 W/kg which are considerably smaller than 1.6 W/kg.

REFERENCES

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6. IEEE Std. 1528 - Draft "Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Body Due to Wireless Communication Devices: Experimental Techniques," IEEE SCC34.

Table 1. Above-lap position. The SARs measured for the Proxim Model 8455 wireless CardBus Card (nominal conducted power of 21 dBm) inserted into a laptop computer at 5.18 GHz

1-g SAR = 0.445 W/kg

a. At depth of 1 mm

0.816	0.801	0.777	0.762	0.748
0.748	0.773	0.781	0.784	0.762
0.768	0.778	0.780	0.784	0.773
0.799	0.771	0.796	0.761	0.772
0.749	0.759	0.747	0.755	0.703

b. At depth of 3 mm

0.596	0.579	0.571	0.558	0.552
0.558	0.573	0.571	0.576	0.558
0.567	0.578	0.578	0.576	0.572
0.589	0.573	0.583	0.561	0.573
0.552	0.559	0.555	0.554	0.520

c. At depth of 5 mm

0.420	0.404	0.406	0.396	0.394
0.405	0.412	0.403	0.410	0.396
0.406	0.417	0.415	0.411	0.412
0.421	0.414	0.414	0.402	0.414
0.393	0.400	0.401	0.393	0.373

d. At depth of 7 mm

0.288	0.274	0.283	0.275	0.272
0.288	0.288	0.278	0.283	0.274
0.286	0.296	0.292	0.287	0.291
0.296	0.292	0.287	0.282	0.293
0.274	0.281	0.284	0.271	0.260

e. At depth of 9 mm

0.201	0.192	0.201	0.197	0.188
0.208	0.203	0.196	0.197	0.194
0.207	0.215	0.209	0.205	0.210
0.214	0.209	0.205	0.202	0.211
0.193	0.202	0.204	0.188	0.183

Table 2. Above-lap position. The SARs measured for the Proxim Model 8455 wireless CardBus Card (nominal conducted power of 21 dBm) inserted into a laptop computer at 5.32 GHz

1-g SAR = 0.559 W/kg

a. At depth of 1 mm

1.147	1.177	1.136	1.118	1.083
1.044	1.061	1.057	1.027	0.983
0.942	0.972	0.996	0.977	0.972
0.933	0.919	0.964	0.943	0.911
0.866	0.879	0.885	0.847	0.825

b. At depth of 3 mm

0.833	0.847	0.821	0.807	0.779
0.772	0.784	0.783	0.755	0.723
0.692	0.708	0.722	0.713	0.705
0.678	0.674	0.703	0.686	0.665
0.637	0.644	0.643	0.625	0.607

c. At depth of 5 mm

0.581	0.584	0.568	0.557	0.537
0.550	0.560	0.560	0.536	0.513
0.492	0.497	0.505	0.503	0.492
0.474	0.479	0.494	0.480	0.469
0.453	0.456	0.448	0.446	0.431

d. At depth of 7 mm

0.392	0.386	0.378	0.370	0.356
0.380	0.389	0.387	0.370	0.354
0.341	0.340	0.342	0.345	0.331
0.322	0.333	0.338	0.327	0.322
0.314	0.315	0.302	0.310	0.297

e. At depth of 9 mm

0.265	0.254	0.249	0.245	0.237
0.260	0.271	0.266	0.255	0.244
0.239	0.236	0.236	0.239	0.224
0.222	0.237	0.235	0.224	0.225
0.220	0.221	0.203	0.218	0.207

Table 3. Above-lap position. The SARs measured for the Proxim Model 8455 wireless CardBus Card (nominal conducted power of 21 dBm) inserted into a laptop computer at 5.745 GHz

1-g SAR = 0.259 W/kg

a. At depth of 1 mm

0.438	0.438	0.450	0.450	0.461
0.474	0.450	0.471	0.480	0.454
0.485	0.456	0.457	0.451	0.456
0.456	0.475	0.451	0.470	0.462
0.450	0.440	0.487	0.453	0.449

b. At depth of 3 mm

0.321	0.320	0.335	0.328	0.334
0.344	0.334	0.339	0.343	0.336
0.352	0.336	0.337	0.327	0.332
0.340	0.345	0.331	0.340	0.331
0.329	0.324	0.350	0.325	0.313

c. At depth of 5 mm

0.226	0.226	0.242	0.231	0.234
0.242	0.241	0.235	0.236	0.242
0.247	0.240	0.240	0.228	0.233
0.246	0.242	0.235	0.237	0.228
0.231	0.230	0.239	0.221	0.204

d. At depth of 7 mm

0.156	0.156	0.170	0.158	0.160
0.167	0.171	0.158	0.159	0.172
0.169	0.168	0.165	0.154	0.158
0.173	0.165	0.162	0.160	0.153
0.156	0.157	0.156	0.143	0.124

e. At depth of 9 mm

0.108	0.110	0.121	0.111	0.113
0.119	0.124	0.110	0.112	0.126
0.117	0.120	0.112	0.106	0.109
0.122	0.114	0.114	0.111	0.105
0.104	0.107	0.099	0.091	0.073

Table 4. Above-lap position. The SARs measured for the Proxim Model 8455 wireless CardBus Card (nominal conducted power of 21 dBm) inserted into a laptop computer at 5.825 GHz

1-g SAR = 0.249 W/kg

a. At depth of 1 mm

0.434	0.404	0.412	0.410	0.395
0.444	0.434	0.432	0.432	0.411
0.415	0.440	0.442	0.447	0.428
0.442	0.466	0.444	0.437	0.418
0.432	0.439	0.432	0.432	0.397

b. At depth of 3 mm

0.316	0.301	0.300	0.299	0.297
0.325	0.318	0.314	0.318	0.301
0.306	0.323	0.320	0.321	0.312
0.329	0.341	0.331	0.327	0.311
0.326	0.320	0.314	0.325	0.294

c. At depth of 5 mm

0.221	0.218	0.211	0.212	0.218
0.230	0.226	0.221	0.227	0.213
0.219	0.230	0.224	0.223	0.220
0.239	0.243	0.241	0.239	0.226
0.240	0.226	0.221	0.238	0.211

d. At depth of 7 mm

0.149	0.156	0.146	0.150	0.159
0.159	0.158	0.153	0.160	0.148
0.154	0.161	0.154	0.153	0.152
0.172	0.172	0.174	0.174	0.164
0.174	0.157	0.154	0.171	0.148

e. At depth of 9 mm

0.100	0.113	0.103	0.113	0.119
0.114	0.112	0.110	0.117	0.105
0.112	0.116	0.110	0.111	0.108
0.127	0.128	0.131	0.131	0.126
0.128	0.112	0.112	0.122	0.106

Table 5. End-on position. The SARs measured for the Proxim Model 8455 wireless CardBus Card (nominal conducted power of 21 dBm) inserted into a laptop computer at 5.18 GHz. Distance to the bottom of the flat phantom = 2.5 cm.

1-g SAR = 0.976 W/kg

a. At depth of 1 mm

1.793	1.780	1.808	1.742	1.707
1.745	1.719	1.706	1.696	1.676
1.705	1.718	1.776	1.735	1.730
1.719	1.759	1.755	1.753	1.723
1.704	1.748	1.773	1.758	1.750

b. At depth of 3 mm

1.310	1.314	1.320	1.276	1.249
1.279	1.272	1.260	1.241	1.212
1.245	1.252	1.274	1.255	1.247
1.253	1.271	1.271	1.265	1.244
1.239	1.265	1.278	1.270	1.260

c. At depth of 5 mm

0.918	0.932	0.924	0.898	0.878
0.902	0.910	0.897	0.874	0.841
0.875	0.878	0.875	0.871	0.859
0.877	0.879	0.882	0.873	0.860
0.866	0.879	0.883	0.878	0.869

d. At depth of 7 mm

0.616	0.636	0.622	0.608	0.595
0.615	0.632	0.618	0.594	0.563
0.594	0.595	0.577	0.581	0.568
0.592	0.583	0.588	0.578	0.573
0.584	0.589	0.587	0.584	0.579

e. At depth of 9 mm

0.405	0.426	0.412	0.407	0.400
0.416	0.438	0.421	0.402	0.377
0.404	0.403	0.381	0.387	0.372
0.398	0.383	0.390	0.379	0.381
0.393	0.395	0.390	0.386	0.387

Table 6. End-on position. The SARs measured for the Proxim Model 8455 wireless CardBus Card (nominal conducted power of 21 dBm) inserted into a laptop computer at 5.32 GHz. Distance to the bottom of the flat phantom = 2.5 cm.

1-g SAR = 0.902 W/kg

a. At depth of 1 mm

1.695	1.704	1.684	1.652	1.584
1.636	1.672	1.655	1.667	1.599
1.621	1.662	1.632	1.6560	1.592
1.605	1.641	1.658	1.640	1.592
1.582	1.661	1.674	1.642	1.619

b. At depth of 3 mm

1.227	1.229	1.215	1.190	1.149
1.186	1.211	1.195	1.200	1.152
1.167	1.191	1.178	1.188	1.144
1.153	1.172	1.187	1.175	1.144
1.132	1.188	1.200	1.181	1.164

c. At depth of 5 mm

0.849	0.846	0.837	0.819	0.798
0.824	0.840	0.826	0.825	0.793
0.803	0.814	0.813	0.813	0.784
0.791	0.797	0.811	0.803	0.784
0.772	0.811	0.821	0.812	0.800

d. At depth of 7 mm

0.562	0.556	0.551	0.538	0.530
0.549	0.557	0.547	0.541	0.522
0.528	0.530	0.536	0.530	0.512
0.519	0.515	0.530	0.524	0.512
0.502	0.530	0.536	0.534	0.527

e. At depth of 9 mm

0.365	0.359	0.356	0.348	0.345
0.360	0.364	0.357	0.350	0.338
0.344	0.340	0.349	0.338	0.329
0.336	0.327	0.344	0.337	0.329
0.322	0.344	0.345	0.348	0.344

Table 7. End-on position. The SARs measured for the Proxim Model 8455 wireless CardBus Card (nominal conducted power of 21 dBm) inserted into a laptop computer at 5.745 GHz. Distance to the bottom of the flat phantom = 2.5 cm.

1-g SAR = 0.944 W/kg

a. At depth of 1 mm

1.866	1.826	1.768	1.766	1.735
1.800	1.812	1.774	1.770	1.748
1.680	1.736	1.767	1.749	1.722
1.708	1.732	1.780	1.755	1.732
1.684	1.707	1.733	1.717	1.716

b. At depth of 3 mm

1.347	1.312	1.274	1.261	1.232
1.298	1.297	1.273	1.259	1.243
1.205	1.231	1.250	1.235	1.211
1.202	1.222	1.253	1.238	1.217
1.194	1.211	1.222	1.218	1.219

c. At depth of 5 mm

0.927	0.899	0.877	0.857	0.831
0.893	0.885	0.871	0.853	0.841
0.824	0.829	0.840	0.826	0.806
0.801	0.816	0.835	0.827	0.808
0.803	0.817	0.818	0.822	0.825

d. At depth of 7 mm

0.607	0.586	0.578	0.555	0.533
0.587	0.576	0.569	0.550	0.540
0.539	0.532	0.535	0.523	0.506
0.503	0.516	0.527	0.523	0.506
0.513	0.524	0.520	0.528	0.533

e. At depth of 9 mm

0.386	0.375	0.375	0.355	0.338
0.379	0.369	0.366	0.352	0.341
0.349	0.338	0.337	0.326	0.311
0.310	0.320	0.328	0.325	0.310
0.324	0.333	0.328	0.337	0.344

Table 8. End-on position. The SARs measured for the Proxim Model 8455 wireless CardBus Card (nominal conducted power of 21 dBm) inserted into a laptop computer at 5.825 GHz. Distance to the bottom of the flat phantom = 2.5 cm.

1-g SAR = 0.777 W/kg

a. At depth of 1 mm

1.418	1.430	1.476	1.466	1.446
1.463	1.452	1.505	1.489	1.467
1.458	1.477	1.484	1.491	1.460
1.432	1.436	1.464	1.467	1.452
1.425	1.447	1.474	1.470	1.450

b. At depth of 3 mm

1.001	1.014	1.045	1.033	1.026
1.038	1.030	1.061	1.063	1.034
1.029	1.046	1.047	1.045	1.029
1.010	1.018	1.029	1.031	1.022
1.007	1.023	1.046	1.036	1.023

c. At depth of 5 mm

0.670	0.682	0.701	0.689	0.691
0.699	0.692	0.708	0.721	0.689
0.688	0.701	0.699	0.690	0.686
0.673	0.684	0.683	0.683	0.680
0.675	0.684	0.703	0.691	0.685

d. At depth of 7 mm

0.425	0.433	0.446	0.433	0.440
0.445	0.440	0.447	0.461	0.431
0.434	0.443	0.438	0.428	0.430
0.421	0.4331	0.425	0.425	0.424
0.428	0.432	0.447	0.434	0.436

e. At depth of 9 mm

0.264	0.267	0.277	0.265	0.274
0.278	0.274	0.278	0.284	0.261
0.268	0.273	0.264	0.258	0.262
0.254	0.267	0.255	0.256	0.256
0.267	0.266	0.277	0.265	0.276

Table 9. The peak 1-g SARs measured for the Proxim Corporation Model 8455 wireless CardBus Card (nominal conducted power of 21 dBm) inserted into a laptop computer.

		1-g SAR in W/kg			
PC position relative to the flat phantom	Spacing to the bottom of the phantom	5.18 GHz	5.32 GHz	5.745 GHz	5.825 GHz
"Above-lap": bottom of PC pressed against bottom of the flat phantom	1 cm	0.445	0.569	0.259	0.249
"End-on": card edge at 90° relative to the bottom of the flat phantom	2.5 cm	0.976	0.902	0.944	0.777

Fig. 1. Photograph of the Proxim Corporation Model 8455 CardBus card inserted into a laptop computer.

Fig. 2. A picture of the Model 8455 CardBus card placed on the laptop computer.

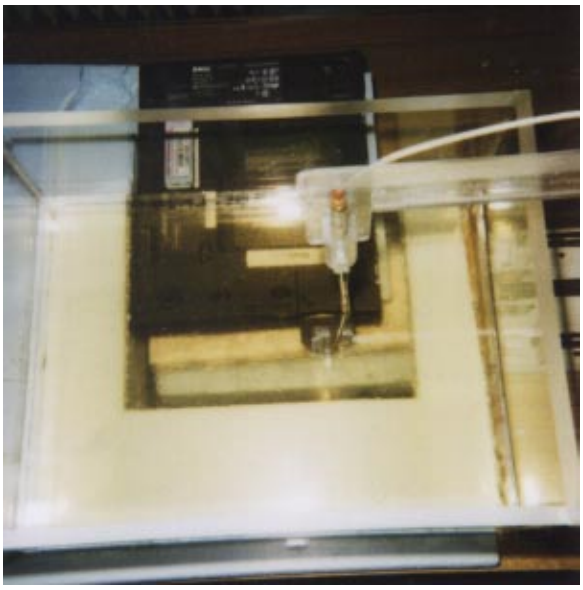

Fig. 3. Photograph of the Proxim Corporation Model 8455 wireless CardBus card inserted into a laptop computer with its bottom pressed against the bottom of the planar tissue-simulant phantom to simulate "above-lap" placement of the wireless PC. A Styrofoam block is used under the base to prevent bending of the 2 mm thin base of the phantom.

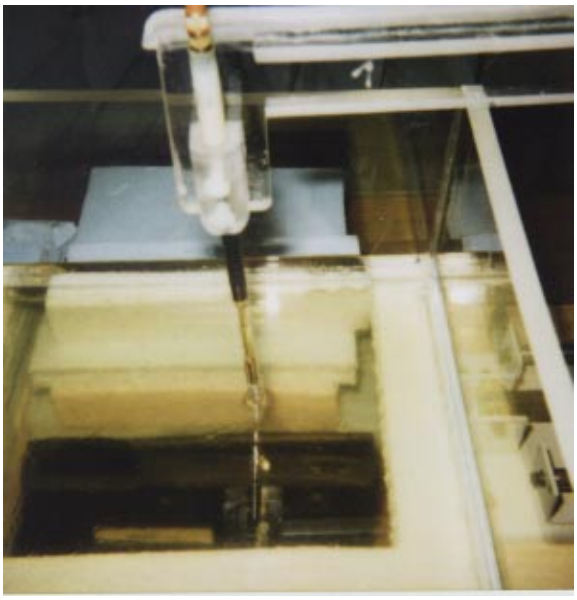

Fig. 4. Photograph of the Proxim Model 8455 wireless CardBus card inserted into a portable computer (as in Fig. 1) placed with the card edge at 90° and separated from the bottom of the phantom by 2.5 cm for "end-on" testing of SAR. As in Fig. 3, here too, a Styrofoam block is used under the base to prevent bending of the 2 mm thin base of the phantom.

APPENDIX A

Uncertainty Analysis

The uncertainty analysis of the University of Utah SAR Measurement System is given in Table A.1. Several of the numbers on tolerances are obtained by following procedures similar to those detailed in [5], while others have been obtained using methods suggested in [6].

Table A.1. Uncertainty analysis of the University of Utah SAR Measurement System.

Uncertainty Component	Tolerance ± %	Prob. Dist.	Div.	C_i 1-g	1-g u_i ± %
Measurement System					
Probe calibration	2.0	N	1	1	2.0
Axial istropy	4.0	R	√3	$(1\text{-cp})^{1/2}$	1.6
Hemispherical isotropy	5.5	R	√3	$\sqrt{c_p}$	0.0
Boundary effect	0.8	R	√3	1	0.5
Linearity	3.0	R	√3	1	1.7
System detection limits	1.0	R	√3	1	0.6
Readout electronics	1.0	N	1	1	1.0
Response time	0.0	R	√3	1	0.0
Integration time	0.5	R	√3	1	0.3
RF ambient conditions	0	R	√3	1	0
Probe positioner mechanical tolerance	0.5	R	√3	1	0.3
Probe positioning with respect to phantom shell	2.0	R	√3	1	1.2
Extrapolation, interpolation, and integration algorithms for max. SAR evaluation	5.0	R	√3	1	2.9
Test Sample Related					
Test sample positioning	3	R	√3	1	1.7
Device holder uncertainty	3	R	√3	1	1.7
Output power variation - SAR drift measurement	5	R	√3	1	2.9
Phantom and Tissue Parameters					
Phantom uncertainty - shell thickness tolerance	10.0	R	√3	1	5.8
Liquid conductivity - deviation from target values	0.4	R	√3	0.7	0.2
Liquid conductivity - measurement uncertainty	1.5	R	√3	0.7	0.6
Liquid permitivity - deviation from target values	0.8	R	√3	0.6	0.3
Liquid permittivity - measurement uncertainty	3.5	R	√3	0.6	1.2
Combined Standard Uncertainty		RSS			8.3
Expanded Uncertainty (95% Confidence Level)					16.6