Results Obtained During the Summer of 2017

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July 27, 2017

1 Introduction

2 Comparing PLD Matlab to PLD CST

In this section the PLD-distributions calculated in Matlab with separate efields for each antenna is compared to a corresponding PLD-distribution derived in CST. This is done for the *Duke-tongue*-model with an added salt water bolus below the chin. This model is from now on referred to as *Duke-tongue-salt*. The distributions is compared for the frequencies 400, 600 and 800 MHz in terms of the quality parameters HTQ, tumor coverage (25%, 50% and 75%) as well as the maximum value in the tumor and the mean value of the entire distribution within the model. The distributions were normalized before comparison and consequently the maximum in tumor and the mean can be seen as percentages of the absolute maximum.

This comparison was performed for an unfocused setup as well as a setup which attempted to focus in the tumor using phase and amplitude settings derived from a time reversal simulation. The data obtained from the unfocused setup is presented in Table 1 and the result from focused setup is presented in Table 2. Images of the focused distributions are presented in Appendix A.

Table 1: This table displays the quality parameters HTQ, tumor coverage of 25, 50 and 75 %, the maximum PLD-value in the tumor and the mean distribution value for different frequency for normalized PLD calculated in Matlab and CST, respectively. In this case all antennas have the amplitude 1 and phase shift 0.

	MATLAB			**CST**			**Difference**		
Frequency:	**400**	**600**	**800**	**400**	**600**	**800**	**400**	**600**	**800**
HTQ	2.02	2.03	2.00	1.78	1.33	1.48	0.24	0.70	0.53
TC25	0.20	0.21	0.24	0.10	0.72	0.59	0.10	0.51	0.35
TC50	0	0	0	0	0.48	0.21	0	0.48	0.21
TC75	0	0	0	0	0.21	0.035	0	0.21	0.035
$\mathbf{Max_{tumor}}$	0.40	0.41	0.43	0.31	0.998	0.90	0.089	0.59	0.46
Mean	0.018	0.19	0.020	0.027	0.063	0.034	0.0088	0.044	0.014

Table 2: This table displays the quality parameters HTQ, tumor coverage of 25, 50 and 75 %, the maximum PLD-value in the tumor and the mean distribution value for different frequency for normalized PLD calculated in Matlab and CST, respectively. In this case all antennas have radiated with settings derived by a time reversal simulation.

	MATLAB			**CST**			**Difference**		
Frequency:	**400**	**600**	**800**	**400**	**600**	**800**	**400**	**600**	**800**
HTQ	1.18	0.93	1.67	1.16	0.83	0.99	0.043	0.10	0.67
TC25	0.54	0.83	0.37	0.53	0.49	0.30	0.0046	0.34	0.068
TC50	0.081	0.028	0	0.096	0.29	0.16	0.015	0.26	0.16
TC75	0	0	0	0	0.12	0.054	0	0.12	0.054
$\mathbf{Max_{tumor}}$	0.58	0.52	0.32	0.59	1.00	1.00	0.0090	0.48	0.68
Mean	0.014	0.022	0.027	0.029	0.025	0.015	0.015	0.0035	0.012

3 Comparing PLD Octree to PLD Matlab

In this section the PLD distribution calculated from efields from each antenna as matrices are compared to PLD calculated using the Octree-format. The distributions is compared for the frequencies 400, 600 and 800 MHz in terms of the quality parameters HTQ, tumor coverage (25%, 50% and 75%) as well as the maximum value in the tumor and the mean value of the entire distribution within the model. The distributions were normalized before comparison and consequently the maximum in tumor and the mean can be seen as percentages of the absolute maximum.

This comparison was done for fields calculated with amplitude 1 and phase 0 for each antenna. The resulting values for the quality parameters can be found in Table 3.

Table 3: This table displays the quality parameters HTQ, tumor coverage of 25, 50 and 75 %, the maximum PLD-value in the tumor and the mean distribution value for different frequency for normalized PLD calculated in Matlab and PLD calculated using Octrees, respectively. In this case all antennas have the amplitude 1 and phase shift 0.

	MATLAB			**Octree**			**Difference**		
Frequency:	**400**	**600**	**800**	**400**	**600**	**800**	**400**	**600**	**800**
HTQ	2.02	2.03	2.00	2.02	2.03	2.00	$1.10 \cdot 10^{-5}$	$1.11 \cdot 10^{-4}$	$1.25 \cdot 10^{-4}$
TC25	0.20	0.21	0.24	0.20	0.21	0.24	0	0	0
TC50	0	0	0	0	0	0	0	0	0
TC75	0	0	0	0	0	0	0	0	0
Max$_{\mathbf{tumor}}$	0.40	0.41	0.43	0.40	0.41	0.43	$1.16 \cdot 10^{-7}$	$2.98 \cdot 10^{-8}$	$8.94 \cdot 10^{-8}$
Mean	0.018	0.019	0.020	0.020	0.019	0.020	$3.00 \cdot 10^{-4}$	$7.63 \cdot 10^{-7}$	$9.33 \cdot 10^{-7}$

4 Comparing Optimized PLD with Amsterdam

Table 4: This table displays the HTQ, tumor coverage of 25, 50 and 75 %, the maximum PLD-value in the tumor and the mean distribution value when comparing a normalized calculated optimized PLD distribution to a normalized optimized distribution from Amsterdam. The compared frequency is 450 MHz and the model is duke with a tongue-tumor. The mean excludes all elements outside the body.

	HTQ	**TC25**	**TC50**	**TC75**	**Max$_{\mathbf{tumor}}$**	**Mean**
Amsterdam	5.03	0	0	0	0.0521	0.0018
Gothenburg	5.75	0	0	0	0.0352	0.0020
Difference	0.72	0	0	0	0.0169	-0.0002

5 Comparing Temperature Parameters

The thermal parameters used in temperature calculation are heat capacity, thermal conductivity, density and rest perfusion. The first three parameters are equal or almost equal (percentage difference ¡ 1%) for our calculations and the Amsterdam values. Rest perfusion varies a bit.

The Amsterdam team use the parameter W_b [kg/m3/s], which is valid at average steady state hyperthermic conditions. At these conditions, they assume muscle perfusion is increased a factor 5 and cerebellum with 10%. Perfusion for other tissue types are yeilded with linear interpolation:
Perfusion=2,75+0,9319*restPerfusion. Thyroid, bone and cartillage is assumed

to be constant.

We get the rest perfusion [m3/s/kg] from database sheet
"Thermal_dielectric_acoustic_MRproperties_database_V3.0_not_updated".
When we use this rest perfusion as it is the values vary a lot from Amsterdam values. When we modify this rest perfusion according to the linear model of Amsterdam values are more alike, but still differ for some tissue types. A table of all tissue types, the dutch parameter W_b and our modified rest perfusion*density^2 (to obtain the same unit kg/m3/s) is given below. The percentage difference is presented. Tissues with a percentage difference higher than 10% are higlighted in red. These tissues are Bones, Fat, Lung, Mandible, SAT, Skull, Tendon Ligament and Vertabrae.

Mod rest perf modified to fit Amsterdam values: linear model

Tissuename	*W_b dutch* *[kg/m3/s]*	*Mod rest perf*rho^2* *[kg/m3/s]*	*Difference* *[%]*
Air_exterior	0	0	0
Air_internal	0	0	0
BloodA	182.0000	181.9998	-0.0001
Blood_vessels	5.2942	5.2942	-0.0001
Bones	0.3484	0.6666	47.7387
GrayMatter	15.6829	15.6527	-0.1930
Whitematter	6.3387	6.3265	-0.1926
Cartilage	0.6718	0.7086	5.1960
Cerebellum	15.7846	15.7543	-0.1926
CSF	0	0	0
Commissura_anterior	6.3492	6.3553	0.0961
Commissura_posteor	6.3492	6.3553	0.0961
Connective_tissue	0.6649	0.6566	-1.2658
Cornea	0	0	0
Ear_cartilage	0.6718	0.7086	5.1960
Ear_skin	4.6948	5.0785	7.5556
Esophagus	5.9726	5.9726	-0.0000
Eye_lens	0	0	0
Air_esophagus	0	0	0
Eye_Sclera	9.1084	8.9858	-1.3645
Eye_vitreous_humor	0	0	0
Fat	1.0229	0.9010	-13.5374
Hippocampus	15.7703	15.9461	1.1026
Hypophysis	17.9477	18.1720	1.2343
Hypothalamus	15.8698	16.0682	1.2348
Intervertebral_disc	0.6738	0.7126	5.4545
Larynx	0.6738	0.7126	5.4545
Lung	4.4504	1.1126	-299.9995
Mandible	0.3340	0.6127	45.4927
Marrow_red	5.0398	5.0398	0.0000
Medulla_oblongata	12.2856	12.3565	0.5739
Midbrain	12.2856	12.3565	0.5739
Mucosa	12.8247	12.8247	0.0002
Muscle	3.3818	3.4042	0.6590
Nerve	5.4584	5.4479	-0.1927
Pharynx	0	0	0
Pinealbody	17.9477	18.1720	1.2343
Pons	12.2856	12.3565	0.5739
SAT	1.0229	0.8961	-14.1598
Skin	4.6948	5.0785	7.5556
Skull	0.3359	0.6201	45.8333
Spinalcord	5.5552	5.7421	3.2557
Teeth	0	0	0
Tendon_Ligament	0.6190	0.7262	14.7540
Thalamus	14.4238	14.4931	0.4782
Thyroid_gland	103.3409	104.3345	0.9524
Tongue	4.1366	4.3354	4.5871
Trachea	3.3663	3.4958	3.7035
Air_trachea	0	0	0
Vein	182.0000	181.9998	-0.0001
Vertebrae	0.3340	0.6127	45.4927
Tumor	1.6909	1.7169	1.5152
Water-singleFreq	0	0	0

6 Comparing Temperature Distribution with Amsterdam

In this section temperature distributions are calculated using the PLD optimized in Amsterdam both through Amsterdam's temperature calculation and Gothenburg's temperature calculation. The data obtained is presented in table 5 and images of the distributions are presented in Appendix B.

Table 5: The table shows values from a comparison of a temperature calculations. A PLD matrix from Amsterdam is converted to temperature using both Amsterdam and Gothenburg's temperarture conversions. The compared frequency is 450 MHz and the model is duke with a tongue-tumor. The displayed values are the temperature for 10, 50 and 90 % in the tumor and the healthy tissue. The maximum temperature in both tumor and healthy tissue is also displayed as well as the mean of the entire model. The mean excludes all elements outside the body.

	Tumor tissue				**Healthy tissue**				**Total**
	T10	**T50**	**T90**	**Max**	**T10**	**T50**	**T90**	**Max**	**Mean**
Amsterdam	3.44	2.91	1.84	1.27	7.99	0.0069	-17.00	-22.00	-11.88
Gothenburg	4.06	3.34	2.08	1.42	7.42	0.0060	0.00	-1.74	-0.71
Difference	0.62	0.43	0.24	0.15	0.57	0.0009	17.00	20.26	11.17

7 Obtained Results of Single Frequency Optimization

Results using the single frequency optimization have been generated for two models; NasalWerT and TongueSalt. A table presenting the uncertainty of particle swarm by showing values for two NasalWerT optimization can be found in Appendix C.

Table 6: This table displays the values of HTQ, tumor coverage of 25, 50 and 75 %, the maximum % of all PLD that is in the tumor and the mean of normalized PLD in the model (the air outside the model is excluded). The values are calculated for an optimized PLD distribution for different frequencies (MHz) for the duke nasalWerT model. Particle swarm was set to 20 particles, 20 iterations and 10 stall iterations.

Frequency:	**HTQ**	**TC25**	**TC50**	**TC75**	$\mathrm{Max}_{\mathrm{tumor}}\%$	**Mean**
400	0.9031	0.0053	0.0008	0.0001	1	0.0012
425	0.9101	0.0053	0.0007	0.0001	1	0.0012
450	0.9091	0.0060	0.0008	0.0001	1	0.0013
475	0.9208	0.0050	0.0007	0.0001	1	0.0012
500	0.9248	0.0050	0.0008	0.0001	1	0.0012
525	0.9424	0.0082	0.0013	0.0001	1	0.0015
550	0.9311	0.0058	0.0008	0.0001	1	0.0013
575	0.9322	0.0062	0.0008	0.0001	1	0.0013
600	0.9944	0.0067	0.0008	0.0001	0.9147	0.0013
625	0.9266	0.0077	0.0005	0	0.7354	0.0012
650	0.9291	0.0077	0.0005	0	0.7111	0.0012
675	0.9347	0.0076	0.0004	0	0.7077	0.0012
700	0.9467	0.0068	0.0003	0	0.6605	0.0012
725	0.9388	0.0076	0.0005	0	0.7085	0.0012
750	0.9505	0.0078	0.0007	0.0001	0.7997	0.0013
775	0.9466	0.0074	0.0004	0	0.6986	0.0012
800	0.9499	0.0078	0.0005	0	0.7407	0.0013
825	0.9460	0.0078	0.0005	0	0.7135	0.0013
850	0.9535	0.0067	0.0004	0	0.7385	0.0012
875	0.9456	0.0080	0.0005	0	0.7281	0.0013
900	0.9474	0.0084	0.0007	0.0001	0.7605	0.0013

Table 7: This table displays the values of HTQ, tumor coverage of 25, 50 and 75 %, the maximum % of all PLD that is in the tumor and the mean of normalized PLD in the model (the air outside the model is excluded). The values are calculated for an optimized PLD distribution for different frequencies (MHz) for the duke tongue salt model. Particle swarm was set to 20 particles, 20 iterations and 10 stall iterations.

Frequency:	**HTQ**	**TC25**	**TC50**	**TC75**	$\text{Max}_{\text{tumor}}\%$	**Mean**
400	0.6439	0.9994	0.9360	0.4471	1.0000	0.0393
425	0.5955	0.9967	0.8974	0.4552	1.0000	0.0317
450	0.7330	0.9988	0.7026	0.1008	0.8148	0.0396
475	0.6237	0.9986	0.7365	0.1521	0.8374	0.0307
500	0.6627	0.9927	0.8250	0.4335	1.0000	0.0339
525	0.6570	1.0000	0.8744	0.3689	1.0000	0.0417
550	0.6519	0.9985	0.8245	0.3628	0.9502	0.0354
575	0.7640	0.9473	0.6716	0.3390	0.9651	0.0426
600	0.6070	1.0000	0.8926	0.4662	1.0000	0.0352
625	0.6834	0.9971	0.7977	0.3008	0.9720	0.0351
650	0.6375	1.0000	0.8893	0.4547	1.0000	0.0297
675	0.6409	0.9781	0.8329	0.4265	1.0000	0.0308
700	0.6609	1.0000	0.8827	0.4660	1.0000	0.0353
725	0.6445	1.0000	0.8257	0.3161	1.0000	0.0285
750	0.6689	0.9828	0.8051	0.4308	1.0000	0.0316
775	0.6617	0.9947	0.7885	0.2897	1.0000	0.0237
800	0.6333	0.9949	0.7913	0.3096	1.0000	0.0242
825	0.6380	0.9975	0.8696	0.4238	1.0000	0.0303
850	0.7802	0.9928	0.7440	0.2015	1.0000	0.0320
875	0.6420	0.9998	0.8515	0.4148	1.0000	0.0321
900	0.6395	1.0000	0.8125	0.4345	1.0000	0.0302

Images for the results showing the best HTQ values for both models are presented in Appendix D.

8 Obtained Results of Double Frequency Optimization

This section presents results from optimizations using two frequencies. First, the actual optimization with Double is shown in table **??** and then the results of a simpler version that combines already optimized E-fields are presented in table **??**.

Table 8: This table displays the HTQ values for optimized PLD distributions using combined frequencies, with the Double Optimization.

[MHz]	**400**	**425**	**450**	**475**	**500**
400	0.8982	0.9100	0.9105	0.8996	0.9069
425	0.9048	0.9197	0.9087	0.9158	0.9109
450	0.9029	0.9134	0.9198	0.9170	0.9255
475	0.9045	0.9103	0.9169	0.9206	0.9189
500	0.9090	0.9101	0.9152	0.9179	0.9229

Table 9: This table displays the HTQ values for optimized PLD distributions when different frequencies have been combined but not optimized together, which can be used as a simpler and much quicker way to estimate the combination of multiple frequencies. The used optimization was Combine Single.

[MHz]	**400**	**425**	**450**	**475**	**500**
400		0.9014	0.9014	0.9014	0.9014
425	0.9014		0.9072	0.9084	0.9084
450	0.9014	0.9072		0.9074	0.9074
475	0.9014	0.9084	0.9074		0.9191
500	0.9014	0.9084	0.9074	0.9191	

The time shares that were used for both table **??** and table **??** are presented in Appendix E.

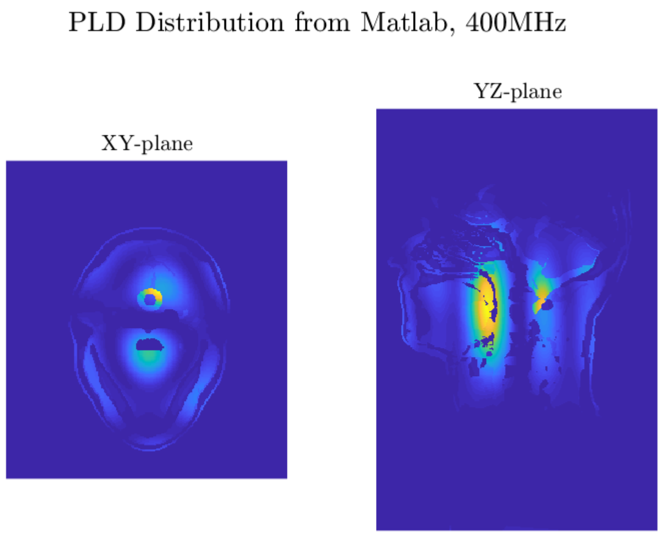
9 Obtained Results After Temperature Transformation

The results from single frequency optimization for model nasalWerT, see table 6 were transformed into temperature.

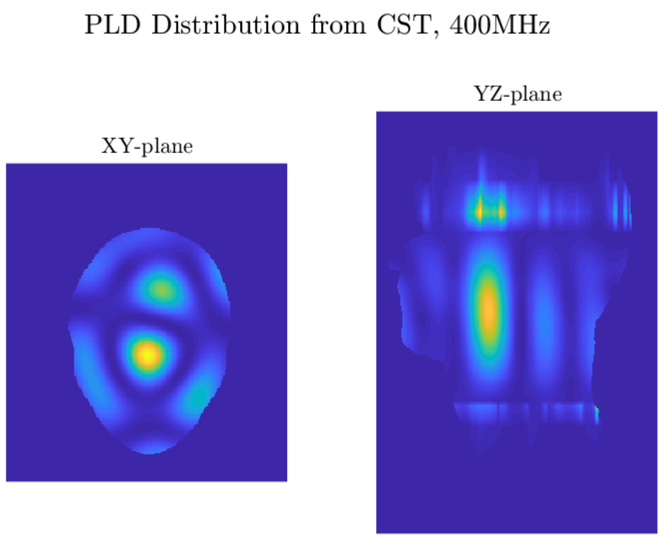
Table 10: This table displays the mean temperatures in 10, 50 and 90 % of the tumor tissue and the heatlhy tissue. It also presents the maxmium tempertature in the tumor and healthy tissue. The values are calculated from an optimized PLD distribution for different frequencies (MHz) for the duke nasalWerT model, see table 6

	Tumor tissue				**Healthy tissue**			
	T10	**T50**	**T90**	**Max**	**T10**	**T50**	**T90**	**Max**
400	7.9003	6.8381	4.9857	2.6799	7.3416	0.0002	0	-1.7827
425	7.5327	6.5391	4.8214	2.5912	6.9842	0.0002	0	-1.7865
450	7.6784	6.6123	4.7463	2.5546	7.1855	0.0001	0	-1.7885
475	7.9168	6.8766	5.0513	2.7185	7.3662	0.0002	0	-1.7797
500	7.7469	6.7126	4.9079	2.6457	7.2202	0.0002	0	-1.7831

A Comparing PLD Matlab to PLD CST

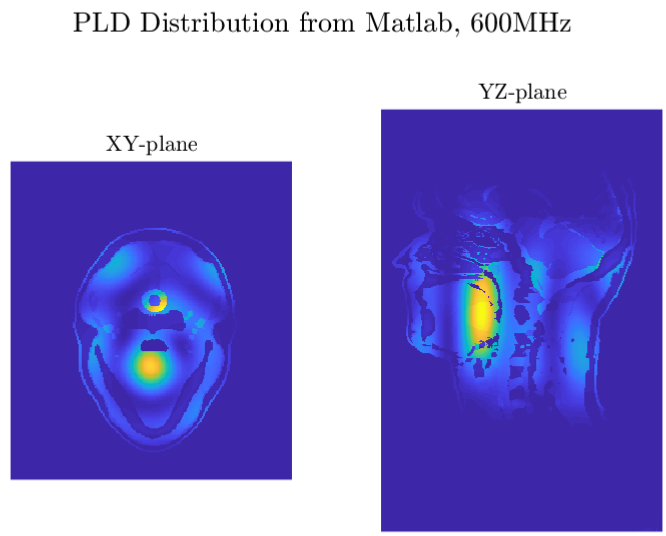


(a)

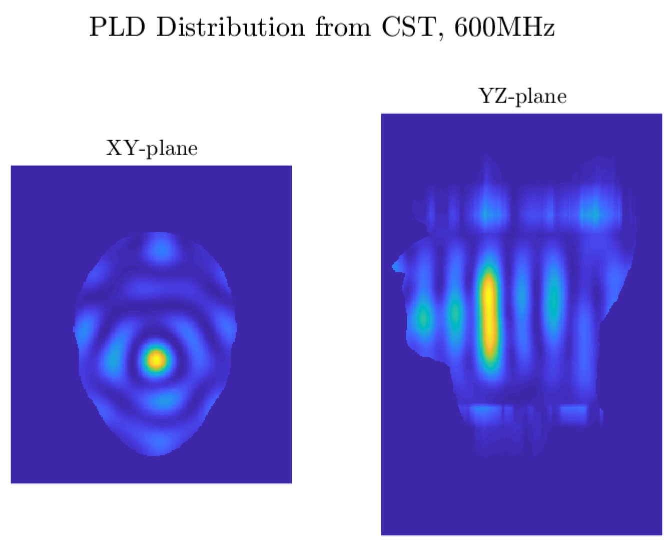


(b)

Figure 1: Subfigure 1a illustrate the PLD distribution calculated in Matlab and Subfigure 1b show the PLD distribution from CST. Both are derived for the frequency 400 MHz and with settings from a time reversal simulation.

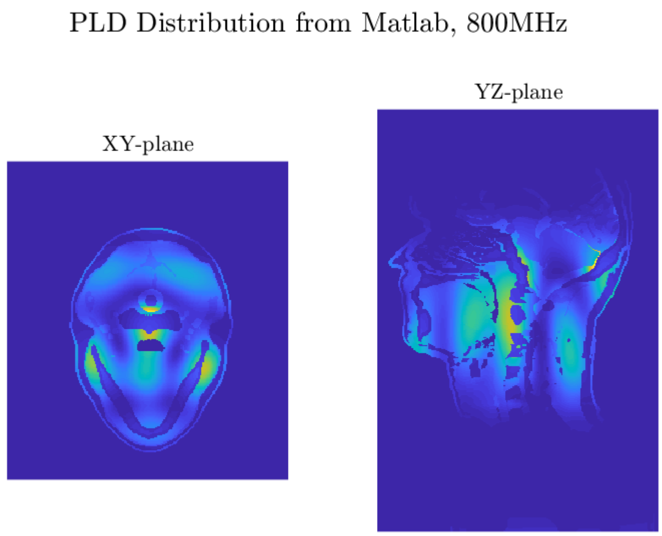


(a)

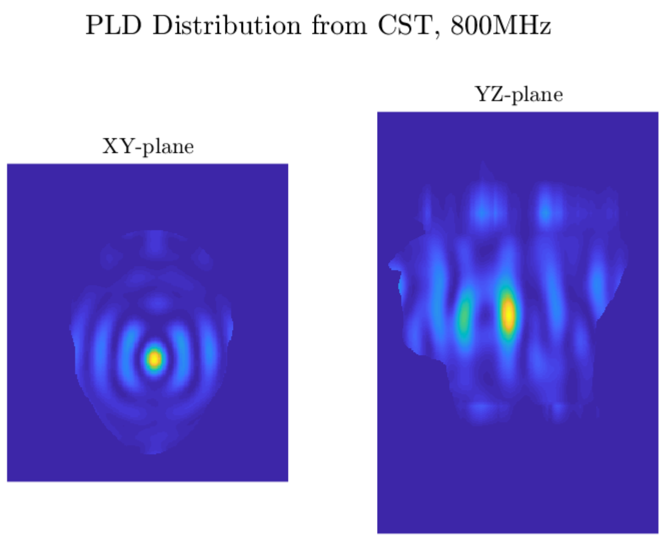


(b)

Figure 2: Subfigure 2a illustrate the PLD distribution calculated in Matlab and Subfigure 2b show the PLD distribution from CST. Both are derived for the frequency 600 MHz and with settings from a time reversal simulation.



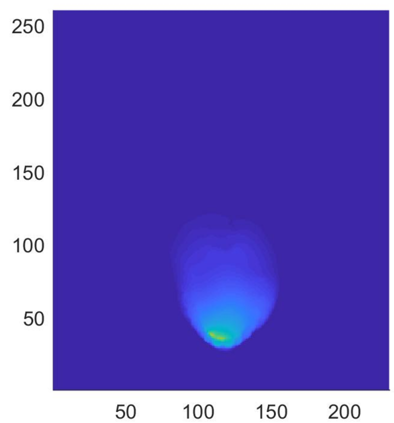
(a)



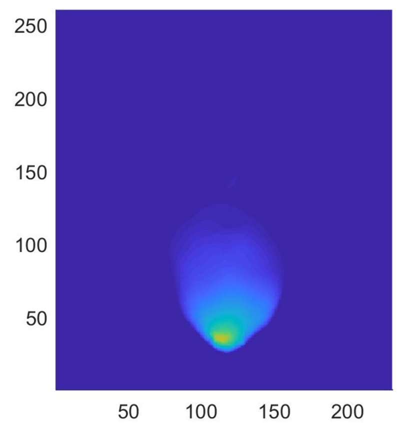
(b)

Figure 3: Subfigure 3a illustrates the PLD distribution calculated in Matlab and Subfigure 3b show the PLD distribution from CST. Both are derived for the frequency 800 MHz and with settings from a time reversal simulation.

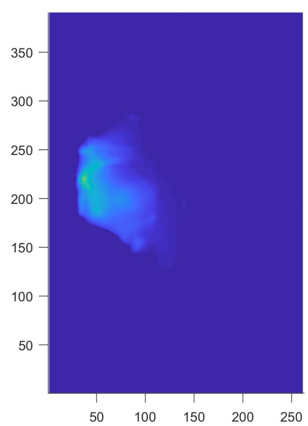
B Comparing Temperature Distribution with Amsterdam



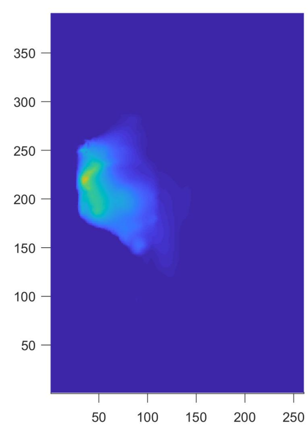
(a)



(b)



(c)



(d)

Figure 4: Subfigure 4a illustrates the temperature distribution with the head view from above after temperature conversion of the tongue tumor PLD using Amsterdam's method. Subfigure 4c shows the same but view from the left side of the head. Subfigure 4b shows the temperature distribution from above after temperature conversion of the tongue tumor PLD using Gothenburg's method. Subfigure 4d shows it from the left side of the head. All are derived for the frequency 450 MHz.

C Randomness of Particle Swarm When Using Single Frequency Optimization

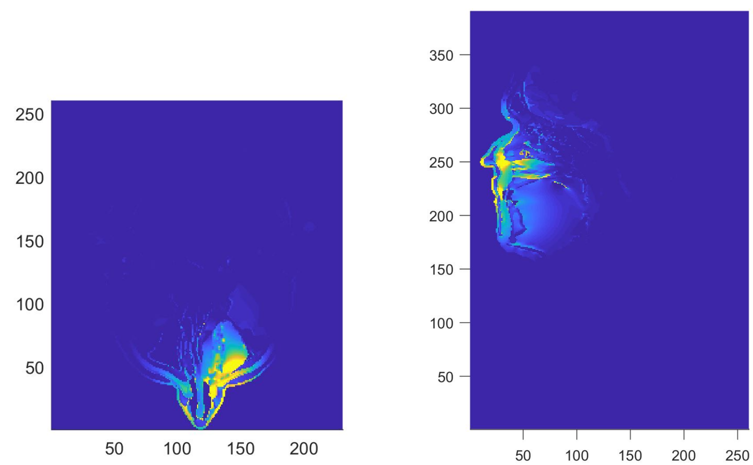
The results in this section show the difference in results between two optimizations of the model NasalWerT using single frequency optimization.

Table 11: This table displays the difference in HTQ, tumor coverage of 25, 50 and 75 %, the maximum % of all PLD that is in the tumor and the mean of normalized PLD in the model (the air outside the model is excluded) between two optimizations of the model NasalWerT. The values are calculated for an optimized PLD distribution for different frequencies (MHz) for the duke nasalWerT model. Particle swarm was set to 20 particles and 10 stall iterations. The first run had 50 iterations and the second 20 iterations, which had showed a similar quality of results according to our study of iterations vs HTQ.

Frequency:	**ΔHTQ**	**ΔTC25**	**ΔTC50**	**ΔTC75**	$\Delta \mathbf{Max_{tumor}}\%$	**ΔMean**
400	0.0069	0.0023	0.0004	0	0	0.0002
425	0.0078	0.0028	0.0006	0.0001	0	0.0002
450	0.0132	0.0019	0.0004	0.0001	0	0.0001
475	0.0070	0.0026	0.0005	0	0	0.0002
500	0.0066	0.0029	0.0005	0.0001	0	0.0002
525	0.0080	0.0005	0.0001	0	0	0.0001
550	0.0084	0.0021	0.0004	0.0001	0	0.0002
575	0.0144	0.0016	0.0005	0	0	0.0001
600	0.0522	0.0007	0.0006	0.0001	0.2766	0.0002
625	0.0153	0.0016	0.0003	0	0.0822	0.0001
650	0.0194	0.0018	0.0003	0	0.0699	0.0001
675	0.0185	0.0017	0.0002	0	0.0591	0.0001
700	0.0100	0.0010	0.0001	0	0.0261	0.0001
725	0.0215	0.0018	0.0003	0	0.0763	0.0001
750	0.0076	0.0018	0.0005	0.0001	0.1440	0.0001
775	0.0147	0.0016	0.0002	0	0.0570	0.0001
800	0.0131	0.0019	0.0003	0	0.0988	0.0001
825	0.0194	0.0020	0.0003	0	0.0761	0.0001
850	0.0102	0.0006	0.0002	0	0.0913	0.0001
875	0.0231	0.0022	0.0003	0	0.0905	0.0002
900	0.0208	0.0022	0.0005	0.0001	0.0929	0.0002

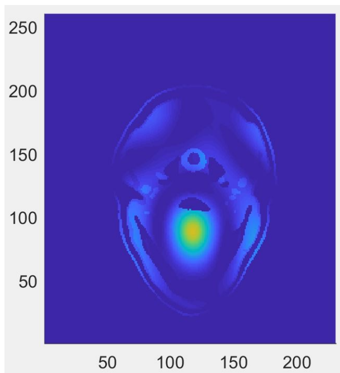
D Obtained Results of Single Frequency Optimization

The images for the PLD distributions with the best HTQ values based on optimization with a single frequency are presented below for the model nasalWerT and tongue-salt.

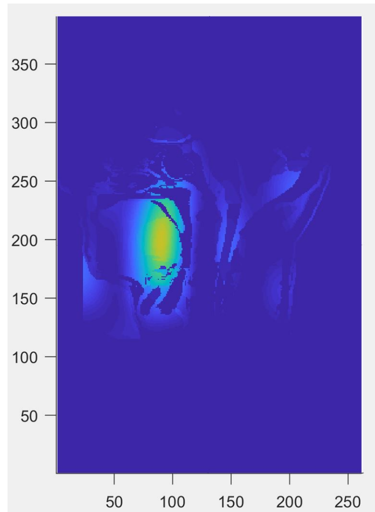


(a) (b)

Figure 5: The images illustrate the PLD distribution for frequency 400 MHz, which gave the lowest HTQ value, 0.9031, for an optimization of nasalWerT using single frequency optimization. Subfigure 5a shows the distribution from above and 5b shows the PLD distribution from the side.



(a)



(b)

Figure 6: The images illustrate the PLD distribution for frequency 425 MHz, which gave the lowest HTQ value, 0.5955, for an optimization of tongue-salt using single frequency optimization. Subfigure 6a shows the distribution from above and 6b shows the PLD distribution from the side.

The histograms presenting the amplitudes of the settings that give the lowest HTQ value are presented below.

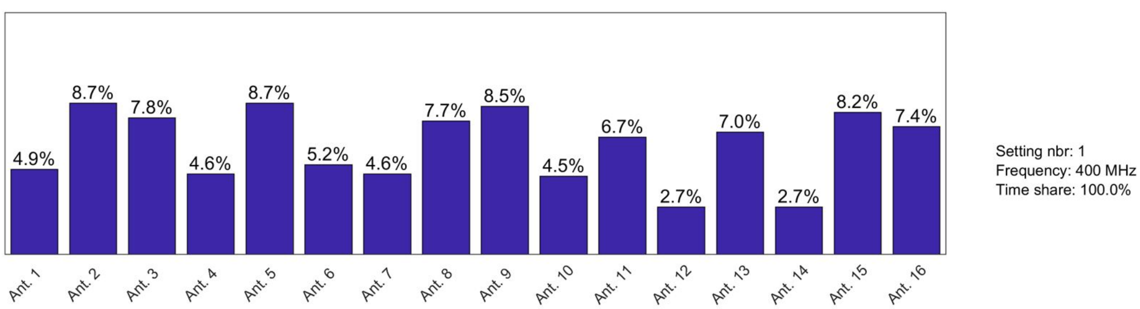


Figure 7: The amplitudes for model nasalWerT are presented in this histogram showing the frequency and settings that give the lowest HTQ value, 400 MHz.

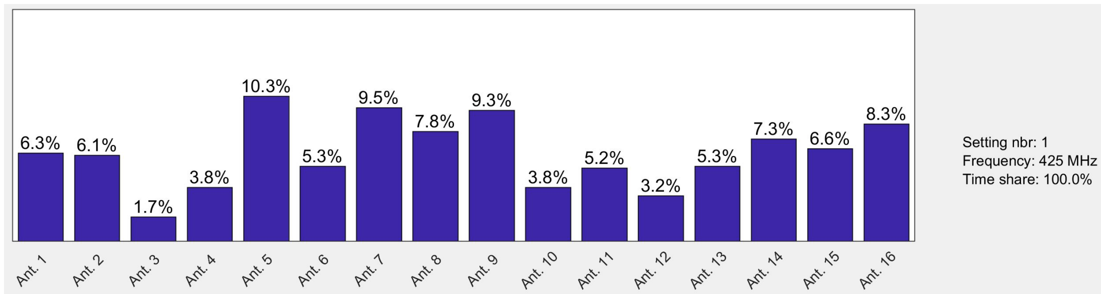


Figure 8: The amplitudes for model tongue-salt are presented in this histogram showing the frequency and settings that give the lowest HTQ value, 425 MHz.

E Time Shares for Double and Combine Single Optimizations

Table 12: This table displays the time shares for optimized PLD distributions using combined frequencies, with the Double Optimization. The first time share in each cell shows the time for the frequency in the column and the second for the frequency in the row.

[MHz]	400	425	450	475	500
400	0.73 - 0.27	0 - 1	1 - 0	1 - 0	1 - 0
425	0.02 - 0.98	0 - 1	1 - 0	1 - 0	1 - 0
450	0 - 1	0.61 - 0.39	0.21 - 0.79	1 - 0	0.99 - 0.01
475	0 - 1	0 - 1	0.52 - 0.48	1 - 0	0.80 - 0.20
500	0 - 1	0 - 1	0 - 1	0 - 1	0.25 - 0.75

Table 13: This table displays the time shares for optimized PLD distributions when different frequencies have been combined but not optimized together, which can be used as a simpler and much quicker way to estimate the combination of multiple frequencies. The used optimization was the Combine Single.

[MHz]	400	425	450	475	500
400		1 - 0	1 - 0	1 - 0	1 - 0
425	0 - 1		0.35 - 0.65	1 - 0	1 - 0
450	0 - 1	0.65 - 0.35		1 - 0	1 - 0
475	0 - 1	0 - 1	0 - 1		1 - 0
500	0 - 1	0 - 1	0 - 1	0 - 1	