Microwave Oven FDTD Project

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1 Problem Statement

Goal of this assignment is to simulate the heating of a plate containing food inside a microwave oven by using the FDTD method on any programming language or ready-to-use software. The plate contains a piece of meat which is shaped as a disc with diameter $d = 8cm$ and height $h = 2cm$ and two potatoes which have a spherical shape with radius $r = 2cm$. The plate is disc shaped with diameter $d = 14cm$ and height $h = 1cm$, forming together with the food the so called "Mickey's face". The electrical properties assumed for each material can be seen in Table 1.

Table 1: Electrical properties for the materials used

Material	**915 MHz**		**2.45 GHz**	
	ϵ_r	σ $[S/m]$	ϵ_r	σ $[S/m]$
Potato	65	1.02	54	2.18
Meat	55	0.95	52	1.74
Plate	6	0.001	6	0.001

Four simulations are then to be performed with the plate inside the microwave oven. In each simulation, the plate has to be rotated inside the microwave oven 90° from the previous run. For each simulation, the average SAR value is to be computed for each potato and the meat (assuming the density of all food items to be equal to the density of water). Based on all computed SAR values, the uniformity of heating inside the microwave oven is to be tested.

2 Modeling in SEMCAD

We will now provide a brief step-by-step overview of the model developed in SEMCAD to simulate the problem. Firstly, a circle with center at the axes origin and with radius $R = 70mm$. This circle is then extruded at a height of $h = 10mm$ to create a disc like shape which corresponds to our plate. The result can be seen in Figure 1.

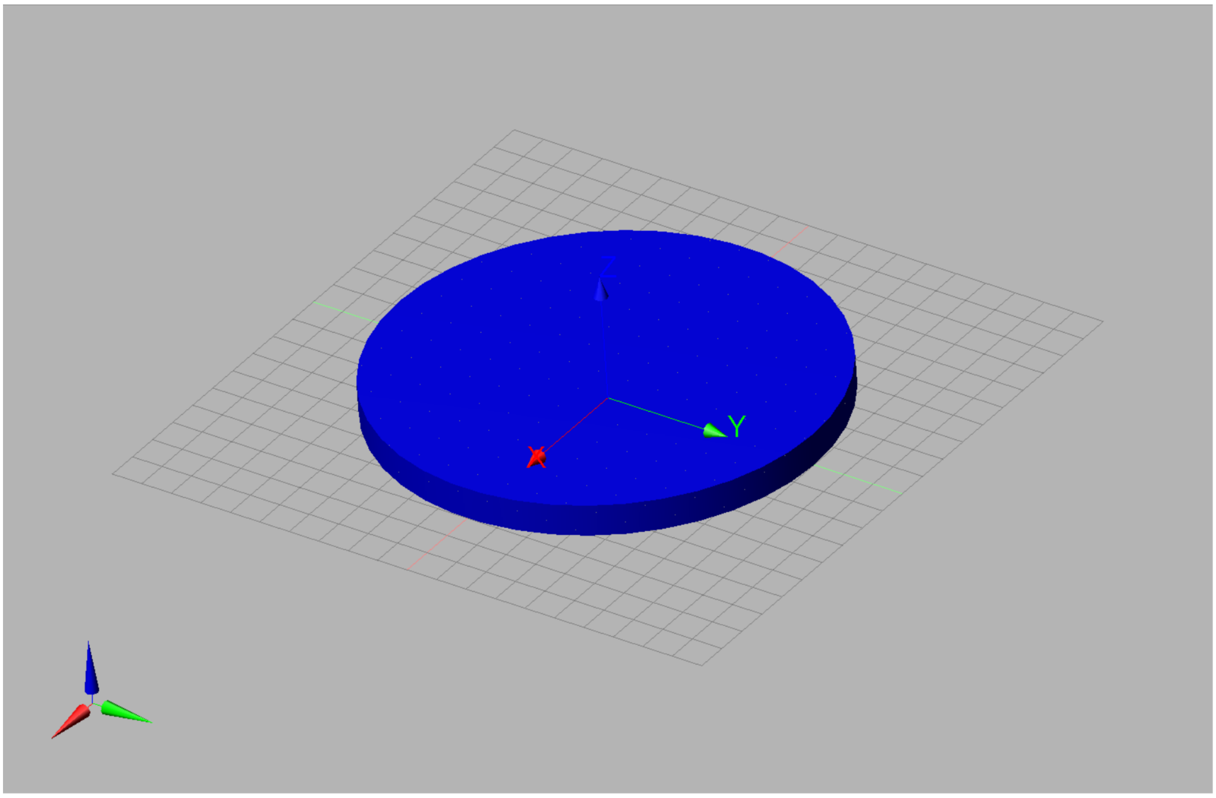

Figure 1: The plate which will contain the food

We can use the same process to create a secondary disc on top of the plate with radius $R = 40mm$ and a height of $h = 20mm$. This second disc will correspond to the meat. Next up, we create two identical spheres with radius $R_{sphere} = 20mm$. These two spheres correspond to the two potatoes and are placed mirrored to the Y-axis on top of the plate. The plate with the food on top can be seen in Figure 2.

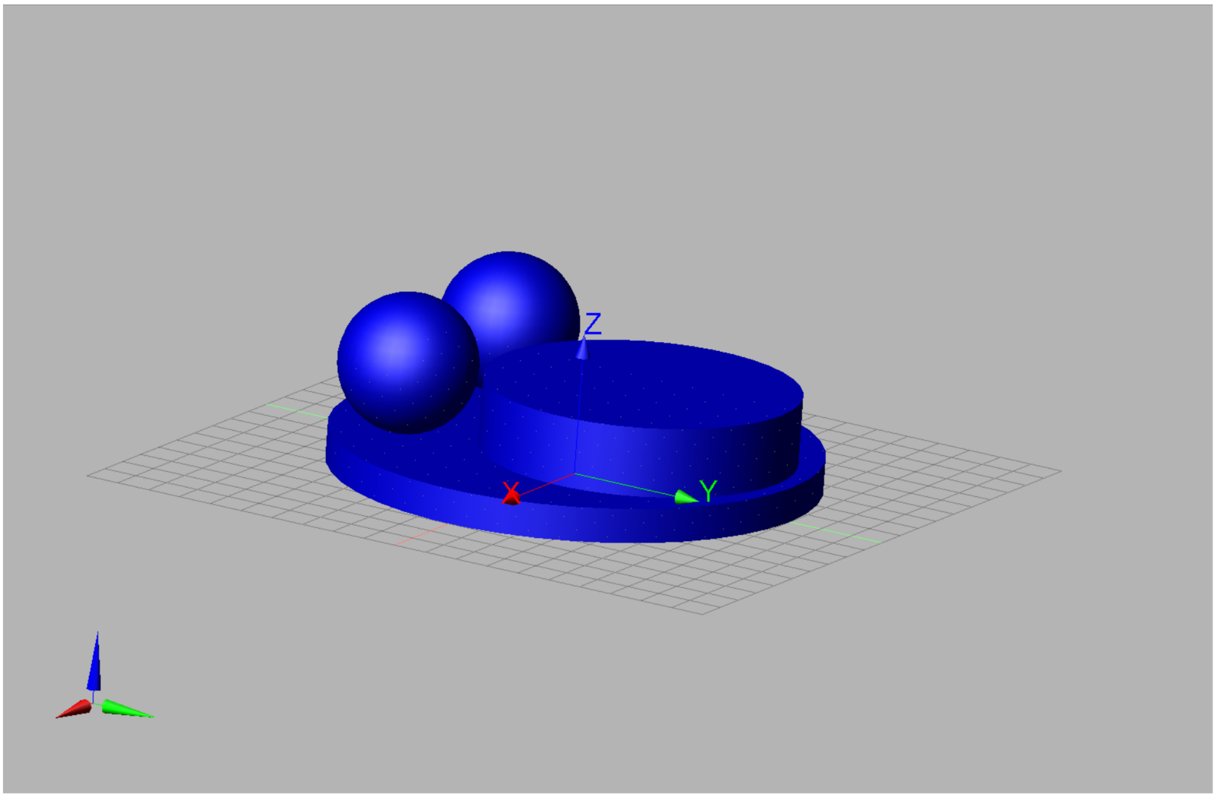

Figure 2: The plate with the meat and the two potatoes sitting on top

Having modeled the plate and the food, we can proceed with the creation of the microwave. For this, we will use the typical dimensions of a typical LG microwave ($350mm \times 350mm \times 220mm$). This microwave oven can be seen in Figure 3. Note that the waveguide for this model sits on the side of the oven. We can slowly create all of the microwave oven's walls in SEMCAD and ensure that we leave adequate opening on the walls to place the waveguide source. As a last step, we can unite all walls and label the final solid as *Microwave Walls* in order to treat it as a single object later on during the simulations. The final result can be seen in Figure 4.

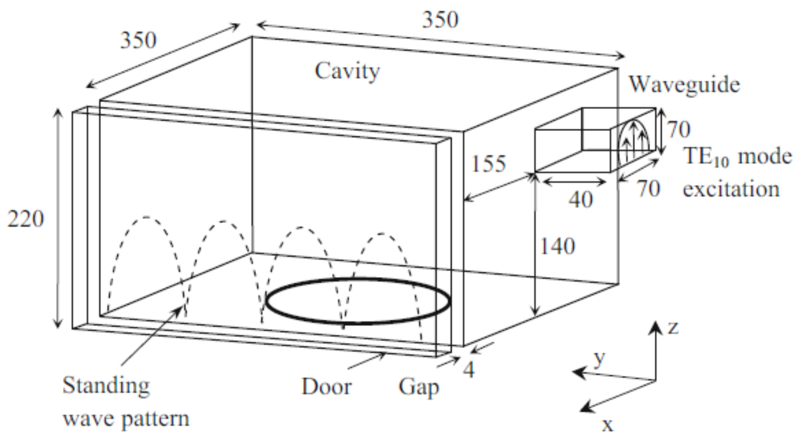

Figure 3: The microwave oven schematic which was used as a basis for the assignment

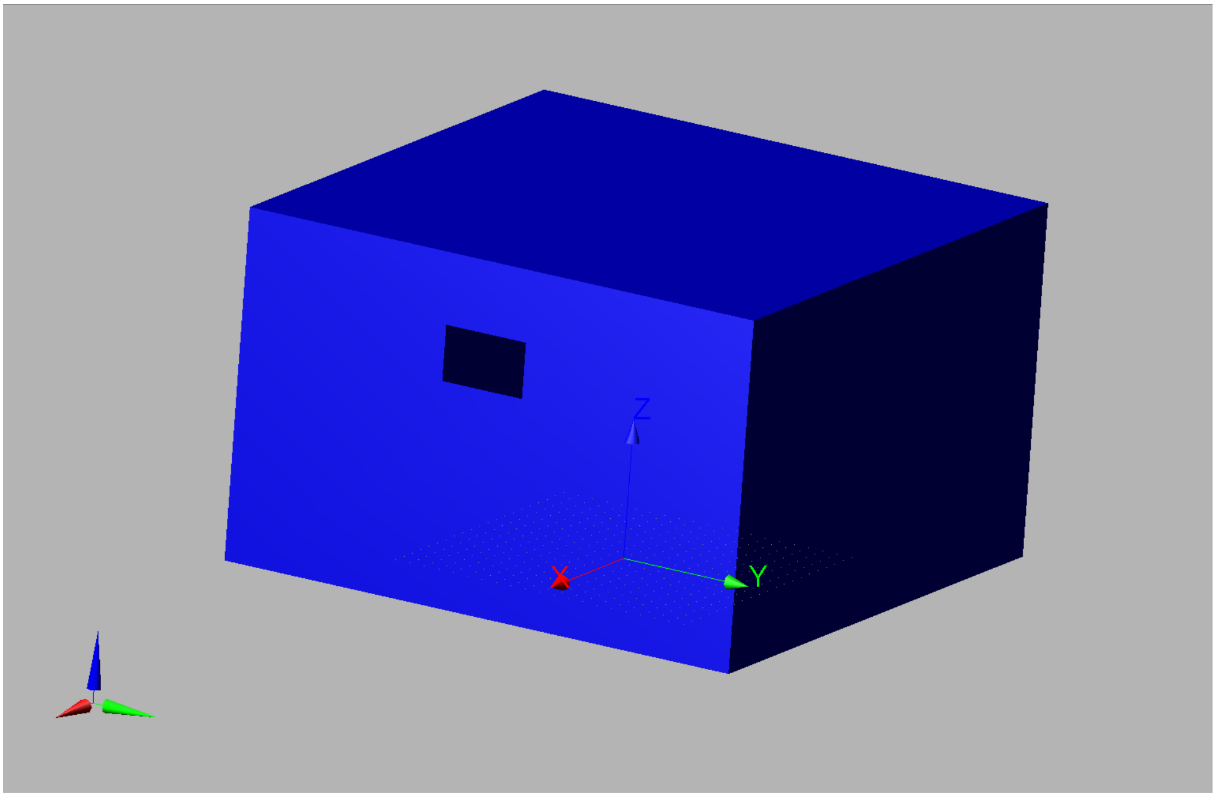

Figure 4: The microwave oven in SEMCAD. Note the opening which will house the waveguide source.

As a final step, we create the waveguide according to the schematic of Figure 3 and place a TE_{10} waveguide source at the end of the waveguide. We will place absorbing boundary conditions on the other side. The final microwave oven model containing the food can be seen in Figure 5.

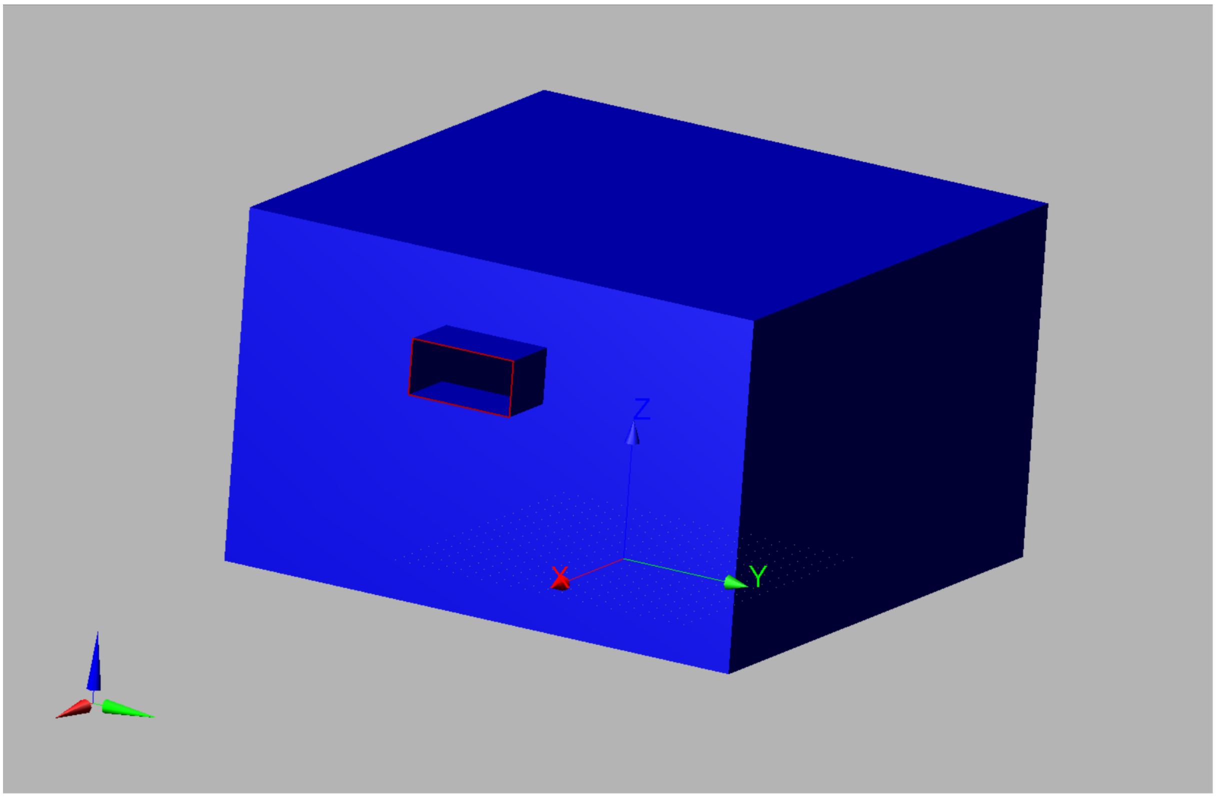

Figure 5: Final model in SEMCAD including the waveguide source and the plate with the food inside

3 Simulation

3.1 Basic properties

We will run simulations at both frequencies, namely $915MHz$ and $2.45GHz$. To ensure that the waves inside the microwave have adequate time to reflect on the walls at least once, we have to do some computations. Let us first calculate the wavelength at free space for each frequency using the equation:

$$c = \lambda f \tag{1}$$

Based on this equation, we find out that $\lambda_{f=915MHz} = 0.32m$ and $\lambda_{f=2.45GHz} = 0.12m$. We have seen in the previous section the dimensions of the microwave oven, which translate to about $N = 1.09$ wave lengths for $f = 915MHz$ and $N = 2.917$ wave lengths for $f = 2.45GHz$. To ensure that the wave reflects at least once, we have to ensure that our simulation runs for a minimum of $2N$ periods. Nevertheless, due to the capabilities of SEMCAD, we will run the simulations for a total of $10N$ periods. We then add a field sensor around the plate, which will be used to record the electric field and compute the corresponding SAR values. We ensure to correctly add each materials properties at the grid initialization. We assume that the walls of the microwave behave like PEC. The total grid size in our microwave is $95 \times 95 \times 69$, resulting in a total of 622725 Voxels. We can then view preliminary results from the field sensor, as seen in Figure 6. We can clearly identify the food items in the microwave.

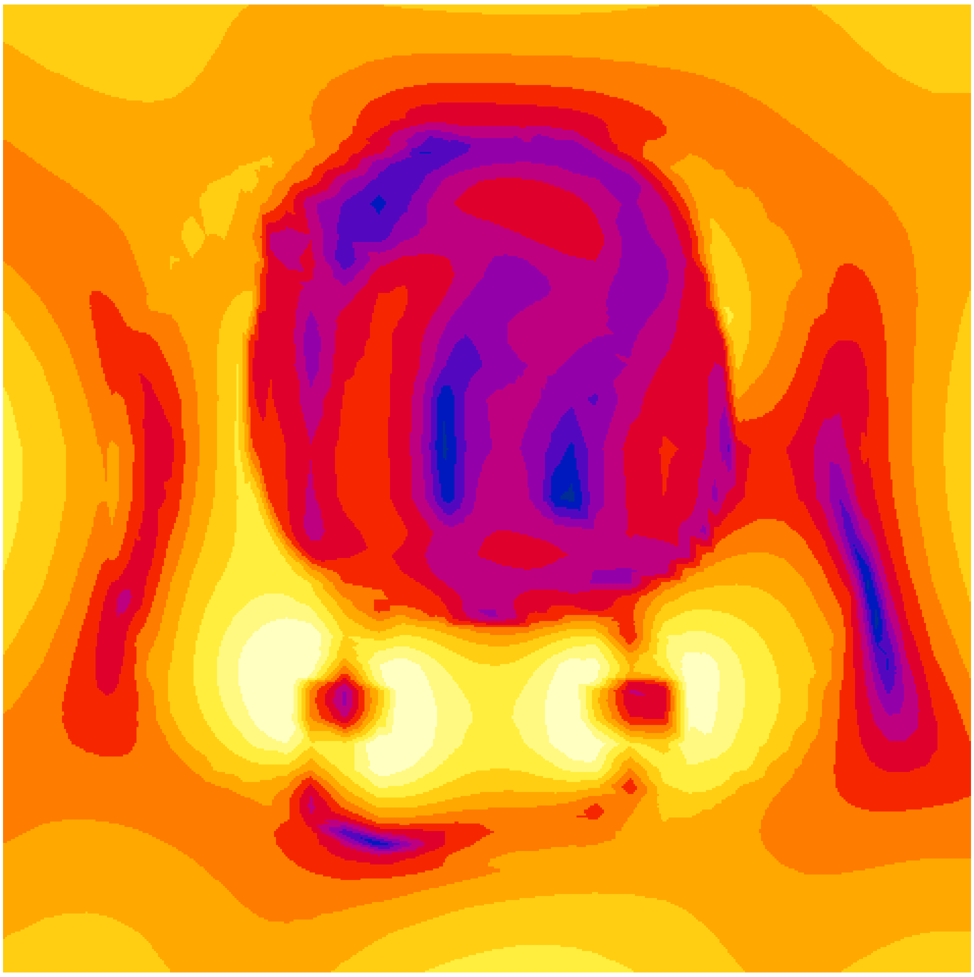

Figure 6: Slice view of the electric field (normalized) inside the microwave oven for $Z = 0.011$

3.2 $f = 2.45\ GHz$ results

We now add the corresponding electrical properties and run a simulation with the source set at $f = 2.45GHz$. We then calculate using SEMCAD the mean SAR and the standard deviation of SAR for each food item separately by using the voxels that correspond to each item. We rotate the plate 90° and repeat the process above. The results can be found below:

Table 2: Voxel SAR results for $f = 2450MHz$ and $\theta = 0°$

	μ_{SAR} [W/kg]	σ_{SAR} [W/kg]	Voxel $\frac{\sigma}{\mu}$	Voxel SAR Non-Uniformity [%]
Meat	0.787744	0.619543	0.786478	78.64776
Potato 1	0.576121	0.598649	1.039103	103.9103
Potato 2	0.756255	0.992394	1.312248	131.2248

Table 3: Voxel SAR results for $f = 2450MHz$ and $\theta = 90°$

	μ_{SAR} [W/kg]	σ_{SAR} [W/kg]	Voxel $\frac{\sigma}{\mu}$	Voxel SAR Non-Uniformity [%]
Meat	0.491022	0.306753	0.624724	62.47235
Potato 1	0.389906	0.324065	0.831136	83.11362
Potato 2	0.403871	0.307684	0.761837	76.18373

Table 4: Voxel SAR results for $f = 2450MHz$ and $\theta = 180°$

	μ_{SAR} [W/kg]	σ_{SAR} [W/kg]	Voxel $\frac{\sigma}{\mu}$	Voxel SAR Non-Uniformity [%]
Meat	0.456077	0.35687	0.782478	78.24775
Potato 1	0.607805	0.716363	1.178607	117.8607
Potato 2	0.677399	0.770197	1.136992	113.6992

Table 5: Voxel SAR results for $f = 2450MHz$ and $\theta = 270°$

	μ_{SAR} [W/kg]	σ_{SAR} [W/kg]	Voxel $\frac{\sigma}{\mu}$	Voxel SAR Non-Uniformity [%]
Meat	0.456077	0.35687	0.782478	78.24775
Potato 1	0.607805	0.716363	1.178607	117.8607
Potato 2	0.677399	0.770197	1.136992	113.6992

From all of the results above, we can notice the non-uniformity which exists internally for each food item at all angles. This is also one of the reasons for which the plate has to rotate inside the microwave oven, because if it remained fix we can directly observe from the results above that the food would be non-uniformly cooked. Let us now use the mean value for each item from each rotation to conclude about the non-uniformity for each position.

Table 6: Rotation SAR results for $f = 2450MHz$

	$SAR_{0°}$ [W/kg]	$SAR_{90°}$ [W/kg]	$SAR_{180°}$ [W/kg]	$SAR_{270°}$ [W/kg]	μ_{SAR}	σ_{SAR}	$\frac{\sigma}{\mu}$	Non-Uniformity [%]
Meat	0.787744	0.491022	0.442466	0.456077	0.544327	0.163561	0.300484	30.04836
Potato 1	0.576121	0.389906	0.441979	0.607805	0.503953	0.104628	0.207614	20.76144
Potato 2	0.756255	0.403871	0.272894	0.677399	0.527605	0.227235	0.430691	43.06912

In Table 6 we investigate the mean SAR values for each position inside the microwave. We treat these values as a sample and calculate a mean SAR value and compute the standard deviation for these positions. For this analysis, we observe non-uniformity reaching up to 43%.

3.3 $f = 915\ MHz$ results

Similarly to the previous run, we add the corresponding electrical properties and run a simulation with the source set at $f = 915MHz$. We then calculate using SEMCAD the mean SAR and the standard deviation of SAR for each food item separately by using the voxels that correspond to each item. We rotate the plate 90° and repeat the process above. The results can be found below:

Table 7: Voxel SAR results for $f = 915MHz$ and $\theta = 0°$

	μ_{SAR} [W/kg]	σ_{SAR} [W/kg]	Voxel $\frac{\sigma}{\mu}$	Voxel SAR Non-Uniformity [%]
Meat	0.24367	0.226102	0.927902	92.79025
Potato 1	0.360351	0.261755	0.726389	72.6389
Potato 2	0.60685	0.296665	0.488861	48.88605

Table 8: Voxel SAR results for $f = 915MHz$ and $\theta = 90°$

	μ_{SAR} [W/kg]	σ_{SAR} [W/kg]	Voxel $\frac{\sigma}{\mu}$	Voxel SAR Non-Uniformity [%]
Meat	0.284645	0.516194	1.813466	181.3466
Potato 1	0.314536	0.511054	1.624787	162.4787
Potato 2	0.281024	0.532281	1.894077	189.4077

Table 9: Voxel SAR results for $f = 915MHz$ and $\theta = 180°$

	μ_{SAR} **[W/kg]**	σ_{SAR} **[W/kg]**	**Voxel** $\frac{\sigma}{\mu}$	**Voxel SAR Non-Uniformity [%]**
Meat	0.130998	0.118846	0.907235	90.72352
Potato 1	0.343032	0.16685	0.486398	48.63978
Potato 2	0.133402	0.142909	1.071266	107.1266

Table 10: Voxel SAR results for $f = 915MHz$ and $\theta = 270°$

	μ_{SAR} **[W/kg]**	σ_{SAR} **[W/kg]**	**Voxel** $\frac{\sigma}{\mu}$	**Voxel SAR Non-Uniformity [%]**
Meat	0.263235	0.142716	0.542162	54.21619
Potato 1	0.418735	0.243388	0.581246	58.12459
Potato 2	0.428711	0.248582	0.579836	57.98358

Similar to the results from the $f = 2.45GHz$, we can again notice the non-uniformity which exists internally for each food item at all angles. Let us now use the mean value for each item from each rotation to conclude about the non-uniformity for each position. Continuing our comparison, in Table 11 we compare the mean SAR values from each position and calculate the mean and the standard deviation of the sample. We observe that the non-uniformity values now go up to 55.91%.

Table 11: Rotation SAR results for $f = 915MHz$

	$SAR_{0°}$ **[W/kg]**	$SAR_{90°}$ **[W/kg]**	$SAR_{180°}$ **[W/kg]**	$SAR_{270°}$ **[W/kg]**	μ_{SAR}	σ_{SAR}	$\frac{\sigma}{\mu}$	**Non-Uniformity [%]**
Meat	0.24367	0.284645	0.130998	0.263235	0.230637	0.068501	0.297009	29.70091
Potato 1	0.360351	0.314536	0.343032	0.418735	0.359164	0.043977	0.122444	12.24437
Potato 2	0.60685	0.281024	0.133402	0.428711	0.362497	0.202662	0.559071	55.90712

4 Conclusion & Discussion

In this analysis, each food item is represented by a specific number of voxels in each of the four positions inside the microwave oven. For all these voxels at each of the four positions, we compute the SAR values at each voxel so that we can then compute a mean value for the item and the corresponding standard deviation. We finally compute the ratio σ/μ which indicates the non-uniformity of the SAR values within that item. These results for each fixed position show a large non-uniformity which in some cases goes up to 189% and clearly indicates that for fixed positions, the microwave oven cannot achieve uniform SAR values inside an item (and thus it can also not achieve uniform heating). This is the main reason the microwave oven rotates the plate.

To further support this claim, we get the mean value of SAR computed at each fixed position for each item. We treat these 4 values as a sample for each item separately and compute the mean value of SAR for the four positions and the standard deviation of the sample. The ratio σ/μ in this case will indicate the non-uniformity of the SAR values at different positions. In this case, non-uniformity still exists and ranges from 12% up to 55%, but these values are far lower than the non-uniformity values for each individual item at a fixed position in all cases. We can therefore conclude that a microwave oven needs to rotate the food inside of it in order to achieve better uniformity of heating for the food, compared to a fixed position inside the microwave oven.

References

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