Appendix I: "Calculating the SAR"
HFSS Technical Notes, Ansys Inc. (incorporated by permission)

To calculate the Average SAR, HFSS first subdivides the model space into a grid of voxels properly aligned along the global coordinate system. The density and local SAR values are then mapped over the grid of voxels. Afterwards, HFSS applies the two-pass average SAR algorithm to the voxels. Finally HFSS distributes the average SAR from the voxels back to the FEM mesh. Because this two pass algorithm is very time consuming, HFSS uses parallel processing as much as possible. The algorithm is divided into two phases so that the results of the time consuming phase can be cached and reused while fields change, i.e. due to new combinations from edit sources.

The three figures below are based on figures from IEEE average SAR standard document.
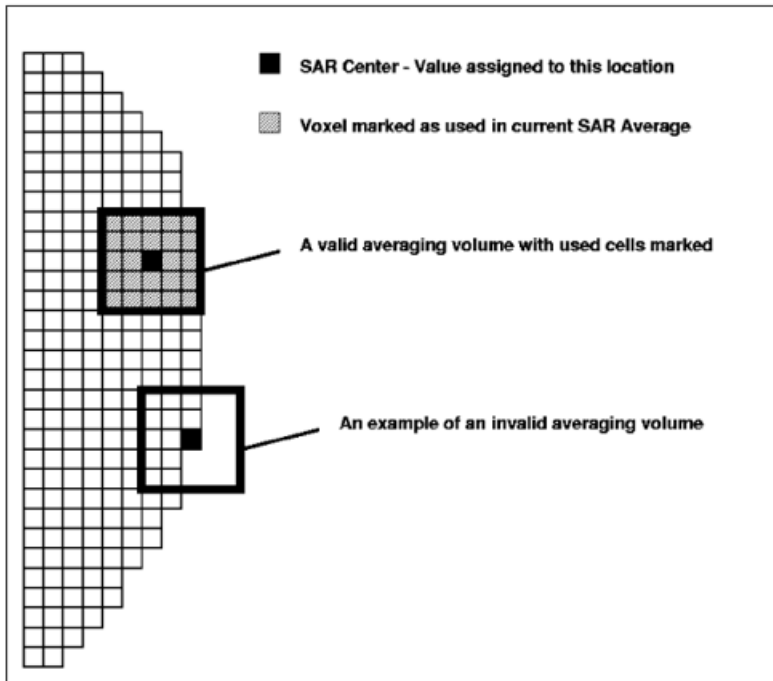

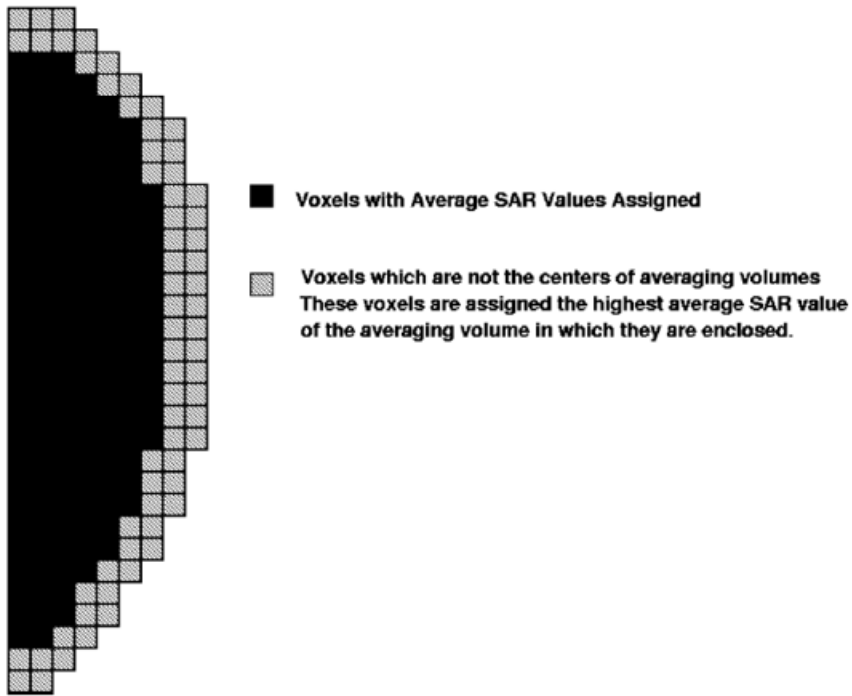**Figure 1**: Voxels for SAR Averaging Volumes

Voxels with Average SAR Values Assigned

Voxels which are not the centers of averaging volumes
These voxels are assigned the highest average SAR value
of the averaging volume in which they are enclosed.

Figure 2: Voxel Assignments

Voxels with Average SAR Values Assigned

Voxels which are not the centers of averaging volumes
These voxels are assigned the highest average SAR value
of the averaging volume in which they are enclosed.

Voxel not included in any valid averaging volume

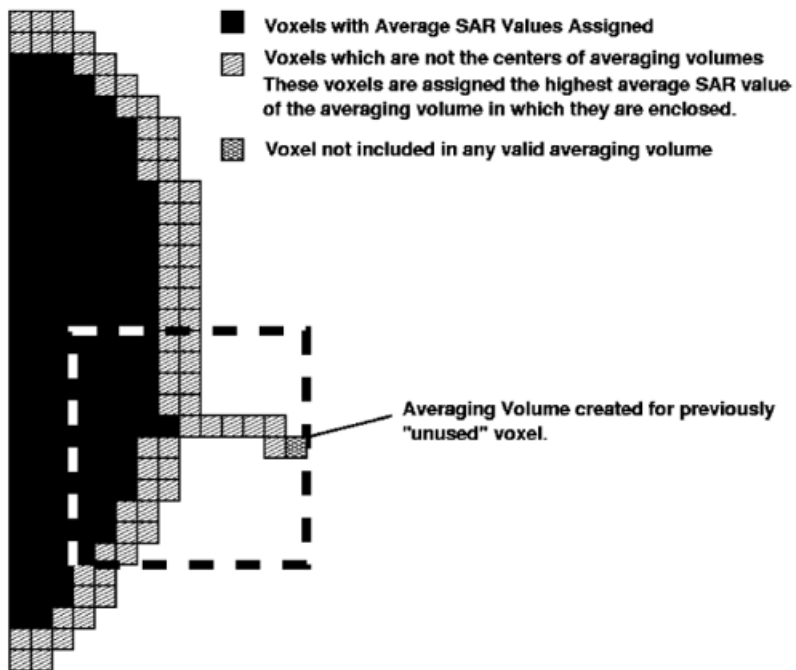**Averaging Volume created for previously "unused" voxel.**

Figure 3: Voxel Use in Average SAR Calculation

HFSS progress messages are included here in parentheses and in red color.

1. Build the grid of voxels.

    a. If we have cached data, load the data. (2nd phase: Reading voxel data) Go to 3.

    b. Otherwise subdivide the model space into a grid of voxels and map density to voxels. See below for details on mapping. (1st phase: Mapping density to voxels…)

2. Collect information for all valid and unused voxels.

    a. Traverse all voxels to collect all valid voxels. For each valid voxel store the extends in one direction and the used ratio of the exterior voxels. See below for requirement for valid voxels. See Figures 1 and 2. (1st phase: 1st pass …)

    b. Traverse all valid voxels to collect all used voxels. (1st phase: 2nd pass ...)

    c. For the unused voxels find possible extends in the 6 directions, see Figure 3. For each unused voxel store an array of directions, extends and ratio of exteriors.

    d. Cache data from a and c.

3. Collect voxels needed for field plot and calculation (field geometry instance).

    a. Get overall elements for field geometry instance.

    b. Get all voxels that cover the nodes of these elements. (2nd phase: Collecting voxels containing elements)

    c. Classify these voxels as valid, used and unused. For each used voxel add all the valid voxels using it to the valid set.

    d. Collect all elements needed to get the data for all the voxels above. (2nd phase: Collecting involved elements)

    e. Map FEM local SAR to voxels. (2nd phase: Mapping data to voxels)

4. Calculate average SAR.

    a. Traverse all valid voxels. For each valid voxel collect average SAR and mark used voxels and propagate average SAR to used voxels. (2nd phase: 1st pass)

    b. Traverse all unused voxels. For each calculate the average SAR on possible directions and take the maximum. (2nd phase: 2nd pass)

5. Distribute average SAR to the FEM mesh from the voxels. For each element node take the SAR value from the voxel which contains this node. (2nd phase: Distributing fields)

This section describes how HFSS maps general data (mass density, local SAR, etc.) from FEM mesh to voxels. For each voxel:

1. Collect all intersecting tetrahedra and calculate data over these tetrahedra.

2. Cut each intersecting tetrahedron by this voxel. This gives a series of new smaller tetrahedra.

    a. For each new tetrahedron get data by interpolating over its parent (the original tetrahedron that it is cut from). Integrate the data to get the total over it.

    b. Add the contributions to get the total over the intersection of this voxel and this tetrahedron.

3. Now add the total from above for all intersecting tetrahedra. This gives the total over this voxel. Now take the average by dividing this total by the voxel volume.

In the above for mass density we use a 50% cutoff ratio to determine if a voxel is counted as tissue, i.e. get the volume contribution from the tissue and see if its ratio against the voxel volume is bigger than this cutoff ratio. The density at each voxel is the total tissue mass divided by voxel volume.

A voxel is valid if the following holds:

1. Expand a cubic volume centered at the voxel evenly in the six directions aligned along the global axis so that the enclosed tissue mass is within 0.0001% of the prescribed mass.

2. Less than or equal to 10% of the cube contains background material in volume.

3. None of the six faces is completely filled with background material.