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Title: HEWLETT-PACKARD HIGH FREQUENCY STRUCTURE SIMULATOR:
            INCONSISTENCIES IN DELTA S AND CONVERGENCE

Author(s): N. Bailey

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The Hewlett-Packard High Frequency Structure Simulator (HFSS) calculates the electromagnetic fields and scattering parameters of closed structures with an arbitrary number of ports. The program solves Maxwell's equations at points on a mesh of tetrahedra within the structure. HFSS begins with a sparse mesh, calculates the fields at the mesh points and derives S-parameters from the fields. It then compares curl H to E and curl E to H. In areas where there is a large difference between curl H and E or curl E and H, the program will add more tetrahedra to the mesh, a process called adaptive refinement. Each pass through this cycle is called an *adaptive pass*. The solution becomes more accurate as more points are added to the mesh, but adding points to the mesh also increases demands on computer memory, CPU time, and disk space. The program will continue making adaptive passes until either the maximum number of allowable passes is reached, the convergence criteria are satisfied, or the computer runs out of memory or disk space.

In order to determine whether the solution has converged, the program compares the S-parameters generated during the current pass to those generated during the previous pass. If the S-parameters are "not changing much" from one pass to the next, the program considers the solution converged. Thus, one must thoroughly understand the various convergence criteria used by the program to trade off solution accuracy versus solution time and computer resources. Though the manuals describe the convergence criteria, there are certain subtleties that are counter-intuitive and not well documented.[1]

The default convergence criterion is the ALLOWABLE DELTA S.[2] The CURRENT DELTA S is compared to the ALLOWABLE DELTA S and when the CURRENT DELTA S is less than the ALLOWABLE DELTA S, the solution is considered "good enough" and the program makes no further adaptive passes. CURRENT DELTA S, according to the manual, "Displays the maximum value of the changes of all S-parameters in the S-matrix. The change for each S-parameter is determined by taking the magnitude of the vector drawn from the S-parameter of one iteration to that of the next."[3]

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[1] This note describes the behavior of HFSS version A.02.01.

[2] One may alternatively specify MATRIX CONVERGENCE CRITERIA. According to the manual, you specify a maximum difference in magnitude and maximum difference in phase for every element in the S matrix. The DELTA S MATRIX would be useful in watching the convergence process if the MATRIX CONVERGENCE CRITERIA are selected. I have never used the MATRIX CONVERGENCE CRITERIA, and have no experience with them.

[3] *HP 85180A High Frequency Structure Simulator: User's Reference* (May 1992), pp. 15-21.

The value of CURRENT DELTA S is displayed in a sidebar on the left-hand side of the VIEW CONVERGENCE DATA screen under the SOLVE menu. Only the current DELTA S is displayed. Previous values are overwritten.

There is a VIEW DELTA S MATRIX button on the VIEW CONVERGENCE DATA screen. Clicking on this button does not display the changes in S-parameters (distance between the S-parameter of one iteration and the next); for despite the name, the elements of the DELTA S MATRIX are not intuitively related to the value of DELTA S. The magnitude of each element in the DELTA S MATRIX is the difference between the magnitude of the S-parameter in one iteration and the next. The phase of an element in the DELTA S MATRIX is the difference in the phase of the S-parameter in one iteration and the next. Though examining the DELTA S MATRIX may tell you that the magnitudes are converging faster than the phases, it will not help you determine the error in the calculated S-parameters (*i.e.*, you cannot determine DELTA S from the elements of the DELTA S MATRIX).

Once the process of adaptive refinement of the mesh is complete, the program can use the current mesh to calculate S-parameters at frequencies other than the adapt frequency. Here too, HFSS contains pitfalls for the unwary. If the program ceased adaptive refinement because the maximum number of adaptive passes was reached, the current mesh is used for finding S-parameters in the frequency sweep. If the program satisfied the ALLOWABLE DELTA S criterion though, the previous mesh -- not the current mesh -- is used in the frequency sweep. The logic behind this bug (HP says it is a feature) is that when the ALLOWABLE DELTA S is exceeded, the solution is "too good." The previous solution is "good enough" and as it contains fewer tetrahedra, it will take less time to solve using this mesh than using the current mesh.

It is possible to fool the program into using the current mesh, even if the ALLOWABLE DELTA S is exceeded. Simply lower the ALLOWABLE DELTA S before setting PERFORM ADAPTIVE ANALYSIS to NO. Now the CURRENT DELTA S no longer exceeds the ALLOWABLE DELTA S, so HFSS will use the current mesh when calculating the S-parameters for the sweep frequency points.

Acknowledgement