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Title: TRANSFERRING CIRCUIT PARAMETERS FROM HFSS TO MMICAD

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## TRANSFERRING CIRCUIT PARAMETERS FROM HFSS TO MMICAD

A. R. Kerr

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HFSS is a powerful Maxwell's equation solver, whose solutions for the S-, Z-, or Y-parameters of a microwave structure can be read into the microwave circuit analysis program MMICAD via a data file written in the Touchstone format. The purpose of this note is to discuss the need for impedance renormalization when HFSS data is transferred to MMICAD via a Touchstone file. This appears not to be documented in the HFSS or MMICAD manuals, and can cause considerable confusion when using HFSS data in MMICAD.

### HFSS

HFSS solves Maxwell's equations in a structure with one or more ports. The ports are regarded as the ends of external uniform waveguides (or transmission lines) connected to the structure, and hence there is a well defined set of electromagnetic modes associated with each port. Within the structure, the coupling between these modes is characterized by the S-matrix of the structure. This is the natural or *generalized* S-matrix which would be measured by a network analyzer designed to mate directly with the ports of the structure, *i.e.*, with the same size and shape of waveguide. As the S-parameters describe only ratios of powers (actually (power ratios)<sup>0.5</sup>) and relative phases, they need not be associated with any unique characteristic impedance or set of port impedances.

HFSS generates the generalized S-matrix of a structure, but also allows one to renormalize the S-matrix to arbitrary port impedances. Renormalization is equivalent to connecting an ideal transformer at each port of the structure, and requires characteristic impedances to be assigned to the original port modes as well as to the new port modes. The renormalized S-matrix is what would be measured with a network analyzer designed with waveguides that did not match the ports of the structure in question; *e.g.*, if the ports of the structure were coaxial with  $Z_0 = 100 \Omega$ , and it was measured with a 50- $\Omega$  coaxial analyzer (neglecting fringing reactances at the connection plane).

HFSS can also derive Z- or Y-parameters from the generalized S-parameters of the structure being analyzed. This, too, requires the specification of characteristic impedances for the port modes. HFSS allows a choice of three characteristic impedances for each port mode,  $Z_{PI}$ ,  $Z_{PV}$ , or  $Z_{VI}$ , of which the latter two require the definition of an "impedance line" to specify the voltage used in calculating the characteristic impedance. (Ref. HFSS Users' Reference, Appendix A).

## Touchstone File Format

HFSS can generate an ASCII file in Touchstone format containing S-, Z-, or Y-parameters. The first (non-comment) line in the file describes the information following it, and has the form:

# <Freq. units> <Parameter (S,Y,Z)> <Format (MA,RI)> <R charac. impedance>

e.g.,: # GHZ S MA R 50

*It appears that HFSS always enters a characteristic impedance of 50  $\Omega$ , regardless of the selection of characteristic impedance or any renormalization in HFSS.*

## MMICAD

When a Touchstone file describing a structure is read into MMICAD, the structure is given the network name assigned in the FILES block of the circuit file. If the frequencies of the file data differ from those specified in the FREQ block in the MMICAD file, the data are interpolated using one of two schemes (see the MMICAD manual). The network is then treated as any other network in a MMICAD circuit file.

In a MMICAD circuit file, the TERM block allows the assignment of a global characteristic impedance (default 50  $\Omega$ ), and also separate terminating impedances for all ports of all networks defined in the circuit file. The roles of the characteristic and terminating impedances in MMICAD, and the characteristic impedance in the first line of the Touchstone file, when a Touchstone file is read into MMICAD, are described below.

### (i) When the Touchstone file contains S-parameters

Terminating impedances assigned in MMICAD's TERM block are used as the port impedances to convert the S-parameters to Z- or Y-parameters. *If these terminating impedances are not assigned in the TERM block, the value of characteristic impedance in the first line of the Touchstone file is used.*

The global characteristic impedance in the TERM block has no effect on the imported S-parameters, or on the Z- or Y-parameters deduced from them.

The impedance in the first line of the Touchstone file (which HFSS appears always to set to 50  $\Omega$ ) is used as the terminating impedance for all ports only if terminating impedances are not assigned in the TERM block.

### (ii) When the Touchstone file contains Z- or Y-parameters

*The impedance in the first line of the Touchstone file (which HFSS appears always to set to 50  $\Omega$ ) is used by MMICAD as a scaling factor.*

The elements of a Z- or Y-matrix imported from the Touchstone file are multiplied by this value. *This leads to absurd results in MMICAD. To avoid this, the Touchstone file must be edited to change "R 50" to "R 1".*

Terminating impedances assigned in MMICAD's TERM block do not affect the imported Z- or Y-matrix. However, if MMICAD needs to compute S-parameters (e.g., if a Smith chart display is called for), the TERM block assignment of port impedances is used.

The global characteristic impedance in the TERM block has no effect on the imported Z- or Y-matrix. It will be used in computing S-parameters only if other terminating impedances are not given in the TERM block.

### Choice of S-, Z-, or Y-Parameters

HFSS results can be imported into MMICAD as Touchstone files containing S-, Z- or Y-parameters. The choice will depend on the application, but the following should be taken into account:

Touchstone files generated by HFSS contain the values of the mode characteristic impedances,  $Z_{PI}$ ,  $Z_{PV}$ , and  $Z_{VI}$ , only as comment lines that cannot be used directly by MMICAD. Their values are, in general, frequency dependent.

The S-parameters written to a Touchstone file by HFSS are either generalized S-parameters or S-parameters renormalized to a set of port impedances entered by the user during the HFSS session. With renormalized S-parameters, *the Touchstone file contains the chosen port impedances, incorrectly labelled as PI, PV, and VI impedances*, as comment lines, but there is no record of the actual  $Z_{PI}$ ,  $Z_{PV}$ , or  $Z_{VI}$ , or of which of these was associated with the generalized S-parameters in renormalizing.

When HFSS generates Z- or Y-parameters, the port impedances chosen must be selected as  $Z_{PI}$ ,  $Z_{PV}$ , or  $Z_{VI}$ . A Touchstone file containing Z- or Y-parameters contains no record of which impedance was used in creating them.

For the TEM mode, the distinctions between  $Z_{PI}$ ,  $Z_{PV}$ , and  $Z_{VI}$  vanish. When all the ports of a network have a TEM dominant mode, therefore, several of the points discussed above become inconsequential.

