Minimizing Coarseness Error

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A major problem with TLM is in the accurate description of edges and corners. It is often found that resonant frequencies are too low and this error is unacceptable in the design of narrow band microwave and millimeter wave filters where the error in frequency can exceed the bandwidth. This reduction in frequency is related to the presence of non-physical field components which decay exponentially away from the discontinuity. Previously, this error has been minimized by performing two simulations at different resolutions and then extrapolating to zero node spacing [1]. The obvious disadvantage of this approach is that two simulations must be performed to solve a single structure. The resolution only in the vicinity of the discontinuity can be increased by using graded mesh [2] or multigrid [3] techniques, but the computer resources required are much greater than for the ideal case of a uniform mesh where the node spacing is determined solely by the highest frequency of interest. More recently, a method has been proposed which addresses the cause of the problem directly by increasing the speed of pulse propagation in the vicinity of the discontinuity [4]. As presented, this method is used to account for the difference in path length around a wire of square cross-section and the ideal circular path, but the technique is more general than this. The increase in speed is brought about by slowing down the speed of propagation in the rest of the problem space by adding stubs and then normalizing to the required material properties (usually free-space). This results in an increase in storage and a reduction in timestep. An enhanced method has been developed in which the changes needed to increase the pulse speed are applied only locally and the rest of the space can be modelled with a uniform mesh and no stubs.

When transferring voltage pulses between adjacent nodes there is essentially a choice of introducing a delay Δt (as is normally done) or of not introducing any delay. For the standard 12-port node, in which the link-line impedances are all equal then, in the absence of stubs, this can be done by treating the nodes as a single entity and pre-calculating the internal pulses (using the standard scattering procedure) and then performing the standard scattering procedure for each node as normal. This is possible because the pulse scattered from any port is independent of both the pulse incident into the same port and the pulse incident from the opposite port. Care must be taken when transferring pulses around corners that the internal pulses are calculated in the correct order. In the presence of open and short-circuit stubs, if the stubs are the same in each direction and the open-circuit stub admittance is equal to the short-circuit stub impedance, then the scattered pulse will depend on the incident pulse from the opposite port. In general, the scattered pulse will also depend on the incident pulse from the same port and it is necessary to solve for the internal pulses simultaneously for all nodes. In this case, however, all six stubs can be varied independently to achieve accurate results.

For example, consider the ridged waveguide shown in Fig. 2. For parameters a=7.112mm, b=3.556mm and d=0.889mm, the expected cutoff frequency is 16.3GHz [1]. Using a standard mesh with a 0.222mm node spacing gives a cutoff of 15.8GHz. Applying a *fast connection* around the corner, as shown in Fig. 3, and stubs to give material properties $\varepsilon_{rx}=\varepsilon_{ry}=\mu_{rz}=1.50$ on the corners yields the correct result. In 3-dimensions, adding stubs to give $\varepsilon_{rz}=\mu_{rx}=\mu_{ry}=1.20$, gives the correct result for the first cavity resonance when the ends of the waveguide a terminated a short-cicuit and this result is independant of the length of the cavity.

[1] Shih, Y. and Hoefer, W. J. R., "The Accuracy of TLM Analysis of Finned Rectangular Waveguides", *IEEE Trans. MTT*, Vol. MTT-28, No. 7, July 1980, pp 743-746.

[2] Scaramuzza, R. and Lowery, A. J., "Hybrid symmetrical condensed node for the TLM method", *Electronics Letters*, Vol. 26, 1990, pp 1947-1949.

[3] Herring, J. L. and Christopoulos, C., "Multigrid transmission-line modelling method for solving electromagnetic field problems", *Electronics Letters*, Vol. 27, 1991, pp 1794-1795.

[4] Duffy, A. P., Herring, J. L., Benson, T. M. and Christopoulos, C., "Improved wire modelling in TLM", accepted by *IEEE Trans. MTT.*

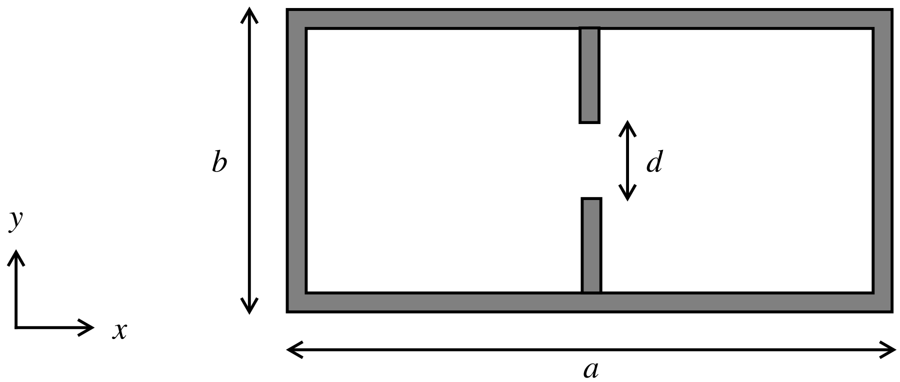

Fig. 2 Ridged waveguide

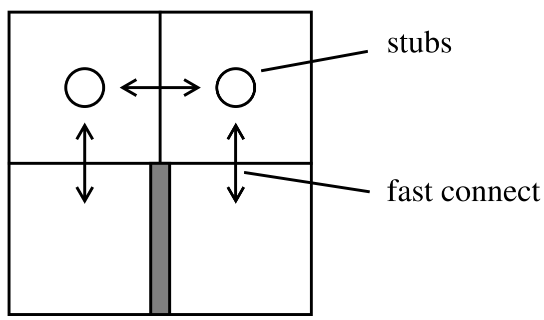

Fig. 3 *Fast connect* around an edge