The precise placement of boundaries within a TLM mesh with applications

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1 Introduction

In traditional TLM models, boundaries can only be placed either across the nodes or half way between the nodes. The length of the boundary being a multiple of $\Delta l/2$. For some problems, the mesh spacing would have to be very small to accurately represent the system being modelled. This results in an unacceptably large requirement for computational memory and time. With precise placements of boundaries, the model can be kept as small as possible consuming acceptable memory requirements, whilst accurately representing the boundary under investigation.

The analysis of waveguides with curved boundaries has been discussed by Johns[1] in 1973. Johns overcame the problem of varying length boundaries not of multiples of $\Delta l/2$, by stipulating that an odd piece of transmission line joining the matrix be of length $\Delta l/2$, and its characteristic admittance altered to account for the difference between its true length and $\Delta l/2$. This required a modification of the impulse scattering matrix for the boundary node. German [2] extended Johns method to the symmetrical condensed node.

Beyer [3] introduced a novel technique for the arbitrary positioning of boundaries within a TLM network. This used a recursive algorithm which replaces the boundary reflection coefficient, leaving the impulse scattering matrix intact.

The equation proposed by Beyer depends on the present incident impulse as well as the previous incident and reflected impulses, which needs to be stored. The method proposed uses an approach based on the superposition of waves. This results in a simpler algorithm that requires no extra memory requirements to store any previous values. The algorithm can be applied for 1,2 and 3-Dimensional acoustic TLM, and should easily be modified for electromagnetic TLM.

2 Theory

With reference to figure 1, boundary C is to be placed a distance l beyond A. To accomplish this, a percentage of the wave is reflected from boundary A, the remainder being allowed to propagate and is totally reflected from B.

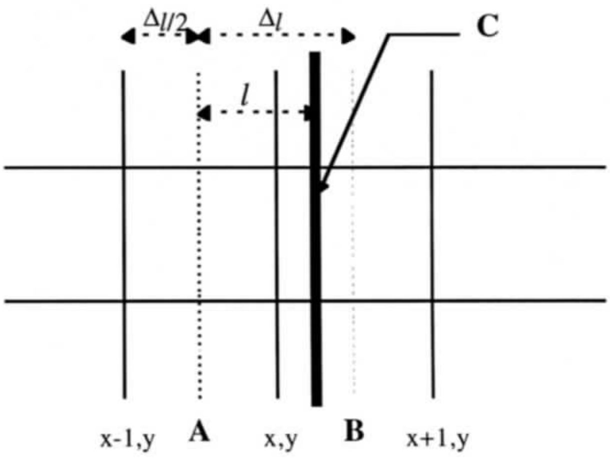

Figure 1 Placing Boundary a distance beyond node.

Assuming a linear relationship between l and the reflection coefficient ρ; the percentage of the wave to be reflected at boundary A is given by $l/\Delta l$. Assuming the wave propagates from left to right towards boundary C (in this example), with being the reflection coefficient of boundary C, we have:

$$
\begin{aligned}
{}_kV_4^i(x,y) &= {}_kV_2^r(x+1,y) = \rho\,{}_kV_4^r(x,y) \\
{}_kV_4(x-1,y) &= {}_kV_4(x-1,y) + \left(\rho - \rho\frac{l}{\Delta l}\right){}_kV_2(x,y) \qquad (1) \\
{}_kV_2(x,y) &= \rho\frac{l}{\Delta l}\,{}_kV_2(x,y)
\end{aligned}
$$

3 Testing

To test the validity of this method, a one cycle raised cosine is propagated towards a target. This target is moved by a tenth of a node at successive simulations.

Figure 2 gives the output of the wave as seen by the receiver for various values of ρ. The values obtained for ρ = 0.0, are exactly the same as if the wave was totally reflected from the boundary at A. Likewise, the values obtained for ρ = 1.0, are exactly the same as if the wave was being totally reflected from boundary B.

From Figure 2, the required time shift is clearly obtained, though there is an amplitude loss as ρ approaches 0.5. The maximum amplitude loss being 8% and occurs at ρ = 0.5. This amplitude loss is to be expected, resulting from the cancellation of the waves occurring as the phase shifted waves meet; however, provided the phase shift introduced is low, this amplitude loss remains low.

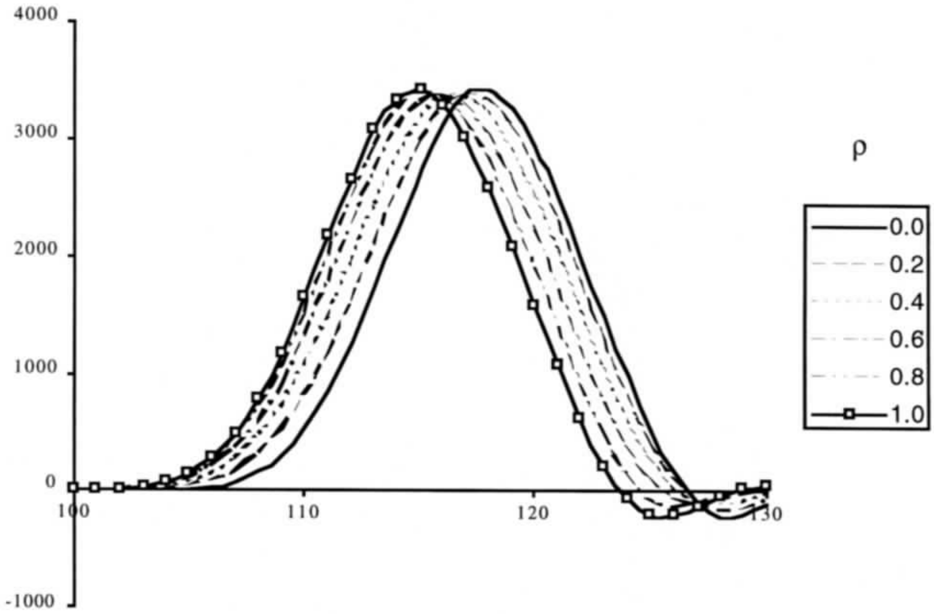

Figure 2 Reflected Wave for various Values of ρ

4 Boundaries placed at an angle to the mesh axes

The traditional method when dealing with boundaries placed at an arbitrary angle to the mesh axes is to use a step wise approximation. By placing the individual points of the line between the nodes using eqn (1), a more accurate representation is obtained. The percentage of the wave to be reflected being obtained from the distance the point on the line is beyond the transmission lines.

To demonstrate the improvements resulting from the precise placement of the individual points of the line between the nodes, a one cycle raised cosine is reflected from a sloping line that is two nodes high.

Figure 3a shows the output when the wave is reflected using the step wise approximation. The wave is clearly disjointed; interference occurring at the ends of the separate line segments. Each separate wave segment being reflected parallel to the corresponding line segment.

Figure 3b shows the output when the wave is reflected using the modified boundary, where at each node step, the reflected coefficient is calculated based on the distance the point on the line is beyond the transmission lines. The wave no longer becomes separated, instead each separate wavelet being reflected at the required distance, instead of a multiple of the node spacing. This results in a smoother wave reflecting parallel to the boundary, and hence provides a more accurate representation of the boundary.

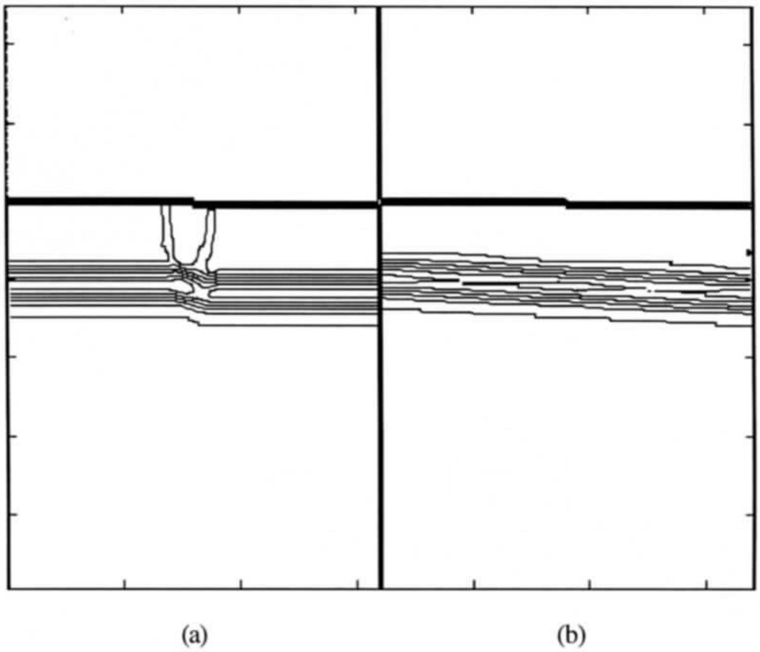

Figure 3 Wave reflected from a boundary at an angle to the mesh axes.

5 Moving Targets

In most realistic situations, the system to be modelled incorporates moving targets. The targets (especially in Acoustics) produce pressure differences, which in turn induce wave motion. Some work has been carried out in order to implement moving targets within TLM. A simulation has been executed where an object is moved through the mesh a node per cycle. Figure 4 shows the output of a frame from the simulation.

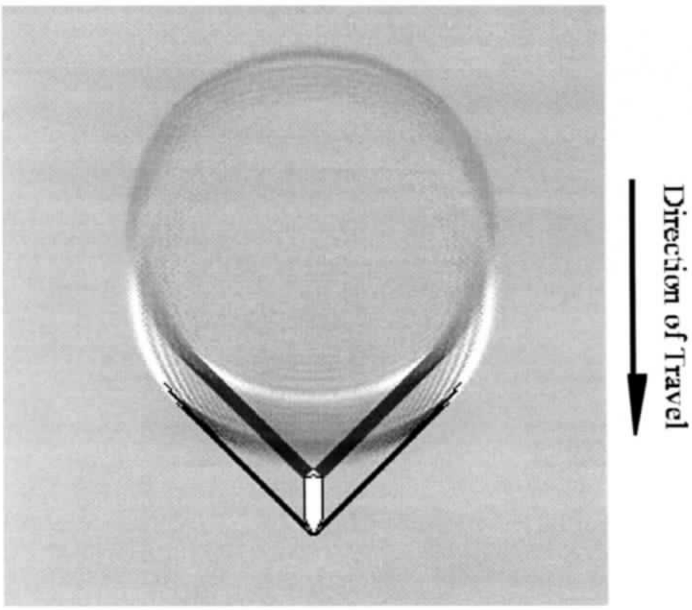

Figure 4 An object moving through the TLM Mesh.

The technique of moving the object through the mesh requires the TLM array to be initialised with the values associated with the pressure of the medium to be modelled. The simulation is then run as normal. When the target is moved, the values of the nodes in front of the object are added to the nodes in front. The target is then repositioned, being moved one node forward.

To implement objects moving at slower speed, the technique needs to be altered with regard to the method for precisely placing the boundary between the nodes. This is to prevent the stop/start action that will otherwise occurs. To achieve the apparent speed, the object will have to be moved one node, then remain where it is until a certain number of cycles have elapsed. By precisely placing the boundary between the nodes, this effect can be smoothed, and a more accurate and smoother wave should result.

6 Conclusion

A new technique for the precise placement of arbitrary boundaries within a TLM mesh has been described. This allows an accurate positioning of boundaries at arbitrary angles to the mesh axes, eliminating the interference caused when using a step wise approximation. As a result, the boundary is more accurately represented without the need for increased computational requirements.

References

1 P.B.Johns and G.F. Slater, 'Transient Analysis of Waveguides with Curved Boundaries', Electronics Letters, **9**, (1973) 486 - 487

2 F.J.German, 'Infinitesimally adjustable boundaries in symmetrical condensed node TLM simulations' 9th Annual Review of Progress in Applied Computational Electromagnetics, Conference Proceedings, 1993, pp 482-490.

3 U.Müller, A.Beyer and W.J.R.Hoëfer, 'Moving Boundaries in 2-D and 3-D TLM Simulations Realized by Recursive Formulas' IEEE Trans. Microwaves Theory and Techniques **MTT40** (1992) 791 - 792,