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ANALYSIS OF MICROSTRIP DISCONTINUITIES USING THE FINITE
DIFFERENCE TIME DOMAIN TECHNIQUE

C. J. Railton and J. P. McGeehan

Centre for Communications Research, Faculty of Engineering,
University of Bristol, BRISTOL, BS8 1TR, UK

ABSTRACT

This contribution demonstrates the potential of the Finite Difference Time Domain technique to
analyse MMIC structures of arbitrary complexity with moderate computational effort and to meet
the requirement for CAD tools capable of treating high density MMIC's. Results are presented for
uniform microstrip, the abrupt termination and the microstrip right angle bend.

INTRODUCTION

The current movement in Microwave Monolithic
Integrated Circuits (MMIC's) is towards higher
operating frequencies, higher component densities
and novel components of increasing complexity.
This trend is made possible by advances in
fabrication technology. Unfortunately, the
available CAD tools for analysing such compact,
high frequency circuits are inadequate for this
task and in order to fully exploit the
fabrication techniques which are available, it is
necessary that the state of the art in CAD also
advance.

The method of analysing MMIC components, which is
utilised in the most advanced CAD package, is the
Spectral Domain Method (SDM) [1]. This method
owes its success largely to the fact that the
asymptotic behaviour of the fields in the region
of a metal edge are known a priori. However, as
the structures to be analysed become more complex, and the interactions between components
become more significant, the SDM loses its
advantages and a method of more general
applicability is required.

The Finite Difference Time Domain (FDTD)
technique has been much used in the analysis of
the scattering of electromagnetic radiation from
objects of complex shape [2,3]. More recently it
has been applied to the analysis of planar
transmission lines such as microstrip and finline
[4].

It is the purpose of this contribution to
demonstrate the potential of the FDTD technique
in the rigorous full wave analysis of MMIC
structures and to show some ways in which the
basic technique may be improved to increase its
versatility and efficiency. Results are presented
for the propagation constant of uniform
microstrip, calculated using this method, which
show excellent agreement with those obtained
using SDM. Results are also presented for the
parameters of structures containing a right angle
bend in microstrip and an abrupt termination in
microstrip. The latter results are compared to
those obtained in [5] by means of the SDM where
good agreement can be seen. Thus it is shown that
the FDTD method has great potential for the
analysis of MMIC components of arbitrary
complexity. Work is currently in progress to
apply this technique to the microstrip step and T
junction discontinuities and to include the
effects of finite strip thickness and
conductivity.

APPLICATION TO UNIFORM MICROSTRIP

In order to demonstrate the validity of the
method, it was first applied to a uniform
microstrip whose geometry is shown in Fig. 1.
Metal walls are placed across the microstrip
forming a resonator in the manner of the problem
analysed in reference [1]. The box was divided up
into regions of different sizes, each of which
contain a fixed number of nodes. By this means, a
greater density of nodes can be placed in the
regions of greater field variations. Since the
asymptotic behaviour of the field at the edge of
the strips is known, the necessity for a high
node density near the edges of the metal can be
mitigated by using a finite difference formula
which takes this into account. An example of this
is described later. The initial field pattern was
chosen to be similar to that which would exist in
the microstrip in the steady state. This choice
of excitation causes the subsequent analysis to
be stable and to converge quickly to the steady
state. By these means the available a priori
information is utilised to speed up the
computation.

1009
In order to find the exact resonant frequencies of the structure, one must Fourier Transform the time sequence. Unfortunately, the Fast Fourier Transform algorithm is not adequate since it only provides the transform at discrete frequencies. It is, therefore, necessary to calculate the transform directly so that the value at any frequency can be ascertained. The positions of the maxima of the transform can then be found using standard methods. If the transform is performed on the raw time sequence, then as well as the desired peak, there will be side lobes of considerable amplitude. These reduce the accuracy of the result and make it difficult to apply an algorithm which automatically finds the position of the maximum. This problem has been overcome by multiplying the time sequence with a windowing function. The effect of this can be seen in Fig. 2, which shows the convergence of the result as more iterations are taken. Fig. 2a. is with a raised cosine window, Fig. 2b. is without windowing. The improvement gained by using the windowing can clearly be seen.

Using these techniques, the theoretical results tabulated in Table 1 have been obtained. It can be seen that using the dominant resonant mode the agreement with the SDM is within 0.25%. Accuracy is less when the higher order modes are used since the mesh size, relative to a wavelength, is larger.

INTEGRATION OF EDGE SINGULARITY

Consider the structure in Fig. 3. Here we have a metal edge whose boundary is somewhere between the \( E_z \) node and the \( H_y \) node. In order to calculate the value of \( H_y \), the standard finite difference formula would include \((E_{z2} - E_{z1})/\Delta x\) which assumes that \( E_z(x) \) varies linearly in the region between the nodes. In fact it is well known that, close to the edge, \( E_z(x) = k\sqrt{r} \) where \( r \) is the distance from the edge and \( k \) is a constant. We can then say:

\[
E_{z1} = k \sqrt{\delta x - \delta} \rightarrow E_z(x) = E_{z1} \sqrt{r} / \sqrt{\delta x - \delta}
\]

Now we require \( \delta E_z / \delta x \) at the \( H_y \) node, i.e. \( r = \delta x/2 - \delta \). Thus:

\[
\frac{\delta E_z}{\delta x} \bigg|_{r=\delta x/2 - \delta} = E_{z1} \frac{1}{2} \sqrt{(\delta x/2 - \delta)(\delta x - \delta)}
\]

We may replace the \( E_{z2} - E_{z1} \) in the standard formula with the above expression which will give a more accurate answer.

This method of incorporating the known asymptotic field behaviour into the finite difference algorithm can also be applied to more complex shapes such as bends, corners or strips having finite thickness.

It is interesting to note that, in the case of a uniform microstrip, if \( \delta/\delta x = (1 + \sqrt{5})/4 \) then the answer given by the two formulae will be the same. This value corresponds to the edge being somewhat less than half way between the \( E_z \) node and the \( H_y \) node.

APPLICATION TO THE ABRUPT TERMINATION

In Fig. 4, we have an enclosed resonator containing a microstrip line which terminates abruptly. We can apply the FDTD method in the same way as for uniform microstrip, taking into account the known behaviour of the field at the 90° corners, in order to calculate the resonant frequencies of the structure. We can calculate the propagation constants at these frequencies using the SDM and then ascertain the effective length extension of the termination. By performing the calculation for strips of different lengths, the dependence of the effective extension on frequency can be found.

In Table 2 the results obtained for the abrupt termination are compared to those given in [5]. It can again be seen that good agreement exists.

APPLICATION TO THE RIGHT ANGLE BEND

Fig. 5 shows the geometry of a microstrip line containing a 90° bend. In order to analyse this structure, we again place the structure under test in a closed box and choose the lengths \( l_1 \) and \( l_2 \) to provide resonant frequencies in the region of interest. Since we are now dealing with a two-port structure, there are three unknown parameters which must be determined for its complete characterisation. Thus it is necessary to find three combinations of \( l_1 \) and \( l_2 \) which will yield the same resonant frequency. In practice, the reflection coefficient is very low and the phase of the transmission coefficient can be calculated using just one geometry.

Table 3 shows the calculated effective length of the strip plotted against frequency. Fig. 6 shows isometric plots of the calculated x and z components of the electric field in the plane containing the metalisation for the geometry of Fig. 5. The expected edge singularities and modal field patterns can clearly be seen.
CONCLUSION

In this contribution it has been demonstrated that the FDTD method has much potential in the area of the analysis and CAD of complex MMIC structures and is capable of being enhanced in a number of ways to improve computational efficiency and accuracy.

References


Fig. 3 Nodes close to the edge of a metal strip

Fig. 4 - Geometry of a microstrip abrupt termination. Dashed lines show the division into regions in the x-y plane.

Fig. 5 - Geometry of a microstrip right angle bend. Strip width = 3.81 mm, εᵣᵣ = 10.

Fig. 6a - Plot of intensity of Eₓ in the plane of the strip for the geometry of Fig. 5, strip length = 12 mm.

Fig. 6b - Plot of intensity of Eₓ in the plane of the strip for the geometry of Fig. 5, strip length = 12 mm.

Table 1 - Results for a uniform microstrip.

<table>
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<tr>
<th>Length of strip (mm)</th>
<th>Resonant frequency (GHz)</th>
<th>εₑₑ from FDTD</th>
<th>εₑₑ from SIM</th>
<th>% difference</th>
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Table 2 - Results for microstrip abrupt termination.

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Table 3 - Results for the geometry of Fig. 5. Strip width = 3.81 mm.

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<th>Length of strip (mm)</th>
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<th>εₑₑ from FDTD</th>
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