ing for the cutoff frequencies of 900MHz, 1.0 and 1.1GHz by
setting $I_{D}$ to 40, 52 and 66mA, respectively. It can be seen that a
zero (defined by eqn. 2) placed very close to 2GHz shifts the roll-
of characteristics away from -80dBdec. This effect can be allevi-
ated by increasing the transconductances of M1 and M2 to push
the zero to higher frequencies. However, this can be accomplished
at the expense of power consumption. Table 1 indicates spurious-
free dynamic range (SFDR), %THD dynamic range (DR) and
power dissipation ($P_{dd}$) of the filter at different cutoff frequen-
cies ($f_0$).

Conclusions: A low-power very-high-frequency current-mode filter
based on vertical stacking of regulated cascode biquads has been
realised. Around a GHz region, moderate dynamic range can be
obtained under low-power consumption owing to bias current
sharing and simple topology.

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3D tetrahedron ray tracing algorithm
Z. Zhang, Z. Yun and M.F. Iskander

A new three-dimensional (3D) tetrahedron mesh ray tracing
(TMRT) method is proposed. It is based on dividing the
propagation region into tetrahedral cells whereby the number of
tetrahedrons is decided by the number of vertices of structures
instead of their dimensions. This method represents a 3D
extension to the 2D procedure described in an earlier paper.
Results from the 3D TMRT method show significant
improvement in computational efficiency and are typically less
than one half of those of the visibility ray tracing approach. These
results were illustrated by calculating the delay spread in a typical
indoor propagation environment.

Introduction: Propagation prediction is very important in the
design of wireless communications systems. The ray tracing
method has become a vital tool for calculating parameters such as
delay spread, angle of arrival, and coverage in typical wireless
communication environments. This is especially true for the
micro- and pico-cell cases where site-specific propagation
information is needed in developing high-quality communication systems
[1].

The conventional ray tracing method is based on a ray-launching
and bouncing procedure which can be very inefficient if no
speed-up algorithm is employed. Several schemes have been deve-
loped to accelerate the ray tracing procedure, e.g. the image
method, the bounding box method, and the utilisation of visibility
[2, 3]. Although these methods have advantages, a more efficient
method is needed to cope with the complex and often computa-
tionally demanding indoor or outdoor/indoor situations while
maintaining good accuracy of the propagation prediction results.
An efficient ray tracing method based on triangular division of the
propagation space has been studied in the two-dimensional (2D)
case [4]. In this Letter we extend the 2D triangular-based algo-
rithm described earlier to a 3D tetrahedron-based algorithm. It is
of significant interest to examine the impact of the 3D implemen-
tation of the proposed procedure on the computational savings
reported earlier for the 2D case.

TMRT method: It is generally known that 3D structures can be
discretised by tetrahedrons. These tetrahedrons may be meshed
such that they are based on the vertices of the object. This discrete-
tisation procedure is somewhat different from normal meshing
methods routinely used in numerical methods such as the finite
element method, where mesh refinement procedures are often
implemented to improve the accuracy of the results. In the pro-
posed method, discretisation is related to only the existing vertices
of the object and no auxiliary nodes are introduced. In the TMRT
method, the size of the tetrahedrons has no effect on accuracy, but
the number of tetrahedrons clearly plays a role in determining the
efficiency of the proposed algorithm. Hence we implemented a
digitisation procedure that is related only to the vertices of the
object in the propagation environment.

Fig. 1 Intersection test on tetrahedron

Fig. 1 shows a typical tetrahedral cell which may be encoun-
tered in the proposed method. After discretising the propagation
domain, the key remaining step in the solution procedure involves
the determination of which face of a specific tetrahedron will be
hit by the incident ray as it continues to propagate in a communi-
cation environment. As may be noted from Fig. 1, there are four
faces – faces 1, 2, 3 and 4 – in a tetrahedron. Assuming there is a
ray incident into the tetrahedron from point $A$ through face 4,
there will be only three faces – faces 1, 2 and 3 – that can possi-
bly be hit by the incident ray. After deciding the hit face, as will be
described later, there are two kinds of interactions that can be
considered. In one case, the hit face is a real wall and hence the
cross point, the reflect, and the transmit rays will need to be calcu-
lated. In the other situation, the hit face is an auxiliary face, in
which case the ray will continue to propagate directly towards the
next neighbouring tetrahedron and the solution procedure will
continue as described above. Because all of the information about
the adjacent tetrahedron related to each face is known, the ray
can quickly go through from one tetrahedron to another by a ‘point-
locating’ method instead of requiring time-consuming searching
algorithms. Avoiding the use of a search algorithm to determine the
‘next’ hit surface constitutes the main computational advan-
tage of the proposed method.

Consider the tetrahedral cell shown in Fig. 1. The incident ray is
originating from point $A (x_0, y_0, z_0$) and is propagating with
normalised direction vector $P(P_{x_0}, P_{y_0}, P_{z_0})$. Hence, the line
describing the incident ray parameters is defined as

$$
x = x_0 + P_{x_0} + \Delta t
\ y = y_0 + P_{y_0} + \Delta t
\ z = z_0 + P_{z_0} + \Delta t$$

(1)

$\Delta t$ in eqn. 1 is a variable that represents the incremental change
in the line length along the ray.

The tetrahedral faces 1, 2, 3 and 4, can be defined by

$$x = x_0 + \Delta t \ y = y_0 + \Delta t \ z = z_0 + \Delta t$$

(2)

Substituting eqn. 1 into eqn. 2, we obtain

$$\Delta t_i = - \frac{a_i \ x_0 + b_i \ y_0 + c_i \ z_0 + d_i}{a_i \ P_{x_0} + b_i \ P_{y_0} + c_i \ P_{z_0}}$$

(3)

Using eqn. 3 and through the calculation of $\Delta t_i$ for each
tetrahedral face, one can determine the ray hit surface and also the
point of intersection. To begin with, when the denominator in
eqn. 3 is zero, the ray will be parallel to the plane and there will
be no intersection. By the sign of the denominator, inner faces
which can be seen from point $A$ along direction $P$ can be decided
and only those faces need extensive calculation of the length $\Delta$, e.g. in the case shown in Fig. 1, only faces 1 and 3 can be seen by the incident ray.

Because tetrahedrons are formed by triangular edges, the face that produces the minimum $\Delta$ is the hit face. If there are two equally minimum positive $\Delta$, the cross edge between two faces which produces the minimum $\Delta$, is the one that will be hit by the propagating ray. If there are three equally minimum positive values of $\Delta$, the vertex opposite to the incident face is the one that will be hit in this case.

Once again, if the hit face is an auxiliary face, no intersection point calculation is needed; calculations will just proceed to the next tetrahedron and the solution procedure will be repeated. If the hit face is a real wall, the calculated value of $\Delta$ from eqn. 3 is substituted in eqn. 1 and the coordinates of the intersection point will be obtained.

![Fig. 2 Layout and transmitter position](image2)

**Table 1: 3D ray tracing results**

<table>
<thead>
<tr>
<th>TMRT</th>
<th>Vis</th>
<th>Ratio (TMRT/Vis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>24.2</td>
<td>70.2</td>
</tr>
<tr>
<td>T2</td>
<td>18.6</td>
<td>46.8</td>
</tr>
<tr>
<td>T3</td>
<td>21.5</td>
<td>51.6</td>
</tr>
<tr>
<td>Average</td>
<td>21.4</td>
<td>56.2</td>
</tr>
</tbody>
</table>

![Fig. 3 Time delay result](image3)

**References**


**Linearly polarised radial stub fed high performance wideband slot antenna**

P.H. Rao, V.F. Fusco and R. Cahill

A wideband printed slot antenna fed by a radial stub operating over the mobile communication bands PCN (1.716-1.880GHz) and UMTS (1.9-2.0GHz and 2.1-2.2GHz) is presented. The impedance bandwidth of the antenna achieved for a $VSWR \leq 2$ is 34% and the radiation patterns remain stable over the entire frequency band of operation (1.7-2.4GHz) with cross-polarisation levels of less than -20dB. Simulated and measured radiation pattern and return loss results are presented.

**Introduction:** A major advantage of the slot antenna over dipole antenna configurations is the higher bandwidth that can be achieved and the lower feed interaction effect with respect to radiation pattern influence. To achieve operation over a broad band of frequencies, various methods of feeding the slot antenna have been attempted [1, 2]. In this Letter we show that by using a radial stub as a series element on a 50Ω feeder line we can achieve a wide impedance bandwidth match and stable radiation patterns over the frequency range 1.7-2.4GHz, covering PCN, UMTS and Bluetooth frequencies.

**Antenna configuration and design:** The antenna designed at 2.2GHz as centre frequency, consists of a printed slot on a $t_{1} \times 1.5 t_{1}$ ($L \times W$) ground plane fed by a 50Ω microstrip transmission line loaded with an open circuited radial stub. The antenna was fabricated on a double-sided etched Taconic material of $\varepsilon_{r} = 2.5$ and height (h) 1.57mm. Considering the known broadband advan-