back radiation. These features make this element suitable to develop base station antennas.

A prototype has been manufactured and measured. The measured return losses (in the range of −24 dB) and isolation between polarizations of the same patch (in the range of 36 dB) for a 24% bandwidth show excellent antenna performances.

These elements will be used in reconfigurable antennas using advanced RF combination circuits.

REFERENCES


in Table I, which was optimized by measurements to operate within the UWB frequency range by simulations. The antenna consists of an L-shaped radiator, with its vertical section shorted to a 100 × 100 mm ground plane. The antenna is fed by a 50 Ω co-axial probe of a 0.6 mm-radius, which is connected to an L-shaped feeding plate at the bottom of the radiator. The feeding plate is suspended above the ground plane and positioned in a way such that the antenna is symmetrical about the x-axis. The vertical section of the L-shaped plate is separated from the vertical wall of the radiator and the horizontal section of the radiator. The electromagnetic coupling exists between the vertical sections of the L-shaped radiator and feeding plate, the vertical section of the feeding plate and the horizontal section of the radiator, as well as the horizontal section of the feeding plate and the ground plane form a broadband feeding structure. The horizontal section of the feeding plate increases the capacitance at the feed point to compensate for the increase in the inductance due to the long probe across a broad impedance bandwidth.

### Table I

<table>
<thead>
<tr>
<th>d</th>
<th>l₁</th>
<th>l₂</th>
<th>w₁</th>
<th>w₂</th>
<th>h</th>
<th>h₁</th>
<th>h₂</th>
<th>q</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>6</td>
<td>11</td>
<td>6</td>
<td>20</td>
<td>9</td>
<td>3.5</td>
<td>0.5</td>
<td>3</td>
</tr>
</tbody>
</table>

III. RESULTS

The impedance performance of the antenna was measured using the HP N5240A Vector Network Analyzer and simulated using Zeland.
TABLE II
INITIAL ANTENNA DIMENSIONS USED IN THE SIMULATION (IN MILLIMETERS)

<table>
<thead>
<tr>
<th>d</th>
<th>l_1</th>
<th>l_2</th>
<th>w_1</th>
<th>w_2</th>
<th>h_1</th>
<th>h_2</th>
<th>q</th>
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<td>7</td>
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<td>9</td>
<td>3.5</td>
<td>0.25</td>
</tr>
</tbody>
</table>

IE3D. Fig. 2 shows the simulated and measured impedance performance of the antenna. Good agreement is observed between the measured and simulated results. The antenna covers a bandwidth of 3–12 GHz for $|S_{11}| < -10$ dB. The measured radiation patterns in the principal $xz$- and $yz$-planes at 3, 5, 7, and 9 GHz are also shown in Fig. 3(a)–(d).

It can be observed that the radiation patterns are stable across the entire bandwidth of 3–12 GHz in terms of the maximum radiation direction and beamwidth. The maximum gain in the $xz$-plane is greater than 4 dBi across the UWB bandwidth as shown in Fig. 4. The gain is affected by the size of the ground plane. The beam squinting is 40–45° from the boresight due to the asymmetrical structure of the antenna. The decrease in the gain at the boresight was caused by the beam squint as shown in Fig. 3(a) and (c). However, the squinted beam is conducive to the indoor applications where the antenna is installed such that the ground plane of the antenna is parallel to the vertical wall or perpendicular to the ceiling.

IV. PARAMETRIC STUDY

A parametric study was conducted to investigate the effects of the antenna parameters on the impedance matching. The effects of varying the distance ($d$) between the vertical section of the radiator and the feed plate, the distance between the horizontal section of the feed plate and the ground plane ($h_1$), the separation between the horizontal section of the radiator and the vertical section of the feed plate ($h_2$), position of the feed point ($q$) are studied. In the simulations, except for the parameter of interest, the other parameters are kept the same. The initial dimensions of the antenna used in the simulation are given in Table II.

As shown in Fig. 5(a), increasing $d$ predominantly affects the matching around 6–10 GHz due to a decrease in the resistance. The matching in this band is improved with an increase in $d$ but deteriorated at 3.5 GHz due to an increase in the capacitance. Also, it is noted that at 10.5 GHz, an increase in the $d$ results in an increase in the resistance and inductance.

The impedance matching is also very sensitive to the changes in $h_1$ as shown in Fig. 5(b). Increasing $h_1$ improves the matching slightly at 3.5 GHz but the increase in the resistance and inductance at 6–10 GHz results in deterioration in the matching. Also, the upper edge frequency is lowered when $h_1$ is reduced.

The lower and upper edge frequencies are affected by changes in $h_2$. By decreasing $h_2$, the lower and upper edge frequencies are reduced, which is accompanied by an improvement in the impedance matching across the entire operating bandwidth as observed from Fig. 5(c). The position of the feed point can be varied to change the impedance matching at the lower resonance as well as the bandwidth.

From Fig. 5(d), as the $q$ increases, the lower resonance experiences better matching but at the expense of reducing the upper edge frequency, resulting in a reduction in the bandwidth.

Fig. 4. Measured peak gain.

Fig. 5. Effects of varying (a) $d$ (b) $h_1$ (c) $h_2$ (d) $q$ on the impedance matching.
V. Conclusion
An electromagnetically coupled plate antenna with modified feeding structure has been presented for UWB applications. By controlling the electromagnetic coupling between the feeding plate and the radiator as well as the ground plane, a broad impedance bandwidth of more than 120% has been achieved. The measurement results have demonstrated the stability in the radiation performance of the antenna across the entire operating bandwidth with a peak gain greater than 4 dBi. Also, a parametric study on the impedance matching has been conducted so as to enable antenna engineers to design according to the required specifications. The proposed antenna with enhanced performance is suitable to be deployed on the wall or ceiling in an indoor environment. In addition, the antenna is mechanically robust as well as easy and low cost to manufacture.

Full-Wave Simulation of Time Modulated Linear Antenna Arrays in Frequency Domain
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Abstract—An effective frequency domain full-wave approach is proposed for the simulation of time modulated (TM) linear arrays with variable aperture size (VAS) time schemes. The full-wave simulation of the TM linear arrays is fulfilled by combination of the frequency domain full-wave simulation results of the corresponding regular linear arrays at multiples of the modulation frequency. Numerical simulation results of two TM linear arrays with VAS time schemes are presented and are compared with reported measurement results, and close agreement is obtained through comparison.

Index Terms—Antenna arrays, frequency-domain, time modulation.

REFERENCES

I. Introduction
The time modulated (TM) antenna arrays were proposed and experimentally demonstrated in 1960s [1], [2]. Recently, the TM antenna arrays have regained their research interests, due to their attractive features in the design of low/ultra-low sidelobes and shaped patterns [3]–[10]. The major advantage of the TM arrays is that there is an additional degree of design freedom—time—as compared to their conventional counterpart. The amplitude excitations of TM arrays only require a low dynamic range ratios or even a uniform distribution while designing low/ultra-low sidelobe patterns, which are much easier for hardware implementation [6].

Previous analysis of TM antenna arrays are all based on pattern multiplication approach, where each array element is assumed to have the same radiation pattern and the total far field of a TM array is obtained by the multiplication of the element pattern and the array factor. In order to investigate the TM arrays thoroughly, more accurate analysis or full-wave simulation of TM arrays are thus necessary. The difficulty of the full-wave simulation of TM antenna arrays originates from the fact that the excitations on each of the array elements are periodic time modulated signals. The pulse repetition frequency (prf) is much lower as compared to the carrier frequency in a TM array. If conventional time domain full-wave simulation approach (e.g., finite difference time domain method) is adopted to simulate the TM array, enormous number of time steps will be required before the simulation process reaches a truly stable state. For TM arrays with lower time modulation frequency, the required number of time steps will be prohibitively huge and even make it impossible for the simulation.

In this communication, a frequency domain full-wave simulation approach is proposed for the analysis of TM antenna arrays. The time-domain excitation signals are decomposed into Fourier series, thus obtaining the excitation distributions at the central operating frequency and the sideband frequencies. Traditional frequency domain full-wave simulation approaches are then adopted to simulate the corresponding static antenna array at the central frequency and the sideband frequencies, using the corresponding excitation distributions at each frequency. The frequency domain radiation patterns are then combined to form the

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