4. CONCLUSION

The problem of electromagnetic scattering from finite perfectly conducting (PEC) plates has been analyzed by using the matrix-free windowed plane wave spectral (WPWS) expansion technique, and the resulting solution has been further refined by using the spectral transformation. The role of windowing the spectrum of the solution for the induced currents in order to improve edge behavior and the corresponding RCS has been demonstrated. Numerical results have been presented to illustrate the accuracy of the technique by comparing them with those derived using the rigorous MoM analysis. The study has shown that the RCS behavior at angles close to grazing is strongly controlled primarily by edge singularities rather than current distribution in the interior of the plate. It has been demonstrated that a spectral transformation accompanied by a filtering of the WPWS solution is able to capture the edge behavior quite accurately.

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rise to lower operating frequency of the antenna. In this paper we show that a dual-frequency operation is achieved by using a tapered meander slot antenna with a short-ended microstrip line feed. The tapered meander slot antenna was derived from [3] in which a meander line was tapered to achieve operation at lower frequencies. The bands of interest for this research project are those of wireless local area networks (WLANs), and personal communication systems (PCS).

2. MEANDER SLOT ANTENNA DESIGN

The initial design of a tapered meander slot antenna is shown in Figure 1 where the slot width is 1.5 mm and L1 varies from 0 to 0.75 mm. The antenna is constructed by making a meander slot in a perfectly conducting plane supported by a dielectric substrate of 1.905 mm thickness and relative dielectric constant of 9.2. The antenna is excited by a microstrip feed line. The edge of the feed line is shorted to the perfectly conducting plane using a shorting wall. The width and length of the feed line can be adjusted to achieve a good input match. The improved design is shown in Figure 2 where the horizontal slots of the meander are varied in width from 1.5 to 0.5 mm in order to support the 1800 MHz as well as the 2400 MHz operating frequencies.

3. SIMULATION AND RESULTS

A. Confirmation of Simulated Results

The Advance Design System (ADS) software package of Agilent Technologies [4] is used to analyze this type of antenna. To confirm the results produced by ADS, the finite difference time domain (FDTD) method is used for the computation of the return loss of a sample case. For the sake of simplicity and speed in the FDTD simulation a design with dimension divisible by 0.5 mm is used. For this reason an initial design similar to that of Figure 1 is simulated with the second horizontal slot at 22 mm long instead of 21.75 mm and L1 equal to zero with a slot width of 1.5 mm. The width of the excitation strip and L2 is equal to 2.5 mm and 2 mm, respectively.

To achieve stability in the FDTD simulation of the antenna, parameters were chosen to give 30 cells per wavelength at the highest usable frequency. The meander slot is oriented in the y-z plane with 40 cells between the antenna and the absorbing boundary giving a total mesh dimension of 84 × 156 × 144 cells in the x, y, and z directions, respectively. The special increments \( \Delta y \) and \( \Delta z \) were chosen to be 0.5 mm and \( \Delta x \) was chosen as 0.476 mm to give a dielectric substrate height of 4 \( \Delta x \). The width of the slot is 6 \( \Delta z \), and the spacing between the meander turns is 8 \( \Delta z \). The

![Figure 2](data:image/png;base64,)<br><br>**Figure 2** Top view of a tapered meander slot antenna with variable slot width [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

![Figure 4](data:image/png;base64,)<br><br>**Figure 4** Return loss for the tapered meander slot antenna design of Fig. 1 [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

![Figure 3](data:image/png;base64,)<br><br>**Figure 3** Comparison of return loss computations based on ADS and FDTD simulations [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

![Figure 5](data:image/png;base64,)<br><br>**Figure 5** Input resistance for tapered meander slot antenna design of Fig. 1 [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]
The width of the excitation strip is 5 \Delta z. The time step used in the simulation is \Delta t = 0.852 \text{ ps}, the Gaussian half width is \tau = 25.017 \text{ ps}, and the time delay \tau_0 = 4.5 \tau \text{[5]}. A total number of 4000 time steps were used in order to ensure that the time domain response approaches zero. The results are shown in Figure 3 which shows the comparison of the return loss derived from the ADS simulation and the FDTD method. Good agreement is observed which validates the design procedure using ADS.

**B. Simulated Design**

An initial design of Figure 1 is done with the width of the excitation strip and L2 equal to 2.25 and 2 mm, respectively. The return loss is shown in Figure 4. It can be seen that with an increase in L1 the operating frequency of the antenna is shifted down. The design presented in Figure 1 yields a maximum bandwidth of about 700 MHz when L1 is 0.75 mm and a minimum bandwidth of about 670 MHz with L1 equal to zero. It is found that the increase of L1 leads to an increased variation of the input resistance as shown in Figure 5.

The return loss observed from the design of Figure 2 is shown in Figure 6. As the horizontal slot width (W1) is varied from 1.5 to 0.5 mm the second resonance at 2420 MHz remains constant whereas the first resonance is shifted down from about 2040 MHz to about 1803 MHz. The numerical results of Figure 7 indicate that the variations of the input resistance of this design increases with the decrease of W1.

In order to achieve a design working at both 1800 MHz and 2400 MHz operating frequencies both designs of Figure 1 and Figure 2 were combined. With L1 equal to 0.25 mm and W1 equal to 0.5 mm, Figure 8 shows the return loss of the resulting design operating at 1800 MHz and 2400 MHz. The input resistance is depicted in Figure 9 and shows more variation within the operating frequencies compared to the initial case with no tuning.

The radiation pattern for the final design is shown in Figures 10 and 11 operating at 1800 and 2400 MHz, respectively. The bandwidth at the first resonance centered at 1800 MHz is 130 MHz with a directivity of about 3.62 dB. The operating bandwidth of the second resonance at 2400 MHz is about 350 MHz with directivity of 4.22 dB. Extensive simulation results reveal that the radiation pattern remains constant over both operating bandwidths. For the sake of providing parametric study for antenna designers, further analysis of the final design working at 1800 and 2400 MHz was achieved. In what follows the effects of the spacing between turns, \( d_s \), and the taper angle are reported.

Figure 12 shows the return loss due to changes in the spacing between turns annotated by S. It is shown that both operating...
frequencies are shifted up for an increase in S, with S equal to 4
mm being the case of the final design. When ds is varied from 11
to 15.5 mm small changes in the first operating frequency are
observed. However, from the return loss of Figure 13, the second
operating frequency is clearly being shifted down as ds is in-
creased. Figure 14 again demonstrates this behavior by showing a
very slight increase of the operating frequency at the first reso-
nance and a more apparent decrease of the operating frequency at
the second resonance as ds is increased.

Figure 15 shows the return loss for the initial design of Figure
1 with L1 equal to zero as the taper angle is varied. As expected,
increasing the taper angle causes a decrease in the operating
frequencies of the antenna due to the overall length of the meander
slot being increased. With an increase in the taper angle a decrease
in the bandwidth of operation is observed. Variations in the di-
electric substrate height and dielectric constant value were also
looked at and the effects on the return loss as seen in Figures 16
and 17 are found to be minimal. Figure 16 shows the operating
frequencies shifting down for an increase in the substrate height. In
Figure 17 the operating frequency is shifted down also for an
increase in the dielectric constant.
5. CONCLUSION

A new design of a tapered meander slot antenna is presented with dual-band operation at 1800 and 2400 MHz with 130 MHz and 350 MHz bandwidths, respectively. The antenna dimensions are small to fit in most currently used personal communication devices. This antenna shows no significant variations in radiation pattern characteristics over the bandwidths of both operating frequencies. The effect of geometrical and electrical parameters have been studied and reported to aid in the design process of this class of antennas.

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