performances. Future work will focus on adding the buffer stages (input and output) with a view to improving linearity and noise performance.

ACKNOWLEDGMENTS
The authors would like to acknowledge H. Lafontaine and S. Kovacic for their help with models and technology.

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A WIDEBAND COPLANAR-WAVEGUIDE-FED MULTI-SLOT ANTENNA FOR RADAR APPLICATIONS
Cuthbert M. Allen, Abdelnasser A. Eldek, Atef Z. Elsherbeni, and Charles E. Smith
Center for Applied Electromagnetic Systems Research (CAESR) Department of Electrical Engineering University of Mississippi University, MS 38677

Received 20 March 2003

ABSTRACT: A small multi-slot antenna is designed for RF and microwave sensors and radar applications. The design was realized using a series of parallel slots with tapered lengths, fed by a coplanar waveguide (CPW) to support wideband operation. The designed multi-slot antenna provides a 50% bandwidth centered at 10 GHz with 50Ω input impedance. The operating bandwidth remains almost constant regardless of the length of the feeding mechanism. This feature is demonstrated by several numerical simulations. Return loss, input impedance, radiation pattern, gain, and efficiency of the proposed design are computed and analyzed to support X-band operation.


Key words: wideband; multi-slot; coplanar waveguide

1. INTRODUCTION
Microstrip patch elements are commonly used as building blocks for antenna arrays. These antennas exhibit low profile and lightweight properties, as well as low cross polarization radiation in some designs. However, microstrip antennas inherently have narrow bandwidths and in general are half-wavelength structures operating at the fundamental resonant mode [1]. In this study, a CPW fed multi-slot antenna is designed for radar systems with wide-band operation and reduced size in mind.

Coplanar waveguide (CPW)-fed microstrip antennas have recently been attracting increased attention. The CPW was proposed in 1969 by Wen [2], and has been used extensively since then in millimeter-wave applications. The unique feature of this transmission line is that it is uniplanar in construction, which implies that all of the conductors are on the same side of the substrate [2]. Since microstrip antennas (MSAs) are planar geometries, it is desirable to feed MSAs with CPW for integration with MMICs. The main advantages of the CPW feed, as compared to the microstrip-line feed, are its low radiation loss and low dispersion, thus making it suitable for antenna arrays.

This paper presents a wideband antenna, which is a follow-up of a dual-tapered meander-slot antenna fed with a CPW, presented in [3], with a wideband operation of 17% at 10 GHz. Here, the CPW feeding mechanism is maintained and multiple parallel slots of varying lengths perpendicular to the CPW line replace the meander slots. This configuration enhances the fields in the parallel slots; thus, larger bandwidth and smaller antenna size are realized.

2. GEOMETRY
The antenna is constructed by making a series of parallel slots with ascending lengths in a perfectly conducting plane, supported by a 30-mil-thick dielectric substrate with a relative dielectric constant of 3.2 with a loss tangent of 0.0029 at 10 GHz. The parallel slots are all connected at their base to a CPW line. Figure 1 shows the top view of the antenna and its design parameters. The width of the parallel slots is 1 mm, and the length of the CPW feed is 5.25 mm.

The top view of the CPW-fed multi-slot antenna is shown in Figure 1. The CPW feed and multiple parallel slots are connected at their bases. The width of the parallel slots is 1 mm, and the length of the CPW feed is 5.25 mm.

### TABLE 1 Dimensions of the Presented CPW-Fed Multi-Slot Antenna in mm

<table>
<thead>
<tr>
<th>L1</th>
<th>L2</th>
<th>L3</th>
<th>Ws</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.75</td>
<td>8</td>
<td>6</td>
<td>1</td>
<td>2.5</td>
<td>2.5</td>
<td>1.75</td>
</tr>
</tbody>
</table>
with width $W$ and gap $G$ equal to 2.5 and 1 mm, respectively. The other dimensions are given in Table 1.

3. SIMULATION AND RESULTS

The related simulation and analysis are performed using Agilent Technologies’ commercial computer software package, Advanced Design System (ADS), which is based on the method of moments (MoM) technique for layered media. The ADS simulator, called Momentum, solves mixed potential integral equations (MPIE) using full-wave Green’s functions [4]. The design shown in Figure 1 was originally analyzed with $d_3$ held constant at zero (that is, there is no extended tuning slot). With $d_3$ held at zero and $d_2$ held at 1.5 mm, $d_1$ was varied; the resultant return loss is shown in Figure 2. The return loss in Figure 2 shows that decreasing $d_1$ increases the resonant frequency, while it does not affect the bandwidth.

Figure 3 shows the return loss when $d_3$ and $d_1$ are held at 0 and 2.5 mm, respectively. These results show that the resonant frequency and the bandwidth of the antenna are increased when $d_2$ is decreased. However, the return loss at the center frequencies increases as $d_2$ is decreased.

Next, while varying $d_3$, $d_1$ and $d_2$ were held constant at 2.5 and 1 mm, respectively. Increasing the tuning slot extension ($d_3$) increased the return loss at the resonant frequency. The related results are shown in Figure 4. However, extending $d_3$ slightly increases the bandwidth and reduces the variation of the input resistance across the bandwidth of operation of the antenna, as shown in Figure 5.

Another way in which the operating bandwidth of the antenna could be adjusted is by controlling the length $L_f$ (the length of the CPW feed line). Figures 6 and 7 show the return loss and input resistance for different lengths of $L_f$, respectively. Clearly when $L_f$ is reduced the bandwidth of the antenna shifts up with an increase in bandwidth. However, when $L_f$ is increased the bandwidth shifts down with a decrease in total bandwidth. From Figure 6 a bandwidth of 50% centered at 10 GHz is achieved for $L_f$ equal to 4 mm. The results in Figure 7 show that the input resistance exhibits less variation within the bandwidth of operation when $L_f$ is increased. Therefore, the shortest possible length of CPW feed should be used.

Since any changes in the CPW feed line length affects the performance of the antenna, a method needs to be developed to feed the antenna from sources with varying distances from the antenna feed point. This is necessary because it may not be practical to feed the antenna at exactly that point. To accomplish this, a 50$\Omega$ CPW transmission line is designed along with a
transition line to connect the antenna to the 50Ω CPW line. The design of the 50Ω CPW transmission line yields values for W and G as 5.718 and 0.25 mm, respectively. The length of the transition line from the 50Ω CPW line to the antenna is 0.27 mm. Figure 8 shows the arrangement used with this antenna. Figure 9 presents the return loss of the antenna with the source now applied to the 50Ω CPW line. For different lengths of the 50Ω CPW line, the bandwidth of the antenna remains almost constant. The
results shown in Figure 9 are for the antenna design with \( L_f \) set at 4 mm. Note that the bandwidth of operation does not change as much as it did in Figure 6, and the resonant frequency does not shift.

To confirm the results produced by ADS Momentum, the finite-difference time-domain (FDTD) method is used. The return loss for the antenna design with \( L_f \) set at 4 mm operating over the entire X-band range of frequencies is reproduced along with the input resistance. To achieve stability in the FDTD simulation of the antenna, parameters were chosen to support 30 cells per wavelength at the highest usable frequency. The multi-slot antenna is oriented in the \( x-y \) plane with 30 cells between the feeding edge of antenna and the related absorbing boundary. The other three edges are extended to the absorbing boundary in order to simulate an infinite ground plane similar to the design analysis used in ADS. The total mesh dimensions are \( 135 \times 155 \times 63 \) cells in the \( x, y, \) and \( z \) directions, respectively. The spatial increments \( \Delta x \) and \( \Delta y \) are chosen to be 0.25 mm and \( \Delta z \) is chosen to be 0.254 mm. Therefore, the dielectric substrate is 3 \( \Delta z \) to give a total of 30 mil, and the width of the slots is 4 \( \Delta y \). The time step used in the simulation is 0.43559 ps, the Gaussian waveform half width is \( \tau = 12.709 \) ps, and the time delay \( t_e = 4.5 \tau \) [5]. A total number of 5000 time steps is used in order to ensure that the time domain response approaches zero. The results are shown in Figures 10 and 11, which show the return loss and input resistance derived from the ADS and the FDTD simulations, respectively, for comparison. Good agreement, which validates the design procedure using ADS Momentum, is observed.

The radiation pattern of the multi-slot antenna designed with \( L_f \) equal to 4 mm is shown in Figure 12 at an operating frequency of 10 GHz. The antenna design has a directivity of 4.829 dB, a gain of 4.385 dB, and an efficiency of 90.8%.

4. CONCLUSION
A new design of a CPW fed multi-slot antenna has been presented, operating with a bandwidth of about 50%, centered at 10 GHz. The multi-slot antenna provided high efficiency of about 90% and directivity of 4.829 dB. This antenna shows no significant variations in radiation pattern characteristics over the bandwidth of operation. The effect of geometrical and electrical parameters were studied and reported to aid in the design process of this new class of antennas.

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