Improvements in the Performance of Microstrip Antennas on Finite Ground Planes Through Ground Plane Edge Serrations

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***Abstract*—This paper explores how edge serrations on a truncated ground plane affect the performance of a microstrip antenna. The investigation includes both simulations and measurements of a range of serration dimensions. Improvements in performance through ground plane edge serration include lower cross-polarization level, increased beam width, and slight impedance tuning compared to a microstrip antenna on a simple finite ground plane.**

***Index Terms*—Finite ground, microstrip antennas.**

I. Introduction

THE MICROSTRIP patch is a popular antenna choice for many communication products, due in part to its conformability, compact size and well-known design equations. In many of these applications, such as wireless local area networks, Bluetooth systems, and RFID tagging, only a small ground plane is available. However, once the ground plane is truncated, the antenna's frequency and radiation performance can be affected substantially [1], [2]. This is especially true when the ground plane dimensions are forced to be comparable to the patch size. Noghanian and Shafai [1] report significant changes in the radiation pattern of a microstrip antenna with a finite ground plane, in particular, increases in E-plane pattern beamwidth and decreases in H-plane pattern beamwidth as the ground plane extension from the patch becomes less than one-quarter free space wavelength. The patterns equalize at a point where the ground plane is between one-half and one wavelength in extent. In a similar experimental study, Sanad [2] also describes the effect of a finite ground plane and its role in directivity and radiation pattern, concluding that the overall directivity decreases as the dimension of the ground plane is reduced. Along with experimental studies, several researchers (e.g., [3] and [4]) have shown numerically that currents will develop along the outer boundary of a finite ground plane instead of within the projected center current distribution directly beneath the source. These currents result in spurious radiation manifested in diffraction of both leaky and surface waves.

To reduce the effects of these edge currents on antenna behavior, this work applies ideas used to reduce edge currents in compact range reflectors. Two popular methods to reduce these edge currents are blended rolled edges and serrations. Burnside and Lee [5] studied the performance tradeoffs between the two and concluded that the blended edges slightly outperform the serrations. However, given the planar nature of microstrip antennas, edge treatments should be planar to remain compatible with monolithic fabrication processes. Therefore, this paper investigates the use of serrations as an edge treatment for a microstrip antenna ground plane as a means of reducing the diffracted fields caused by the truncation.

The following section describes the serrated structures and the experimental design. Section III provides both measurements and simulations that show the effects of the ground plane serrations. Improvements in performance through ground plane edge serration include lower cross-polarization levels, increased beamwidth, and slight impedance tuning of the fundamental and higher order modes compared to the microstrip antenna on a simple finite ground plane.

II. Structure of Serrated Ground Plane

To demonstrate the effects of a serrated microstrip ground plane, three identical square ($L = W = 40.23$ mm) microstrip antennas designed for operation at 2.44 GHz are considered. Fig. 1 shows the geometries for the three antenna structures. Initially all three antennas reside on equal sized square dielectric slabs (Duroid® 5880 substrate, $\varepsilon_r = 2.2$, $h = 1.52$ mm) with unperturbed ground planes, SMA probe feeds identically positioned at $W/2$ and 13.4 mm from the edge in the L dimension, with the patch elements centered over their respective ground planes. The extension of the ground plane in all planar dimensions from the patch edges was fixed at a distance of $7h$ ($\approx \lambda_{\text{eff}}/10$). For two of the antennas, triangular serrations were then removed from the edges of the ground plane inward to create the three cases. The only dimension altered during the course of the experiment was the depth of the serration Δ_{serr} (measured from the outer edge of the ground plane toward the patch).

III. Antenna Performance

Figs. 2 and 3, respectively, show the simulated and measured return loss and measured impedance plot for the fundamental patch mode and the measured return loss for the next two harmonics. All simulations were performed using IE3D® [6]. The data demonstrates that both the impedance match and fundamental resonant frequency are moderately affected by the use of serrations. Slight frequency offsets between measurements and simulations arose from fabrication tolerances. In higher-order

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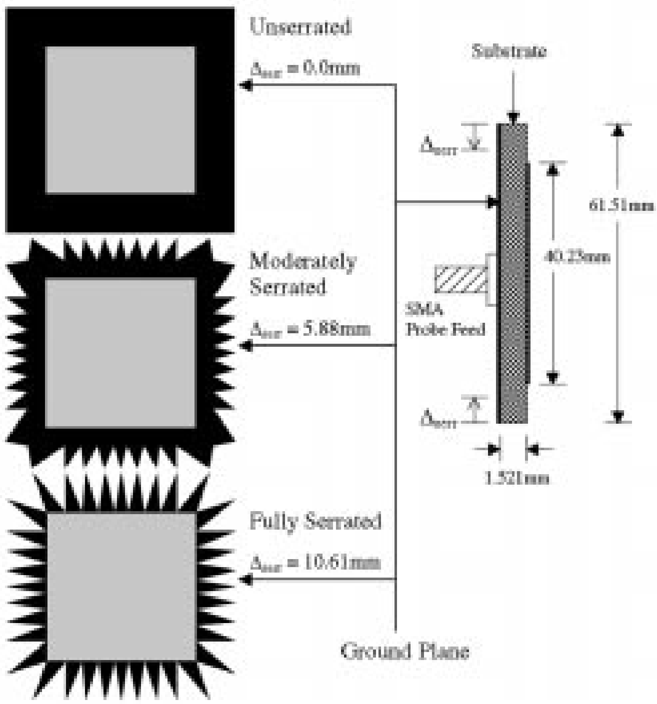

Fig. 1. Patch antenna with different serrated ground plane geometries.

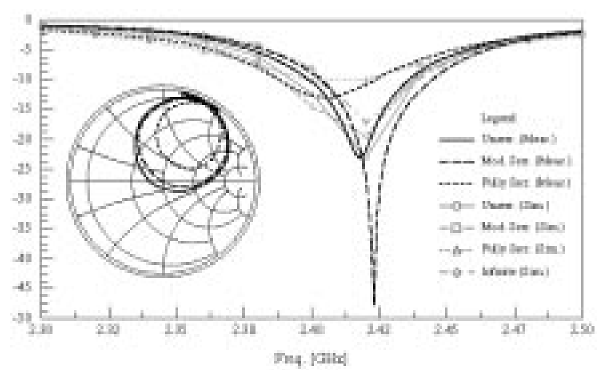

Fig. 2. Measured and simulated return loss (S_{11}) of first patch mode and measured impedance plots (inset) for three ground plane geometries.

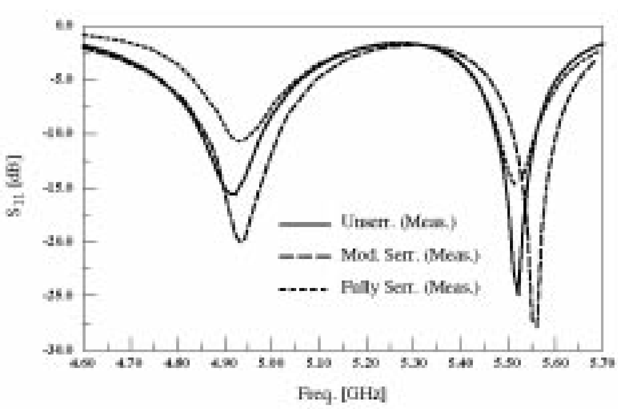

Fig. 3. Measured return loss (S_{11}) for second and third patch modes.

patch modes, the serrations also have an effect in that the patch with a moderately serrated ground plane is tuned to a better match as well as higher 2 : 1 VSWR bandwidth than that with

TABLE I

MEASURED 3, 8, AND 10 dB BEAM WIDTHS (IN DEGREES) FOR THE THREE ANTENNA CASES. SIMULATIONS OF AN IDENTICAL ANTENNA WITH AN INFINITE GROUND PLANE POSSESSED 3-dB BEAMWIDTHS OF (E-PLANE, H-PLANE) = (90.5°, 80.0°), 8 dB (173.3°, 173.3°), AND 10 dB (176°, 176°)

	Unserrated		Mod. Serration		Full Serration	
BW	E-Plane	H-Plane	E-Plane	H-Plane	E-Plane	H-Plane
3dB	86.44	84.03	93.41	83.05	105.53	83.18
8dB	149.4	143.41	166.68	146.04	198.19	140.13
10dB	172.12	164.2	190.86	165.14	227.34	157.83

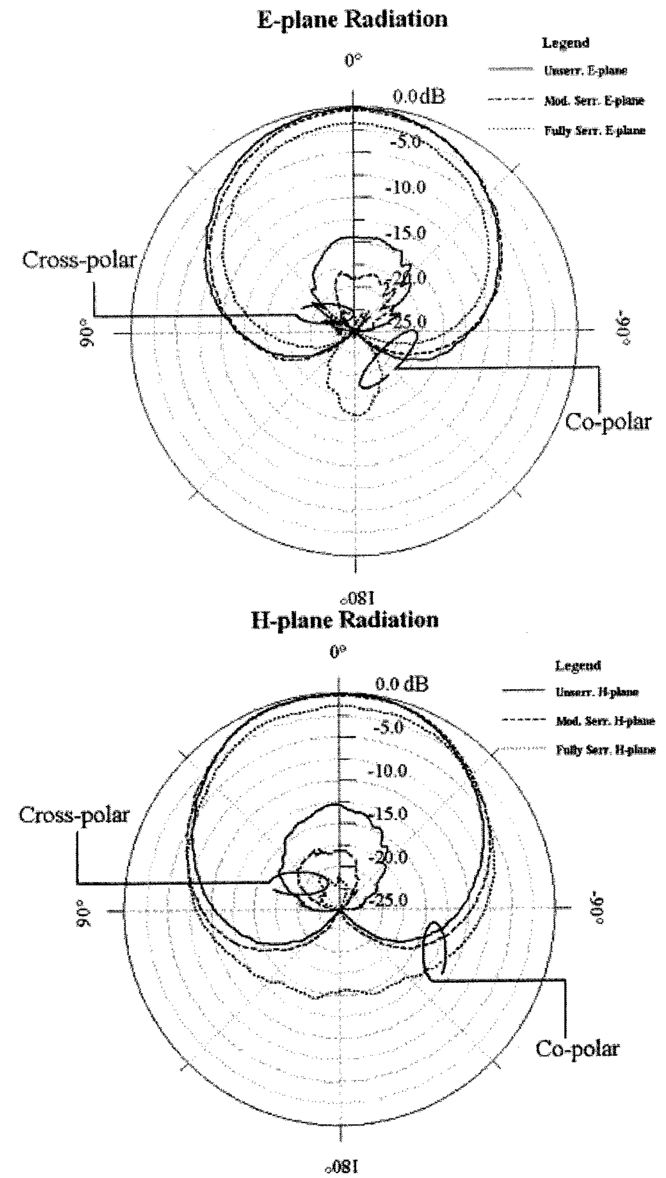

Fig. 4. Measured E- and H-plane co-polar and cross-polar radiation patterns.

the unchanged ground plane. However, the first resonant mode was the main focus of the study.

The most important effects of the serrated ground plane occur in the co- and cross-polar radiation patterns, described in Table I and Fig. 4. In the unserrated finite-ground-plane case, E- and H-plane patterns are equalized with a relatively equivalent shape as the angle approaches 90° from boresight. The effective dimensions of the ground plane decrease as the length of serrations increase, so the observed slight decrease in H-plane beamwidth and increase in E-plane beamwidth follow the conclusions of [1]. An important development not previously reported is the decrease in cross-polar radiation in both the E- and H-plane patterns as the length of the serration is increased. Fig. 4 depicts the decrease in the magnitudes of the cross-polar radiation patterns in both planes, with a decrease of more than 9 dB from unserrated to fully serrated. The energy previously in the cross-polar component appears to be distributed to both the forward and backplane directions.

IV. Conclusion

The results of this experimental and simulation study suggest that serrations in the finite ground plane can alter the performance of a microstrip antenna in several ways. The most significant effect is the considerable decrease in cross-polar radiation as the length of the serration is increased. This phenomenon may be due to the fact that the serrations along the edges of the ground plane act to diminish the circulating action of the currents along the outer boundary of the ground plane. Their presence creates a pseudopolarizing effect that translates into a significant decrease in cross-polar radiation. The energy previously in the cross-polar component appears to be distributed to both the forward- and back-plane directions, increasing the front-to-back ratio and decreasing the maximum gain slightly. Both the radiation and frequency response effects illustrated here provide a means to decrease the undesired effects of the finite ground plane and maintain higher polarization purity than that provided by a simple finite ground plane. The ground plane treatment can easily be integrated into antenna designs for portable wireless devices. This ground plane configuration is currently being examined to improve the axial ratios of circularly polarized patch antennas on finite ground planes.

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