# Micromachined Reconfigurable Out-of-Plane Microstrip Patch Antenna Using Plastic Deformation Magnetic Actuation

J.-C. Langer, J. Zou, C. Liu, *Senior Member, IEEE*, and J. T. Bernhard, *Senior Member, IEEE*

***Abstract*—A new reconfigurable out-of-plane microstrip patch antenna is presented. Using micromachining processes, a microstrip antenna designed for operation around 26 GHz is covered with a thin layer of magnetic material and released from the substrate. Application of an external dc magnetic field causes plastic deformation of the antenna at the boundary point where it is attached to the microstrip feed line, resulting in a patch positioned at an angle over the substrate. Frequency and pattern reconfigurability are demonstrated with measurements. Results indicate that versions of this structure may be used to expand or enhance the capabilities of traditional planar arrays.**

***Index Terms*—Micromachined antenna, out-of-plane antenna, reconfigurable antenna.**

## I. Introduction

Several researchers have proposed angled feed lines [1] or sloped substrates [2], [3] to achieve wider impedance bandwidths with microstrip antennas. However, all of these proposals require complicated and labor-intensive fabrication techniques to achieve the desired out-of-plane structure. One group has recently demonstrated a micromachined magnetically reconfigured frequency selectable surface that works by rotating an array of small monopoles [4]. We use a similar process, called plastic deformation magnetic assembly (PDMA) [5], to develop a new out-of-plane microstrip antenna that possesses a range of operating characteristics depending on the angle at which the structure resides.

The following section describes the antenna structure and the plastic magnetic deformation actuation. Section III provides measurements that illustrate the potential of this antenna to operate in a variety of operating frequency and radiation pattern modes. Section IV discusses several practical issues that need to be addressed before these antennas can be put into the field. Finally, Section V summarizes the work and offers directions for further research.

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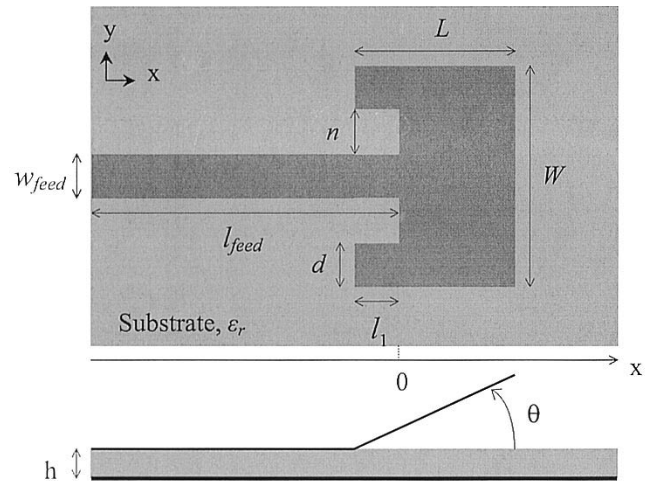


Fig. 1. Top and side views of a magnetically actuated out-of-plane microstrip antenna.

## II. Antenna Structure and Actuation

Fig. 1 depicts the basic antenna geometry. The glass substrate has a thickness of 600 $\mu$m with a relative permittivity of 2.16. The antenna has a length, $L$, equal to 4.46 mm and a width, $W$, equal to 5 mm. The inset feed position, $l_1$, is 1.4 mm with a notch width, $n$, equal to 1 mm. The feed line has a 50-$\Omega$ characteristic impedance with width, $w_{\rm feed}$, equal to 2 mm and length, $l_{\rm feed}$, equal to 11.1 mm.

The micromachining techniques and magnetic actuation that permit the patch to be elevated at an angle over the substrate are described in detail in [5]. The antenna is fabricated over a sacrificial layer residing on the substrate. A thin layer of magnetic material (permalloy) is then electroplated on the antenna surface. By etching away the sacrificial layer between the antenna and substrate, the antenna is released and connected only by its feed line. With no applied magnetic field, the structure remains in place. When an external field $H_{\rm ext}$ is applied, the flexible region created at the junction between the released and unreleased microstrip line is plastically deformed and the structure is bent by an angle $\theta$. After this plastic deformation, the antenna will remain at a certain rest angle $\theta_r < \theta$ above the substrate even after $H_{ext}$ is removed. A photograph of the bent antenna is provided in Fig. 2.

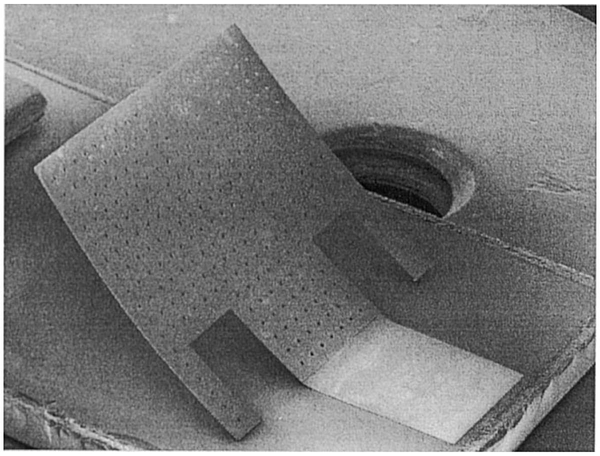

Fig. 2. Photograph of the out-of-plane microstrip antenna.

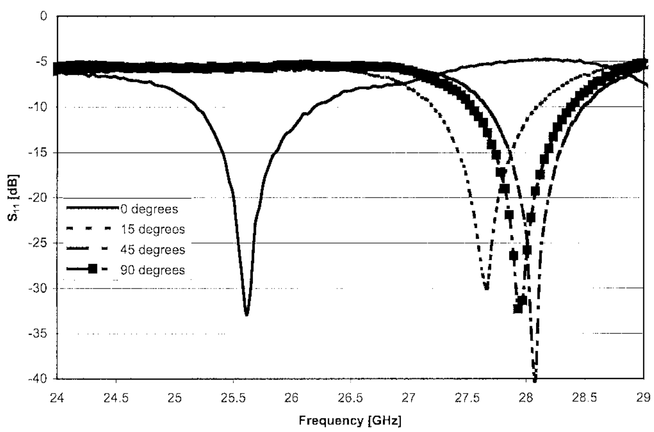


Fig. 3. Measured return loss for a number of patch bend angles.

## III. Measurement Results

Fig. 3 provides measured return loss for four angular positions of the antenna: 0°, 15°, 45°, and 90°. The unbent antenna operates at 25.6 GHz with a 1-GHz 2 : 1 VSWR bandwidth. As the antenna is bent over the substrate with angles less than 45°, its operating frequency increases due to the apparent reduction in electrical length caused by decreasing values of the structure's effective permittivity. Increases in operating frequency are continuous (i.e., smooth with no jumps) while the instantaneous bandwidth remains relatively constant. Changes are most dramatic for small angles (<15°) and increase much less quickly as the angle progresses toward 45°. As the bend angle exceeds 45°, the patch behaves more as a bent monopole or horn antenna and the operating frequency decreases slightly toward a final value of 27.9 GHz.

The measured return loss exhibits a relatively uniform loss of about 5 dB across the entire band that does not appear in finite-difference time-domain (FDTD) simulations (using XFDTD® from Remcom, Inc.) of the structure. This loss is caused by the resistive loading of the permalloy coating (conductivity of approximately $5 \times 10^6$ S/m) that could not be included in the simulations. In the measurements, an instantaneous 2 : 1 VSWR bandwidth of about 1 GHz is obtainable for a tunable range between 25.6 and 28 GHz. Simulated results that do not include the loss introduced by the permalloy layer achieve a lower instantaneous bandwidth of about 0.85 GHz and a slightly larger tuning range. Methods to mitigate the losses introduced by the permalloy are discussed in the next section.

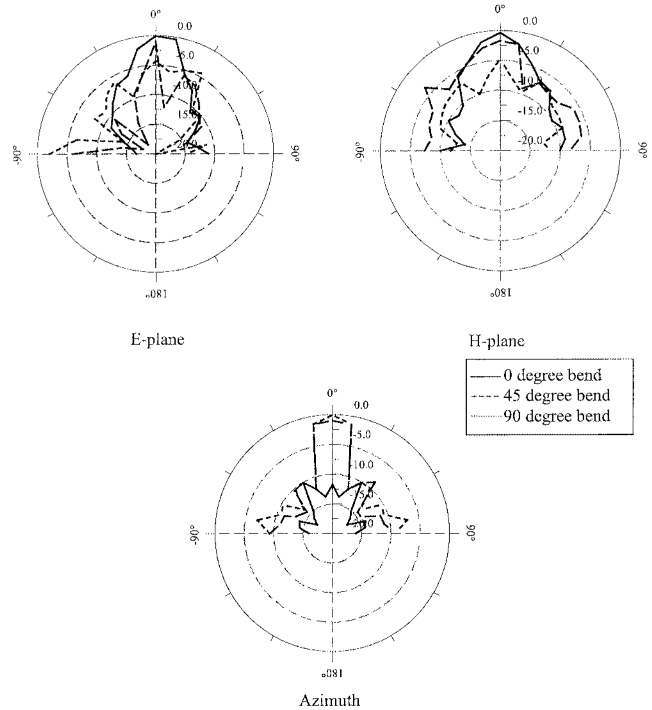


Fig. 4. Normalized measured co-polar radiation patterns in the $E$-plane, $H$-plane, and azimuth for three bend angles over the substrate. Cross-polar measurements (not shown here) are all at least 3 dB below co-polar measurements. The $-90°$ direction in the $E$-plane and the 0° in the azimuth are toward the unfed side of the antenna.

Radiation patterns were measured with a HP8510C vector network analyzer using a specially designed high frequency anechoic chamber. The chamber is equipped with a standard gain horn mounted to a rotating arm so that the antenna under test remained stationary during the measurements. Measurement planes ($E$-plane, $H$-plane, and azimuth) and polarizations (co-polar and cross-polar) are fixed and defined for a flat microstrip antenna and measurements were taken every 10°. Measured co-polar radiation patterns for the 0°, 45°, and 90° configurations are presented in Fig. 4. The cross-polar levels in all planes were at least 3 dB lower than the co-polar levels on boresight and are omitted to preserve readability of the graphs. The relatively poor cross-polarization performance may be due to the substrate's size and asymmetry for this particular antenna. The nonideal substrate size (which extended roughly 2 mm from each patch edge) and a slight substrate asymmetry were due to an uneven dicing of the antenna away from the rest of the fabrication substrate. Placement of holes in the patch's surface that allow the release of the patch from the substrate may also contribute to the cross-polar characteristics.

The co-polar patterns are appropriate for the 0° patch and exhibit a more pronounced end-fire characteristic as the patch is bent from 45° to 90°. In the $H$-plane, additional lobes appear at 45° and $-45°$, as the antenna behaves more like a monopole on a finite ground plane with increasing bend angle.

## IV. Discussion

The measurements presented in Section III illustrate the kinds of variability in both frequency and radiation characteristics that can be achieved with out-of-plane microstrip antennas. The results indicate that the patch's mode of operation changes from a microstrip radiator for angles up to 45° to that of a bent monopole or even a horn antenna for angles higher than 45°. The ability to easily construct low-profile but out-of-plane elements in an array can be used to widen the operating bandwidth and/or obtain desirable modes of operation not usually obtained with traditional planar arrays.

While this work demonstrates the capabilities of magnetically-actuated antenna tuning, it also raises several important practical issues. First, the plastic deformation method used here is not ideal for continuous tuning over the lifetime of the antenna since it will eventually result in stress failure at the joint. This particular method is more suitable for a small number of reconfigurations.

Second, the strength of the external magnetic field necessary to bend the patch is directly related to the size of the structure. This limits both the antenna size and the deployment scheme (i.e., bending in-plant or *in situ* on a platform). While resident magnetic field sources may prove to make the structure too heavy and bulky, future in-plant production could pass an array over a long magnetic strip to actuate each row uniformly. The elements could then be fixed in position with a nonconductive coating in a final processing step.

Third, the presence of the magnetic material on the patch causes significant losses. We are currently developing alternate actuator designs that separate the magnetic material and patch as well as fabrication processes to remove the magnetic material and fix the antenna position after final tuning is complete.

## V. Conclusion

A new micromachined out-of-plane reconfigurable microstrip antenna that uses plastic deformation magnetic assembly has been demonstrated. This structure offers a wide range of frequency and radiation behavior that could be used to enhance the capabilities of planar arrays.

A number of areas of investigation related to this structure are currently underway. First, a design model is being developed to predict the characteristics of the antenna as a function of geometry and bend angle. Additionally, we are developing new fabrication processes and actuation designs that will help to mitigate the effects of the magnetic material on antenna operation and allow continuous reconfiguration after deployment.

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