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Physical Realization and Reflection Phase Characteristics of a Flexible High Impedance Surface

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***Abstract*—This paper presents the fabrication and reflection phase measurements of a flexible high impedance surface (FHIS). The surface is fabricated by using DuPont pyralux polyimide as the substrate. Cyanoacrylate is used to adhere the samples of polyimide. The reflection phase response of the FHIS, which is curved in the form of a cylinder, is measured in the anechoic chamber and compared with that of the flat FHIS. As expected, reflection phase characteristics of the curved FHIS are polarization dependent and slightly different than those of the flat one. The measured reflection phase characteristics of the curved FHIS will be compared with simulations which presently are under consideration.**

I. Introduction

High impedance surfaces (HIS) have been widely used in antenna applications as artificial ground planes for more than a decade because of their unique electromagnetic properties. It has been reported that HISs are very efficient to improve the radiation performance of antennas within a certain bandwidth [1]. In addition, they are extensively employed in the low profile antenna designs.

Another emerging research topic that began to arouse the interest of the researchers is the design of flexible antennas that can conform with any types of surfaces and operate in harsh environmental conditions. Indeed, in the literature, there are a few examples of flexible antenna designs with different flexible substrates [2]- [4].

The physical properties of flexible antennas make them promising candidates for conformal antenna applications. On the other hand, the successful results obtained by HISs in the radiation performance improvement and low profile antenna realizations enhanced their utilization in radiating systems. The combination of these two facts together with the increasing interest in flexible antennas led the authors to a quest of a conformal artificial ground plane, referred to as flexible high impedance surfaces (FHIS).

Reflection phase characteristics of a HIS, for a plane wave incidence, can be obtained numerically by employing the periodic structure of HIS with reasonable computational resources. Instead of modeling the entire structure, a single unit cell with appropriate boundary conditions can be used to compute the reflection phase response [1]. However, this approach cannot be utilized for a FHIS which has an arbitrary shape. Because, in this case either the surface geometry or the incident field is aperiodic, depending on the selection of the coordinate system. For such a problem, there are three ways to obtain the reflection phase of a FHIS.

- To model the entire structure.
- To use special numerical methods particularly developed for this problem.
- To perform measurements.

Modeling of the entire structure can be computationally intractable because of the electrical dimensions of the problem. There are some numerical methods developed for the radiation problem from a periodic structure excited by aperiodic sources [5], [6]. However, since such codes are not readily available, it can be time consuming to implement these codes. Therefore, at the present time, the most convenient approach is to perform measurements. This will be followed by modeling and simulations to the the extent possible. Indeed, the basic motivation of this paper is this discussion. Furthermore, to the authors' knowledge, the reflection phase characteristics of a non-planar HIS have not been reported previously. Similarly, this is the first time where fabrication of a FHIS is reported.

The organization of this paper is as follows. In the second section, the basic properties of the flexible dielectric and fabrication process is explained. Then, the measurement setup and procedure are discussed. In fourth section, the measurement results are reported for the case of a FHIS which is curved in the form of a cylinder and the reflection phase response of the FHIS is compared to that of the flat one for different incident field polarizations. Finally concluding remarks are summarized.

II. Physical Realization of the FHIS

The fabrication process of the FHIS started with an investigation of an appropriate flexible material. After an extensive survey, *Pyralux polyimide* substrate of *DuPont Corporation* [7] was selected as the dielectric substrate of the FHIS. This was a 10 mil($\sim$ 0.254mm)-thick substrate with 2.0 oz copper cladding on both sides. It is known that the bandwidth of a HIS depends on the thickness of the substrate. The thickness of the ployimide, resulting in a narrow bandwidth, makes it inconvenient for X-band (8-12 GHz) operations. Hence, to improve the bandwidth of the FHIS, it was suggested to glue two samples of polyimide on top of each other after removing the copper cladding on one side of each sample. For this purpose, *super glue (cyanoacrylate)* was employed to adhere the samples. Together with the adhesive, the thickness of the of the new substrate became 25 mils ($\sim$ 0.635mm) which can result in a practical bandwidth. Fig. 1 illustrates a schematic drawing of this new substrate.

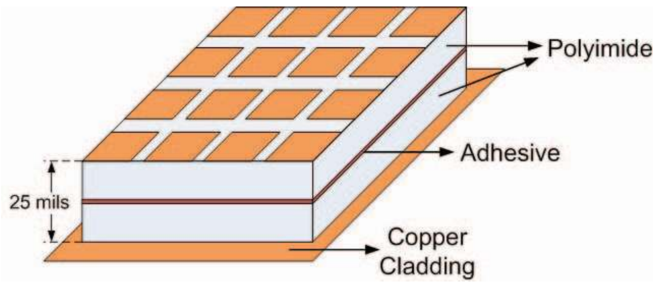

Fig. 1. Schematic drawing of the FHIS after the adhesion of the two samples and chemical etching.

Another issue regarding the polyimide and the adhesive is their electrical properties. The relative permittivity of polyimide is known to be 3.5. However, there is not accurate information about the relative permittivity of the adhesive. According to the limited and rough data, the relative permittivity of the cyanoacrylate was considered to be around 4. During the numerical simulations, cyanoester, with a relative permittivity of 3.8, was used to model the adhesive.

The periodic geometry of the FHIS, which is composed of square patches, was obtained by photolithography which is similar to making photographic contact prints. A negative of the image (the copper "artwork") was generated on a transparent film. This was referred to as the "mask". The mask was placed on top of the photo-sensitized substrate, which was then exposed to UV light. The substrate was "developed" to harden the parts of the "photo-resist" that were exposed, and then washed to remove the parts of the photo-resist that were shielded from the light by the mask. Finally, the copper cladding of the substrate that is not covered by the photo-resist pattern is chemically etched away. The finalized FHIS is shown in Fig. 2.

III. The Measurement Setup and Procedure

There are two possible ways to measure the HIS reflection phase. In one method, a dimensionally small HIS consisting of a small number of cells is placed in the cross section of a waveguide. Since the images of the HIS in the conducting walls of the waveguide simulate an infinite array of cells, the cross sectional dimensions of the waveguide must be exactly equal to an integral number of HIS cells plus one inter-cell spacing (1/2 on either side of the sample). This would require the construction of custom waveguide sections and transitions because conventional half-octave waveguides (WR-90 X-band, for example) do not have square or 2:1 aspect ratio cross sections.

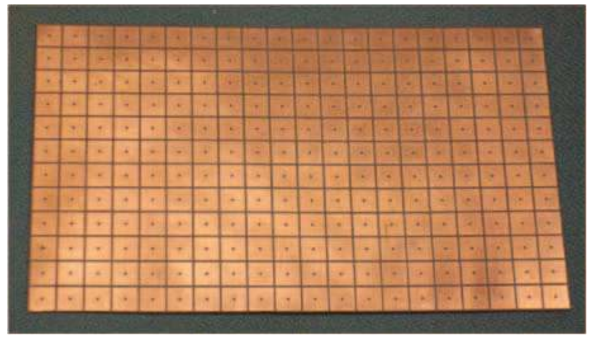

Fig. 2. FHIS after photolithography and chemical etching.

The other method of measuring the reflection phase involves measuring the free-space, broadside RCS of the HIS. This is the method that was used in this study. The measurements were performed at the Electro Magnetic Anechoic Chamber (EMAC) of Arizona State University (ASU).

First, a 6″-length of PVC pipe having a diameter of 6″ was cut in half. The back side of the cylinder is removed so that there will not be a reflection from it when measuring the empty fixture for the background subtraction. Then, in the center of one of the halves, an aperture was cut. The FHIS is then taped to the fixture as shown in Fig. 3. Note that this is an aggressive level of curvature. Then, an aperture was cut in a piece of microwave absorber, slightly smaller than the dimensions of the HIS. The piece of the observer was carved out of a solid block to reasonably fit the curvature of the FHIS. The purpose of this absorber was to minimize diffraction effects by shadowing the edges of the FHIS.

After finishing the measurement setup, the FHIS was placed at the quietest location in the chamber and the measurements were performed. Three scattering measurements as a function of frequency were collected: one of the FHIS, one of the empty absorber fixture, and one in which a flat aluminum plate was inserted into the fixture instead of the FHIS. The scattering of the empty fixture was subtracted from both the plate and the FHIS measurements. The resulting measurements were then time-domain gated to remove the effects of feed horn coupling and scattering from the compact antenna test range reflector. Finally, the FHIS measurement was normalized by the plate measurement.

IV. Measurement Results

The measurements were initiated with reflection phase of the flat FHIS to verify the validity of the design. These results were also used as a reference in the comparison of flat and curved cases.

The FHIS was designed to operate around 9.0 GHz when it is flat. The FHIS was composed of periodically laid square patches of 7.9 mm width and 0.5 mm proximity. However, the measured center frequency of the flat FHIS was 9.1 GHz. The measured and simulated reflection phase responses of the

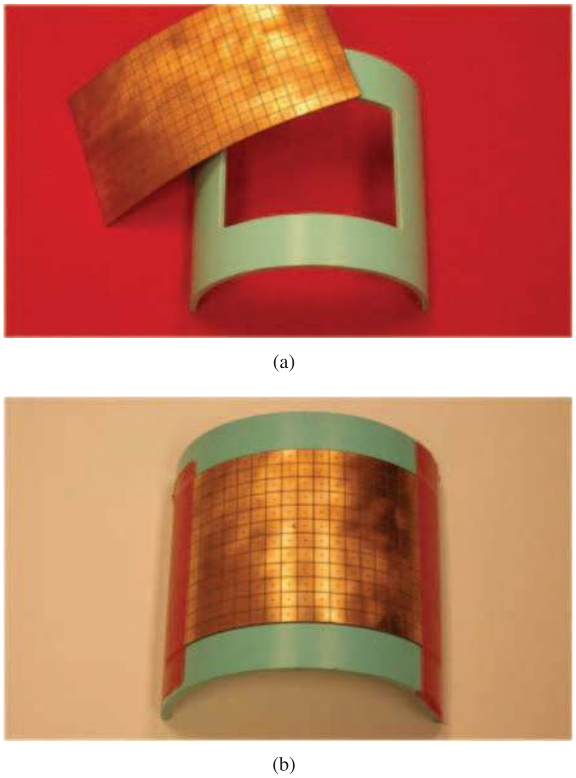

Fig. 3. Photographs of the PVS pipe and the FHIS. (a) An aperture was cut out from the PVC pipe. (b) The FHIS was taped on the PVC.

flat FHIS are compared in Fig. 4. The differences between the simulations and measurements can be attributed to the inaccuracies in the relative permittivity of the adhesive, because of limited data, and the imperfections in the fabrication process.

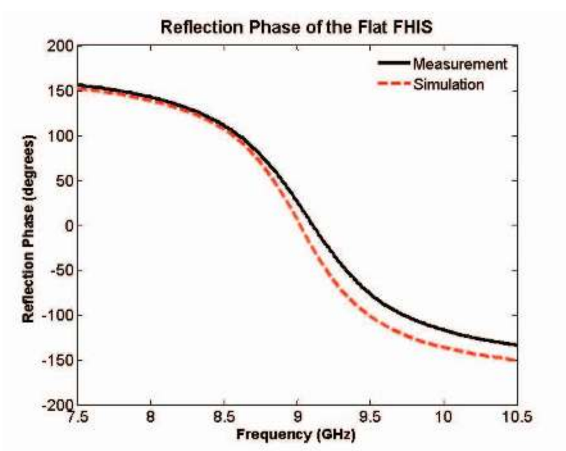

Fig. 4. Comparison of the measured and simulated reflection phase response of the flat FHIS.

After the measurements of the flat FHIS, the reflection phase of the curved FHIS was measured by following the aforementioned procedure. Although the reflection phase of a flat HIS with square patches is polarization independent, this is not true for a curved HIS because a curved surface is not symmetric. Hence, the curved measurements were performed for two polarizations: perpendicular and parallel to the axis of the cylinder. The results are illustrated in Fig. 5. It is apparent that the reflection phase responses of the curved and flat FHIS are different, as expected. The results of these experiments are also summarized in Table I.

TABLE I
THE CENTER FREQUENCIES AND BANDWIDTHS FOR THE THREE FHIS CONFIGURATIONS

	Center Frequency (GHz)	Bandwidth (MHz)
Flat	9.10	945 (10.38%)
Curved (Perpendicular Pol.)	9.02	907 (10.06%)
Curved (Parallel Pol.)	8.97	880 (9.81%)

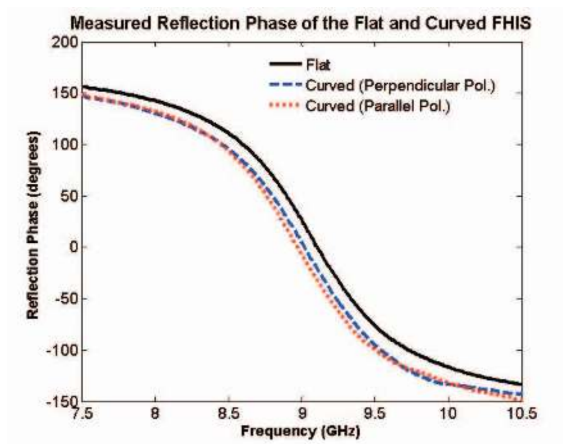

Fig. 5. Comparison of the measured reflection phase response of the flat and curved FHIS for different polarizations.

It can be observed that, for both polarizations, the center frequency and the bandwidth of the curved FHIS are lower than the flat one. On the other hand, the response of the curved FHIS for perpendicular polarization is closer to the response of the flat FHIS. There are several mechanisms contributing to this result. Since our surface is curved, the angle of incidence at each point of the surface is different i.e. the surface impedance, with respect to the direction of propagation, of the FHIS is different at each point. Moreover, the impedance of the free space is dependent on the type of polarization of the incident wave and the angle of incidence. Therefore, the overall response of the surface is determined by the relationship between the free space impedance and surface impedance of FHIS for different polarizations and radii of curvature [8].

V. CONCLUSION

A flexible high impedance surface was fabricated and its reflection phase characteristics were measured. DuPont pyralux polyimide was selected as the flexible substrate. In order to improve the bandwidth of the FHIS, the thickness of the substrate was increased by adhering two samples of the material. Cyanoacrylate was used as the adhesive.

The reflection phase response of the FHIS, which was curved in the form a cylinder, was measured in the EMAC of ASU. It was observed that the reflection phase of the curved FHIS is polarization dependent. The center frequency and the bandwidth of the curved FHIS was slightly lower than those of the flat one for both polarizations. It was also observed that the center frequency and the bandwidth of the curved FHIS were slightly higher for perpendicular polarization.

As it was done for the flat case, the measured reflection phase characteristics of the curved FHIS will be compared with simulations which presently are under consideration.

ACKNOWLEDGMENT

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