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High Impedance Surface as an Antenna Without a Dipole on Top

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Abstract—This paper presents a fully planar antenna based on a metamaterial consisting of a planar array of dogbones. The unit element of this high impedance surface (HIS) is composed of a layer with dogbone shaped conductors on top of a thin dielectric substrate backed by a metal ground plane. A HIS as an intermediate-gain antenna at C band is demonstrated. Previously, HISs have been employed in order to improve the radiation performance of antennas on top of them, this yields to low profile planar antenna applications. In this paper the idea is to eliminate the antenna above the HIS and instead use the HIS itself as an antenna. The direct use of a HIS as an antenna thus allows designing even thinner antennas. The leaky wave modes supported by this kind of metalayer have been previously demonstrated, and the main principle of this HIS antenna is the excitation of such modes in the finite array of dogbones to achieve broadside radiation. Various ways of exciting this antenna are explained and radiation patterns are given as simulation results. Also antennas in various sizes are compared with respect to the broadside gain.

Keywords—planar metamaterial layer; leaky waves; high impedance surface; metamaterials;

I. INTRODUCTION

Artificial magnetic conductors (AMCs) are used in antenna applications to improve radiation performance [1]. High impedance surfaces (HISs) are an example of AMCs that are helpful in the search for low-profile planar antennas with increased broadside directivity. High impedance surfaces with sub-wavelength thickness help to miniaturize antennas. An electrically conductive plane can hinder thin planar antenna solutions by producing image currents that destructively interfere with the radiating currents on the antenna. In principle AMCs support image currents that have the same phase as the overlaying antenna, thus resulting in constructive interference of the radiated fields and enhanced radiation performance. This paper proposes using a HIS structure itself as an antenna, rather than using the HIS to improve the radiation performance of other types of antennas. This is because it has been observed in various simulations that a HIS exhibits radiation phenomena. This proposed antenna, an AMC without a dipole on top, has an even lower profile than the dipole over an AMC, and can be fabricated by using only two metal layers: the ground and the patterned array structures on top. This antenna can be fed at

various locations as shown in this paper. A similar idea has been investigated in [2].

In [3, 4] it has been shown that a metalayer made of paired dogbones exhibits a “magnetic resonance” due to the anti-symmetric current distribution. Because of the image principle the magnetic resonance corresponding to the anti-symmetric mode is related to the HIS properties, as also noticed in [1]. Since each element is resonating with a significantly high quality factor, closely spaced resonators are also excited, and the radiated field can be interpreted as provided by the electric field across the gaps.

Alternatively, in-plane modal analysis of a metalayer carried out in [5] establishes that the metalayer supports surface waves, proper and improper leaky wave modes with anti-symmetric current distribution. Therefore the AMC supports possible leaky wave modes that contribute to the radiation of this antenna.

The usage of a HIS as an antenna can result in thinner low-profile planar antennas. Though this antenna is not made by a CRLH (Composite Right-/Left-Handed) transmission line metamaterial as those shown in [6, 7], there is still a relation with those shown there. Indeed, even though for the sake of comparison the AMC considered here is exactly the same as that in [1], this antenna could be modeled as a transverse (leaky) transmission line with series capacitors.

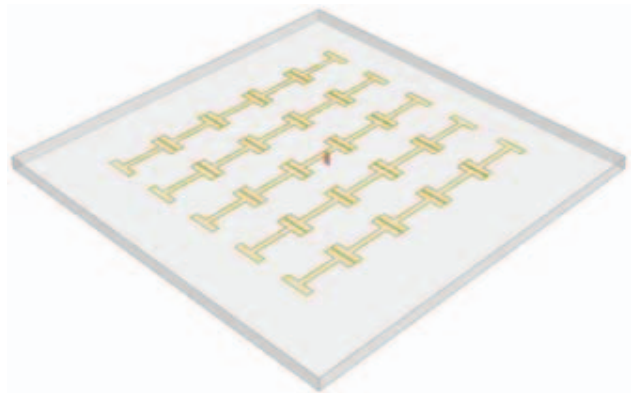


Figure 1. HIS antenna consisting of arrayed dogbones over a ground plane, with one element fed by lumped port. There is no dipole on top.

II. ANTENNA DESIGN

The antenna is designed to achieve broadside radiation by the excitation of the central dogbone in the array. The antenna is composed of an array of metal dogbones on top of a thin dielectric slab with a metal ground plane below, as illustrated in Figure 1 and Fig. 2. This structure was used previously as an HIS to improve the radiation properties of a folded dipole in [1].

Broadside radiation from leaky wave antennas is discussed in [8]. The total radiation from leaky waves traveling in opposite directions on the surface is able to create a single broadside beam. The broadside beam is on the verge of splitting into two beams when the phase constant and attenuation constant of the radiating mode are equal. This condition does not only govern the broadside radiation frequency of two leaky waves in opposite directions but also indicates the magnetic resonance frequency [5]. The frequency band containing the magnetic resonance is thus important for leaky waves radiating at broadside.

Various ways of feeding the antenna are demonstrated here. The methods of feeding are compared to investigate the possibility to improve the input match and radiation pattern. Also the input impedance, gain and radiation patterns of various HIS sizes are compared.

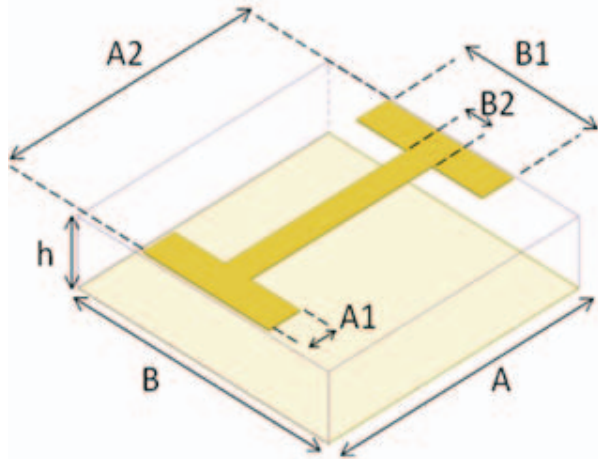


Figure 2. The unit element dimensions ($A=B=7\text{mm}$, $A1=0.683\text{mm}$, $A2=0.875\text{mm}$, $B1=3.5\text{mm}$, $B2=0.7\text{mm}$, $h=1.6\text{mm}$, metal thickness: $35\mu\text{m}$)

A. Feed Methods Utilized in Simulations

The simulations are carried out in Ansoft HFSS and the implementations of different types of feed mechanisms are examined. To feed the antenna, the center dogbone in the arrays is driven via one or two lumped ports.

The various feeding methods are illustrated in Figure 3. The center dogbone is excited by lumped ports between the stem of the dogbone and ground plane, or differentially between dogbones or inside the center dogbone. The excitation of the waves in a symmetrical manner is important to achieve broadside radiation. The feeding methods are briefly explained as follows:

- (a) Shunt asymmetric excitation: one lumped port from the ground plane to the dogbone, located off the center of the dogbone.
- (b) Shunt anti-symmetric excitation: two lumped ports from ground plane to the dogbone. The ports are equidistant from the center of the dogbone and the excited with a phase difference of 180° .
- (c) Series excitation in the gap between dogbones: one lumped port between two adjacent dogbones in the center of an array is used.
- (d) Series excitation splitting the dogbone: the central part of the dogbone is split into two parts and a lumped port is inserted into the gap. The excitation is anti-symmetric if the port is at the center of the dogbone and asymmetric if the port is not at the center. The asymmetric case is studied.

To guarantee the symmetry of the radiation pattern, the number of elements in the array is set to 8×7 for the case in which the lumped port excitation is placed between two adjacent dogbones at the center of the array, and is set to 7×7 for the other types of feeding.

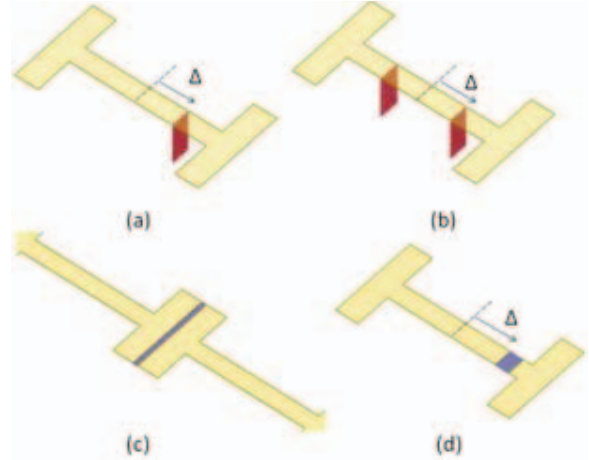


Figure 3. Various feed types (a) shunt asymmetrically placed port (b) shunt anti-symmetrical two ports (c) series port connecting two dogbones (d) series port inside dogbone)

In Figure 4, the input impedance is plotted against frequency. The real and imaginary parts of the impedance for different types of feeds are examined to have an idea about matching at the antenna input port. The input resistance values vary over a wide range in the 5-8GHz interval. The shunt anti-symmetric feed and series feed in the gap between two dogbones exhibit similar behavior and crosses the 50Ω line at around 6.8GHz, while other feeding methods have very low input resistance. The input reactance of the shunt anti-symmetric feed is inductive dominantly throughout the frequency range of the simulations, while input reactance values of the series feed inside the dogbone and the shunt asymmetric feed stay capacitive. The series port connecting two dogbones is capacitive from 5GHz up to 6GHz, turning inductive thereafter. The input resistance is the most important

parameter for matching and has significant values for the frequencies higher than 6GHz. However the input reactance stays around manageable values for series feeding.

B. The Radiation Pattern and Gain of the HIS Antenna

Dependence of the gain on array size and frequency was also studied, and the unit elements are combined in array configurations of 3×3, 5×5 and 7×7 elements.

This radiation pattern plots are given for the feed type (b) – shunt anti-symmetric excitation- by setting the phase difference of the ports properly (**Error! Reference source not found.**). The two lumped ports located symmetrically on either side of the central dogbone are called the anti-symmetrical ports to put emphasis on the excitation with 180° difference.

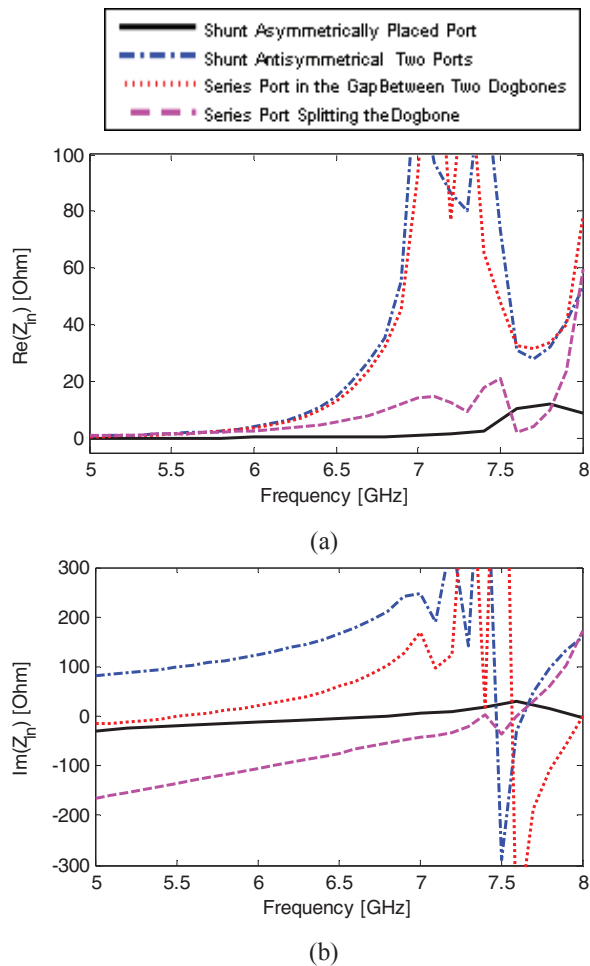


Figure 4. Comparison of the real and imaginary parts of the input impedance with respect to different types of feeding methods.

The accepted gain pattern for co-polarized component of 3×3, 5×5, and 7×7-element arrays at 6.6GHz is provided in Figure 6 for both E- and H-planes. The radiated field is polarized along the stem of the dogbones. The accepted gain in broadside is 7.28dB, 8.45dB, and 8.84dB at 6.6GHz respectively for 3×3, 5×5, and 7×7 arrays.

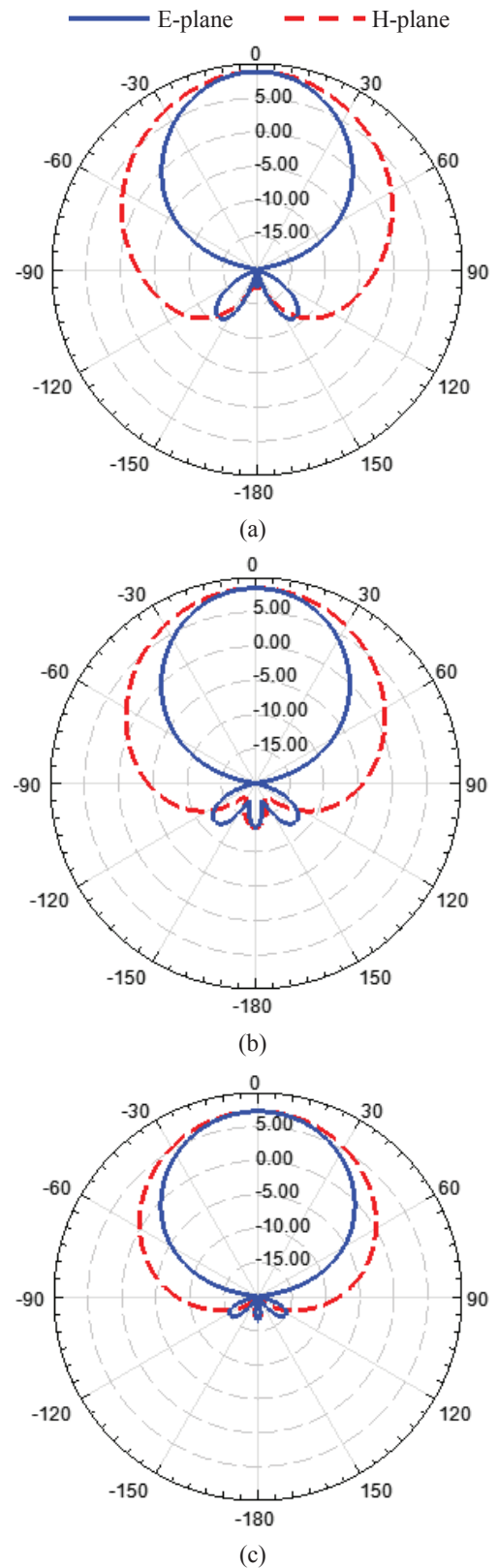


Figure 5. The accepted gain pattern in E- and H-planes at 6.6GHz of an HIS antenna made of (a) 7×7, (b) 5×5, (c) 3×3 array of dogbone elements.

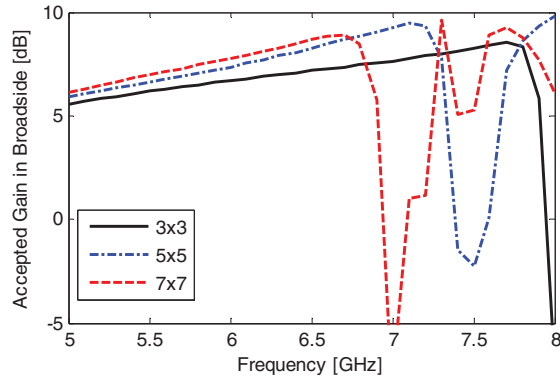


Figure 6. Accepted gain at broadside versus frequency for different dimensions (number of element) of the HIS.

The accepted gain in broadside versus frequency is provided in Figure 6. The broadside gain improves with respect to increased frequency up to some specific frequency for each array size, and then a sharp decrease in gain is observed due to deformations in the radiation pattern. This decrease in broadside gain is mainly due to splitting of the beam in E-and/or H-planes. It is clear that the frequency, at which loss of gain occurs, tends to decrease as the number of elements in the array increases. This fact points to resonant characteristics related to the size of antenna. It should be noted that the shape of the radiation patterns are preserved up to the frequencies where the broadside gain is prone to sharp decreases.

III. CONCLUSIONS

The HIS surface of dogbone shaped conductors is a promising low-profile thin antenna. Accepted gain of 7 dB is achieved. The input matching conditions are to be satisfied to utilize this HIS as an antenna. Integration of the dogbone elements with active circuit components may even improve the abilities of this antenna. Electronic beam forming and smart antenna applications are also possible future applications. This structure thus proposes an easy-to-fabricate, versatile antenna type.

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