

SAND REPORT

SAND2010-6663

Unlimited Release

Printed September 2010

Meandered-Line Antenna with Integrated High-Impedance Surface

Michael A. Forman

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia National Laboratories is a multiprogram laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Approved for public release; further dissemination unlimited.



Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government, nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represent that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof, or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof, or any of their contractors.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865) 576-8401
Facsimile: (865) 576-5728
E-Mail: reports@adonis.osti.gov
Online ordering: <http://www.doe.gov/bridge>

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd
Springfield, VA 22161

Telephone: (800) 553-6847
Facsimile: (703) 605-6900
E-Mail: orders@ntis.fedworld.gov
Online ordering: <http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online>



Meandered-Line Antenna with Integrated High-Impedance Surface

Michael A. Forman
Sandia National Laboratories
P.O. Box 969
Livermore, CA 94551-0969 USA
Michael.Forman@Sandia.GOV

Abstract

A reduced-volume antenna composed of a meandered-line dipole antenna over a finite-width, high-impedance surface is presented. The structure is novel in that the high-impedance surface is implemented with four Sievenpiper via-mushroom unit cells, whose area is optimized to match the meandered-line dipole antenna. The result is an antenna similar in performance to patch antenna but one fourth the area that can be deployed directly on the surface of a conductor. Simulations demonstrate a 3.5 cm ($\lambda/4$) square antenna with a bandwidth of 4 % and a gain of 4.8 dBi at 2.5 GHz.

Acknowledgment

Sandia National Laboratories is a multiprogram laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Contents

Introduction.....	7
High-Impedance Surface.....	7
Meandered-Line Dipole Antenna.....	10
Integrated Topology.....	11
Conclusion.....	12

Figures

1	Sievenpiper high-impedance-surface with unit cell dimensions.....	8
2	Fabricated high-impedance surface.....	8
3	Meandered-line dipole geometry.....	10
4	Meandered-line dipole current density and far-field radiation pattern.....	10
5	Four unit-cell HIS and integrated meandered-line dipole antenna.....	11
6	MLA with integrated HIS current and far-field radiation pattern.....	12

Tables

1	Design parameters for the high-impedance surface.....	9
---	---	---

This page intentionally left blank

Meandered-Line Antenna with Integrated High-Impedance Surface

Introduction

Due to the miniaturization of wireless systems, antennas are being reduced in volume and placed in close proximity to other system elements. In these configurations novel topologies are required to both maximize gain and minimize near-field coupling. Antennas incorporating Sievenpiper high-impedance electromagnetic surfaces [1] are capable of providing such performance improvements and thus enabling reductions in volume [2] and flexible methods of deployment.

A high-impedance surface (HIS) is an electrically thin in-phase reflector which provides surface-wave suppression. Within a given frequency band the currents from a near-by antenna and its image are in phase, as opposed to being 180° out of phase as with standard conductors. Furthermore, because surface waves are suppressed, power loss through the dielectric is minimized. These two properties result in a net increase in radiation efficiency from the use of a HIS as compared to a standard conductor.

A Sievenpiper high-impedance surface is implemented by means of a via array in a dielectric with capacitive patches on top. The vias and patches provide lumped-circuit equivalents that are modeled as a parallel resonant circuit. The geometry and thus the lumped-circuit equivalents are tuned to exhibit a high impedance over a predetermined frequency band. This structure is not a photonic band gap (PBG) material, in that it does not suppress surface waves through Bragg scattering from a periodic unit cell, thus unit cells can be a fraction of the free-space wavelength. The structure is instead a composite right/left-handed (CRLH) metamaterial whose subwavelength unit cells act as a homogeneous effective dielectric.

In the following work a novel antenna topology is presented. A meandered-line dipole antenna is placed over a finite-width, high-impedance surface. The high-impedance surface is implemented with just four Sievenpiper via-mushroom unit cells, whose dimensions are optimized to match the meandered-line dipole antenna. The result is an antenna similar in performance to patch antenna but one fourth the size that can be deployed directly on the surface of a conductor. Applications include electrically small RFID tags which are deployed on conductive surfaces.

High-Impedance Surface

Surface impedance can be modeled as a parallel resonant circuit that is tuned to exhibit high impedance over a predetermined frequency band [1]. In reference to the geometry shown in Figure 1, fringing electric fields between adjacent top patches can be represented as a capacitance and magnetic fields in the dielectric generated by current through the vias and ground can be represented as an inductance. A sheet impedance can be defined to be equal to the impedance of the

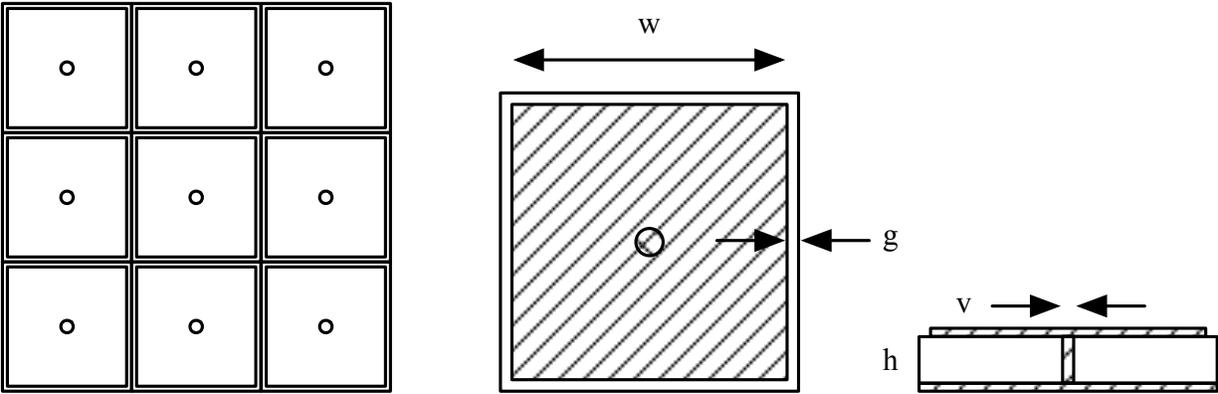


Figure 1. A Sievenpiper high-impedance-surface unit cell with dimensions marked. Because resonant frequency is a function of the edge capacitance, a minimum of four cells are required for the surface to function as a high-impedance surface.

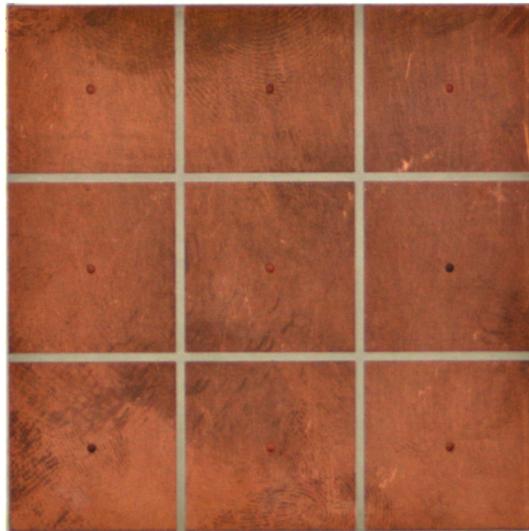


Figure 2. A three-by-three high-impedance surface fabricated from RT/Duriod 6006, used for testing of dipole integration.

equivalent parallel resonant circuit

$$Z = \frac{j\omega L}{1 - \omega^2 LC} \quad (1)$$

Table 1. Design parameters for the high-impedance surface.

Parameter	Value
Substrate	RT/Duroid 6006
ϵ_r	6.15
h	2.54 mm
t	8.5 μm
w	18.2 mm
g	1.0 mm
v	1.0 mm
f_0	2.45 GHz

High impedance occurs near the resonant frequency, ω_0 , where

$$\omega_0 = \frac{1}{\sqrt{LC}}. \quad (2)$$

This frequency marks the center of the high-impedance surface's forbidden frequency bandgap.

At frequencies far from the resonant frequency the high-impedance surface behaves like a conductor. Thus an antenna in parallel with the surface will be mirrored by an opposing current on the surface, reducing its radiation efficiency. At the resonant frequency an antenna lying parallel will be mirrored by an in-phase current on the surface, increasing its radiation efficiency.

The bandwidth of the high-impedance region is defined as the frequencies, where the radiation drops to half of its maximum value and occurs where the surface impedance is equal to the impedance of free space. For normal radiation, one has the following equation

$$\left| \frac{j\omega L}{1 - \omega^2 LC} \right| = \eta. \quad (3)$$

Solving for ω , eliminating higher-order terms in light of realistic values of L and C , and, given that $Z_0 \ll \eta$, the stop band can be approximated by

$$\omega = \omega_0 \left(1 \pm \frac{1}{2} \frac{Z_0}{\eta} \right), \quad (4)$$

which is the range, over which an antenna radiates efficiently on a high-impedance surface. The total bandwidth is approximately equal to the characteristic impedance of the surface divided by the impedance of free space. This is the bandwidth over which the reflection coefficient falls between $\pm 90^\circ$ and represents the maximum usable bandwidth for a parallel antenna over a resonant surface.

The surface fabricated in the following work is designed using previously published values [3, 4] to operate at 2.45 GHz and simulated to verify performance. The substrate is fabricated on Rogers RT/Duroid 6006, with a unit cell approximately 20 mm ($\lambda/6$) square. The simulated bandwidth is 12%. Values are summarized in Table 1 and the fabricated substrate is shown in Figure 2.

Meandered-Line Dipole Antenna

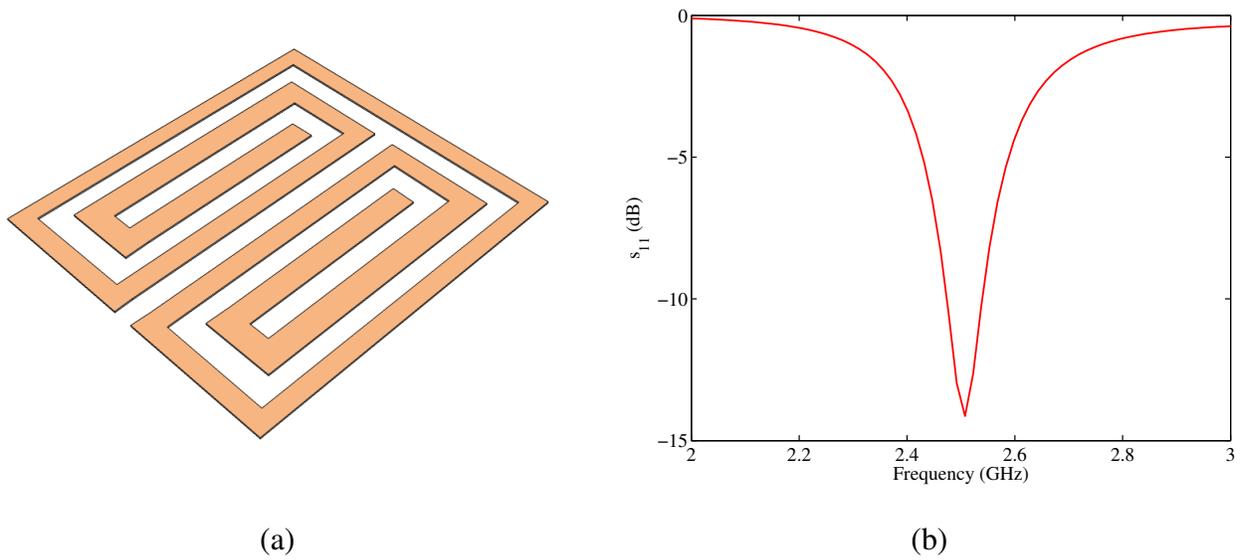


Figure 3. Meandered-line dipole geometry (a) and the simulated frequency response (b). The return loss is -14 dB and bandwidth is 6% at 2.5 GHz.

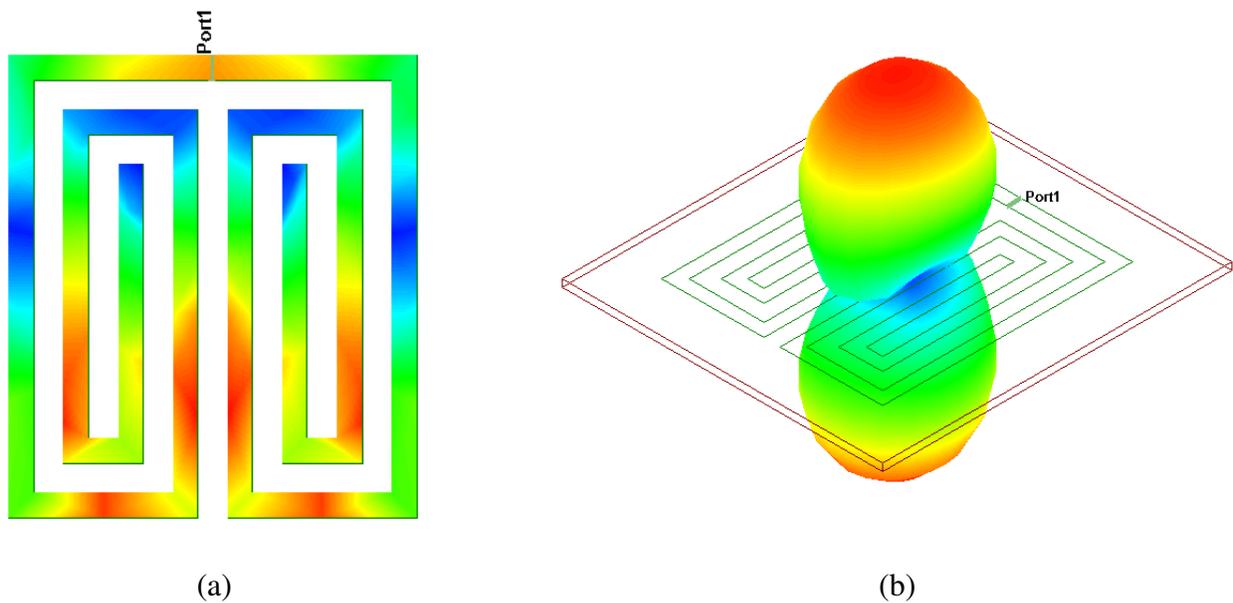


Figure 4. Meandered-line dipole current density and far-field radiation pattern. The antenna radiates bidirectionally with a gain of 2.2 dBi.

A uniplanar microstrip meandered-line antenna (MLA), shown in Figure 3, is designed to operate at 2.5 GHz. The spiral topology is chosen as the radiation from aligned currents in adjacent arms adds constructively in the far field, increasing radiation efficiency [5]. The optimized antenna is 3.2 cm wide by 3.5 cm tall or approximately $\lambda/4$ on a side. The width of the dipole is 3.1 mm. Operating at a frequency of 2.5 GHz, the antenna has a return loss of -14 dB, and a bandwidth of 6%, as seen in Figure 3b.

The current density and far-field radiation pattern are shown in Figure 4. The antenna radiates bidirectionally with a gain of 2.2 dBi. The addition of a perfect magnetic reflector, approximated by a high-impedance surface, will reflect the downward radiation upward without the 180° phase change of a metal conductor, resulting in a theoretic maximum unidirectional gain of 5.2 dBi.

Integrated Topology

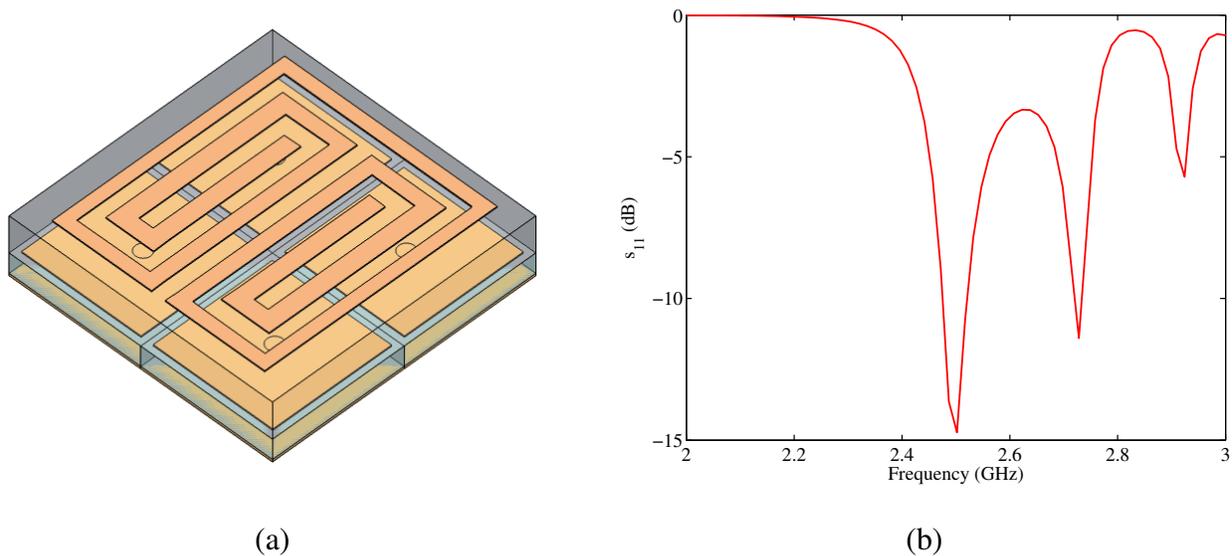


Figure 5. A four-unit-cell high-impedance surface and integrated meandered-line dipole antenna (a) and its simulated frequency response (b).

Beginning with the independently designed high-impedance surface and meandered-line dipole antenna, the structures are integrated (Figure 5a) and optimized. Note that the high impedance surface has been reduced to a finite width of just four unit cells with a footprint constrained to match that of the meandered-line antenna. The critical dimensions of the high-impedance surface and meandered line antenna are optimized parametrically to provide the desired performance at the design frequency. The optimized antenna is 3.5 cm square with an antenna width of 1.9 mm. The high impedance surface gap is 0.25 mm with a via diameter of 1.0 mm. The antenna is 5 mm above the top of the high-impedance surface separated by free space.

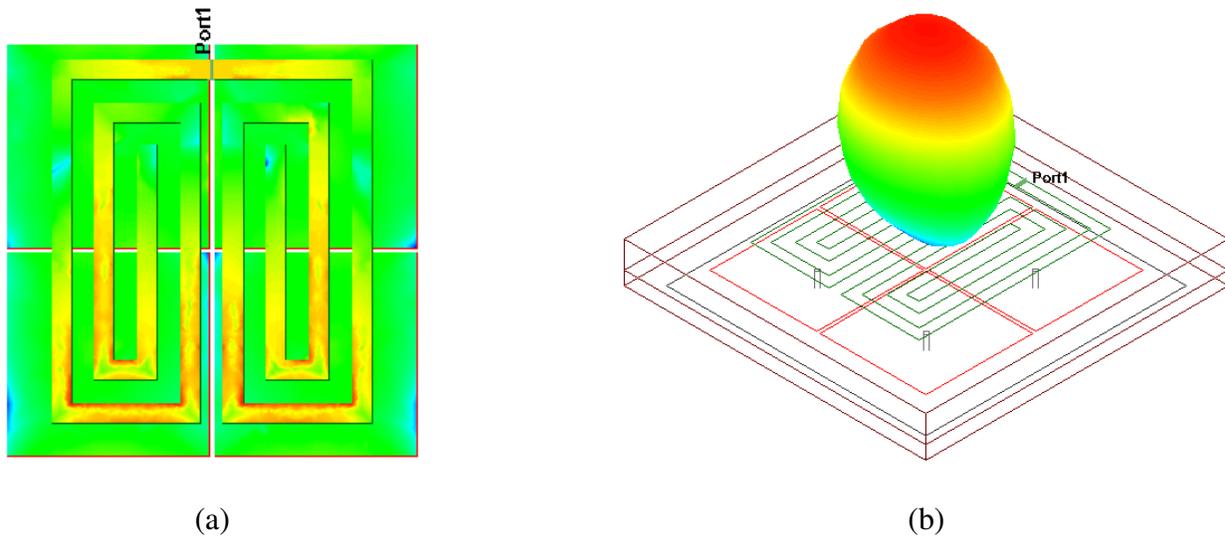


Figure 6. Current density on the integrated meandered-line dipole antenna high-impedance surface (a) and the resulting far-field radiation pattern (b). Maximum gain for the unidirectional radiator is 4.8 dBi, 0.4 dB less than the maximum expected value of 5.2 dBi. This is likely due to radiation and loss from the high-impedance surface.

In Figure 5b it can be seen that the integrated antenna has a center frequency of 2.5 GHz, a return loss of -14.5 dB, and a bandwidth of 4%. A decrease in bandwidth from 6 to 4% is an expected outcome of coupling two bandwidth-limited structures. It is believed that the second and third resonances in the frequency response are a result of modes created by the interaction of the antenna with the high-impedance surface.

The current density and far-field radiation pattern of the reduced-volume antenna are shown in Figure 6. The antenna radiates unidirectionally with a gain of 4.8 dBi, 0.4 dB less than the maximum theoretic maximum value of 5.2 dBi. This loss is likely the result of ohmic losses in the high-impedance surface.

Conclusion

A reduced-volume antenna composed of a meandered-line dipole antenna over a finite-width, high-impedance surface is presented. This structure has a performance similar to a patch antenna with an area one fourth as large. Future work includes the use of a high-permittivity dielectric to further reduce the size of the structure. Upon completion, the circuit will be fabricated and characterized.

References

- [1] D. Sievenpiper, L. Zhang, R. Jimenez Broas, N. Alexópoulos, and E. Yablonovitch, “High-impedance electromagnetic surfaces with a forbidden frequency band,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 47, no. 11, 1999.
- [2] S. Hrabar, J. Bartolic, and Z. Sipus, “Waveguide miniaturization using uniaxial negative permeability metamaterial,” *IEEE Transactions on Antennas and Propagation*, vol. 53, pp. 110–119, jan 2005.
- [3] J. R. Sohn, H. Tae, J. Lee, and J. Lee, “Comparative analysis of four types of high-impedance surfaces for low profile antenna applications,” *IEEE Antennas and Propagation Society International Symposium*, vol. 1A, pp. 758–761, jul 2005.
- [4] S. Clavijo, R. E. Diaz, and W. E. McKinzie III, “Design methodology for sievenpiper high-impedance surfaces: an artificial magnetic conductor for positive gain electrically small antennas,” *IEEE Transactions on Antennas and Propagation*, vol. 51, pp. 2678–2690, oct 2003.
- [5] Constantine A. Balanis, *Antenna Theory: Analysis and Design*, chapter 1, Harper & Row, New York, 1982.