High-Impedance Electromagnetic Ground Planes

D. Sievenpiper*, L. Zhang, E. Yablonovitch

Electrical Engineering Dept., University of California, Los Angeles
***now at HRL Laboratories, Malibu, CA**

Abstract – **A new type of metallic electromagnetic structure has been developed that is characterized by having high surface impedance. Although it is made of continuous metal, and conducts DC currents, it does not conduct AC currents within a forbidden frequency band. Unlike normal conductors, this new surface does not support propagating surface waves, and it reflects electromagnetic waves with no phase reversal.**

I. Introdction

In some situations, the presence of electric conductors can adversely affect the performance of electromagnetic devices, particularly those involving radio communication. Conductive surfaces are useful as reflectors, but they reverse the phase of reflected waves. They also support propagating surface waves, which can have deleterious effects on antenna performance.

By texturing a conducting surface, it is possible to alter its electromagnetic properties. [1, 2] By employing a special geometry, the texture can be made much less than one wavelength in depth and period. [3, 4] This new surface has the following two important properties: (1) it prevents the propagation of electric currents along the metal surface, and (2) it reflects in-phase, rather than out-of-phase as a normal metal surface does. This new surface is characterized by having high electromagnetic surface impedance. The high-impedance surface can provide a useful new ground plane for novel low-profile antennas, [5] and other electromagnetic structures.

II. Geometry

A high-impedance surface, shown in cross section in Figure 1, consists of an array of metal protrusions on a flat metal sheet. It can be fabricated using printed circuit board technology, in which the vertical connections are formed as metal plated vias, which connect metal plates on the top surface to a solid conducting ground plane on the bottom surface.

Figure 1 Cross-sectional view of a high-impedance, textured metal ground plane, consisting of metal protrusions on a flat conducting surface.

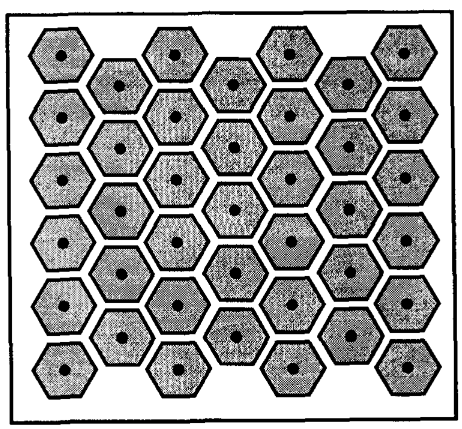

Figure 2 Top view of a high-impedance surface, consisting of a triangular lattice of hexagonal metal plates. The spots in the center of each hexagon are vertical conducting vias that connect to the ground plane.

The metal elements are arranged in a two-dimensional lattice, and can be visualized as mushrooms or thumbtacks protruding from the flat metal surface. An example of a top view is shown in Figure 2.

III. Effective Medium Model

Many properties of the high-impedance surface can be explained using an effective medium model. The structure is assigned a surface impedance equal to that of a parallel resonant LC circuit. The use of lumped parameters to describe electromagnetic structures is valid when the wavelength is much longer than the size of the individual features.

A voltage applied parallel to the surface causes charges to build up on the ends of the top metal plates. This can be described as a capacitance. As the charges slosh back and forth, in response to a radio-frequency field, they flow around a long path through the vias and the bottom metal surface. Associated with these currents is a magnetic field, and thus an inductance. The structure acts as a kind of two-dimensional electric filter, to prevent the propagation of currents along the surface. The origin of the effective circuit elements is illustrated in Figure 3.

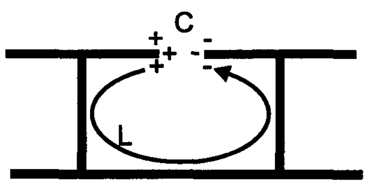

Figure 3 Origin of the capacitance and inductance in the effective medium model.

Near the LC resonance frequency, the structure exhibits high surface impedance. The tangential electric field at the surface is finite, while the tangential magnetic field is zero, and electromagnetic waves are reflected without the phase reversal that occurs on a flat metal sheet. Hence, in this frequency range, the structure is sometimes called a "magnetic conductor".

The reflection phase for such a structure, calculated using the effective medium model, is shown in Figure 4. At low frequencies, the reflection phase is π, as it is on a flat metal surface. Near the resonance frequency, where the surface impedance is high, the reflection phase crosses through zero. At higher frequencies, the phase approaches $-\pi$.

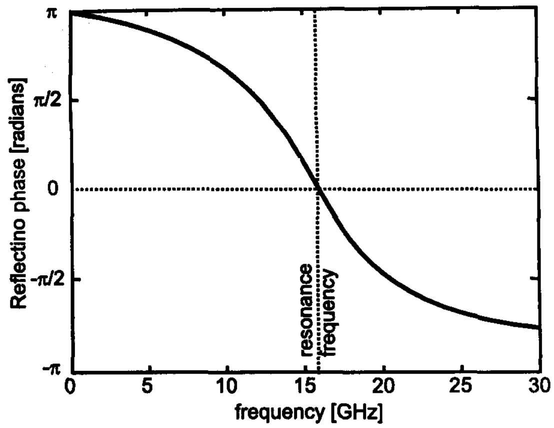

Figure 4 Calculated reflection phase of textured, high-impedance ground plane, based on an effective medium model

The behavior of surface waves on the textured ground plane can be calculated from the effective surface impedance, [6] yielding the dispersion diagram shown in Figure 5. Bound surface waves occupy the region below the light line. Below the resonance frequency, where the surface is inductive, it supports propagating TM surface waves. Above the resonance frequency, where it is capacitive, it supports propagating TE surface waves. Above the light line, TE surface waves exist as radiative, leaky waves, which radiate efficiently into free space. Using a more accurate effective medium model, [7] this high-impedance region has been shown to correspond to a surface wave band gap.

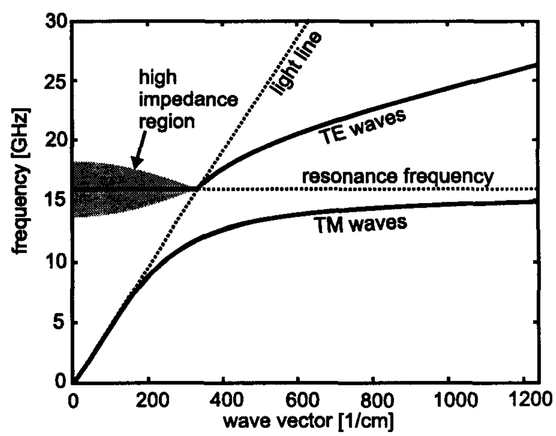

Figure 5 Surface Wave dispersion diagram, calculated using an effective medium model.

V. Measurements

The reflection phase of the textured surface can be measured using a pair of microwave horn antennas. Both the transmitting and the receiving horn are aimed at the surface, and the phase of the reflected wave is monitored as a function of frequency. A flat metal surface, which is known to have a reflection phase of π, is used as a reference. The measured reflection phase of a textured, high-impedance surface is shown in Figure 6.

In the present example, the structure is 1.5 mm thick. The period of the metal hexagons is 2.5 mm. The gap width between them is 150 μm. The metal plated vias have a diameter of 350 μm. The dielectric constant of the circuit board material is 2.2.

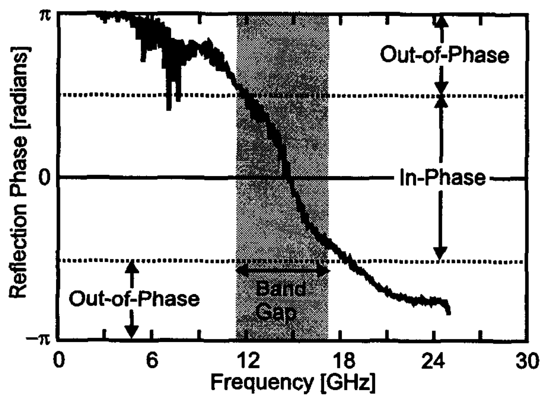

Figure 6 Measured reflection phase of the high-impedance textured surface.

The measured data agree well with the effective medium model. Near the resonance frequency, the surface reflects in-phase. This range also corresponds roughly to the measured surface wave band gap.

The surface wave properties of the textured ground plane can be measured using a pair of small monopole antennas positioned near the surface. Small probes can couple to all wave vectors, and can excite surface waves that do not ordinarily interact with external plane waves. The polarization of the probes can be varied to distinguish the polarization of the surface waves. In TM polarized surface waves, the electric field arcs out of the surface in vertical loops. These waves can be measured by placing monopole probes in a vertical orientation, at the edges of the ground plane.

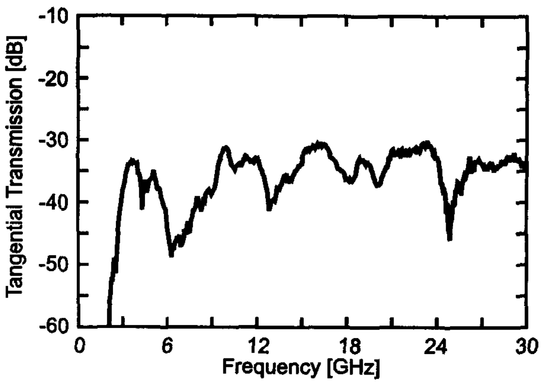

Figure 7 TM transmission across a flat metal ground plane.

A TM surface wave measurement of a flat metal surface is shown in Figure 7. The data has variations of 10-15 dB due to multipath interference, but remains relatively flat over a broad spectrum. The transmission drops off at low frequencies because the small probes are inefficient at exciting long wavelengths.

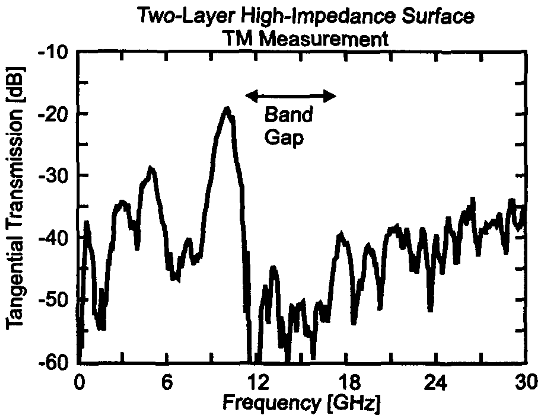

Figure 8 TM transmission across a textured ground plane.

The TM transmission across the textured metal surface is shown in Figure 8. The transmission is strong at low frequencies, and exhibits the same multipath interference seen on the metal surface. At 11 GHz, the transmission drops by about 30 dB, indicating the edge of the TM surface wave band. The TE band edge is not apparent in this measurement, but the region corresponding to the surface wave band gap is indicated on the graph with an arrow.

In TE surface waves, the electric field is parallel to the surface. They can be measured with a pair of small monopole probes oriented parallel to the sheet. On a flat metal surface, a TE surface wave measurement produces no significant signal, because any antenna that excites TE waves is shorted out on a conducting surface.

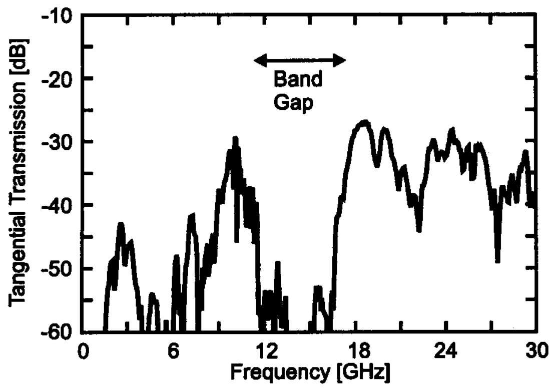

Figure 9 TE transmission across a textured ground plane.

The TE transmission across the textured surface is shown in Figure 9. A sharp jump of 30 dB occurs at 17 GHz, indicating the TE band edge. Beyond this frequency, the transmission is flat, with only small fluctuations due to multipath interference. The TE probes also couple slightly to TM surface waves, so there is an additional transmission peak at 11 GHZ, at the TM band edge. Both TM and TE probes tend to couple slightly to both surface wave polarizations. However, the cross-coupling is weaker between the TM probe and the TE surface waves because of the symmetry of the vertical monopole.

Thus, a surface wave band gap is measured between the TM band edge at 11 GHz and the TE band edge at 17 GHz. Within this range, neither type of measurement produces significant transmission. Currents cannot propagate across the surface, and any currents induced in the surface radiate rapidly into free space.

VI. Conclusion

A new type of metallic electromagnetic structure has been presented that is characterized by having high surface impedance. It is made of continuous metal, and conducts DC currents, but it does not conduct AC currents within a forbidden frequency band. Instead, any currents that are induced in the surface radiate efficiently into surrounding space. This new surface also reflects electromagnetic waves with no phase reversal, behaving as a kind of magnetic conductor. The structure can be described using a lumped parameter circuit model, which accurately predicts many of its electromagnetic properties. This unique material is applicable to a variety of electromagnetic problems, including new kinds of low-profile antennas.

VII. Acknowledgements

This work was supported by Army Research Office grant DAAH04-96-1-0389, HRL subcontract number S1-602680-1, and Office of Naval Research grant N00014-99-1-0136.

References:

[1] W. Barnes, T. Priest, S. Kitson, J. Sambles, "Photonic Surfaces for Surface-Plasmon Polaritons", Phys. Rev. B 54, 6227 (1996)

[2] P.-S. Kildal, "Artificially Soft and Hard Surfaces in Electromagnetics", IEEE Trans. Ant. Prop. 38, 1537 (1990)

[3] D. Sievenpiper, "High-Impedance Electromagnetic Surfaces", Ph.D. Dissertation, University of California, Los Angeles, 1999

[4] D. Sievenpiper, E. Yablonovitch, U. S. provisional patent application, serial number 60/079953, filed on March 30, 1998

[5] D. Sievenpiper, R. Broas, E. Yablonovitch, to be published in these proceedings

[6] S. Ramo, J. Whinnery, T. Van Duzer, Fields and Waves in Communication Electronics, 2nd ed., John Wiley and Sons, New York (1984)

[7] L. Zhang, D. Sievenpiper, N. Alexopolous, E. Yablonovitch, to be published in these proceedings