Antennas on High-Impedance Ground Planes

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Abstract – **A new type of metallic electromagnetic structure has been developed that is characterized by having high surface impedance. Unlike normal conductors, this new surface does not support propagating surface currents, and it reflects electromagnetic waves with no phase reversal. This unique material can serve as the ground plane for new kinds of low-profile antennas.**

I. Introduction

A flat metal sheet is used in many antennas as a reflector, or ground plane. [1] The presence of a ground plane redirects half of the radiation into the opposite direction, improving the antenna gain by 3 dB, and partially shielding objects on the other side. Unfortunately, if the antenna is too close to the conductive surface, the image currents cancel the currents in the antenna, resulting in poor radiation efficiency. Furthermore, surface currents can radiate from ground plane edges, causing multipath interference.

A new type of metallic electromagnetic structure has been developed that is characterized by having high surface impedance. [2, 3, 4] Unlike normal conductors, this new surface does not support propagating surface currents, and it reflects external plane waves with no phase reversal. An example of such a structure is shown in Figure 1. In this embodiment, hexagonal metal patches are connected to a solid metal sheet by conducting vias. Such a structure is easily fabricated using printed circuit board technology

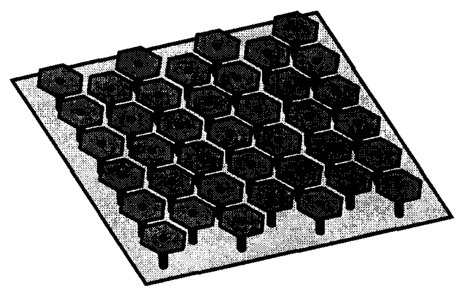

Figure 1 The high-impedance ground plane consists of a two-dimensional array of metal protrusions connected to a flat metal surface.

Because it does not support propagating surface currents, an antenna on a high-impedance ground plane can produce a smoother radiation pattern than a similar antenna on a conventional metal ground plane, with less power wasted in the backward direction. Furthermore, this new kind of surface allows for low-profile antenna designs, with radiating elements lying flat against the high-impedance ground plane.

II. The Vertical Monopole

One of the simplest antennas is a vertical, quarter-wavelength monopole, shown in Figure 2. On an infinitely large ground plane, an antenna of this type would ideally have a smooth, half-doughnut shaped radiation pattern, with a null on the axis of the wire, and no radiation in the backward direction. In reality, the ground plane is always finite, and its edges contribute to the radiation pattern. The antenna generates surface currents in the ground plane, which then radiate from edges and corners. The combined radiation from the wire and the ground plane edges interfere to form a series of

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lobes and nulls at various angles. Furthermore, the edges radiate backwards as well as forwards, causing a significant amount of wasted power in the backward hemisphere.

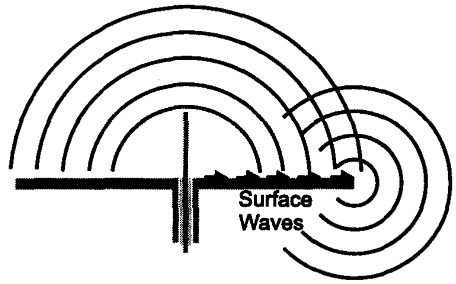

Figure 2 A monopole antenna on a smooth, metal ground plane excites surface currents which radiate edges.

The radiation pattern of a monopole antenna on a metal ground plane is shown in Figure 3. The antenna is 3 mm long, and the ground plane is 5 cm square. The frequency of the measurement is 35 GHz. The important features of the antenna pattern are the ripples that appear in the forward direction, and the amount of wasted power in the backward direction. These features are both due to surface currents that propagate away from the antenna and radiate from the ground plane edges.

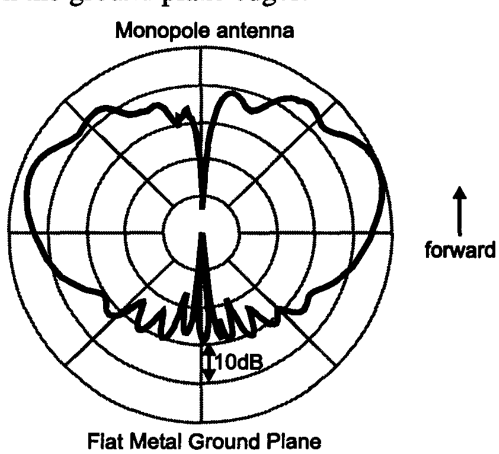

Figure 3 Radiation pattern of a monopole antenna on a finite, metal ground plane.

If the metal ground plane is replaced with a high-impedance ground plane, as shown in Figure 4, the surface currents are suppressed. While driven currents can exist on any reflective surface, they do not propagate on our high-impedance ground plane. Any induced currents are localized near the antenna, and never reach the ground plane edges.

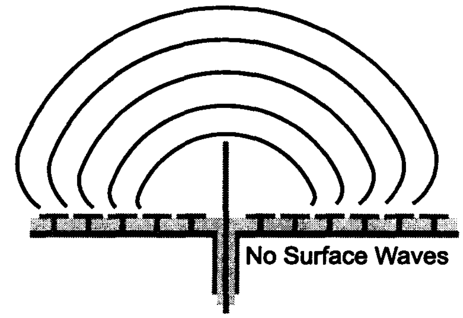

Figure 4 A monopole antenna on a high-impedance ground does not excite propagating surface currents.

The radiation pattern of a monopole antenna on a high-impedance ground plane is shown in Figure 5. The TM band edge of this structure occurs at 30 GHz. The measurement is performed at 35 GHz, within the surface wave band gap. The radiation pattern in the forward direction is smooth, showing only two main lobes, and the power wasted in the backward direction is significantly reduced.

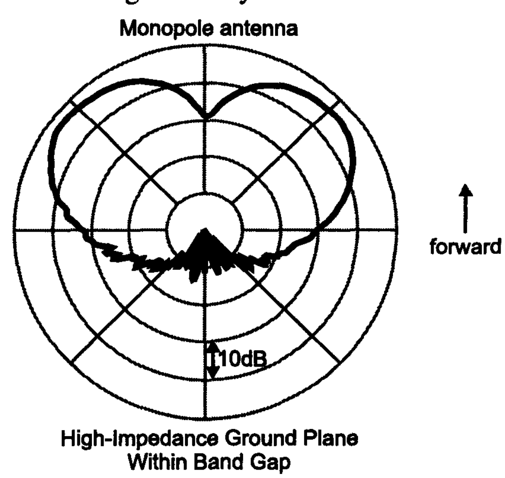

Figure 5 Radiation pattern of a monopole antenna on a high-impedance ground plane.

If the antenna is operated outside the band gap, the ground plane behaves very much like an ordinary flat sheet of metal. Figure 6 shows the radiation pattern of the monopole antenna on the high-impedance ground plane, operated within the TM surface wave band, at a frequency of 26 GHz. Because of the presence of surface waves, the pattern contains many lobes and nulls, and a significant amount of power is wasted in the backward hemisphere.

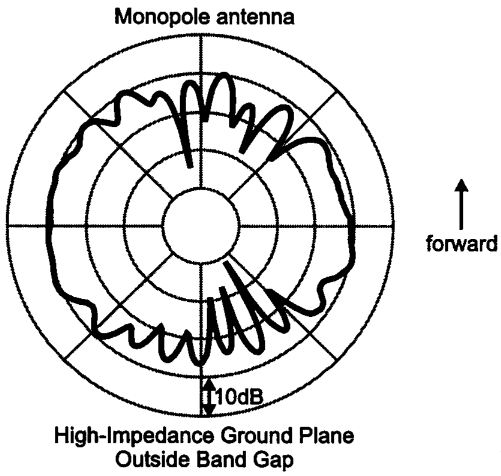

Figure 6 Monopole antenna on a high-impedance ground plane, operated at a frequency outside the band gap.

III. Horizontal Wire Antenna

The other important property of the high-impedance surface is that it reflects in-phase, rather than out-of-phase. This is equivalent to a reversal of the direction of the image currents. This unusual property allows antennas to be constructed that are not possible on a flat, conducting ground plane. An example, shown in Figure 7, is a wire antenna that has been bent over so that it lies parallel to a conducting surface.

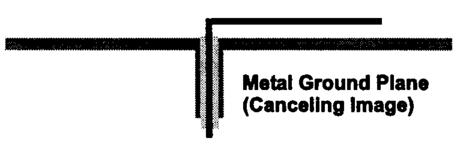

Figure 7 A horizontal wire antenna on a flat metal ground plane is an inefficient radiator.

An antenna of this type radiates very poorly on an ordinary, metal ground plane because the image currents cancel the currents in the antenna. The return loss of this antenna is shown in Figure 8. Most of the power is reflected back toward the generator, so the radiation efficiency is poor. In this example, the antenna was 1 cm long, and separated by a distance of 1 mm from a 3 cm square ground plane.

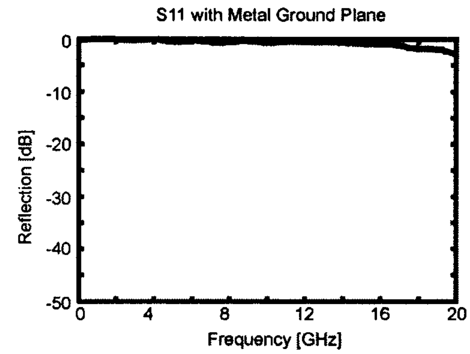

Figure 8 Return loss of a horizontal wire antenna on a flat metal ground plane, indicating poor radiation performance.

A similar wire antenna on a high-impedance ground plane is shown in Figure 9. Below the TM band edge, the antenna performance is similar to the one on the metal ground plane. The surface impedance is low, and the image currents cancel the currents in the antenna. Consequently, the antenna radiates poorly in this range.

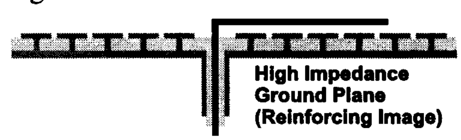

Figure 9 A horizontal wire antenna is not shorted out on a high-impedance ground plane.

Within the band gap, which spans from 11 GHz to 17 GHz in this case, the antenna has a much lower return loss, as shown in Figure 10. The return loss is about -10 dB, indicating that only 10% of the power is being reflected back to the generator. In this range, the image currents reinforce the antenna currents, so that it radiates efficiently. Above the TE band edge, the return loss is low because of coupling to TE surface waves. There is also strong coupling to TM waves near the TM band edge, where the density of states is very high.

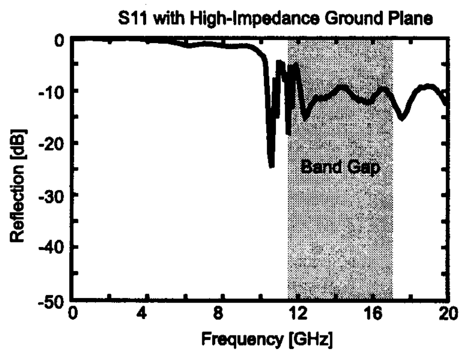

Figure 10 Return loss of a horizontal wire antenna on a high-impedance ground plane.

Although the antenna radiates over a broad band, it only produces a smooth pattern within the surface wave band gap. Outside the band gap, the pattern may contain lobes and nulls due to multipath interference from propagating surface waves.

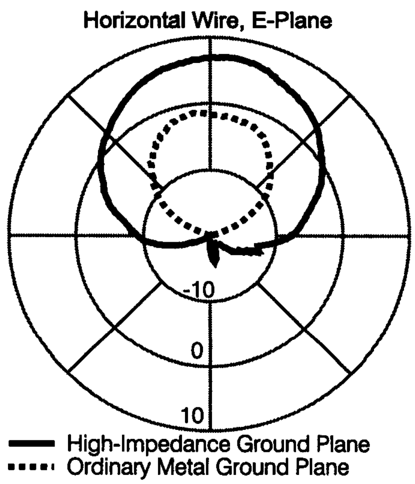

Figure 11 E-plane radiation patterns for two horizontal wire antennas.

The radiation pattern of both antennas is shown in Figure 11 and Figure 12. The data in the radiation patterns supports the return loss data, in that the signal level is about 10 dB higher on the high-impedance ground plane. Furthermore, the pattern is smooth and symmetrical for the antenna on the high-impedance ground plane, and has fewer ripples than the antenna on the flat metal ground plane.

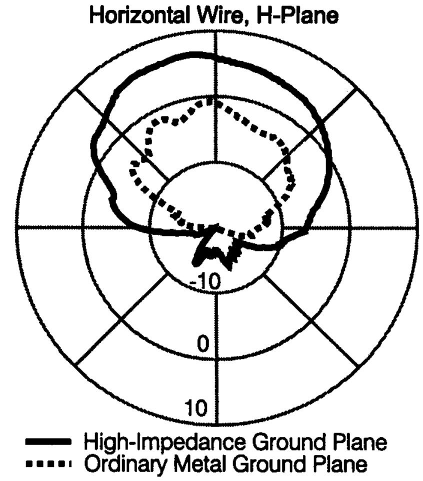

Figure 12 H-plane radiation patterns for two horizontal wire antennas.

IV. Conclusion

Antennas have been demonstrated that take advantage of the two important properties of the new, high-impedance ground plane: (1) the suppression of propagating surface currents, and (2) the reflection of electromagnetic waves with no phase reversal. An improvement in the radiation pattern of a simple vertical monopole has been demonstrated, and a new class of antennas has been introduced, in which the radiating element lies directly adjacent to the ground plane.

V. Acknowledgements

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