Magneto-dielectric Substrates for Antenna Miniaturization

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Planar antennas are highly preferred in mobile systems because of their characteristics such as ease of fabrication and integration, compactness and low profile. Moreover, backing the planar antenna with a ground plane, as in the case of a microstrip patch antenna, offers increased front-to-back ratio, while shielding the rest of the system from the fields of the antenna.

On the other hand, planar antennas printed on metal-backed substrates have limited bandwidth and efficiency. This problem stems from the fact that the radiated field from the image of the antenna's electric current tends to cancel out the radiated field from the antenna current, since the image of the horizontal antenna current on a ground plane is in close proximity and opposite to the direction of the antenna current itself. The cancelation of the radiated fields results in increased stored electromagnetic energy which causes narrow bandwidth and low efficiency.

Antenna miniaturization is a difficult problem since gain and bandwidth are bounded with fundamental limits depending on the size of the antenna. One way for miniaturization is to alter the geometry of the antenna, such that the electrical length of the current path is increased. A more straightforward way is to increase material loading by increasing the permittivity of the substrate, since the resonant length of the antenna scales with $1/\sqrt{\epsilon_r \mu_r}$. Using high permittivity substrates results in narrow bandwidth and low radiation efficiency, since the stored electrical energy is increased. Increasing the thickness of the substrate can improve the bandwidth at the expense of increased surface-wave loss. Moreover, increasing the thickness is not consistent with the aim of miniaturization. Using high impedance surfaces as the antenna ground plane is another option to improve the efficiency and the bandwidth. However, these structures also increase the overall size and suffer from narrow bandgap when miniaturized using high permittivity substrates.

It was shown by Hansen and Burke (*Microwave Opt. Technol. Lett.*, 26, 75–78, 2000) that magneto-dielectric substrates, defined as substrates with both ϵ_r and μ_r greater than 1, can be used to miniaturize patch antenna without deteriorating the bandwidth. This initiated the research on artificial magneto-dielectric substrates which were realized by resonating embedded circuits stacked in a dielectric substrate (H. Mossallaei, K. Sarabandi, *IEEE Trans. Antennas Propagat.*, 52, 1558–1567, 2004). Although $\mu_r > 1$ was achieved with this approach, the substrates reported were lossy, bulky and showed $\mu_r > 1$ only in the direction of the stacked embedded circuits.

A more promising approach to realize magneto-dielectric substrates is through material synthesis where magnetic metallic particles are compounded with dielectrics (N. J. Tang et. al, *Nanotechnology*, 15, 1756-1758, 2004). In this paper, advantages of such magneto-dielectric substrates are discussed through electromagnetic simulations of microstrip patch antenna. In addition, preliminary results on the frequency response of magneto-dielectric materials as well as the realization and characterization of these materials in the GHz range will be discussed.

In this study, patch antennas on infinite and finite ground planes are addressed on 1mm thick substrates with ϵ_r equal to 4.4, with μ_r of the substrates swept from 1 to 25. The substrate loss used was 0.02. All antennas were designed at 2.45GHz. It was found that, increasing μr of the substrate increases gain, bandwidth and efficiency while decreasing the size of the antenna. As an example, a patch antenna with a patch size of 9.5mm×11mm on a substrate with $\epsilon_r = 4.4$ $\mu_r = 11$ can have 5.8dBi peak gain, 4% bandwidth and 65% efficiency. These values are outstanding, when compared to a patch antenna with a patch size of 28.5mm×28mm on $\epsilon_r = 4.4$ $\mu_r = 1$ substrate with only 0.5dBi gain, 2% bandwidth and 28% efficiency. This means an 87% miniaturization in the patch area can be achieved while increasing the bandwidth by 2%, efficiency by 37% and gain by 5.3dBi by increasing the μ_r of the substrate to 11. The fundamental limits calculated by using Harrington's gain and McLean's Q formulas give -0.46dBi for gain and 3.33% for bandwidth.

In this paper, the results for antenna miniaturization are presented. The effects of increasing permeability on efficiency, gain, bandwidth, and front-to-back ratio of the antenna are discussed along with their comparison to fundamental limits.