Near Chu-limit performance in electrically small antennas based upon metamaterial spherical resonators

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We present the design, fabrication, and experimental characterization of a new class of electrically small antennas whose bandwidth performance approaches the Chu limit. The antennas are based upon recently reported spherical microwave resonator structures (H.R. Stuart and C. Tran, Appl. Phys. Lett. Vol. 87, 151108, 2005). The resonators consist of an axially symmetric periodic array of printed circuit boards (PCBs), each containing identical split-ring patterns, assembled to form a resonating spherical object. The resonators were designed to mimic the electromagnetic behavior of the negative permittivity sphere. It is has been shown that an electrically small negative permittivity sphere is characterized by a Q-factor that is 1.5 times the Chu limit (H.R. Stuart and A. Pidwerbetsky, IEEE APS International Symposium, 2005, paper 9.7). Scattering measurements of the microwave resonators forming the basis of these antennas confirm that 1.5x Chu limit behavior can be achieved experimentally in these structures.

In this paper, we demonstrate antennas formed by coupling these resonators to an impedance-matched transmission line feed. We use a balanced coplanar transmission line that is printed on one of the PCBs forming the antenna. It is not necessary to establish a direct electrical connection between the transmission line and each of the rings of the resonant sphere. Rather, it is sufficient to restrict connections to structures within a single plane, eliminating the need to make electrical connections between PCBs and simplifying the assembly process. The incident energy excites a collective resonant mode of the entire sphere (an electric dipole resonance), thereby inducing currents in each of the rings of the structure. The presence of the ring elements outside of the feed plane is critical towards achieving the excellent bandwidth behavior: we present results for a four-ring antenna with a Q-factor at 1.8x the Chu limit, and a six-ring antenna with a Q-factor at 1.4x the Chu limit, each with an electrical size ka~0.5 and a radiative efficiency >90% as measured by the Wheeler cap method. The antennas described here perform comparably to the folded spherical helix antenna (S.R. Best, IEEE Trans. Ant. Prop. Vol. 52, p. 953, 2004) of the same electrical volume, in terms of both radiation efficiency and impedance bandwidth. The metamaterial approach offers an advantage in terms of fabrication: a volumetric radiating element is formed using purely planar, non-interconnected building blocks (an array of PCBs). This is particularly advantageous at higher frequencies, where the physical size of the antenna becomes much smaller.