

Sub-Wavelength Magnetodielectric-Core Spherical Antennas Approaching the Chu Lower Bound – A Review of Recent Results

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This presentation relates and reviews recent results on the reduction of the radiation quality factor Q of sub-wavelength spherical antennas by use of a magnetodielectric core to minimize the stored energy inside the spherical surface current distribution and thus approach – and even reach – the Chu lower bound. These results were published in a series of eight papers from 2010-2014 (O.S.Kim, O. Breinbjerg, and A.D. Yaghjian, *IEEE Transactions on Antennas and Propagation*, vol. 58, no. 6, pp. 1898-1906, June 2010 to T.V. Hansen, O.S. Kim, and O. Breinbjerg, *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 3, pp. 1456-1460, March 2014). In addition to reviewing these results, we will discuss how the physical mechanisms for the 3D spherical surface current distribution with a spherical core may also be observed for the 1D dual-layer surface current distribution with a planar-slab core.

The Chu lower bound for the radiation quality factor Q_{Chu} is based on the *external* stored energy, i.e., the stored energy of the field external to the spherical surface current; and if the *internal* stored energy is taken into account the radiation quality factor Q becomes $1.5Q_{Chu}$ for the TM_{10} electric dipole antenna and $3.0Q_{Chu}$ for the TE_{10} magnetic dipole antenna for vanishingly small antennas. In order to reduce the radiation quality factor Q it is thus necessary to reduce the internal stored energy. For the TE_{10} magnetic dipole antenna, it was known for long (H.A. Wheeler, *Proceedings of the IRE*, vol. 46, no. 9, pp. 1595-1602, 1958) that this can be achieved by use of a high-permeability magnetic core inside the spherical surface current distribution for vanishingly small antennas. However, for antennas of non-zero size the presence of cavity resonances may increase – not decrease – the radiation quality factor, and it is necessary to take the limiting influence of such resonances on the reduction of the stored energy into account.

Using spherical vector wave functions an analytical exact solution for the internal and external fields – and thus the radiation quality factor – of an electric, or magnetic, spherical surface current distribution with a magnetodielectric core can be established. On basis hereof, this presentation will summarize the following specific results, most of which concern sub-wavelength TE_{10} magnetic dipole antennas:

- Dependence of the radiation quality factor on the core permeability.
- Optimal electrical antenna size in terms of the core material wavelength.
- Lower bound for the radiation quality factor of solid core antennas.
- Magnetic-coated PEC core antennas reaching the Chu lower bound – both TE_{10} and TM_{10} .
- Closed-form expressions for internal stored energy and dissipated power of spherical vector wave functions of arbitrary order for lossy cores.
- Dependence of the radiation quality factor and radiation efficiency on the core loss tangent.
- Quality factor and radiation efficiency of dual-mode self-resonant spherical antennas with solid magnetodielectric or magnetic-coated PEC core.