Some New Aspects of Fundamental-Limit Theory on Antennas

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Since Wheeler (Proc. IEEE, vol. 69, pp. 1479-1484, 1947) introduced the concept of the fundamental limits on small antennas, there have been efforts to find an exact formulation for minimum radiation Q. Chu (J. Appl. Phys. vol 19, pp. 1163-1175, 1948) derived a minimum radiation Q expression using circuit models corresponding to spherical-mode wave impedances. Later, Collin (IEEE Trans. on AP, vol. 12, pp. 23-27, 1964) derived expressions for the radiation Q based on the evanescent energy stored near an antenna that are not restricted to the spherical modes and also were developed for cylindrical waves. Fante (IEEE Trans. on AP, vol. 17, pp. 151-155, 1969) used the same approach of considering excitation of both TM and TE modes. Foltz and Mclean (IEEE AP Symposium, 1999) extended the fundamental-limit theory to antennas with a large aspect ratio. Grimes (Radio Science, 34, pp. 281-296, 1999) investigated radiation Q with a time-domain approach.

Fundamental-limit theory shows that the designer must trade off antenna size, gain, and bandwidth, and that improvement of all quantities in the same design is impossible. Efforts over the past half century have focused on the accuracy of the theory. Only the TM_{01} spherical mode has been emphasized because the TM_{01} mode provides the minimum radiation Q, although such a mode provides an omni-directional radiation pattern.

In this study, we explore some new variations on the fundamental-limit theory of antenna performance. First, we discuss some implicit assumptions of bandwidth and pattern related to the specific mode of consideration and how these assumptions vary for the different spherical modes. Secondly, we demonstrate the radiated power of electrically-small antennas will vary as a function of antenna size and source conditions, including voltage, current, and power sources. The previous investigations of the fundamental-limit theory only evaluated antenna performance based on the relationship between the stored energy and the radiated power of the radiation impedance without consideration of source loading. Thirdly, we show an equivalent pole-residue model of the Chu's circuit model. Based on the pole-residue model, we suggest the concept of an ideal antenna for use in fundamental-limit theory. These aspects are considered using theory, numerical simulations, and experimental data.