Evaluation of Total Antenna (Q) in Terms of the Q_n of Modes Provided by Theory of Characteristic Modes

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The study of the antenna Quality factor (Q) has been an active topic of research for a long time. Its importance is directly related to its connection to the antenna frequency bandwidth. Many authors have discussed the problem of formulating the Q of an antenna. Chu, Mclean, Wheeler, Gustafsson, Thal, Yaghjian, Harrington and Vandenbosch were among many whom studied the Q bounds of electrically small antenna (ESA) and Q in general. Several studies were taken from Chu sphere, employing scattering theory and applying quasi-static energy approximations to name few; however, these approaches require specific assumptions on polarization and absorption efficiency, and provide little insight into the type of excitation needed to realize an optimal Q.

Recently, a modal approach based on the theory of Characteristic modes (CM) originally introduced by Garbacz and popularized by Harrington was used to obtain the Q limit for an arbitrary shaped antenna. The authors obtained the lowest order mode for ESAs and considered it to be the lower bound of Q which can be readily obtained. However, this approach is applicable only to ESAs because of the assumption of one dominant mode (lowest order mode) operation. Unfortunately, it cannot be used to compute the total Q as it assumes a constant eigncurrent which is not valid for antennas that are not electrically small.

The overall goal of this work is to provide a new rigorous expression of total Q in terms of Q_n using Characteristic Mode (CM) analysis. This new expression explicitly shows the weighted contribution of each mode's Q_n and the interaction between them. The derivation of this expression starts from Yaghjian and Best well-known expression for Q and the evaluation of the Q using input impedance/admittance in conjunction with CM Modal admittance. This expression is very useful because it provides physical insight; therefore, it will be very helpful in antenna design.