Improved Circuit Models for Wheeler Cap Efficiency Measurements

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The Wheeler cap method (H.A. Wheeler, Proc. IRE, vol. 36, no. 8, 1959) is one of the most well-known approaches for estimating antenna radiation efficiency. It works by comparing the input impedance of the antenna measured in free space to the input impedance observed when the antenna is placed in a conducting cavity. The antenna is assumed to exhibit radiation and ohmic losses that can be modeled as radiation and loss resistances, respectively. The free space measurement includes the effects of the radiation and ohmic losses, while the input impedance measured in the Wheeler cap includes the effects of ohmic losses alone.

The Wheeler cap method is conventionally restricted for use with electrically small antennas by (1) the implicit use of a simplistic loss model that fails to adequately capture the loss mechanisms in electrically larger structures, and (2) the fact that larger antennas require larger Wheeler caps, which can support cavity resonance modes. Both of these effects can produce catastrophic results when the traditional Wheeler cap method is applied, with efficiency estimate values less than zero or greater than unity, or sudden non-physical efficiency drop-outs near the operating frequencies of resonant structures.

Higher order circuit models with more sophisticated loss mechanisms have been developed for use with Wheeler cap measurements (e.g., C. Cho et al., IEEE Trans Antenna Propag., vol. 62, no. 1, 2014). These models often use circuits consisting of repeating subunits. Frequently, genetic algorithms have been used to assign component values to each RLCM element in the equivalent circuit. An alternative approach is to decompose the antenna's admittance response into a set of sub-admittances. Vector fitting (B. Gustavsen and A. Semlyen, IEEE Trans. Power Delivery, vol. 14, no. 2, 1999), a popular rational function decomposition technique, can be used for this purpose. A modification to the standard vector fitting process obtains fits to the rational function form

$$Y = \sum \mathrm{Y_k} = \sum \left(\frac{\mathrm{s} * \mathrm{c_k}}{\mathrm{s} - \mathrm{a_k}} + \frac{\mathrm{s} * \mathrm{c_k}^*}{\mathrm{s} - \mathrm{a_k}^*} \right) \tag{1}$$

The coefficients of the resulting fit, $\{\mathrm{a_k},\ \mathrm{c_k}\}$, map to component values in a characteristic mode-derived circuit model (J.J. Adams, J.T. Bernhard, IEEE Trans Antennas Propag., vol. 61, no. 8, 2013) that accurately captures admittance responses for a broad range of structures. By comparing circuit models generated from both free space and Wheeler cap admittance measurements, improved loss models and efficiency estimates can be obtained. The improved Wheeler cap processing technique is shown to produce accurate efficiency results for a series of microstrip antennas in regimes where the conventional Wheeler cap method fails.