URSI GASS 2023, Sapporo, Japan, 19 – 26 August 2023

Efficiency Optimization of Electrically Small Antennas using Network Characteristic Modes

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Following the fundamental laws of electromagnetism, miniaturizing an antenna is always associated with a dramatic degradation of its performances, especially in terms of impedance bandwidth and radiation efficiency. While it is always possible to enhance the impedance bandwidth of an electrically small antenna (ESA) using an external matching circuit, its radiation efficiency still always mediocre. The main reason behind the efficiency degradation is represented in the decreases of the antenna radiation resistance as its electrical size tend to be small with respect to the operation wavelength. To address this issue, in this paper, we propose a simple methodology based on network characteristic modes theory [1] to enhance the ESAs radiation efficiency. By embedding some passive loads inside the antenna body, the proposed approach optimize the antenna radiation efficiency using Differential evolution algorithm. Let consider an electrically small dipole antenna of electrical size of $ka = 0.44$ (at 700 MHz). Inside the dipole, two (N=2) loaded ports are created in addition to the excitation one (Fig. 1). Using the network characteristic modes theory, the antenna radiation efficiency can be expressed as follow[2]:

$$\eta_{radiation} = \frac{\sum_1^N |\alpha_n|^2}{\sum_1^N \gamma_n |\alpha_n|^2} \tag{1}$$

Where α_n are the modal weighting coefficients and γ_n is the real part of the eigenvalue λ_n of the generalized eigenvalue equation given by eq (2).

$$[\mathrm{Z} + \mathrm{Z}_{\mathrm{Load}}]\bar{\mathrm{I}}_n = \lambda_n [\mathrm{R}_{\mathrm{Lossless}}]\bar{\mathrm{I}}_n \tag{2}$$

Here Z, $\mathrm{Z}_{\mathrm{Load}}$ and $\mathrm{R}_{\mathrm{Lossless}}$ are respectively the $N \times N$ antenna impedance matrix, the diagonal matrix of loads and the resistance matrix of the antenna considering a lossless materials (substrate and conductor). Therefore, by optimizing, the loads values $\mathrm{Z}_{\mathrm{Load}}$ we can optimize the eigenvalue λ_n and consequently the antenna radiation efficiency given by eq (1). In this example, the optimization algorithm yields two inductances of equal values $L_1 = L_2 = 47.6$ nH. With this loads the antenna radiation efficiency is enhanced up to 11% at 700 MHz compared to the unloaded (original) antenna (Fig. 2). More details and experimental results will be presented at the conference.

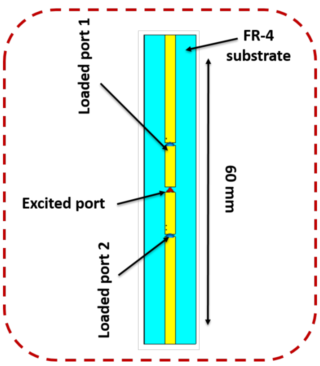

Figure 1. Electrically small dipole antenna

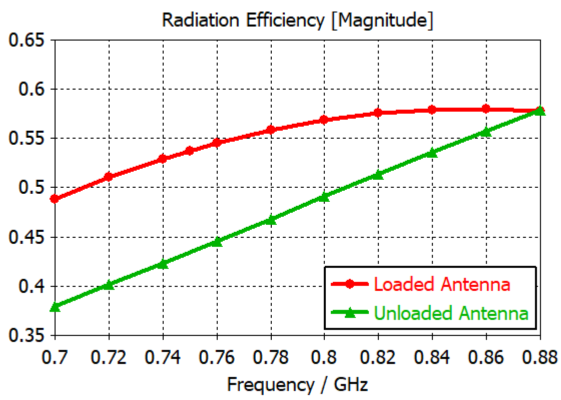

Figure 2. Radiation efficiency versus frequency

References

[1] J. Mautz and R. Harrington, "Modal analysis of loaded N-port scatterers", *IEEE Trans. Antennas Propag.*, vol AP-21, no. 2, pp 188-199, Mar, 1973.

[2] R. Li, D. McNamara, G. Wei and J. Li, "Increasing Radiation Efficiency Using Antenna Shape Optimization Approach," in IEEE Antennas and Wireless Propagation Letters, vol. 17, no. 3, pp. 393-396, March 2018, doi: 10.1109/LAWP.2018.2791585