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Near-field Energy Around Antennas: Research using FDTD Computed Poynting Localized Energy, Flow Velocity and Normalized Lagrangian

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Space-time distribution of electromagnetic (EM) energy around various multi-functional antennas and its intrinsic connection with parameters like impedance matching, bandwidth, directive gain and mutual coupling, has been a matter of active research for several decades [1]. In the context of ultra-dense 5G networks enabled by compact wireless-enabled devices and internet-of-things (IoT), the assessment of antenna near-field (NF) energy distribution is becoming increasingly critical. It has also become imperative to look into the subject *beyond the conventional realms of antenna-Q factor and reactive energy*, and make efforts to look into finer details of non-propagating energy around antennas [1]. Very recently, we have proposed a new *Poynting Localized energy* approach for this purpose, which utilizes FDTD (Finite-difference time-domain) framework [1]-[2].

Using FDTD, we can model a wide variety of antennas (wire-based, printed and lumped circuit loaded), and excite them with various temporal signals like differentiated and modulated Gaussian pulses [1], [2]. By computing the corresponding near-zone electric and magnetic fields and applying suitable interpolation schemes, we can evaluate a NF Poynting flow term. By subtracting this term from the total energy density, we estimate the Poynting localised energy density at any point, and further apply spatial and temporal averaging schemes to shed light onto the near-field energy dynamics close to antenna systems in general. In [1] and [2], we elaborately demonstrate the intrinsic connection of space-time Poynting Localized energy distribution with gain enhancement in strongly coupled antenna systems (eg. Yagi-Uda arrays), as well as mutual coupling between closely spaced antenna elements.

At this juncture, we direct attention to other interesting constructs like *energy flow velocity* $\mathbf{v}_e$ and *normalized EM Lagrangian* l, which are applied by researchers for deeper exploration of EM energy distribution and exchange around radiators [3]-[5]. Using FDTD-computed electric field $\mathbf{E} = \mathbf{E}(\mathbf{r},t)$ and magnetic field $\mathbf{H} = \mathbf{H}(\mathbf{r},t)$ around any antenna, we can evaluate $l = l(\mathbf{r},t)$ and $\mathbf{v}_e = \mathbf{v}_e(\mathbf{r},t)$ as:

$$l = \frac{\frac{1}{2}\varepsilon\mathbf{E}\cdot\mathbf{E} - \frac{1}{2}\mu\mathbf{H}\cdot\mathbf{H}}{\frac{1}{2}\varepsilon\mathbf{E}\cdot\mathbf{E} + \frac{1}{2}\mu\mathbf{H}\cdot\mathbf{H}} \text{ and } \mathbf{v}_e = \frac{\mathbf{E}\times\mathbf{H}}{\frac{1}{2}\varepsilon\mathbf{E}\cdot\mathbf{E} + \frac{1}{2}\mu\mathbf{H}\cdot\mathbf{H}}. \tag{1}$$

While [5] emphasizes upon the importance of $\mathbf{v}_e$ and l quantities in assessing the transitions from radiating to electrostatic/magnetostatic field regimes, mainly analytical space-time currents (eg. Exponentially decaying) are used for study there. However, complex shaped printed/wire antennas excited by arbitrary temporal signals will not yield analytically tractable field-expressions. Therefore, our future research will deal with FDTD computation of $\mathbf{v}_e$ and l around antennas, potentially leading to new directions in MIMO antenna design, energy harvesting, wireless power transfer and electromagnetic interference mitigation applications.

References

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