Reactive, Localized, and Stored Energies: The Fundamental Differences and Proposals for New Experiments

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The question of energy is fundamental in electromagnetics and has been around since the inception of the modern theory of electromagnetic fields by Faraday and Maxwell. However, the topic remains shrouded with serious conceptual difficulties in both the physical literature [1] and the engineering side, see for example the recent antenna near field theory and the open questions left there [2]. The present paper aims at providing a fresh view on the topic taking into account recent progress in both theoretical and applied research. We highlight some subtle and not well-acknowledged differences between three types of basic energy processes in general antenna systems: *reactive* energy, *localized* energy, and *stored* energy. The explication will rely on careful analysis of the way the energy concept is used in various applications, such as matching (reactive energy), near field control and functions (localized energy), and energy harvesting and retrieval (stored energy).

The paper will show that reactive energy is essentially involved with a model of energy that was originally motivated within the history of the subject by the demands of input impedance matching. Localized energy will then be developed as a more general energy density concept focused on understanding how electromagnetic energy tends to move around the source in space and time. A new experiment that can be used to measure degrees of energy localization in the near zone will be outlined.

Finally, stored energy will be defined tentatively in terms of a time-domain transient model coupled with a process involving near-zone energy localization and its conversion to radiation field at the far zone. An idealized experiment that can be used in principle to define and measure this stored energy will be proposed. It is suggested that a time-domain extension of the work [2] will be needed for future theoretical evaluation of this stored energy and for planning developing the physical apparatus needed to perform the proposed idealized experiment.

[1] Marc Lange, *An Introduction to the Philosophy of Physics: Locality, Fields, Energy*, and Mass, Wiley-Blackwell, 2002.

[2] Said M. Mikki and Yahia Antar, "A theory of antenna electromagnetic near fields-Parts I,II," *IEEE Trans. Antennas Progat.*, vol. 59*,* no. 12, pp. 4691–4724, December 2011.

[3] Thorkild B. Hansen and Arthur D. Yaghjian, *Plane-Wave Theory of Time-Domain Fields: Near-Field Scanning Applications*, Wiley-IEEE Press, 1999.