The Physics and Engineering of Metamaterial-inspired Electrically Small Scattering and Radiating Systems

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The introduction of metamaterials and metamaterial-inspired structures into the tool set of RF engineers and Optical physicists has led to a wide variety of advances in discovery within research areas treating structures that radiate (e.g., RF antennas) and scatter (e.g., optical nano-antennas). The increased awareness of complex media, both naturally occurring and artificially constructed, which has been stimulated by the debut of metamaterials, has enabled paradigm shifts in terms of our understanding of how devices and systems operate and our expectations of their performance characteristics. These shifts include the trends of miniaturization, enhanced performance (total radiated power, bandwidth and directivity) and multi-functionality. New techniques have been developed that are impacting practical realizations. These include dispersion engineering (tailoring material and geometry resonances), scattering mitigation (cloaking, active jamming, perfect absorbers), field localization (sensors, nonlinearities), and output beam shaping (leaky wave broadside radiators, sub-diffraction limit resolution in remote sensing, and highly directive beams for energy transfer and low probability of intercept systems).

A number of advances in the use of metamaterial-inspired constructs to improve the overall efficiency, directivity and bandwidth performance of electrically small antennas (ESAs) in several frequency regimes and nano-antennas at optical frequencies will be reviewed briefly. Several metamaterial-inspired designs have been fabricated and tested; these measurement results are in very nice agreement with predictions. While initial efforts emphasized simply high overall efficiencies without using any external matching networks, more recent resonant near-field parasitic (NFRP) designs have also explored the ability to exhibit multi-functional performance, higher directivity and enhanced bandwidths in electrically small systems. Multi-functionality is achieved by combining multiple NFRP elements. Higher directivity is obtained by augmenting the NFRP antenna with structured ground planes (high impedance surfaces or artificial magnetic conductors), as well as simultaneously exciting electric and magnetic multipoles (Huygens multipole sources). Enhanced bandwidths and loss mitigation are achieved by augmenting the NFRP antenna internally with non-Foster (active) elements. While these RF engineering paradigm shifts will be reviewed, it will be emphasized that the same concepts have been extended to optical nano-structures. Nano-lasers, nano-Huygens structures, active nano-jammers (dark states), and nano-amplifiers (bright states), which arise from these considerations and exhibit enhanced radiation and scattering performance characteristics, will be discussed.