# Toroidal dipolar response in metamaterials: illusion or reality

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**Abstract**

We will give a review of our recent and ongoing work in the filed of toroidal electrodynamics, where we have successfully been able to apply metamaterial approach and develop electromagnetic metamaterials the resonant response of which cannot be attributed to the excitation of conventional magnetic or charge multipoles and can only be explained by the existence of the induced toroidal dipole.

Toroidal multipoles are fundamental electromagnetic excitations, which cannot be represented in terms of the existing standard multipole expansion. Toroidal multipoles are associated with toroidal current configurations and were first considered by Zel'dovich back in 1957 [1], but only some 20 years ago become the subject of growing interest owing to their peculiar electromagnetic properties. For example, electromagnetic interactions with toroidal currents were predicted to disobey such widely accepted principle as the action-reaction equality. Toroidal currents can also form charge-current configurations generating vector potential fields in the absence of radiated electromagnetic waves. Although toroidal moments are held responsible for parity violation in nuclear and particle physics, the effects associated with toroidal excitations in naturally available materials are extremely weak and no direct evidence of their importance for classical electrodynamics has been reported until very recently [2].

In this talk we will give a review of our recent and ongoing work in the filed of toroidal electrodynamics, where we have successfully been able to apply metamaterial approach and develop a new type of metamaterials supporting toroidal excitations. In particular, we will present the results of microwave experiments and numerical modelling for a range of toroidal metamaterial structures, the resonant response of which cannot be attributed to the excitation of conventional magnetic or charge multipoles, and can only be explained by the existence of the induced toroidal dipole. Toroidal excitations are routinely neglected in the constitutive relations, boundary conditions, electromagnetic forces and in the calculation of momentum loss and radiation intensity of charge-current configurations, and we believe our results indicate a need for the revision of some aspects of electrodynamics involving structures of toroidal symmetry.

## References

[1] Ia .B. Zel'dovich, Electromagnetic interaction with parity violation. *Sov. Phys. JETP* 6, 1184-1186 (1958).

[2] T. Kaelberer, V. A. Fedotov, N. Papasimakis, D. P. Tsai and N. I. Zheludev, Toroidal Dipolar Response in a Metamaterial, *Science* 330, 1510 (2010).