Physical Bounds and Limitations of Cloaking and Invisibility Using Passive Metamaterials

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One of the most exciting applications of metamaterials is based on their anomalous and often counterintuitive scattering properties, which may allow the realization of invisibility devices, or cloaks, capable of drastically suppressing the scattering from a given object. After several years from the first theoretical proposals for metamaterial cloaks, several proof-of-concept realizations have been presented, highlighting relevant challenges associated with suppressing the scattering over a reasonable bandwidth and with a robust design. The exploration of the cloaking performance has so far been mostly limited to monochromatic signals and idealistic geometries. Bandwidth is however a fundamental issue in any practical application, and recent experiments have highlighted the significant constraints of current cloaking technology. A better understanding of the fundamental limits of these concepts is of vital importance to transform ideal cloaks into practical devices. A few recent papers have pointed out that broadband invisibility may pose serious problems in terms of causality [D.A.B. Miller, Opt. Expr. 14, 12457 (2006); H. Hashemi, et al., Phys. Rev. Lett. 104, 253903 (2010)], but with simplified analysis limited to ideal geometries and specific cloaking techniques, which appear too restrictive in the general sense.

In our talk we will establish fundamental bounds on the bandwidth of cloaking, fundamentally based on causality, passivity and linearity, and applicable to any passive cloaking scheme. We apply Bode-Fano theory of broadband matching, well established in microwave engineering, to the reflection and scattering coefficients of planar and spherical scatterers, in both the quasi-static and dynamic regimes. These theoretical limitations only depend on the size and electromagnetic properties of the scatterer to be hidden. Therefore, given the object to be cloaked, our approach provides fundamental limits on the realizability of given cloaking specifications in terms of bandwidth and total scattering reduction. Our results fundamentally prove important and general theorems, such as: ideal cloaking can only be achieved over a zero-measure bandwidth; the overall available bandwidth for given level of scattering suppression gets severely limited when the object to be cloaked becomes electrically large; the total scattered cross-section of a cloaked object integrated over all frequencies is necessarily larger than in the uncloaked case. We also discuss how absorption can come into the picture and the fundamental constraints on performance of cloaked sensors and receiving antennas. Our results represent a pivotal achievement to understand the applicability of cloaking devices to real-world applications, such as camouflaging, non-invasive sensing and energy.