Random Media Effects on Reciprocity and Imaging

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There has been extensive work reported on electromagnetic nonreciprocity in microwave and optical technologies, including ferrite-based and magnetless technologies, time reversal, thermodynamics, non-linear systems, and others. This paper is concerned with the effects of random media on imaging and detection of electromagnetic waves. The Lorentz reciprocity theorem for deterministic linear and anisotropic media is well known for the time harmonic case, which can be derived from Maxwell's equations. If the transmitter and receiver are switched, the fields satisfy the reciprocity relationship. However, if the medium is random, it requires additional considerations. In this paper we consider some examples.

First, let us consider the reciprocity in imaging when the medium is random. When the medium is random and inhomogeneous, switching the transmitter and receiver does not give the same image. An example is the "shower curtain effect". The image of a person close to the opposite side of a shower curtain can be seen clearly, whereas a person farther from the shower curtain is difficult to see. This imaging can be explained in terms of the mutual coherence function (MCF) or the modulation transfer function (MTF). A question may be raised: If the transmitter and the receiver are switched, is the power received the same? Does the received power depend on the inhomogeneity of the medium and the antenna characteristics?

Next, consider the time-reversal mirror. Consider a wave emitted by a point, and the field is time-reversed by a time-reversal mirror. The time reversal wave will form an image at the transmitting point even if the medium is randomly located, if the medium does not move or change in time. However, if the medium is not fixed in time, the image will not be formed.

One of the important examples of non-reciprocity is the one-way line, where the wave propagates in one direction only. This has been discussed by Rayleigh, who pointed out that a one-way line requires a lossy material. However, there has been theoretical and experimental evidence in microwave waveguides that shows the one-way line, apparently violating the second law of thermodynamics. This so-called "thermodynamic paradox" was resolved on the basis that lossless Maxwell's equations are "improperly posed", creating the thermodynamic paradox, whereas "properly posed" Maxwell's equations do not show any thermodynamic paradox.

Next, consider the reciprocity of the radiative transfer. It should be noted that the radiative transfer theory, which is equivalent to Boltzmann's equation and neutron transport theory, deals directly with the transport of energy and therefore it is based on the addition of powers rather than the addition of fields. It satisfies the necessary conditions of power conservation, but the sufficient conditions are not included. The complete derivation of the equations of transfer should start with Maxwell's equations, and several intensive research efforts have been reported. Therefore, radiative transfer does not cover the cases including multiple scattering and correlations. This has led to the study of coherence of multiple scattering and correlations such as the backscattering enhancement and the memory effects which are outside of the conventional radiative transfer.