Dispersion Engineering: Controlling the signs of various delays, indices, and velocities

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Abstract: The principles of Dispersion Engineering are formulated in terms of our ability to design media with any combination of signs associated with various delays. It is shown how a combination of negative index of refraction and abnormal group velocity can be used to achieve this goal.

The dispersive response of materials can be described by various indices, velocities, or in terms of the more versatile language of delays (e.g. phase delay, group delay, group delay dispersion, etc.) The paradigm of Dispersion Engineering – as motivated by our desire to manage, manipulate, and compensate the dispersive effects – can be formulated in terms of our desire to control the values and the signs associated with the aforementioned delays. The two recent discoveries of (a) materials with a negative index of refraction (NIR) and (b) media supporting abnormal group velocities (negative or superluminal group velocities) provide researchers with opportunities to control the values and signs of the aforementioned dispersive effects beyond what originally was thought possible. In the forthcoming presentation, we will concentrate on the first two dispersive terms, i.e. the phase and group delays, and show how a combination of NIR meta-materials and abnormal group velocities can be used to design materials with arbitrary signs for the aforementioned delays.

We begin our discussion by extending the magnetic and NIR response to THz and infrared frequencies by using purely dielectric scatterers. The application of Mie scattering theory to a collection of spheres results in an effective negative permeability and phase index which exhibit negative phase and group delays within its corresponding anomalous dispersion region. The composite also possesses other combinations of signs, associated with the aforementioned delays, away from this region. We further verify our results by using full photonic band calculations and a scattering matrix method.

We then revisit lower frequencies and consider a periodically loaded transmission line. In this case the required diversity in the signs associated with the phase and group delays are achieved by the periodic inclusion of filters with the desired signs for the aforementioned delays. In particular, we consider the design and implementation of a negative group delay loading element, which in contrast to the higher frequency results, provides a signal gain in addition to the commonly observed time advancement associated with a negative group delay.