Pulse Propagation and Negative Group Delay in Metamaterials

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Metamaterials in which both permittivity and permeability are negative quantities have received much attention in recent times. These materials are expected to exhibit many unusual behaviors such as inverted refraction, Doppler shift, and Cherenkov radiation. Perhaps, a less investigated, and yet equally exciting aspect of metamaterials is the dynamics of the pulse propagation when an electromagnetic wave packet (EMWP) is propagated through such media.

Previous work has shown that under appropriately design circumstances an EMWP can travel with group velocities exceeding the speed of light in vacuum (superluminal) or with negative group velocities without violating the requirements of special relativity [1–3]. While for these abnormal velocities to occur the former case requires a passive optical barrier such as photonic crystals [1], the later has been demonstrated in an active medium such as an inverted Cesium vapor [3]. The metamaterials provide a possibility to obtain a negative group velocity and a negative group delay (a group advance) without the need for an active medium.

In this work the possibility of negative group delay for metamaterials is investigated. First, the transmission phase, and hence the group delay, for a slab having the permittivity and permeability of the split-ring-resonator/wire is calculated. Second, the pulse propagation through a suitably designed passive RLC loaded transmission line which emulates the aforementioned dispersion relation [4] is considered. It is observed that metamaterials in addition to supporting the backward waves also support a negative group delay. This means that the peak of the transmitted pulse would leave the medium prior to the peak of the incident EMWP entering it. Despite this counter intuitive behavior, there is no violation of the principle of causality, since there is no causal connection between the incoming and outgoing peaks, and the pulse front remains luminal under all circumstances. This phenomenon can be understood in terms of pulse reshaping by means of constructive and destructive interferences and can be used in designing faster interconnects and transmission lines.

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