Detection of Superluminal Propagation at Low or Near Resonance Frequencies and
the Dynamics of the Forerunners

From: Kevin J. Malloy and Mohammad Mojahedi
Center for High Technology Materials
1313 Goddard SE
Albuquerque, NM 87106
e-mail: malloy@chtm.unm.edu

To: Marc G. Millis
Subject: First Report

Since the initiation of our grant by NASA, a team consisting of Dr. Kevin J. Malloy (PI, Professor of Electrical Engineering at CHTM/UNM), Dr. Mohammad Mojahedi (Research Assistant Professor, CHTM/UNM), and Dr. Raymond Chiao (Professor of Physics, University of California at Berkeley) has been working to accomplish the objectives of grant NAS3-00103. In order to prioritize the planned actions and to further our working relationships, Dr. Mojahedi had a successful visit to UC Berkeley during the month of May. In series of meetings, Dr. Mojahedi and Dr. Chiao were able to discuss the theoretical difficulties and possible solutions to the problem of calculating the Sommerfeld forerunner for structures such as distributed Bragg reflectors (DBR) and undersized waveguides, and for frustrated total internal reflection in side-by-side prisms. According to our understanding, the velocity of the Sommerfeld forerunner is the only physical velocity which must obey Einstein causality.

More to the point, in our recent publication (Mojahedi, et. al) titled “Frequency Domain Detection of Superluminal Group Velocities in a Distributed Bragg Reflector” in the April issue of IEEE Journal of Quantum Electronics, (Pages 418-424), we have described the frequency-domain detection of the superluminal group velocities in a DBR [also known as one dimensional photonic crystal (1DPC)]. One of the important achievements of this paper is the fact that it describes the correct experimental procedure for measuring the transmission phase and hence the group delay and group velocity, for an electromagnetic wave propagating through a DBR. This is of considerable importance particularly in light of existing controversies and some authors’ efforts to represent the frequency-domain measurements and the consequent mathematical construction (Fourier
transform) of the time-domain signal (all performed using the network analyzer capabilities) as the genuine physical signals for which the concept of the front (Sommerfeld forerunner) is not applicable.

Finally, we must mention that within the past few weeks we were informed of the experiment by L.J. Wang et. al. at NEC Research Institute, in which the authors were able to observe “Gain-Assisted Faster-than-c Light Propagation.” It is worth noting that the theoretical foundation and experimental approach for this experiment was proposed earlier by one of us (see “Amazing Light,” by Raymond Chiao, pages 91-108, and the references within Wang, et al.’s paper), and was discussed in our BPP proposal. In Chiao’s proposal and its later implementation, effects such as electromagnetic induced transparency (EIT) made the chosen gain medium (rubidium vapor) inappropriate; In the case of Wang’s experiment, cesium vapor adequately served the purpose.

We plan to continue our efforts here at CHTM and UC-Berkeley to further our understanding of the topic of superluminal velocities.

From: Kevin J. Malloy and Mohammad Mojahedi
    Center for High Technology Materials
    1313 Goddard SE
    Albuquerque, NM 87106
    e-mail: malloy@chtm.unm.edu

To: Marc G. Millis
Subject: Second Report

I wanted to take this opportunity to discuss with you some of the progress that we have been making here at CHTM and UC-Berkeley. I have attached a copy of our recent publication in Physical Review E, titled “Time-domain detection of superluminal group velocity for single microwave pulses” appearing in October issue of Physical Review E pages 5758-5766 (please note our acknowledgement of your program). The subject of this paper is closely related to the goals and objectives described by BPP program.
The paper describes the first direct time domain measurement of superluminal group velocities for single microwave pulses tunneling through the band gap of a one dimensional photonic crystals (1DPCs). In addition to the superluminal behavior $V_g = (2.38 \pm 0.15)c$, it is shown that the superluminal wave packet suffers minimal dispersion despite of its evanescent propagation. This point is of some interest particularly in regard to the comments made to the opposite effect by Landau, Lifshitz, Sommerfeld, Brillouin, etc. (Please see the article for complete references.)

At the same time, since the experiment is performed directly in time domain with single microwave pulses, there remains little or no ambiguity associated with indirect detection of the pulses via auto-correlation techniques or frequency domain measurements. Furthermore, this paper is the first coherent and conclusive effort trying to purge some of the misrepresentations and misunderstandings effecting the subject of superluminal group velocities. In particular some claims made by other authors regarding the unfeasibility of generating a front (also known as Sommerfeld forerunner or precursor) and the relation between strictly time limited and strictly band limited signals is discussed, and it is shown that any physically attainable signal must have a front which its propagation obeys Einstein causality.

In light of the importance of the Sommerfeld forerunner and its relevance to the Einstein causality, the last section in the paper describes the functional form and the frequency of oscillations for these earliest parts of a signal for any causal medium including photonic crystals, undersized waveguides, etc. It is shown that having a knowledge of the susceptibility kernel for any given medium (photonic crystal, etc.) is sufficient in order to calculate the frequency of the oscillations and the functional form of the Sommerfeld forerunner. This is of particular importance since in some of our work we have obtained an analytical expression for the index of refraction of a 1DPC. Therefore, the next step would be converting the information regarding the index of refraction (or equally well the dielectric constant) to its temporal representation [i.e. the susceptibility kernel, see equation (10) of the paper].

Finally I wanted to let you know that in collaboration with “Microwave Science Inc.” we have submitted a SBIR to NASA, purposing to use our frequency domain setup (discussed in our previous publication in the Journal of Quantum Electronics) to measure
the index of refraction for a Carbon-Carbon sail. As you well know the Carbon-Carbon sail is a light material system which may have promising future in designing solar sails.

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Albuquerque, NM 87106
e-mail: malloy@chtm.unm.edu
To: Marc G. Millis
Subject: Third Report

I wanted to take this opportunity to submit our Quarterly Report. There are three subjects that I would like to bring to your attention. First, I have attached a copy of a recent article by John Fleck, the science writer for Albuquerque Journal, discussing our work at CHTM founded by your program at NASA. I thought you may like to have a copy of this, particularly, since informing the general public of new scientific research and discoveries seems to be of much interest to NASA. I must add that on January 10, 2001, I gave a talk to a public group (New Mexican for Science and Reason) discussing our research which was received favorably by the audience.

Second, I have attached a copy of the paper co-authored by Ray, published on July 2000, in Phys. Rev. A, which has direct relevance to our collaboration with NASA. The paper in essence discusses the superluminal propagation in the limit of very weak pulse (one or few photon limit.) This is of particular interest because Aharonov, Reznik, and Stern (ARS) [Phys. Rev. Lett. 81, 2190 (1998)] have argued that in the limit of few photons signal must be exponentially large in order to distinguish it from the quantum noise, in other words, the signal-to-noise ratio becomes vanishingly small. However, the paper co-authored by Ray, indicates that if ARS condition is replaced by a weaker condition, the signal-to-noise ratio can exceed unity even for one photon pulse. It is worth mentioning that the original experiment by Chiao and Steinberg, [Phys. Rev. Lett. 71, 708, (1993)] although involved the detection of single photon, but the results were interpreted in terms of statistics of many photons.

Third, a recent work by Pendry, [IEEE Transactions on Microwave Theory and Techniques, 47, 2075, (1999)] and another work by Smith, [Phys. Rev. Lett., 84, 4184,
(2000)], have suggested the possibility of manufacturing a composite medium for which both permittivity and permeability are negative values. This medium has an unusual property in which the group velocity is negative. Although the authors mention this fact in their papers, it is clear that they have not fully appreciate the point regarding negative velocity and its implication. The negative group velocity is another manifestation of what can generically be referred to as abnormal velocities, with superluminality as one of its subclass. The meaning of negative velocity is that the transmitted pulse leaves the medium prior to the peak of the incident pulse entering the medium. Although on its face, this seems to be a violation of causality, there is no violation of Einstein Causality and for the sake of brevity I’ll postpone that discussion to some other time. Now, the difference between the negative velocity and superluminal velocity is the fact that for the later the time associated with propagation is still a positive number where as in the former case the time of flight of the envelope is negative. This medium unusual behavior is not excluded to the negative group velocity and indeed other electromagnetic phenomena such as Doppler shift, Cherenkov radiation, Snell’s law, and radiation pressure all have unusual characteristics. We would like to investigate this medium further and we believe the results can be quit beneficial to BPP program.