Wigner-Smith Time Delays in Electromagnetics

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Abstract: In 1960, Felix Smith published a seminal paper entitled "Lifetime Matrix in Collision Theory" that expressed time delays experienced by particles interacting with a potential well (Lifetime in Collision Theory, Phys Rev, vol. 118, no. 1, 1960). Starting from the Schrodinger equation, Smith showed that these time delays can be expressed as the diagonal of the product of the system's scattering matrix and its frequency derivative, a quantity known today as the Wigner-Smith (WS) time delay matrix. While the correspondence between the Schrodinger and Helmholtz equations has been used to compute WS time delay matrices for 2D electromagnetic cavities, Smith's theory never has been formally extended to the Maxwell case. Here, we develop a WS formalism for electromagnetic fields and establish relationships between time delay and scattering matrices for closed geometries (waveguide networks with potentially non-TEM terminations), open structures (scatterers), and mixed systems (antennas). For each of the above, we show that the time delay matrix can be computed as the volume integral of properly renormalized electric or magnetic fields, and use time delay matrices to express frequency derivatives of impedance matrices. For open systems, we establish relationships between the eigenmodes of the time delay matrices and characteristic modes, and develop schemes to compute time delay matrix elements from surface currents. Finally, we leverage WS time delay matrices to categorize scattering phenomena involving multiscale structures comprising both smooth and rough surfaces, as well as quasi-resonant cavities.

Bio: Eric Michielssen received his M.S. in Electrical Engineering (Summa Cum Laude) from the Katholieke Universiteit Leuven (KUL, Belgium) in 1987, and his Ph.D. in Electrical Engineering from the University of Illinois at Urbana-Champaign (UIUC) in 1992. From 1992 to 2005, he served on the faculty at UIUC. In 2005, he joined the University of Michigan, Ann Arbor, where he currently is the Louise Ganiard Johnson Professor of Engineering and Professor of Electrical Engineering and Computer Science. He also serves as the institution’s Associate Vice President for Advanced Research Computing and Co-Director for its Precision Health Initiative.

Eric Michielssen received a Belgian American Educational Foundation Fellowship in 1988 and a Schlumberger Fellowship in 1990. Furthermore, he was the recipient of a 1994 International Union of Radio Scientists (URSI) Young Scientist Fellowship, a 1995 National Science Foundation CAREER Award, and the 1998 Applied Computational Electromagnetics Society (ACES) Valued Service Award. In addition, he was named 1999 URSI United States National Committee Henry G. Booker Fellow and selected as the recipient of the 1999 URSI Koga Gold Medal. He also was awarded the UIUC's 2001 Xerox Award for Faculty Research, appointed 2002 Beckman Fellow in the UIUC Center for Advanced Studies, named 2003 Scholar in the Tel Aviv University Sackler Center for Advanced Studies, selected as UIUC 2003 University and Sony Scholar. In 2011 he received the UM College of Engineering David E. Liddle Research Excellence Award. In 2014 he was the recipient of the IEEE APS Chen-To-Tai Distinguished Educator Award, and in 2017 he received the IEEE APS Sergei A. Schelkunoff Transactions Prize Paper Award. He is a Fellow of the IEEE (elected 2002) and a member of URSI Commission B.

Eric Michielssen authored or co-authored over 200 journal papers and book chapters and over 400 papers in conference proceedings. His research interests include all aspects of theoretical and applied computational electromagnetics. His research focuses on the development of fast frequency and time domain integral-equation-based techniques for analyzing electromagnetic phenomena, and the development of robust optimizers for the synthesis of electromagnetic/optical devices.