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Time-Domain Aspects of Wave Chaotic Scattering in Complex Systems

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We consider the general problem of time-domain waveforms injected into complex scattering systems. Such systems typically show the property of wave chaos: in the short wavelength limit ray trajectories scattering inside the system will show extreme sensitivity to initial conditions. The wave properties of such systems can be treated statistically, for instance with the Random Coupling Model (RCM).[1] Here we extend the RCM from the frequency domain to the time domain (TD). The modes of the system are treated as driven damped harmonic oscillators, and the ports (with their radiation impedances) are included explicitly and drive the modes. Ports presenting both linear and nonlinear load impedances can now be treated in the TD-RCM. We also include the effects of direct and short orbits in the enclosure by means of a time-domain generalization of short-orbits treated by RCM in the frequency domain.[2] The treatment is able to handle arbitrary injected waveforms, and allows investigation of a variety of statistical properties of the induced voltage waveforms appearing in all of the ports.

Experiments have been carried out to test the predictions of the TD-RCM. Short pulses (5-20 ns long) of 5-10 GHz carrier waves are injected into one port of a three-dimensional wave chaotic enclosure with a volume of approximately 1 m^3. The time-domain signals are recorded at a second port, and scattering details of the enclosure are then changed to create an ensemble of scattering systems with the same volume and loss parameter. Statistical analysis of the measured signals includes compiling the PDF of maximum port voltages and average time-domain RMS power delivered to the port as a function of time. These quantities are compared to the predictions of TD-RCM and found to be in good agreement.

As an application of TD-RCM, we utilize the wave dynamics inside a ray-chaotic-shaped electromagnetic cavity containing nonlinear elements to emulate the complex dynamics of reservoir computing (RC), which is a genre of recurrent neural network (RNN). In the short-wavelength limit, the evolution of electromagnetic fields inside chaotic-shaped enclosure shows complex patterns, and is extremely sensitive to perturbations. We propose new techniques to create virtual RC nodes by both frequency stirring and spatial perturbation.[3] The computational power of the wave chaotic RC is experimentally demonstrated with various benchmark tasks. The wave chaos RC is also mechanically robust, and can be scaled to a wide range of wavelengths from RF to the visible.

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