Use of Reconfigurable Intelligent Surfaces to Modify the Statistical Electromagnetic Properties of Complex Enclosures

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Abstract**—** Electromagnetic environments are becoming increasingly complex and congested, creating a growing challenge for electronics that are susceptible to electromagnetic aggression, particularly in reverberant environments. The use of reconfigurable intelligent surfaces (RIS) provides a potential means of re-directing and re-distributing waves to protect sensitive electronic components in such environments. We have developed several approaches that utilize RIS to modify the electromagnetic fields inside reverberant enclosures for the purpose of taming these fields and protecting sensitive components inside. Examples include the use of RIS to create cold spots at locations inside the cavity where a minimal amount of energy is delivered in a given frequency band. We have also used RIS to create coherent perfect absorption (CPA), and the complementary anti-CPA state. CPA (anti-CPA) is a condition under which all (a minimal amount of) radiation incident on an enclosure is absorbed inside the enclosure. The RIS can be programmed to achieve these conditions using a variety of algorithms and machine learning (ML) methods. In general, we demonstrate that ML proves to be remarkably adept at creating desired scattering properties in the complex enclosure. We have also utilized a nonlinear RIS to actively translate deleterious waves to new frequencies where their effects on sensitive electronics can be minimized. Our technique is enabled by the reverberant nature of the cavity, and is effective with an RIS that covers only about 1.5% of the total cavity surface area.

Keywords-Electromagnetic statistics, reconfigurable intelligent surface, machine learning.

I. INTRODUCTION

We are concerned with the problem of high-power microwave signals disrupting the operation of sensitive electronics located inside complex reverberant environments. Our approach to this problem is to use reconfigurable intelligent surfaces (RIS) embedded within to modify the statistics of electromagnetic waves in the enclosure. The RIS is made up of individually programmable pixels whose normal-incidence reflection phase can be digitally toggled between values of approximately 0 and π in a given frequency range. Our RIS has 240 such pixels, and can significantly modify the fields and scattering properties despite covering only 1.5% of the surface area of the enclosure.

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II. RIS PROGRAMMING AND PERFORMANCE

Several algorithms have been developed to set the RIS pixels to achieve desired properties inside the enclosure. One such algorithm uses a modified steepest descent method to create cold spots and CPA/anti-CPA states in desired frequency ranges [1]. A ML algorithm was also developed to predict the pixel settings of the RIS required to achieve a given scattering profile $S_{21}(f)$ from 3 to 4 GHz inside a complex reverberant enclosure [2]. The ML algorithm was successful at identifying the correct pixel settings 97.7% of the time, and the remaining errors were mainly confined to mis-identifying the state of just one pixel. These algorithms were extensively tested experimentally in a reverberant scattering setting in the microwave frequency range.

III. NONLINEAR RIS

A new nonlinear RIS has been developed to establish new types of control over the reverberant fields. The pixels are made up of square resonant patches that are loaded with 4 varactor diodes. Under global voltage bias, the patches change their resonant frequency, and reflection phase shift, over the 3-4 GHz band. This unique RIS can be used to alter the statistical properties of the enclosure, in part by varying the loss parameter of the enclosure, as described by the Random Coupling Model (RCM) [3]. The RIS can also translate the frequencies of signals reverberating in the enclosure, effectively sequestering highly energetic signals from resonant absorption in sensitive electronics. We shall review the experimental demonstration of the nonlinear RIS and describe its effects on the statistical electromagnetic properties of complex enclosures.

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