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Radio Frequency Directed Energy Weapon Mitigation via Passive Beamforming Reconfigurable Intelligent Surface

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***Abstract*—Reconfigurable intelligent surfaces (RISs) are an emerging transmission technology to aid wireless communication. However, the potential of using RIS to mitigate directed energy weapons (DEW) is not widely recognized. In this paper, we propose to leverage RIS (based on spiral antenna elements) to aid the mitigation of high-energy radio-frequency (RF) sources applied to a DEW. For example, integrating a broadband circularly-polarized antenna system with RIS technology can successfully mitigate DEW attacks across a wide range of frequencies regardless of how the radio waves are polarized. We simulated a spiral antenna that operates within a frequency band of 1.3 GHz to 7 GHz with a 3-dB axial ratio bandwidth (ARBW) covering from 2 GHz to 7 GHz. Full-wave simulation results show the potential promising application of RIS for the mitigation of DEW attacks.**

***Index Terms*—Directed energy weapon (DEW), reconfigurable intelligent surface (RIS), spiral antenna.**

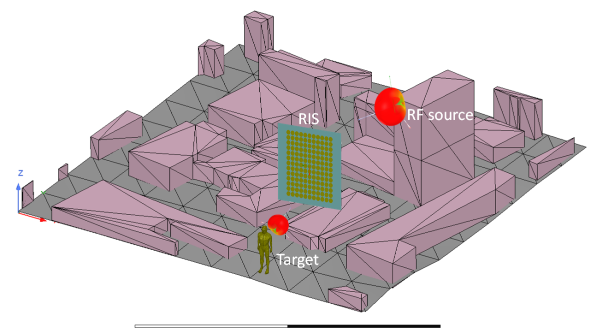

Fig. 1: Ansys SpaceClaim model of city buildings imported into HFSS. A conceptual mock-up of RIS positioned between an RF source and a receiver (human target).

I. Introduction

A reconfigurable intelligent surface (RIS) generally can be thought of as an electronically configurable radio frequency (RF) "lens" or "mirror" to let the signal get through or reflect it via passive beamforming [1]. This enables us to improve a legitimate link between radio nodes or impair RF interference. By deploying a large array of passive electronically tunable reflecting elements in a given environment, the electromagnetic propagation channel (generally regarded as an immutable black box) can be dynamically controlled, which allows for beamforming functionality not only by the radio endpoints but also in the wireless environment [2].

Despite their enormous potential benefits, the possibility of using RIS to mitigate Directed Energy Weapons (DEW) and their effects is not widely recognized. High-power RF sources applied to a directed energy weapon can cause permanent damage (*e.g.*, heat stroke, cognitive impairment, and microwave auditory effect) by releasing concentrated energy in a specific direction [3].

In this paper, we propose to leverage RIS technology to assist in the mitigation of DEW attacks. RISs are composed of an extensive array of passive antennas with electronically tunable properties for beamforming transmissions. Thus, the integration of a wideband circularly-polarized antenna system with RIS technology can potentially be used to alleviate DEW attacks across a wide range of frequencies regardless of the polarization of electromagnetic waves. We simulated a RIS based on a spiral antenna unit cell that achieves an impedance bandwidth (IBW) of 135% (1.3–7 GHz) and a 3-dB axial ratio bandwidth (ARBW) of 100% (2–7 GHz). Thus, at 3.7 GHz, the proposed RIS provides a 16 dB decrease in received power between the "ON" and "OFF" states, which demonstrates the potential promising application of RIS for DEW mitigation.

II. Design and Simulation

A preliminary study that leverages a reconfigurable intelligent surface (RIS) to mitigate directed energy weapons is demonstrated in Fig. 1. To validate this concept, the RIS structure (inspired by the electromagnetic designs in [2, 4]) was positioned between a transmitter (an RF source) and a receiver (a human target) in a 3D electromagnetic simulation software Ansys HFSS, as depicted in Fig. 1. We modeled both the transmitter and receiver antennas as half-wave dipoles operating at 2.4 GHz. However, we simulated the RIS with 11×13 spiral antenna elements (Fig. 2) placed in a periodic arrangement on an FR-4 substrate. The simulated reflection coefficients (S_{11}) and axial ratio (AR) of the spiral antenna are plotted in Fig. 3. The results show that the spiral antenna exhibits circular polarization from 2 GHz to 7 GHz, providing an ARBW of 5 GHz lying within -10dB IBW of 135% (1.3–7 GHz). Thus, the proposed RIS has the potential to work across a wide range of frequencies independent of the polarization of the transmitted EM waves. It should be noted that each spiral antenna is loaded with a switching diode (modeled as a series

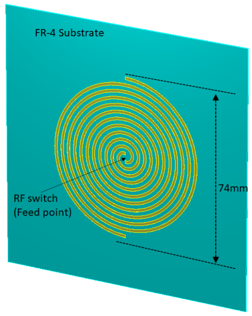

Fig. 2: HFSS model of spiral antenna.

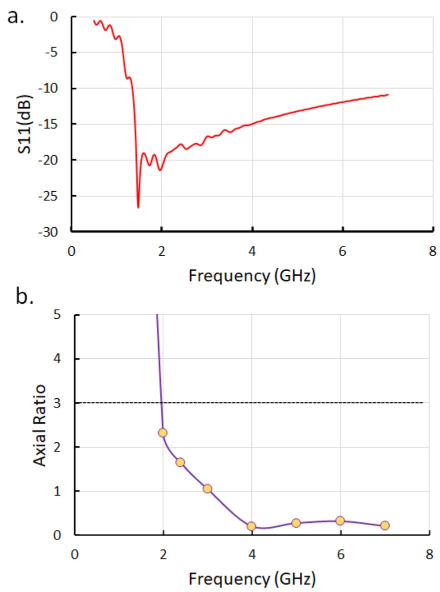

Fig. 3: Simulated results of the spiral antenna. a) $|S_{11}|$. b) axial ratio (AR).

RLC port in simulation) at the center feed point to set the "on" and "off" state of each RIS element. The overall size of the simulated RIS is 1.2 m×1.2 m.

III. Results and Discussion

The simulated results in Fig. 4 show that the received RF power (S_{21}) at the Rx antenna (target location) decreases significantly during the RIS "on" state (when all elements are turned on) compared with the "off" state around 3.7 GHz. When all switches are turned on, the forward-biased diodes present a low-impedance state at the elements' feed points. Under these load conditions, the RIS behaves like an array of half dipoles that efficiently interact with the impinging RF signals. This enables the RIS to function as a mirror that reflects all incident waves away from the target. On the contrary, during the RIS "off" state, the unbiased diodes present a high-impedance state. Thus, the elements weakly interact with the RF signals as the two complementary arms of the spiral antenna by themselves are relatively small to interact strongly with the EM waves. The RIS becomes microwave

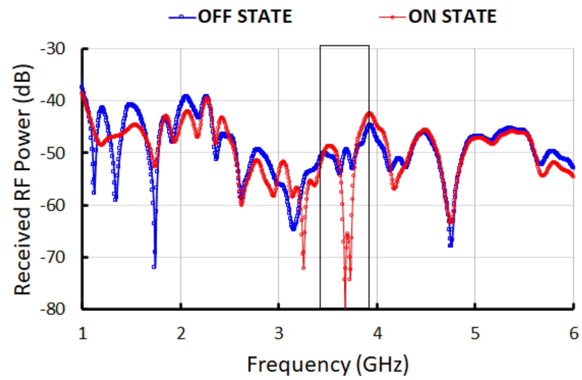

Fig. 4: Simulated RF received power vs. frequency plot

transparent and allows incoming RF waves to pass through it, leading to an increase in the received power (S_{21}), as seen in Fig. 4. It should be noted that the influence of the RIS on the incoming signal should ideally be maximized at the frequency of transmission, which in this case is 2.4 GHz. However, as observed in Fig. 4, the RIS maximum impact occurs at 3.7 GHz during the 'ON" state because the distance between the RIS and the Tx/Rx antenna is 0.5 m, which lies within the near-field region of the RIS leading to some degree of coupling between them. Thus, the frequency shift can be resolved by increasing the separation distance between the RIS and the dipole antennas in simulation, but it can cause an out-of-memory error in HFSS. Thus, around 3.7 GHz, the proposed RIS provides about a 16 dB decrease in received power between the "ON" and "OFF" states. These initial results demonstrate the potential promising application of RIS for DEW mitigation.

IV. Conclusion

We proposed to leverage RIS to assist in the mitigation of DEW. We integrated a circularly polarized, ultra-wideband spiral antenna with RIS technology to potentially mitigate high RF sources applied to DEW.
In the future, we will leverage this concept to prototype RIS that considers wideband circularly-polarized unit elements for passive beamforming against direct energy attacks.

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