Poster: FlexVAA: A Flexible, Passive Van Atta Retroreflector for Roadside Infrastructure Tagging and Identification

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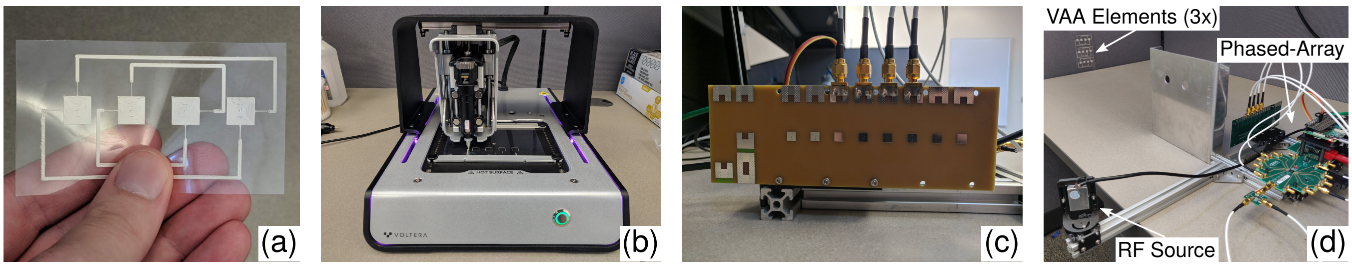

Figure 1: *(a) A single layer, conductive ink printed VAA element on a flexible Mylar sheet. (b) Voltera V-One printer [1] is used for printing the elements. (c) A 4-elements 10.5 GHz custom-made phased-array antenna. (d) Preliminary experimental setup with 3 VAA elements.*

CCS CONCEPTS

• **Hardware** → **PCB design and layout**; **Sensor applications and deployments**.

KEYWORDS

Flexible Electronics; Van Atta Array; Road Infrastructure

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ABSTRACT

We propose *FlexVAA*, a system for identifying roadside infrastructure using flexible, passive wireless retroreflectors. *FlexVAA* can be easily attached to any surface, allowing roadside infrastructure to be upgraded for autonomous systems without impairing existing operations. Preliminary results show that attaching *FlexVAA* to a surface reflects more power than without *FlexVAA* attached. In the future, we plan to arrange multiple *FlexVAA* elements in order to embed data in the passively reflected signal, allowing identification for multiple unique tags.

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1 INTRODUCTION

Traditional roadside infrastructure, such as traffic signs and raised pavement markers [2], is designed to increase safety, allow smooth navigation, and prevent accidents in both the on road and off road areas. For example, optically retroreflective materials are used on vests of roadside workers, on road signs, and inside of raised pavement markers to enhance visibility. A vehicle's headlight sends an incident beam of light towards the object, facilitating direct reflections back to the source. This allows human (eye) or autonomous systems (camera, LiDAR) to identify the presence of those objects and take appropriate actions. Unfortunately, they may not work well under adverse weather conditions, such as heavy rain, dense fog, which limit the visibility of the infrastructure, increase safety hazards, and potentially threaten lives.

Existing solutions, such as [3, 4], proposed passive retroreflective tags for wireless signals to tackle this problem. The key idea is to attach the tag in and around the existing infrastructure and use a wireless transceiver on the car to identify them. The transceiver sends wireless signals toward the retroreflector and receives the signals bounced off of various objects in the environment, including the tags. Then, with additional signal processing, an autonomous system can identify the presence of and differentiate between tags. Since wireless signals can penetrate through low light conditions, heavy rain, and dense fog, the system can enable safer navigation under adverse weather conditions. However, these solutions typically involve designing rigid PCB based surfaces, or some active element that requires connection to a power source. These often require modifications to existing infrastructure and could potentially impair existing operations. For example, a rigid PCB based structure could block some part of the existing road signs or could be damaged when placed on the pavement markers, as these are often run over by cars.

To alleviate these issues, we propose *FlexVAA*; a printed, flexible, passively retroreflective tag for wireless signals that can be attached to any surface with minimal effort and modifications. *FlexVAA* is a conductive ink printed smart sticker that can augment existing roadside optically retroreflectors. By using a transparent substrate, the sticker can avoid disrupting the functionality of existing roadside signs or pavement markers. In addition, printing these stickers with conductive ink allows for them to be manufactured at a much lower cost than is typically associated with the multi-stage process involved in etching PCBs. The passive nature of these stickers means that they require no power to operate and rely on an incident wave from a passing vehicle to energize and reflect signals, much like existing optical retroreflectors. Figure 1(a) shows an example of such a transparent sticker.

We design a proof-of-concept, preliminary retroreflector at 10.5 GHz carrier frequency. Using a low-cost, commercial-off-the-shelf (COTS) PCB printer, Voltera V-One ([1], see Figure 1[b]), we manufacture these tags by depositing conductive ink onto an inexpensive, flexible Mylar substrate. Furthermore, to validate the functionality of the tags, we built a 10.5 GHz phased-array transceiver with traditional PCB printing and assembling COTS components (see Figure 1[c–d]). The preliminary results are promising and show that a surface reflects more power when multiple *FlexVAA* tags are mounted on it than a surface with no *FlexVAA* tags. Our future work will involve arranging stickers in a specific manner to encode data in the reflected signal, so that tags can convey important information, such as the speed limit or STOP traffic sign.

2 *FLEXVAA* DESIGN

To enable the retroreflectivity, *FlexVAA* designs a Van Atta Array (VAA), a phased-array antenna designed to re-radiate incident energy back in the direction of the source [5]. This design can be manufactured out of a single layer of conductive ink, using a COTS printing process. Conductive ink printing allows for speedier and lower cost manufacturing when compared to traditional PCB manufacturing, and enables printing flexible conductors onto flexible substrates.

Van Atta Array (VAA) Primer: A VAA is a structure consisting of a linear array of equally spaced antenna elements, where the elements are symmetrical *w.r.t.* the array center. A pair of elements are connected to each other with transmission lines (see Figure 1[a]). An incident signal, from a remote source, is absorbed by one antenna element and then re-radiated through the connected element on the other end. By precisely setting the length of the transmission lines, the reflected signal can be focused and steered back towards the direction of arrival, making the structure retroreflective.

Flexible VAA Design: We design a customized VAA in a single layer with a rectangular footprint of 72.3 mm (width) × 37.7 mm (height). It consists of four square patch antenna elements with an edge length of 8.28 mm, spaced 16.8 mm from center to center [6]. These four elements are connected with four different transmission lines of lengths 81.79 mm, 46.14 mm, 48.95 mm, and 90.22 mm (top to bottom in Figure 1[a]). Each of these transmission lines has a width of 1.21 mm. We simulate the design in Ansys HFSS [7] to verify its functionality, with two simulation types: One with a Wave Port to obtain the antenna's S parameters, and one with a Radar Cross Section (RCS) setup to verify re-radiated power at a variety of incidence angles. After simulating the reflector design, we manufacture it on the Voltera V-One PCB printer [1] on flexible Mylar substrate. This printer consists of a carriage that moves in the X and Y direction, to which multiple tools can be attached. We attach a syringe that dispenses flexible conductive ink and allows the printer to accurately dispense conductive ink onto our substrate.

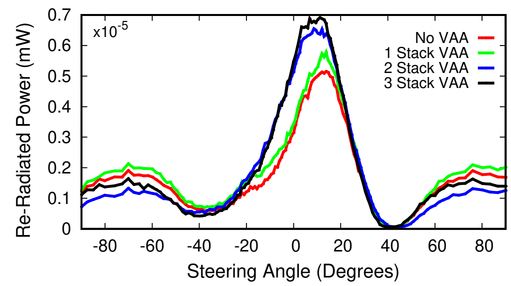

Figure 2: *Plot of measured re-radiated power at different steering angles from different VAA elements.*

To experimentally validate the tag design beyond simulation, we also design and print a 10.5 GHz phased-array transceiver, similar to [8], using traditional PCB manufacturing and assembling COTS components. The transmitter is a 10.5 GHz 40 mA Doppler Radar module, typically used for motion detection. The receiver is a 4-elements patched phased-array connected to an ADAR-1000 beamformer to measure reflected signature at different azimuth angles. This beamformer is connected to an ADALM-PLUTO SDR, and then a Raspberry Pi, which instructs the beamformer to sweep multiple phase angles. The received energy is then down-converted to 4.8 GHz, sampled by the ADALM-PLUTO SDR, and passed to a GNURadio script, running on the Raspberry Pi module. Within GNURadio, we can plot and/or save the re-radiated signal power at various steering angles. Figure 2 shows an example re-radiated power measured for our experimental setup in Figure 1(d).

Stacked VAA for Better Retroreflection: So far, we have looked into the re-radiation of power from a single VAA design, which only increases the reflective power by 0.51 dBm. However, vertically stacking multiple VAA elements allows for more of the incident energy to be reflected back to the source. Stacking 2 VAA elements yields an increase of 1.045 dBm, and stacking 3 VAA elements yields an increase of 1.27 dBm (see Figure 2). Following this trend, stacking more VAA elements should further increase our reflected signal strength. While these results prove the VAA elements work, there are a few factors that could impede their performance.

Limitations: *First*, while our RF source claims to be 10.5 GHz, it actually peaks at 10.44 GHz, introducing a slight mismatch between the RF source and the receiving phased-array. An adjustable frequency RF source would allow us to better match the transmit frequency to our optimal receive frequency. *Second*, there could be variances from element to element when printed on the Voltera V-One; so, reflections from elements may deviate slightly from one another in terms of optimal frequency. This can be addressed by further refining our printing process, as many variables, such as print speed, nozzle diameter, and ink types, can be tweaked to achieve better results. Additionally, having an adjustable RF source, as mentioned before, would allow for verifying the optimal frequency of these manufactured elements.

3 CONCLUSION AND FUTURE WORKS

In this work, we proposed *FlexVAA* to help with the identification of roadside infrastructure for autonomous systems. We prototyped and validated a piece of this solution, by manufacturing multiple VAA elements on the Voltera V-One printer, and testing them to show they successfully reflect an incident signal back towards the source. In the future, we will develop this system further by embedding data into the reflected signal and will validate its functionality in a variety of outdoor environments. We believe that *FlexVAA* can be an effective, low cost solution to augment existing infrastructure without impeding the current operation, enabling smarter and safer transportation of the future.

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