Chipless RFID Paper Review

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Abstract

The recent development in the chipless RFID field allows for identifying and tracking objects using radio frequency signals without the need for traditional RFID chips. This technology has the potential to greatly reduce the cost and complexity of RFID systems, making them more accessible and widely adopted in a variety of industries. This report describes the latest developments in chipless RFID technology and discusses its potential applications and challenges.

1 FerroTag[LCY+19]

FerroTag is a paper-based tagging infrastructure that uses millimeter-wave (mmWave) FMCW radar with RFIDs made of Ferrofluid. It is a low-cost solution for tracking and identifying objects and has a number of potential applications in fields such as supply chain management, asset tracking, and inventory control. FerroTag has several advantages over other RFID technologies. It is low-cost, uses inexpensive materials, and can be printed on a standard printer. It is also lightweight and flexible, making it suitable for various applications. Additionally, it is not affected by metal objects or water, allowing it to be used in various environments.

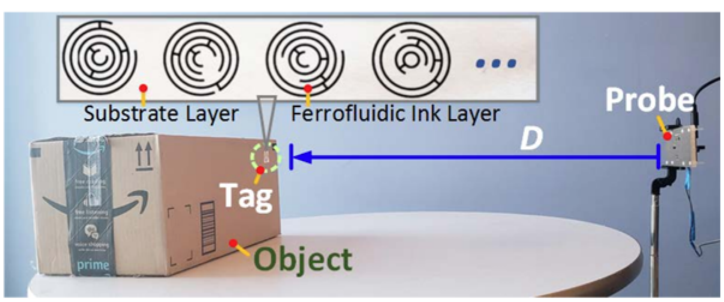


Figure 1: FerroTag in Operation

The RFID tag part uses a combination of ferromagnetic and non-ferromagnetic materials to create unique patterns that can be detected by mmWave scanners. These patterns are printed on a piece of paper, which can be attached to an object to be tracked. When the scanner sends out a mmWave signal, the signal will be reflected back by the FerroTag and detected by the scanner. The pattern of the FerroTag is then decoded by the scanner, allowing the object to be identified. Figure 2 shows the frequency response of six unique patterns. The signal reflected by each tag is analyzed in the frequency domain, and the amplitude of the signal will differ based on the unique shape of each tag.

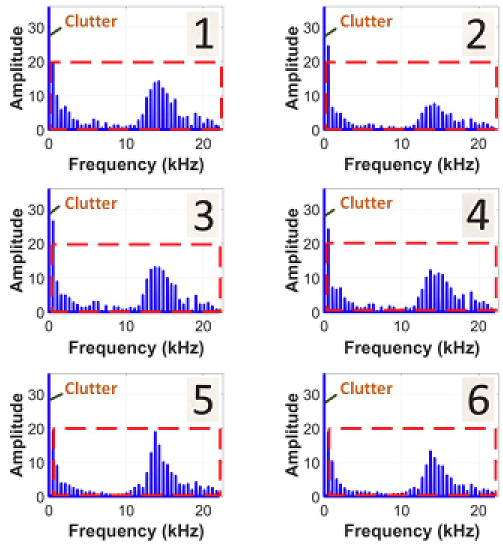


Figure 2: Ferro Tag Frequency Response

The authors have presented a promising solution for tracking and identifying objects using Ferrofulid-based RFID tags and mmWave technology. Although, further research is needed to investigate the credibility of the result since most of the analysis is done by a black box machine learning model, which the public has no access to. If the result can be proven true by a third party, the approach can be used in many other areas that don't require long-range communication, like AR/VR.

2 LiveTag[GLZ19]

LiveTag is made for sensing human-object interaction using passive chipless WiFi tags. It is a novel approach for tracking the movements and interactions of objects and people and has a wide range of potential applications. Even though LiveTag is built as a WiFi tag, the approach could also be used with radar with some tradeoffs. LiveTag uses a combination of passive chipless RFID technology and WiFi signals to detect and track the movements of tagged objects.

The tags are attached to the objects and use the reflections of the WiFi signals to encode information about their location and orientation. The tag is designed to work with 2.4GHz and 5GHz WiFi bands. The content of the information can be customized by changing the orientation and shape of the resonators connected to the antenna, as Figure 3 shows. This information is then detected by a WiFi receiver(usually a phone), which will then be compared with the normal WiFi signal to detect any shift in the frequency domain. The difference between a normal WiFi signal and the signal sent by the LiveTag will be the information that can be decoded.

One of the key advantages of LiveTag is its low cost and versatility. The tags do not require any active components and can be used with a combination of existing WiFi

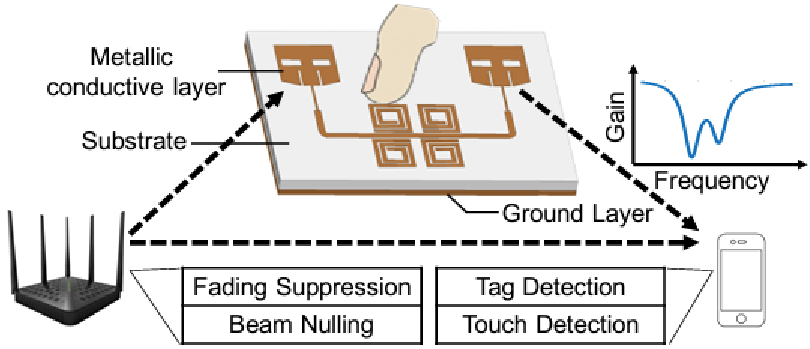


Figure 3: LiveTag Architecture

devices. They can also be attached to many objects, including small and lightweight objects, and are not affected by metal objects or water. Additionally, the WiFi technology allows for a long range, making it suitable for use in various environments. To transform LiveTag into radar-based technology, not much needs to be changed in signal analysis. The largest impact would be the field of view since the Radar has to be pointing in the same direction as the Tag.

3 UniScatter[Unk22]

Most of the state-of-art backscatter tags use VanAtta arrays to retroreflect the radar signal, which provides long-range communication like MilliMetro[SPB+21] can localize a tag at cm-level accuracy at over 100 meters. Although those techniques have the disadvantage of being constrained on a 2D plane which greatly restrained the field of view, those tags usually only work at a fixed frequency, 24GHz for MilliMetro, for example. UniScatter presented a novel approach using a 3D printed Luneburg lens, see Figure 4, as the retroreflector to achieve omnidirectionally and works across a wide frequency band, from 24GHz to 77GHz.

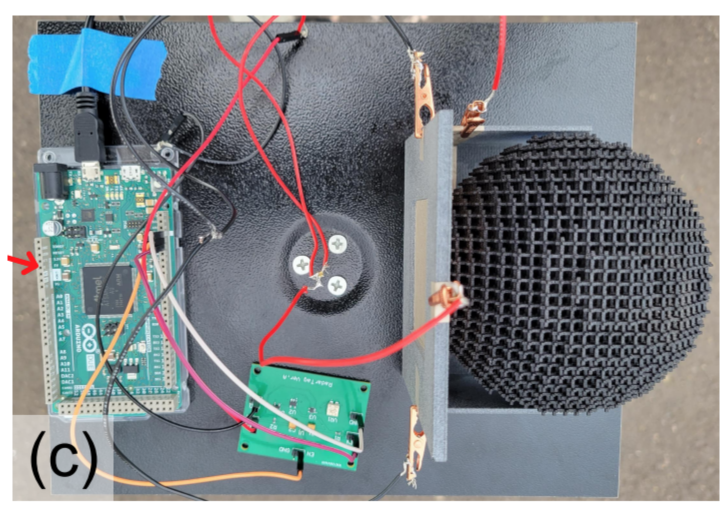


Figure 4: UniScatter Setup

Compared to the traditional switching method, UniScatter uses the unique characteristic of graphene to generate a modulation signal to encode messages. The modulation is done by applying electrochemical doping to the graphene layer, and an additional metal layer is added to boost the signal strength, see Figure 5. As a result, Unisactter can be detected at a max range of 30 m when tested using 24GHz and 77GHz FMCW radar while being omnidirectional.

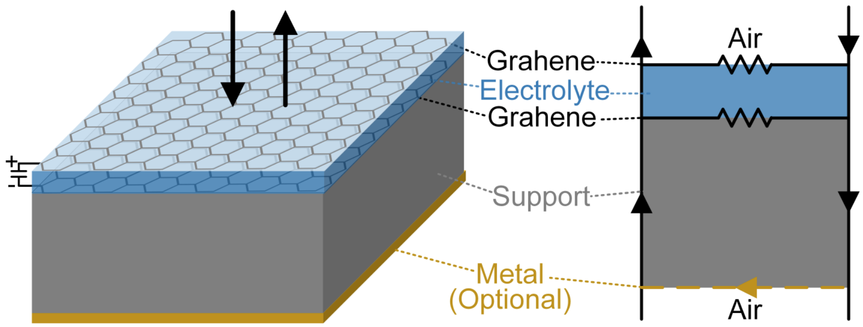
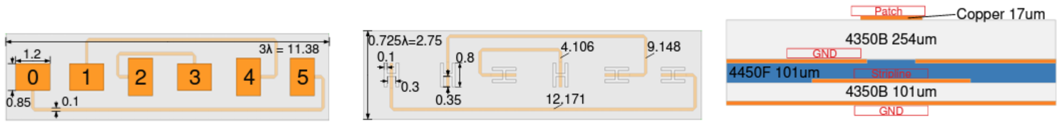


Figure 5: UniScatter Internal Structure

The disadvantage of this approach is it not being chipless. An external power management circuit and a switch control circuit are required, and power consumption is about 50mW due to the large capacitance of the graphene capacitor. Another challenge is the cost and manufacturing complexity of building the 3D-printed Luneburg lens made of graphene. However, another approach uses the Luneburg lens[BAVRT20] can solve these challenges with the tradeoff of short range. For this approach, the author proposed using the shape of the Luneburg to encode the message instead of using the active control circuit. The reflector can be printed using a conventional 3D printer with ABS as the material. The result shows detectable RCS measurement changes when tested with an FMCW radar from 20GHz to 40GHz. However, the maximum range using this approach is 5 meters.

4 Summary of Modern Development[HPMCM19]

This paper summarizes the recent development in chipless RFID until 2019. The author split the paper into two categories: time domain and frequency domain RFID. A time-domain chipless RFID tag uses time-based encoding to store and transmit information. This approach encodes the data in the time delay between different RF signals, creating "0" and "1" like a logic gate. All the papers this report mentioned use frequency domain RFID, specifically, backscatter-based tags. The main advantage is antennas are unnecessary, and the information can be encoded through the uniqueness in the response of radar cross-section(RCS). This paper[NQZ21] uses an array of antennas placed in different orientations to encode information, see Figure 6 for antenna structure, which creates singularities in RCS response. Overall, the most promising way of creating a chipless RFID tag for indoor AR/VR applications that don't involve machine learning is creating backscatter-based tags with unique antenna arrangements as the identification.



(a) Patch antenna (unit: mm) (b) Aperture (unit: mm) (c) Stackup

Figure 6: VAA Antenna Structure

References

[BAVRT20] Ryan A. Bahr, Ajibayo O. Adeyeye, Samantha Van Rijs, and Manos M. Tentzeris. 3d-printed omnidirectional luneburg lens retroreflectors for low-cost mm-wave positioning. In *2020 IEEE International Conference on RFID (RFID)*, pages 1–7, 2020.

[GLZ19] Chuhan Gao, Yilong Li, and Xinyu Zhang. Livetag: Sensing human-object interaction through passive chipless wi-fi tags. *GetMobile: Mobile Comp. and Comm.*, 22(3):32–35, jan 2019.

[HPMCM19] Cristian Herrojo, Ferran Paredes, Javier Mata-Contreras, and Ferran Martín. Chipless-rfid: A review and recent developments. *Sensors*, 19(15), 2019.

[LCY+19] Zhengxiong Li, Baicheng Chen, Zhuolin Yang, Huining Li, Chenhan Xu, Xingyu Chen, Kun Wang, and Wenyao Xu. Ferrotag: A paper-based mmwave-scannable tagging infrastructure. In *Proceedings of the 17th Conference on Embedded Networked Sensor Systems*, SenSys '19, page 324–337, New York, NY, USA, 2019. Association for Computing Machinery.

[NQZ21] John Nolan, Kun Qian, and Xinyu Zhang. Ros: Passive smart surface for roadside-to-vehicle communication. In *Proceedings of the 2021 ACM SIGCOMM 2021 Conference*, SIGCOMM '21, page 165–178, New York, NY, USA, 2021. Association for Computing Machinery.

[SPB+21] Elahe Soltanaghaei, Akarsh Prabhakara, Artur Balanuta, Matthew Anderson, Jan M. Rabaey, Swarun Kumar, and Anthony Rowe. Millimetro: Mmwave retro-reflective tags for accurate, long range localization. In *Proceedings of the 27th Annual International Conference on Mobile Computing and Networking*, MobiCom '21, page 69–82, New York, NY, USA, 2021. Association for Computing Machinery.

[Unk22] Unknown. Uniscatter: a metamaterial backscatter tag for wideband joint communication and radar sensing. *Unpublished*, 2022.