Final Report

Farm-wide WiFi

A Food Agility CRC project

Transforming vehicles, including tractors and trucks, into roving WiFi devices with a range of up to 5 kilometres

foodagility zetifi UTS Charles Sturt University

Project Name: FARM-WIDE WIFI
Project Number: FA103

Citation: Shariati, N, Keshavarz, R, West, N & Winson, D. (2023), FA103 Farm-Wide WiFi Final Public Facing Report, Food Agility CRC, Sydney.
Cover: Two men stand in a field by a Ute equipped with WiFi technology.

IMPORTANT INFORMATION

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Electronically published by Food Agility CRC at www.foodagility.com in January 2024.

The Food Agility CRC is funded under the Australian Government Cooperative Research Centres Program.

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PROJECT DESCRIPTION

This project aimed to advance on-farm connectivity by building antenna arrays that can be fitted to mobile and stationary farming equipment to provide long-range communication. It focussed on the following outcomes to achieve this:

- Create a self-installable FIXED Radio Frequency solution with maximum range @ 10 mbps.
- Create a PORTABLE Radio Frequency solution.
- Create a system that enables the fixed and portable systems to work together (the software that drives the other two).

PROJECT PARTNERS

EXECUTIVE SUMMARY

This project exists to build connectivity infrastructure that will give farmers farm-wide access to the internet, so they can access digital tools (e.g. dashboards, IoT systems etc). The team have been working to address the specific challenges to providing connectivity to passenger vehicles in rural areas.

The project research objective was to develop custom antenna arrays and RF systems for vehicles, enabling long-range rural communications, tackling inadequate rural connectivity for Australian primary producers. The developed cost-effective solution aims to address social, economic, and safety challenges while facilitating research commercialisation in digital agriculture technologies. The technology has undergone laboratory testing and field trials in regional Australia, with the support of industry partner, Zetifi. The developed vehicular communication system meets real-world requirements: reliability, modularity, compact size, antenna isolation, low power consumption, low cost, and easy manufacturing. Simple installation on vehicles has potential for future commercial success.

This project provided a unique solution that simplifies RF/antenna systems, reducing personnel and benefiting the industry by streamlining implementation and maintenance for non-specialized users. The unique solution caters to various applications, providing a family product with enhanced versatility.

IMPACT STATEMENTS

INDUSTRY AND TECHNOLOGY PARTNER

Dan Winson – CEO and Founder Zetifi

The collaboration between UTS, CSU and Zetifi has pushed the envelope in smart antenna technology, propelling the ZetiLink project from concept to reality. UTS's innovative antenna designs have helped develop a novel approach to adaptive radio frequency front-end configurations, bringing a fresh perspective to vehicle connectivity.

Unlike traditional beam steering antennas, Zetifi's software-defined RF front end dynamically adjusts the antenna to a vehicle's location and direction of travel, optimizing the end-to-end RF connection for unparalleled coverage, increased throughput, and significantly lower latency.

The real-world impact of this collaboration is evident in Zetifi's successful development and commercialisation of the ZetiRover—a roaming Wi-Fi hotspot for vehicles and farm machinery. This product stands as a testament to the practical applications of cutting-edge research and development. The ZetiRover not only brings connectivity to remote locations but also enhances operational efficiency in agriculture, showcasing the project's importance for both urban and rural communities.

RESEARCH PARTNER UTS

Negin Shariati

Senior Lecturer and Co-Director, RF and Communication Technologies (RFCT) Lab, UTS
Sensing Innovations Constellation Lead, Food Agility CRC

Rasool Keshavarz

Senior Research Fellow, RF and Communication Technologies (RFCT) Lab, UTS

Our developed technology offers compact size, extended communication range, enhanced data performance, reduced energy requirements, and cost-effective production. The customised systems meet Australian standards, benefiting brand Australia. Our research offers low-cost and manufacturable designs that surpass performance standards, providing unique solutions, and creating a pathway for autonomous IoT devices in remote areas.

The impact of my work has been recognised as a finalist in the IoT Awards Australia 2023 (Announcing the 2022-23 IoT Awards finalists - IoT Enabler Workstreams - IoT Insights - IoTAA

News - Sectorial Workstreams - News - IoT Hub), and is currently under review for Australian Financial Review Higher Education Awards. The research outcomes have been published and presented at Europe's flagship conference (R. Keshavarz, D. Winson, J. Lipman, M. Abolhasan and N. Shariati, "Dual-Band, Slant-Polarized MIMO Antenna Set for Vehicular Communication," 2023 17th European Conference on Antennas and Propagation (EuCAP), Florence, Italy, 2023, pp. 1-5, doi: 10.23919/EuCAP57121.2023.10133527). These achievements highlight the successful research translation and impact of this project in the industry.

Major impacts of this project include:

- Improving brand Australia.
- Customised RF modules and antennas to meet Australian standards and industry requirements.
- Creation of new IP with commercialisation potential.
- Reduce costs and increase simplicity.
- Reduce manpower by simplifying RF and antenna systems for non-specialized users (simple implementation and maintenance).
- Simple and low-cost manufacturing by adopting novel design solutions.
- Enabler for mass production and adoption.
- Pathway to create fully autonomous and automated and IoT devices.
- Developing a solution and focusing on family product/versatility: Different configurations of the developed antennas can create a family product with various properties to meet different purposes/applications.

The project contributes to a sustainable and inclusive future through:

- Focusing on energy efficiency to reduce carbon footprint, contributing to carbon abatement.
- Promoting inclusiveness by ensuring system accessibility to users, including rural areas, and easy integration into diverse vehicles.
- Alignment with UN Sustainability Goals: Reduce inequality and promote sustainable economic growth by enhancing connectivity and information access for all, including rural areas.

The project addresses scalability through:

- Developing a custom-made technology which meets the requirements of real-world automotive applications, making it a reliable connectivity solution for different communication systems and enabling a scalable system.
- Meeting IEC-61850 standards for power systems communication, ensuring interoperability and scalability. Seamless integration with diverse systems enhances flexibility and expands reach, supporting future expansion and enhancing overall capabilities.

RESEARCH PARTNER CSU

Nelson West
Technical Officer (Global Digital Farm), Charles Sturt University, Wagga Wagga

Charles Sturt University's involvement with the Food Agility project FA103 was to perform real world field testing and validation of commercial antenna solutions compared with UTS developed solutions. This was carried out on Charles Sturt University's Global Digital Farm (GDF) which is an integrated digital learning, innovation, and research environment working within a full-scale mixed farming operation. The Global Digital Farm collaborates with public and private institutions to meet research and commercial outcomes. Having the GDF as a real-world testing environment for the antenna solutions was a valuable source of feedback for the project outcomes, with CSU and Zetifi establishing an ongoing collaboration, where new antennas will be tested with Zetifi following the field test protocol developed.

END-USER PROFILE

"Since fitting the Zetifi units we've had complete coverage across our farm and not a single drop out on a call. Being able to pick up Wi-Fi a long way from the vehicles has been great too. It's surpassed my expectations and has been a real game changer for us."

- *Brian Carruthers, West Wyalong NSW*

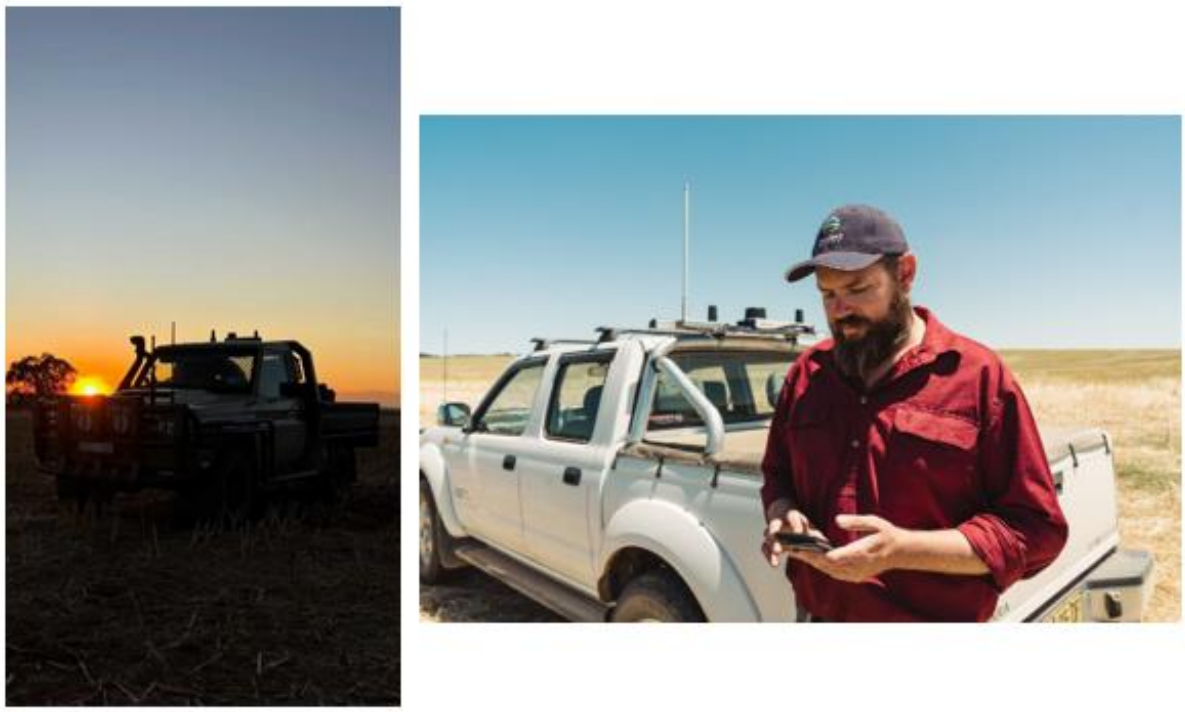


Image 1: Left Brian Carruthers' Land Cruiser Ute fitted with the ZetiRover; Right Nelson West (CSU) using coverage from the ZetiRover fitted on the vehicle in the background.

OBJECTIVES

- Create a self-installable FIXED Radio Frequency solution with maximum range @ 10mbps.
- Create a PORTABLE Radio Frequency solution.
- Create a system that enables the fixed and portable systems to work together (the software that drives the other two).
- Field testing of off-the-shelf antenna systems to assess the baseline performance of commercial Wi-Fi systems (CSU).
- Field testing of UTS developed antennas to compare performance to commercial Wi-Fi systems (CSU).

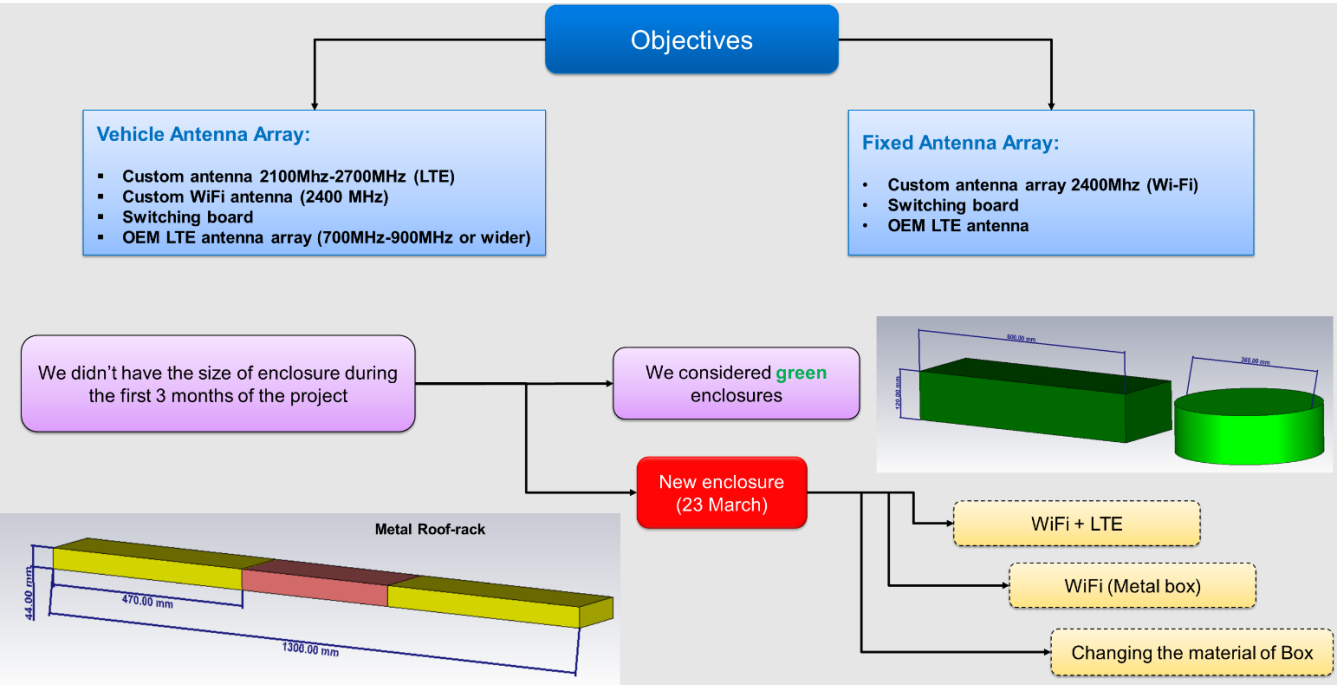


Figure 1: Objectives of FA103.

METHODOLOGY

UTS-RFCT Lab methodology

The R&D project demonstrates the design, fabrication and testing of RF and antenna systems at Wi-Fi and LTE bands to enhance rural and agricultural connectivity. The technology has undergone laboratory testing and field trials in regional Australia, with the support of our industry partner, Zetifi.

The outcomes fulfill the requirements for vehicular communication systems in real-world scenarios, including reliability, modularity, compact size, good isolation between antennas, low power consumption, low cost, and ease of manufacturing.

The systems exhibit simplicity in installation on vehicles, thereby possessing the potential to become commercially viable products in the future. The measurement results indicate that our designed antennas demonstrate improved performance compared to commercially available products.

UTS-RFCT Lab custom-made structures are capable of collecting large amounts of data from farms. This data, combined with historical and satellite data, will address connectivity challenges in areas with limited mobile coverage, resulting in improved reliability of communication, increased productivity, profitability, sustainability, safety, and quality of life.

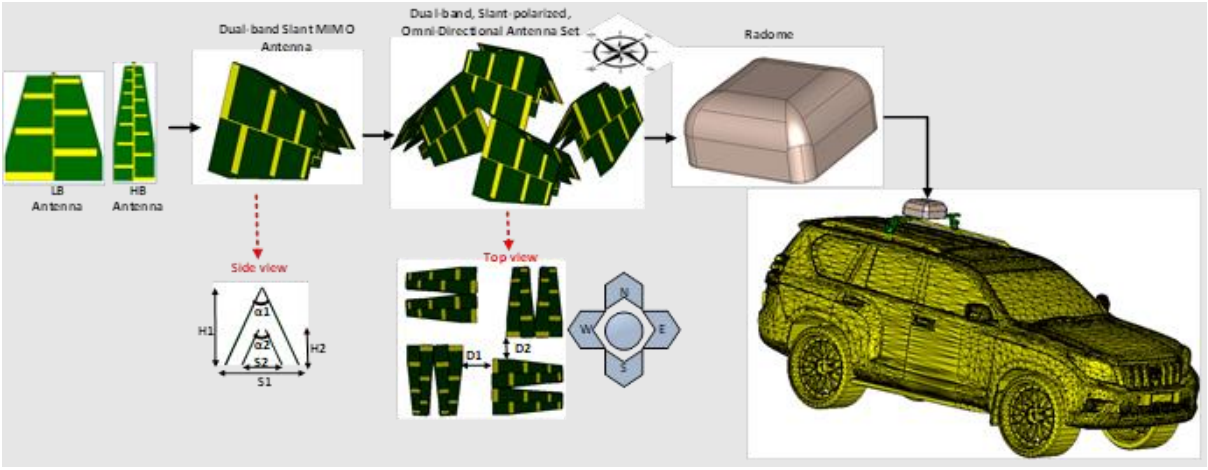


Figure 2: Design Procedure of Antennas for Vehicular Communications.

Global Digital Farm (Charles Sturt University)
Field testing methodology

Field testing locations were identified for fixed and mobile test sites to provide a range of Wi-Fi test scenarios. The continuous cropping fields of the CSU commercial farm were identified as most suitable due to the ability to test with and without obstructions up to 2.4 km from the fixed antenna site.

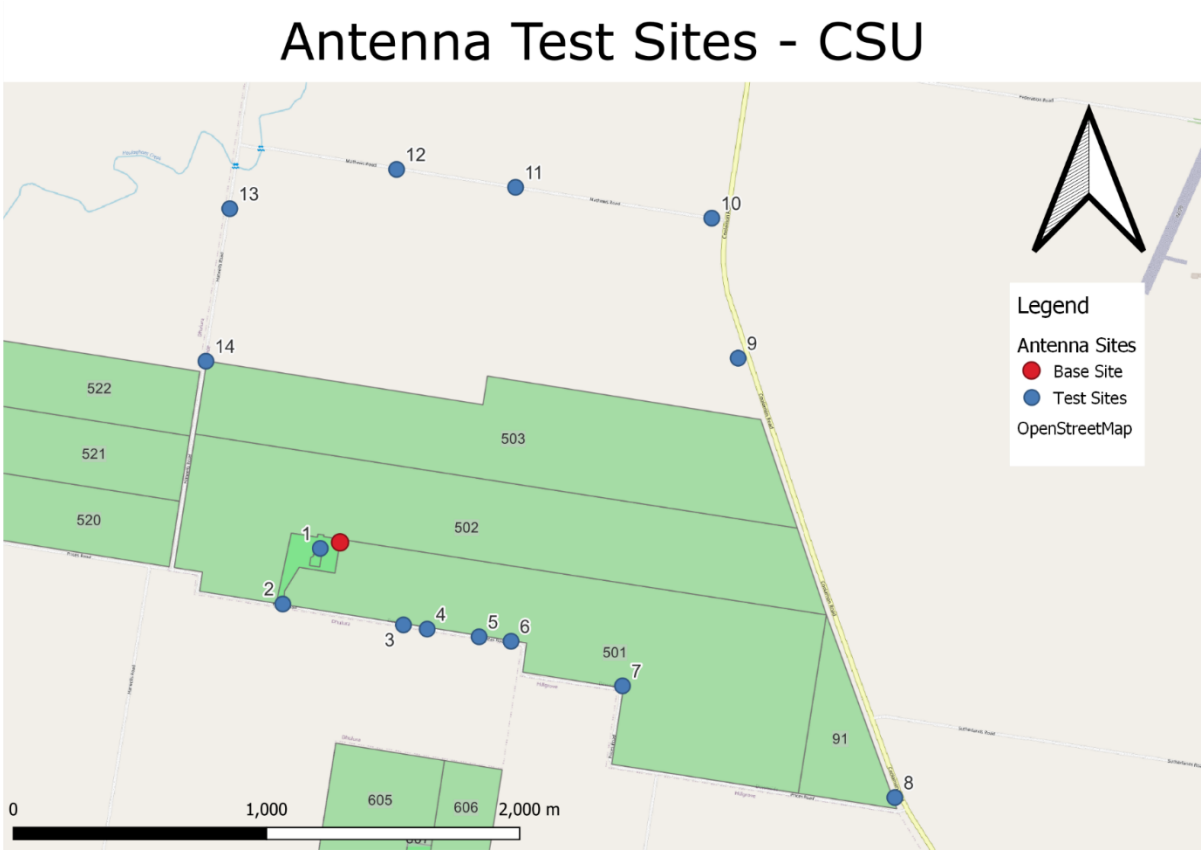


Figure *1* : Map of fixed and stationary Wi-Fi test sites at Charles Sturt University, Wagga Wagga.

Performance of commercially available fixed antennas were assessed by constructing two fixed test sites at 800m within visual line of site. Vehicle mounted antenna performance was assessed by connecting a fixed base station antenna to a range of commercial antenna systems mounted to a vehicle. The vehicle was stopped at multiple test sites at varying distances to the fixed antenna. Signal gain, SSRI, and transmission speeds were analysed to compare baseline performance. Tests were repeated utilising the UTS vehicle antenna array system to compare to baseline performance.

Description of test sites at CSU GDF

Site number	Description	Distance (m)	Vehicle bearing to base station
1	Visual line of site (VLOS) near base station	80	S
2	No VLOS: obstructed by trees	330	E
5	VLOS on Prices Rd	660	SE
7	VLOS on edge of paddock	1250	N
8	VLOS on Coolamon Rd	2400	N

Figure 4: Images of the vehicle mounted antenna field trials at CSU GDF.

RESULTS

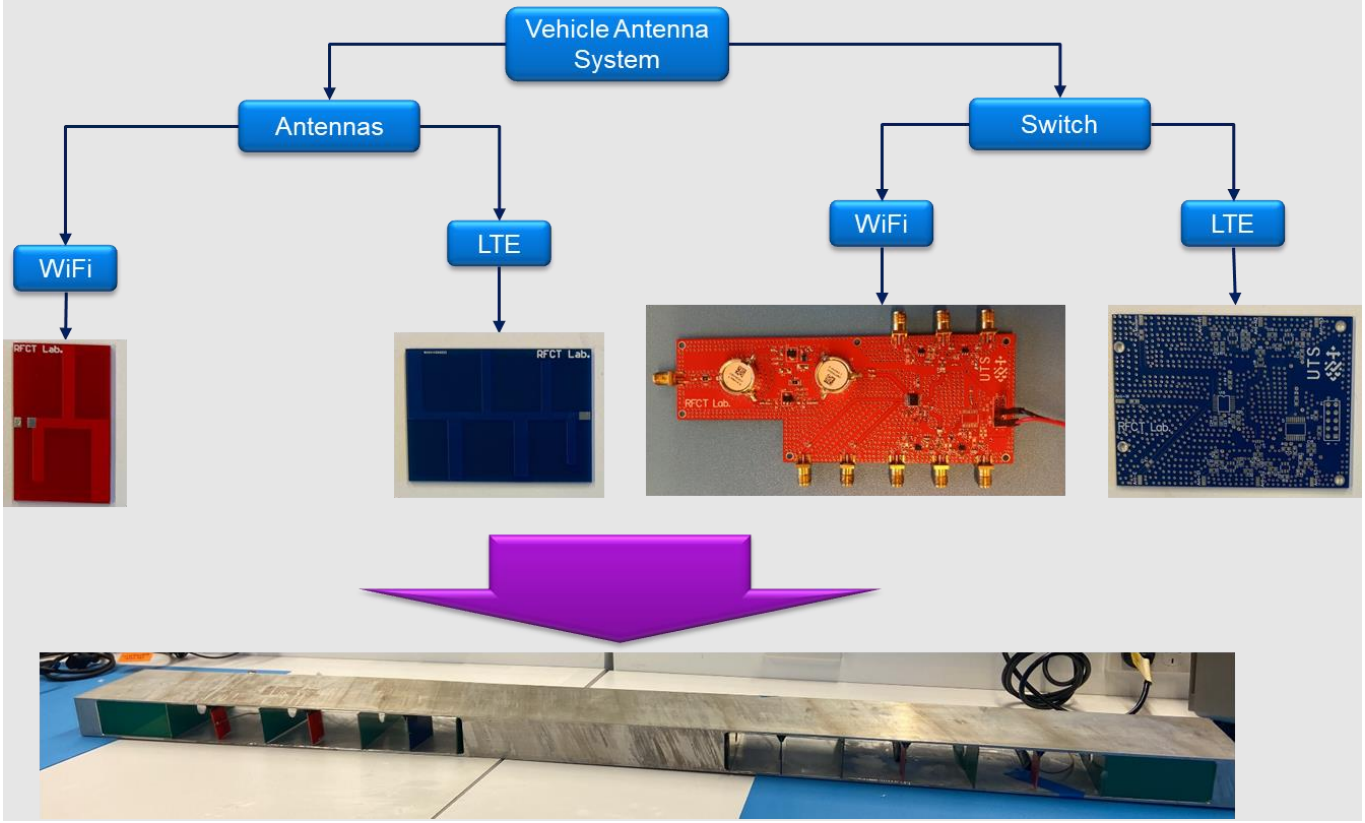
The developed technology can be used to solve connectivity problems in areas with little or no mobile coverage to provide reliable connectivity that increases productivity, profitability, safety and quality of life.

Our technology offers compact size, extended communication range, enhanced data performance, reduced energy requirements, and cost-effective production. The customised systems meet Australian standards, benefiting brand Australia. UTS-RFCT research offers low-cost and manufacturable designs that surpass performance standards, providing unique solutions, and creating a pathway for autonomous IoT devices in remote areas.

Vehicle Antenna Results:

Parameter	Zetifi Expectations	Commercialized Products (OEM)		RFCT lab Antenna Set
		Panorama	RFI	
No. of bands	LTE, Wi-Fi	LTE	LTE, Wi-Fi	**LTE, Wi-Fi**
Frequency (GHz)	LTE: 0.698-0.96 (OEM) and 2.1 - 2.7 Wi-Fi: 2.4	LTE: 0.7 – 2.7	LTE: 0.7– 2.7 WiFi: 2.4	**LTE: 2.1 – 2.7 WiFi: 2.4**
Gain (dB)	LTE: 6 dBi Wi-Fi: 6 dBi	0~3	LTE: 0~4 WiFi: 0~5	**LTE: >6 (SA) and >8.5 (PHA) WiFi: >6 (SA) and >9 (PHA)**
Pattern shape	Omni	Semi-omnidirectional	Semi-omnidirectional	**Omnidirectional**
Polarization	LTE - V Wi-Fi – V	LTE - V	LTE - V Wi-Fi – V	**LTE - V Wi-Fi – V**
MIMO Isolation (dB)	10	...	6	**>20**
Dimension	to be installed into a metal roof-rack	Cannot be implemented inside a roof-rack or even very close to a ground plane.	Cannot be implemented inside a roof-rack or even very close to a ground plane.	**Implemented inside the roof-rack and ground plane doesn't have significant influence on the performance.**
VSWR	2	2~3	LTE: 2.5 WiFi: 2	**LTE: <2 WiFi: <1.5**
Enclosure	Non polar plastic (e.g.. PP, PE, PS or blend - UV stablised)	Plastic	Plastic	**Metal roof-rack**
Cost (AUD)	???	60-80	165	**<30**

Vehicle Antenna, Implementation including RF module:



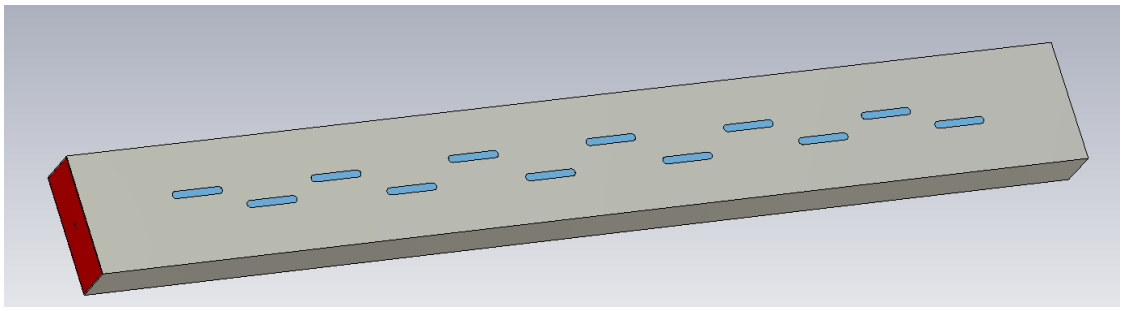
All Antennas are fabricated and tested.

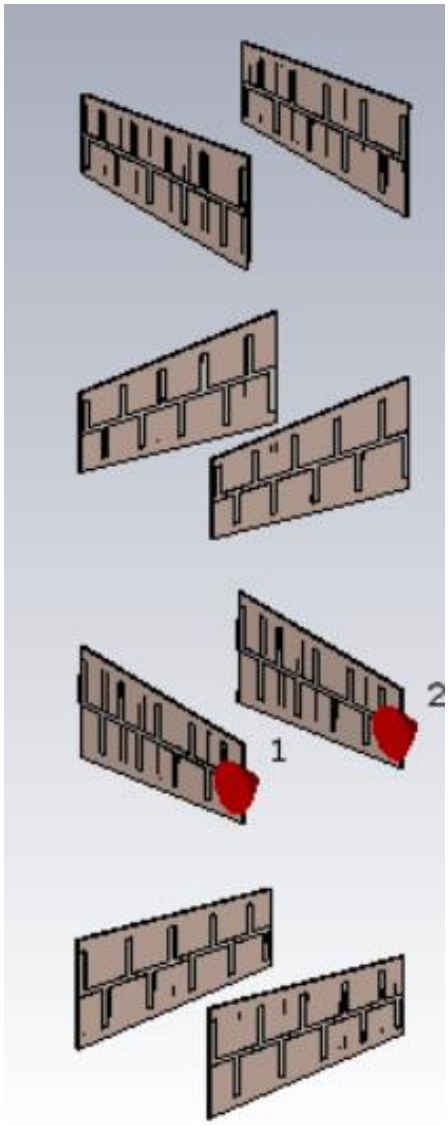
RFCT-UTS Achievements- Vehicle Antenna:

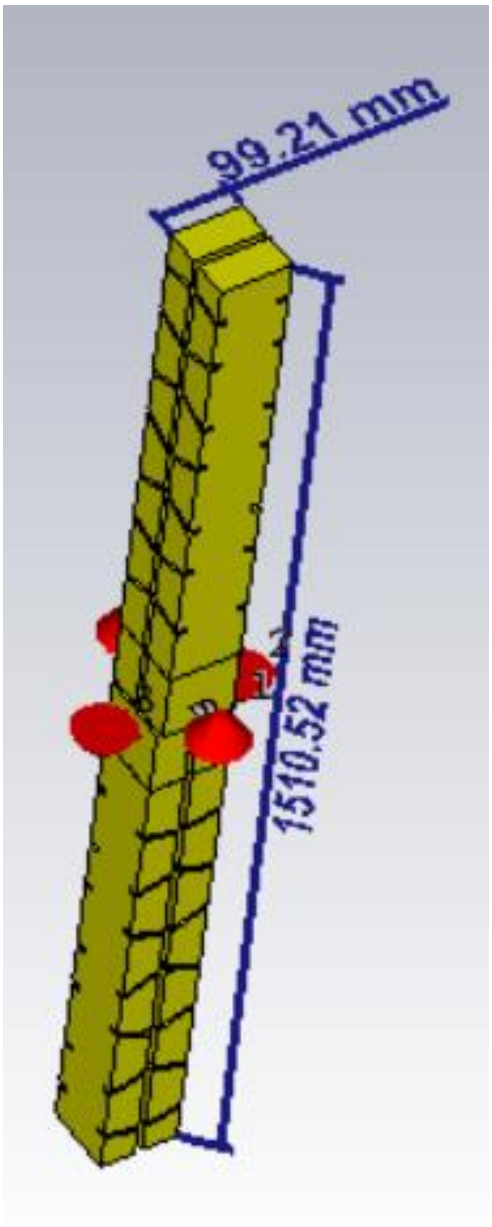
- Proposing a new idea to implement low-cost beamforming system which can be use in different scenarios and applications.
- Including the roof-rack as a part of antenna set to achieve compact size and high gain antenna set.
- High Gain in all directions.
- Low Cost.
- Omnidirectional pattern without any blind angle.
- Compact Size.
- Investigation on different communication scenarios (MIMO, SISO, High gain, …).
- Investigation of OEM antennas in detail and finding the drawbacks.
- Isolated from other parasitic components.
- Ground plane cannot influence the antenna performance.
- Simple manufacturing.
- Excellent isolation between antennas.
- Simple feeding connection (cable feed).

- Universal RF module which can be used for different communication scenarios.

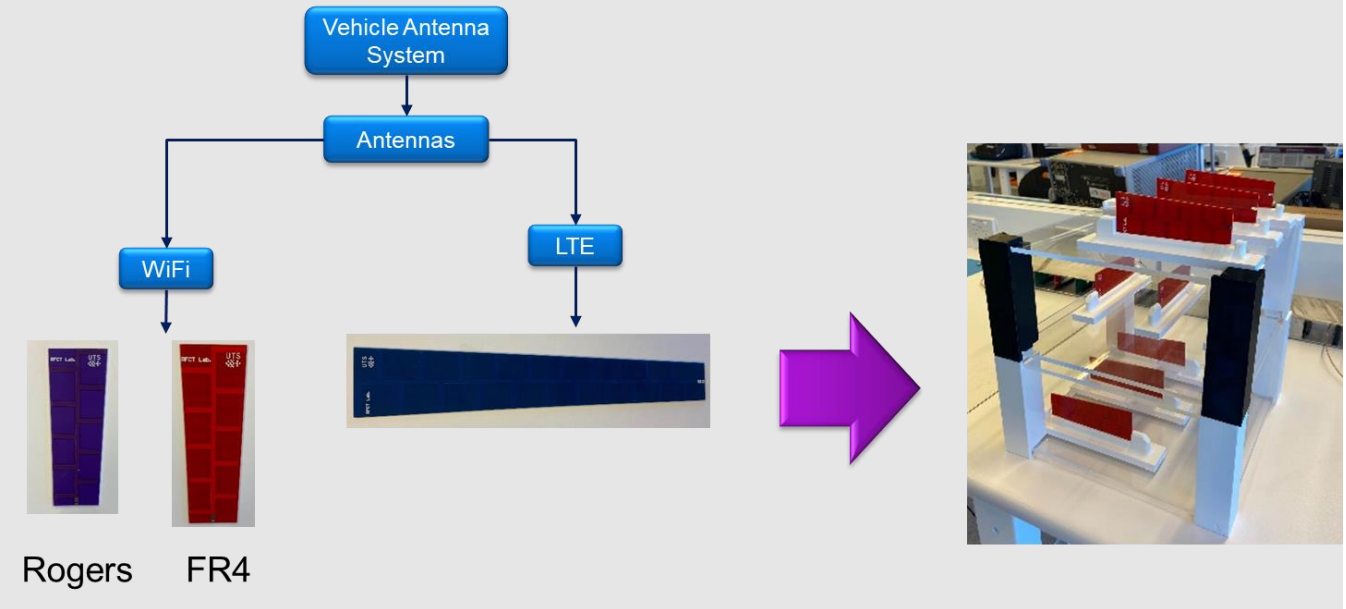
Custom Fixed Antenna Designs:







Fabricated Fixed Antenna:



All Antennas are fabricated and tested.

RFCT-UTS Achievements- Fixed Antenna:

- LTE (1.7~2.7 GHz)- Single antenna for each pole (FR-4): Gain>9 dB (Size: 8×31 cm).
- WiFi (2.4 GHz)- Single Antenna for each pole (FR-4): Gain>9 dB (Size: 6×12.5 cm).
- WiFi (2.4 GHz)- Single Antenna for each pole (Rogers): Gain >10.5 dB (Size: 6×12.5 cm).
- LTE (1.7~2.7 GHz)- Two antennas for each pole (FR-4): Gain>12 dB.
- WiFi (2.4 GHz)- Two Antennas for each pole (FR-4): Gain>12 dB.
- WiFi (2.4 GHz)- Two Antennas for each pole (Rogers): Gain >13.5 dB.

- Fixed antenna size (high gain):
    - LTE- Four poles (360 deg coverage): 32×32×40 cm.
    - WiFi- Four poles (360 deg coverage): 25×25×40 cm.

- Fixed antenna cost (AUD) per product, mass production (>20 products):
    - LTE- Four poles (360 deg coverage)-FR4: $60.
    - WiFi- Four poles (360 deg coverage)-FR4: $25.
    - WiFi- Four poles (360 deg coverage)-Rogers: $150.

We have proposed a modular antenna set in which the antenna gain can be improved by increasing the size.

Results of field trials

Field tests confirmed that the directional signal strength is closely related to the antenna's orientation relative to the base antenna. This outcome validates the correct antenna orientation and wiring configurations. Modifications were made to the construction and design of the UTS antenna, specifically catering to the demands of farm vehicle usage, enhancing its practical utility in rugged environments.

In our recent field trials, aimed at comparing the UTS vehicle antenna with commercially available antennas, we observed several notable outcomes. The results of the experiments found that in the close-range obscured tests, where the UTS antenna outperformed all commercial counterparts, in both transmission and signal strength. This indicates its superior capability in environments with physical obstructions such as trees and wooded areas. In terms of performance under less obstructed conditions, the UTS antenna showed comparable results to its commercial counterparts at close ranges.

When tested at distances greater than 1 km, the UTS vehicle antenna surpassed the performance of commercial products, indicating its suitability for long-range applications. However, it's important to note that beyond 2 km, all tested antennas, including the UTS, showed a marked decrease in signal strength and transmission quality. The maximum distance tested with the UTS antenna resulted in intermittent connections and mixed transmission results, compared with no signal or transmission with the majority or commercial antennas. This finding highlights the need for further experimentation, particularly in regions between 1 and 2 km, both with and without obstructions. Such research could provide more comprehensive insights into the transmission capabilities of these antennas over various distances and conditions.

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, this project report provides an analysis of the market for off-the-shelf antennas and the design process for custom-designed antennas for vehicles and fixed installations. The simulation and measured results of the designed antennas, as well as the design procedure for the switching module have been conducted in this project. Through this investigation, it is evident that designing custom antennas for specific applications can provide superior performance compared to off-the-shelf solutions. The switching module is also an essential component for seamless connectivity and reliable wireless communication. Overall, this report provides valuable insights into the design and implementation of antennas for different applications, which can be useful for researchers, engineers, and industry professionals.

The main contribution of RFCT lab in this project are as follows:

- Roof-rack incorporated as part of antenna set: The RFCT antenna project has incorporated the roof-rack as a part of the antenna set to achieve a compact size and high gain antenna set. This approach allows for a more efficient use of space, and it simplifies the installation process.
- Compact size and high gain antenna set: By incorporating the roof-rack as a part of the antenna set, the RFCT project has achieved a compact size and high gain antenna set. This is important in applications where space is limited, such as in vehicles or drones. Additionally, the high gain antenna set allows for longer range communication.
- High gain in all directions: The RFCT antenna project has achieved high gain in all directions, which is important in applications where the antenna needs to be able to communicate with multiple devices or in different directions. The high gain also helps to mitigate signal loss and interference.
- Omnidirectional pattern without any blind angle: The RFCT antenna project has achieved an omnidirectional pattern without any blind angle, meaning that the antenna can communicate in all directions without any dead spots. This is important in applications where the antenna needs to communicate with multiple devices or in different directions.
- Low cost: The RFCT antenna project has achieved a low cost, which is important in applications where cost is a critical factor, such as in mass-produced devices or in low-budget projects.

- Investigation of different communication scenarios (MIMO, SISO, high gain, etc.): The RFCT antenna project has investigated different communication scenarios, such as MIMO, SISO, and high gain. This allows for the antenna to be optimized for different use cases, and it ensures that the antenna can communicate effectively in a variety of environments.
- Investigation of OEM antennas and finding drawbacks: The RFCT antenna project has investigated OEM antennas and found their drawbacks. This allows for the project to improve upon existing technology and create a better solution for users.
- Isolated from other parasitic components: The RFCT antenna project has ensured that the antenna is isolated from other parasitic components, such as the ground plane. This helps to ensure that the antenna can communicate effectively and that its performance is not impacted by other components.
- Simple manufacturing: The RFCT antenna project has achieved a simple manufacturing process, which is important in applications where the antenna needs to be mass-produced or manufactured quickly.
- Excellent isolation between antennas: The RFCT antenna project has achieved excellent isolation between antennas, which is important in applications where multiple antennas are used in close proximity to each other. This helps to mitigate interference and ensure that the antennas can communicate effectively.
- Simple feeding connection (cable feed): The RFCT antenna project has achieved a simple feeding connection, which makes it easy to connect the antenna to a device. This is important in applications where the antenna needs to be easily integrated into a device or system.
- Universal RF module which can be used for different communication scenarios: The RFCT antenna project has achieved a universal RF module that can be used for different communication scenarios. This allows for the module to be easily integrated into different devices and systems, and it ensures that the antenna can communicate effectively in a variety of environments.

NEXT STEPS

- UTS_RFCT Team will publish the research outcomes of this project.
- Zetifi will create commercialization pathway.
- CSU and Zetifi have an ongoing collaboration where new antennas will be tested with Zetifi following the field test protocol developed.

PROJECT TEAM

- Dan Winson, CEO, Zetifi
- John Lucas, Product Designer, Zetifi
- Paul Maybon, Product Manager, Zetifi
- Negin Shariati, UTS
- Rasool Keshavarz, UTS
- Justin Lipman, UTS
- Mehran Abolhasan, UTS
- Nelson West, CSU
- Jonathan Medway, CSU
- Prof Dave Lamb, Food Agility CRC
- Dr. Mick Schaefer, Food Agility CRC

Farm-Wide WiFi

December 2023

Project No. FA103

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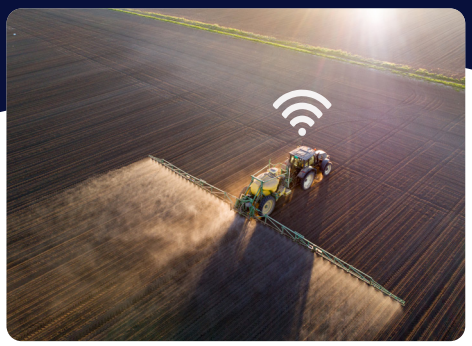
APPENDIX

A brochure for the ZetiRover, one of the products Zetifi has created which has benefited from the learnings from project FA103.

ZetiRover

Roaming Wi-Fi hotspot for vehicles and farm machinery



The ZetiRover is a roaming Wi-Fi hotspot for vehicles and farm machinery. Powerful antennas and innovative multi-carrier software converts patchy coverage into fast long-range Wi-Fi for voice, video and data – on or off the farm.

Don't rely on the coverage of a single carrier. The ZetiRover gives you access to multiple mobile and Wi-Fi networks. You'll be connected, productive and safe in more places than ever.

Superior coverage - the multi-carrier advantage

Multi-carrier technology provides unparalled remote area coverage by seamlessly combining the coverage of multiple cellular (LTE) and Wi-Fi networks (via optional ZetiCell).

Easy setup - use a single ZetiRover for multiple vehicles

Plug and play operation with minimal installation allows you to easily move a single ZetiRover between farm machinery and other vehicles as required.

Optimised for Wi-Fi phone calls and data throughput

Zetifi's network aware radio switching and multi-band modems maximise data speeds and optimise your connection for Wi-Fi phone calls on the move.

Long-range Wi-Fi to connect devices up to 300m away

Powerful antennas broadcast Wi-Fi up to 300m around the ZetiRover so you can be safe and productive whether you're in or out of the cabin.

Easily move the ZetiRover between vehicles.

One device, multiple possibilities.

"Since fitting the Zetifi units we've had complete coverage across our farm and not a single drop out on a call. Being able to pick up Wi-Fi a long way from the vehicles has been great too. It's surpassed my expectations and has been a real game changer for us."

Brian Carruthers
West Wyalong, NSW

For more info visit **zetifi.com/zetirover** or call us on **1300 093 711**

Get to know the ZetiRover

The unique design of the ZetiRover give it a significant advantage in performance and ease of use when compared to alternative coverage extension options. The use of ultra-short cables between the powerful in-built antennas and modems minimises signal loss to maximise signal reception in remote areas. Its ruggedised single-piece design enables simple plug-and-play operation and rapid transfer between vehicles and machinery to provide a convenient connectivity solution for multiple vehicles and applications.

- Tough outer casing and single piece design with minimal installation required enables easy transfer between vehicles through a range of convenient mounting options.
- High-performance integrated cellular (LTE) and Wi-Fi antennas receive and broadcast signals in even the most remote locations.
- Patent-pending ZetiLink™ technology optimises coverage by using collected coverage data to intelligently switch between multiple cellular (LTE) and Wi-Fi connections as required.
- External SIM slots so you can use data from your existing phone plan or elect to use a convenient all-inclusive data plan from Zetifi.
- Wi-Fi 6 and dual category 6 multi-band modems provide exceptional Wi-Fi performance in and around your vehicle.
- Integrated 900MHz Wi-Fi HaLow capability for long-range connections of more than one kilometre to other Wi-Fi HaLow-enabled devices or to provide a mesh connection between other Zetifi devices.

Low-profile weatherproof antenna radome with external antenna ports

High-performance cellular (LTE) and Wi-Fi antennas controlled by ZetiLink™ switching technology

Ruggedised die-cast base, dual-modem circuit board, and external SIM card slots

For more info visit **zetifi.com/zetirover** or call us on **1300 093 711**