OPTIMIZING NETWORK PERFORMANCE WITH SUSTAINABLE PASSIVE ANTENNAS

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EXECUTIVE SUMMARY

The escalating demand for higher data speeds and capacity in 5G networks, coupled with the proliferation of Internet of Things (IoT) devices, has significantly increased energy consumption in base stations due to the energy-intensive processes required for high-frequency transmissions. Green antennas offer a promising solution to this by combining high performance with lower energy consumption, leading to cost savings for operators, but also contributing to a more sustainable future for the telecommunications industry.

To develop these green antennas, current Research and Development (R&D) is focused on areas such as metamaterials and Artificial Intelligence (AI) to develop energy-efficient passive antennas. These innovations aim to address challenges such as antenna size, signal directionality, frequency optimization, and network management by enhancing performance, reducing energy consumption, and enabling intelligent antenna systems. By optimizing antenna design and incorporating AI capabilities, vendors are creating more sustainable and efficient wireless communication solutions.

PROSE's new PROTREEM (**PRO**SE ex**T**ra **E**nergy **E**fficiency **M**ark-up) range of antennas prioritizes sustainability through its design and manufacturing processes. Its antennas feature innovative designs for efficiency and durability, including no-cable solutions, modularity, optimized beam patterns, and Integrated field exchangeable Remote Electrical Tilt (RET) technology. Wind load reduction is achieved through aerodynamic design and advanced engineering. These factors contribute to lower energy consumption, while improving network performance.

High-efficiency antennas offer substantial benefits across areas such as telecommunications, healthcare, and smart cities. In telecommunications, they enhance network coverage, reduce operational costs, and minimize environmental impact. The healthcare sector can leverage their low latency for improved remote device performance, while smart cities benefit from their energy efficiency and ability to handle demanding urban environments, supporting a wide range of IoT applications.

Nevertheless, the widespread adoption of green antennas requires standardization, R&D investment, and lifecycle considerations by vendors. Operators can facilitate this transition through case studies, strategic partnerships, and consumer awareness initiatives.

INTRODUCTION

The passive antenna market is undergoing a period of transformation, marked by a growing emphasis on sustainability and technological advancement. While recent challenges have presented opportunities for optimization, the industry is demonstrating resilience and innovation in response. As demand for eco-friendly solutions intensifies, vendors are investing heavily in R&D surrounding sustainable materials and processes. This shift toward greener technologies is poised to dominate the industry, redefining market standards and shaping the future of telecommunications infrastructure.

PASSIVE ANTENNA MARKET OVERVIEW

Passive antennas are essential components of telecommunication networks, responsible for efficiently transmitting and receiving radio signals. Their strategic placement and design significantly influence network performance, ensuring reliable and high-quality connections. Despite their critical role, the passive antenna market is currently experiencing a period of turbulence. The following analysis delves into the factors contributing to this market downturn and explores the potential for future growth.

Passive antennas are crucial for telecommunication networks, acting as the interface between wireless devices and the network by efficiently capturing and transmitting radio signals. Their placement and design significantly impact network coverage, signal strength, and range. They help maintain signal quality by minimizing interference and distortion, ensuring clear communication. Additionally, passive antennas are cost-effective and durable, making them practical for network infrastructure. Despite being less prominent than active antennas, they are vital for the efficiency and reliability of modern telecommunication networks.

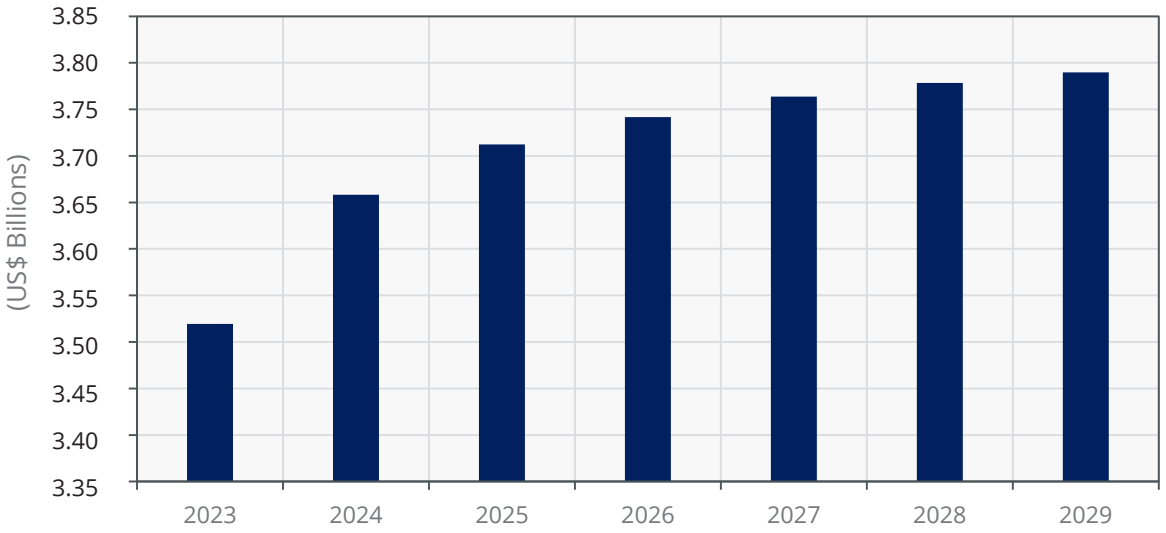
However, Chart 1 (following page) shows that the passive antenna market is currently experiencing a turbulent time in its growth. In 2023, the market declined by 7.2% in revenue Year-over-Year (YoY) and is projected to only grow at a Compound Annual Growth Rate (CAGR) of 1.3% up to 2029. Several factors contributed to this market contraction:

- Vendor focus has shifted toward active and Active-Passive (A+P) antenna solutions, where significant innovation is occurring (see ABI Research's *Passive Antenna Technology Update* report (AN-6144) for further information).
- Global economic headwinds, including rising inflation and a significant reduction in operator Capital Expenditure (CAPEX), including a 50% cut in North America, have dampened spending. This comes on the heels of major operator investments in spectrum acquisition during 2022, further tightening budgets for passive antenna rollouts.

- Operators are prioritizing a clear Return on Investment (ROI) before expanding their 5G infrastructure. This translates into a temporary slowdown in passive antenna deployments as they reevaluate network strategies.
- There has been an increase in R&D costs as a result of an increase in the number of projects, higher technical requirements, shorter development times, and high competition for R&D talent.
- Supply chain disruptions caused by conflicts in several regions affecting shipping lanes have also increased logistics costs and put time pressure on vendors' existing commitments with operators.
- There has been volatility in the prices of several raw materials crucial to passive antennas, including copper, nickel, and aluminum, among others.

Chart 1: Passive Antenna Sales Overview, World Markets: 2023 to 2029

(Source: ABI Research)



Nevertheless, the stabilization of the world economy, which is now projected to grow by 2.7% in 2024, as well as the regained capital for operators to spend on rollouts of 5G Standalone (SA) networks, means that ABI Research has projected a 4.4% increase in the passive antenna market in 2024, followed by a gradually declining increase YoY. The lower spectrum range (<3 Gigahertz (GHz)) is likely to remain dominated by passive antennas due to the size limitations of radio elements for Massive Multiple Input, Multiple Output (mMIMO) configurations in active antenna solutions. While established markets experience a slowdown due to operator caution, Africa, the Middle East, and Latin America, embarking on their 5G journeys, offer a counterpoint. These regions are expected to be key drivers of growth in the passive antenna market, fueled by their network infrastructure buildout needs, illustrating how passive antennas will remain crucial to global network infrastructure.

WHY A NEED FOR SUSTAINABILITY NOW?

The advent of 5G has amplified the demand for efficient and sustainable antenna solutions. To meet the capacity and speed requirements of this technology, antennas must operate at higher frequencies and with greater precision. This increased operational complexity leads to higher energy consumption due to power losses inherent in higher frequency transmissions and the energy-intensive processes involved in precise beamforming. The proliferation of IoT devices and the surge in mobile data usage further exacerbate this issue by increasing the number of base stations.

The global energy landscape has undergone a dramatic shift, with prices escalating due to geopolitical tensions and the transition to renewable energy sources. This financial strain has impacted Mobile Network Operators (MNOs) that withstand the worst of increased electricity costs for powering their infrastructure. Given the energy-intensive nature of base stations, even marginal efficiency gains in components like antennas can yield substantial cost savings.

Beyond economic implications, the urgent need to address climate change is a global priority. The telecommunications industry, while driving innovation and economic growth, contributes to Greenhouse Gas (GHG) emissions. The industry is under increasing pressure to reduce its environmental footprint, which has sparked a movement toward sustainable practices across the entire value chain, from network design and equipment manufacturing to operations and disposal.

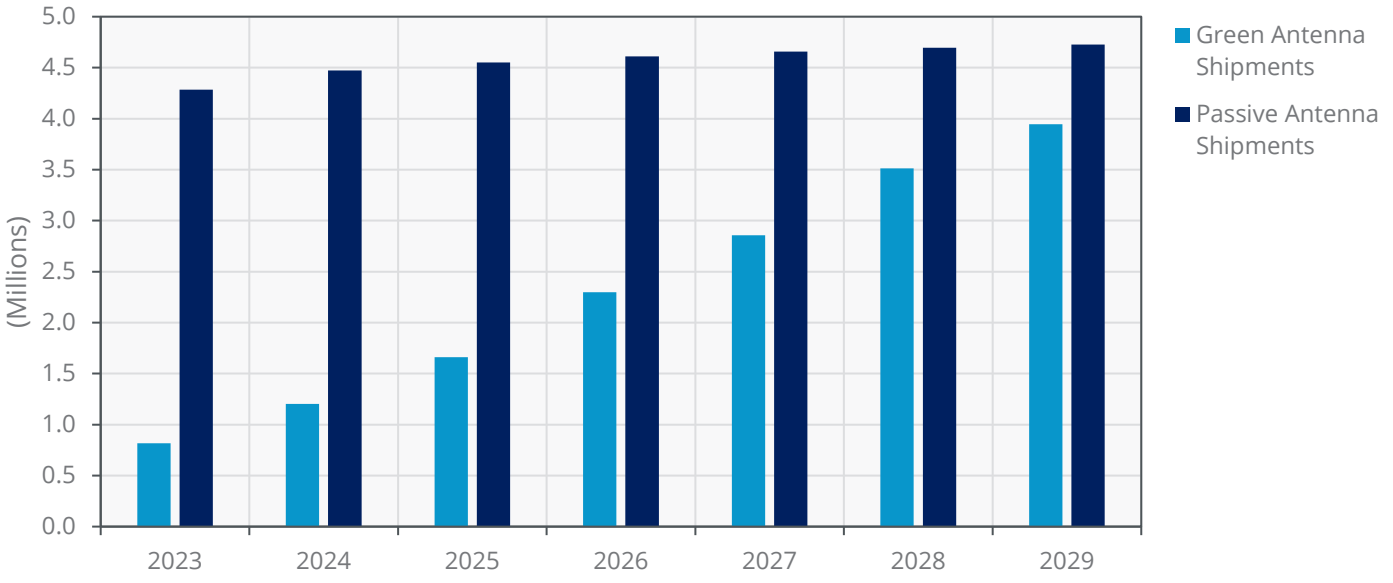
GREEN ANTENNAS

The confluence of factors described above has created a compelling case for sustainable antenna solutions. Operators seek antennas that deliver higher performance, while consuming less power. To meet these demands, antenna vendors are investing heavily in R&D to create advanced materials, optimize antenna designs, and refine manufacturing processes. The goal is to produce antennas that excel in Radio Frequency (RF) performance, while contributing to reduced energy consumption in mobile networks.

Green antennas represent a distinct category within the broader antenna landscape. They are not classified based solely on functionality, but rather on their commitment to environmental sustainability. This focus translates into two key areas of innovation: energy-efficient designs and solutions that minimize visual impact when deployed. Vendors are focusing on addressing key industry priorities of energy and cost efficiency in green antenna design, which will meet operators' priorities.

Chart 2: Green Antenna Shipments, World Markets: 2023 to 2029

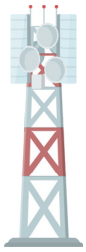
(Source: ABI Research)



As illustrated in Chart 2, shipments of green antennas are forecast to expand at a CAGR of 30% between 2023 and 2029, increasing from around 0.82 million to 3.95 million. Green antenna shipments currently stand at around 19.1% of all antenna shipments globally, with many vendors' green antenna solutions entering the market within the last year. One of the primary drivers behind this growth is a shift in operator requirements. Many Requests for Quotation (RFQs) now stipulate that proposed antennas must adhere to green and sustainable design principles.

Operators will be incentivized to adopt these antennas not only due to the developed technology integrated into their designs, but also as the vendors have focused on addressing key industry priorities—energy and cost efficiency—within their antenna designs, which falls in line with operators' priorities. Despite the increasing focus of vendors on mMIMO antennas to gear toward 5G SA networks, passive antennas are expected to remain a significant part of the market, with this demand driven by regions such as South Asia, Latin America, and Africa. Nevertheless, these traditional passive antennas have inherent energy losses, achieved both through their design and the manufacturing process, which all add to increased energy output and, thus, more Carbon Dioxide (CO_2) emissions. With base stations and their attached antenna units totaling 57% of all electrical power consumption in the passive antenna network, this is a key area for vendors to target in reducing their energy output, but increasing their RF efficiency, hence the projected increase of green antenna shipments.

This then leads to new antenna designs prioritizing environmental sustainability, which demonstrates significant potential for operators. Industry-leading vendors are reporting energy savings of a 26% reduction in base station energy consumption during peak hours through innovations like optimized antenna structures, green materials, and sustainable manufacturing. These advancements offer a convincing value proposition for their wider adoption, as green antennas can reduce the network footprint, while maintaining performance and coverage, a challenge that traditional passive antennas have not effectively tackled.



FUTURE OUTLOOK FOR PASSIVE ANTENNAS

Passive antennas, traditionally considered static components in telecommunication infrastructure, are currently undergoing a significant shift. Driven by the escalating demands for energy efficiency and enhanced network performance, these essential elements are now at the forefront of technological innovation. This section explores the various R&D projects aiming to innovate the field of passive green antennas, with a particular focus on integrating metamaterials and AI. These advancements hold the potential to significantly enhance network capabilities, while reducing environmental impact.

METAMATERIALS

While cost previously limited widespread adoption, recent advancements in metamaterial research are making metamaterials a game-changer for passive antenna design. This tech, once relegated to R&D labs, is now finding its way into base station antennas, enabling the following exciting functionalities:

- **Miniaturization with High Efficiency:** Traditional antennas often struggle to achieve the desired performance, particularly at lower frequencies, due to size limitations. These larger antennas can contribute to increased device size and weight, leading to higher material consumption and energy expenditure during manufacturing and transportation. Metamaterials can create "virtual" antenna lengths that are much larger than the physical size of the antenna itself, enabling highly efficient, miniaturized passive antennas for applications like mobile devices and wearable electronics. This not only reduces the size and weight of devices, but also contributes to a smaller ecological footprint by reducing material consumption and energy expenditure during manufacturing and transportation.

- **Enhanced Directivity and Reduced Side Lobes:** Conventional antennas often radiate some energy in unintended directions. Metamaterials can be used to control the way electromagnetic waves interact with the antenna structure. By incorporating specific metamaterial elements, engineers can tailor the radiation pattern of the antenna, focusing the signal in a desired direction. This reduces side lobes, which are unwanted secondary beams that can interfere with other signals. This improved directivity not only reduces wasted energy, but also minimizes interference with neighboring networks, leading to a cleaner and more reliable wireless communication experience.

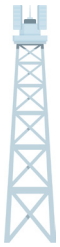
- **Tailored Frequency Response for Multi-Band Applications**: Metamaterials can be used to create antennas that resonate efficiently at specific frequencies, enabling developing passive antennas that can handle multiple communication standards within a single compact design. This is particularly beneficial for devices like smartphones or IoT sensors that may need to operate on cellular networks, Wi-Fi, and Bluetooth® simultaneously. By reducing the number of antennas required for various frequency bands, metamaterial-based antennas can contribute to decreased material consumption and lower production energy, promoting a more sustainable approach to device manufacturing.

BEAM ORIENTATION AND AI

While active antenna technology has witnessed significant advancements in AI integration, a parallel development within passive antennas is poised to revolutionize network management. In the past year, vendors have focused on incorporating AI to empower operators with greater "visibility" into their passive antenna infrastructure. This is achieved through real-time data collection facilitated by AI, enabling faster identification of inefficiencies and improved network optimization. By collecting data on antenna position, height, and azimuth, these sensor units can provide operators with a wealth of Key Performance Indicators (KPIs) for individual antennas, enhancing both performance and energy efficiency. This self-sensing capability represents a cornerstone of future network optimization and sustainability strategies.

Beyond real-time performance feedback, AI integration unlocks a new dimension of control for passive antennas. Traditional antennas allowed for vertical beam adjustment only. However, AI integration empowers remote horizontal adjustment as well. This dynamic beam steering capability allows operators to adapt to various network challenges, such as the emergence of high-rise buildings or fluctuations in user traffic patterns. Notably, the cylindrical design of newer passive antennas facilitates easier integration of this technology compared to traditional rectangular form factors.

Furthermore, AI can optimize low-power periods based on user data traffic patterns, leading to reduced energy consumption. This approach is even more effective due to the minimized dead zones achieved through self-sensing technology. By proactively identifying areas with low traffic and utilizing self-sensing data, AI can confidently activate low-power modes without compromising service quality. Passive antennas equipped with AI will generate vast amounts of data, acting as a crucial foundation for other AI-powered technologies. Digital twins, for instance, rely heavily on real-world data streams to simulate and predict network performance under diverse conditions, helping to optimize network design for reduced environmental impact. As passive antenna innovations incorporating AI are considered a key technology for future networks, they are poised to play a foundational and critical role in developing sustainable and fully autonomous networks.



PROSE'S SUSTAINABLE SOLUTIONS

PROSE PROFILE

PROSE has established itself as a prominent player in the wireless industry, with a strong emphasis on environmental sustainability. The company's PROTREEM antenna series, incorporating eco-friendly materials and energy-efficient design, exemplifies this commitment. PROSE's core values of innovation, flexibility, speed, quality, and support drive its operations. Supported by a global presence, four R&D centers, and a workforce of approximately 3,500, the company is well-positioned to spearhead industry advancements, all while remaining committed to the following goals:

- Advanced technologies used on hyper-efficient products to achieve significant performance improvement
- Eco-design & low-carbon solution
- Enhance user experience & satisfaction
- Support the customers' sustainable goal of a yearly CAPEX & Operational Expenditure (OPEX) reduction

MATERIALS TECHNOLOGY

PROTREEM's sustainability is rooted in its material selection and manufacturing processes. By replacing traditional ferrous metals with non-ferrous and polymer alternatives, the vendor significantly reduces its reliance on resource-intensive materials. This shift eliminates the need for harmful plating processes, which often involve hazardous chemicals and generate toxic waste. Adopting direct tinning as a surface treatment method not only simplifies production, but also minimizes environmental impact by reducing energy consumption and chemical usage. Furthermore, incorporating lightweight aluminum alloy and polymer components offers several sustainability advantages. Aluminum is a highly recyclable material with a lower carbon footprint compared to steel. Polymers, when derived from renewable sources, can also contribute to reduced environmental impact. The lighter weight of these materials reduces transportation emissions and energy consumption during installation, enhancing the product's overall sustainability profile.

PROSE's lifecycle extension project is an additional cornerstone of its sustainability strategy. This initiative involves refurbishing and reusing old antennas, thereby extending their life span, and diverting them from landfills. This circular approach drastically reduces the demand for new materials and manufacturing processes, consequently lowering associated energy consumption and GHG emissions.

ANTENNA DESIGN

PROSE's PROTREEM antenna series incorporates a range of innovative design features to enhance performance, efficiency, and sustainability. By optimizing various aspects of antenna construction and functionality, PROTREEM aims to deliver superior network coverage and capacity, while minimizing environmental impact (please see PROSE's Sustainable Mobile Networks-Antenna Strategies for Energy Efficiency and Improved Coverage whitepaper for more information on the passive antenna research direction to enhance energy efficiency and network coverage).

- **Integrated Solution:** Eliminating passive cables simplifies manufacturing, reduces soldering, and introduces a dielectric and air mix feed network for lower insertion loss and improved efficiency. Additionally, this design allows for individual control of each radiator's phase, as the conventional fixed splitter feed board is replaced. The outcome of fine elevation beam shaping becomes possible, which is crucial for optimizing coverage.
- **Modular Design:** A platform-based, modular approach enhances versatility, reduces part count, and streamlines production.

- **Optimized Beam Patterns:** Focusing on Signal-to-Noise Ratio (SNR), PROTREEM antennas maximize desired signals, while minimizing interference through precise beam pattern optimization.
- **Embedded (Replaceable) RET:** Accurate downtilt control is achieved through Integrated (field exchangeable) RET technology. This enhances cellular network performance by improving coverage, capacity, and user experience, while reducing power consumption and interference.
- **Simulation-Driven Development:** Extensive simulations reduce the number of physical prototypes and testing cycles, accelerating time to market, and minimizing resource consumption.
- **High-Gain and Coverage:** By delivering superior coverage, PROTREEM antennas could potentially enable reducing the number of sites or lowering power consumption, while keeping the same coverage range.

WIND LOAD REDUCTION

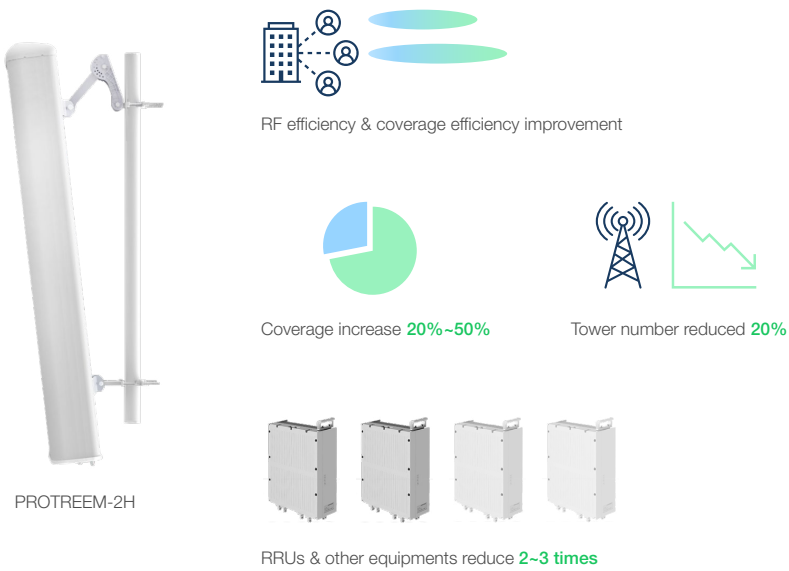
A key focus of the PROTREEM design is to minimize wind load on the antenna, enhancing tower safety and capacity. Reducing the force exerted on the antenna by wind improves the overall structural integrity of the tower, extending its life span and reducing maintenance requirements.

- **Aerodynamic Radome:** Wind tunnel and Computational Fluid Dynamics (CFD) simulations have optimized the radome's shape to reduce wind resistance.
- **Miniature Design:** The antenna's compact size contributes to lower wind drag.
- **Side Aerodynamic Ribs:** These ribs act as "air-lubricated bearings," reducing drag coefficient (Cd) and mitigating vortex-induced vibrations.
- **Bionic Drag Reduction End Cap:** PROSE's patented end cap design delays airflow separation and improves overall aerodynamic efficiency.
- **Turbulence Generator:** This feature reduces maximum wind load by increasing fluid disturbance and preventing flow separation.

COST AND ENVIRONMENTAL BENEFITS

Figure 1: PROTREEM-2H Antenna Benefits

(Source: PROSE PROTREEM Passive Family - High Efficiency BSA, Products Catalog)



- **Optimized Network Infrastructure:** A significantly reduced network footprint is achieved through a 20% decrease in base stations and a substantial reduction (2X to 3X) in Remote Radio Units (RRUs) and other equipment. This streamlined infrastructure not only lowers CAPEX and OPEX, but also reduces the demand for tower sites, leading to decreased site rental costs.
- **Improved Reliability:** A 50% reduction in product failure rate extends equipment life and minimizes waste.
- **Lower Power Consumption:** Approximately 25% less power consumption translates to significant energy savings and reduced carbon footprint.
- **Enhanced System Capacity:** Excellent and stable Passive Intermodulation (PIM) performance boosts system capacity. By mitigating PIM, antennas can operate more efficiently, requiring less power and generating less heat, thereby contributing to overall energy efficiency and system longevity.

PROSE'S ANTENNA PORTFOLIO

The PROTREEM series of antennas exemplifies PROSE's dedication to developing cutting-edge solutions that address the evolving demands of the wireless communication market. By leveraging advanced technologies, such as Integrated (field exchangeable) RET and cable-free solutions, PROSE aims to offer antennas that are not only efficient, but also reliable and adaptable to a wide range of applications.

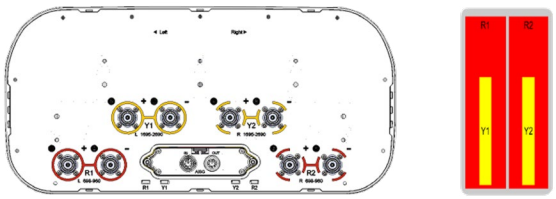
By offering a diverse portfolio of antennas, PROSE aims to provide customers with the flexibility to select the optimal solution for their particular needs, with each product designed to meet specific requirements and cater to different market segments. Several antenna solutions within the PROTREEM family are displayed in Figure 2.

Figure 2: A Selection of PROTREEM Antenna Products

(Source: PROSE PROTREEM Passive Family - High Efficiency Antenna Platform)

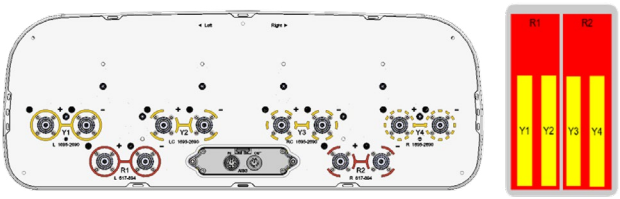
Model No. 2G2WD-21T-H

- 2x (617-894) + 2x (1695-2690) MHz
- Integrated RET (AISG 2.0 Compliant) Field Exchangeable
- 4.3-10 Connectors
- Low Windload Radome
- 2.4m Released



Model No. 2D4WE-71-H

- 2x (617-894) + 4x (1695-2690) MHz
- Integrated RET (AISG 2.0 Compliant) Field Exchangeable
- 4.3-10 Connectors
- Low Windload Radome
- 2.4m Released



USE CASES

These high-efficiency antennas are positioned to address the critical challenges faced by a wide range of industries, such as telecommunications, healthcare, and smart cities, where performance, efficiency, and sustainability are paramount.

The telecommunications industry faces ongoing challenges in expanding network coverage, while optimizing operational efficiency and reducing environmental impact. These high-performance antennas with low-power consumption can contribute to addressing these challenges. By delivering superior signal strength and capacity, while minimizing energy consumption, these antennas can potentially reduce OPEX and carbon footprint. Additionally, their resilience to adverse weather conditions, achieved through features such as PROSE's innovative radome, can enhance network reliability and service continuity.

Additionally, green antennas can benefit the healthcare sector in several ways. Beyond energy efficiency and reduced OPEX, their potential for low latency through innovative technologies like enhanced signal directionality is particularly promising. This can significantly improve the performance of remote medical devices, such as surgical arms, requiring precision and real-time responsiveness.

Smart cities are a key area of deployment for high-efficiency antennas with their focus on sustainability and technological advancement. These antennas support a wide range of IoT applications, from smart metering and environmental monitoring to public Wi-Fi and video surveillance. Their energy efficiency aligns perfectly with the sustainability goals of smart city initiatives, while their ability to operate in challenging urban environments, such as those with high levels of interference and large volumes of data, illustrates their suitability for these complex ecosystems.

CHALLENGES AND RECOMMENDATIONS FOR GREEN ANTENNA ADOPTION

Green antennas hold immense promise for cellular networks, offering compelling benefits such as: improved network efficiency, cost savings for operators, and a significant boost to sustainability efforts. However, their widespread deployment requires addressing several technological and ecosystem challenges. ABI Research recommends the following strategies to facilitate a smooth transition from legacy passive antennas to green sustainable solutions:

Vendors:

- **Standardization:** While initial efforts by the GSMA and The 3rd Generation Partnership Project (3GPP) are underway to increase sustainability in active antennas, industry bodies and vendors need to collaborate on establishing and promoting clear standards for green passive antenna performance. As standardization efforts progress, the technology matures, and costs become more competitive, ABI Research expects wider adoption of green antennas around the world and, subsequently, a more sustainable future for cellular networks.

- **Focus on R&D:** Vendors should enhance green antenna technology by improving the durability and sustainability materials, optimizing designs for various frequencies (such as 5G), and integrating with technologies like FRequency of Earth-Sized Inner Planets (FRESIP) for increased efficiency. Furthermore, creating specific green antenna alliances could support and accelerate R&D, and provide a healthy competitive environment.

- **Lifecycle Considerations:** Vendors must continue to develop sustainable practices throughout the entire antenna lifecycle, from sourcing recyclable materials to minimizing any waste during manufacturing and facilitating efficient end-of-life recycling programs. PROSE's recyclable solutions demonstrate the viability of refurbishing old antennas to create new and upgraded models.

Operators:

- **Case Studies and Testing:** While green antennas offer substantial long-term benefits, their initial costs might be higher through sourcing renewable and recyclable materials. Operators should pursue case studies of small-scale deployments with vendors to demonstrate antenna efficiency, energy savings, and the ROI to incentivize wide-scale adoption of this sustainable antenna practice.
- **Strategic Partnerships:** "Off-the-shelf" green antennas might not optimize energy savings or seamlessly integrate into the existing infrastructure. Through collaboration with vendors, operators can share their specific needs and deployment challenges, allowing vendors to tailor green antenna solutions for maximum efficiency and compatibility.
- **Consumer Awareness:** Operators need to raise awareness among consumers about the environmental benefits of green antennas, as environmentally-conscious consumers who understand its positive impact can influence operator choices.

CONCLUSIONS

Green antennas are poised to become the industry standard for passive antenna solutions, driven by their combination of sustainability and performance. With a focus on energy efficiency, reduced environmental impact, extended life span, and improved performance, green antennas offer a compelling value proposition for telecommunications operators. As the industry accelerates its shift toward low-carbon operations, green antennas will be instrumental in achieving sustainability goals, while enhancing network capabilities.

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