

Reconfigurable Metasurface Panels for Active Electromagnetic Shielding of Protective Domes

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ABSTRACT

The increasing complexity of electromagnetic (EM) environments in defense and communication systems necessitates shielding solutions that are both adaptive and efficient. Conventional static shielding domes, while effective in blocking electromagnetic interference (EMI), are inherently limited by their fixed frequency response, high structural weight, and lack of real-time adaptability. This research investigates the design and performance of reconfigurable metasurface panels for active electromagnetic shielding of protective domes, with the aim of enhancing shielding effectiveness, tunability, and structural efficiency. The study explores the integration of reconfigurable metasurfaces into dome architectures, enabling dynamic control of electromagnetic wave propagation through electronically tunable elements. Performance metrics including shielding effectiveness (in dB), tunable frequency ranges, angular stability, and real-time adaptability were evaluated and benchmarked against conventional static shielding designs. Results indicate that reconfigurable metasurface domes achieve superior shielding performance across wide frequency bands while offering significant weight reduction and improved adaptability. These characteristics make them well-suited for critical applications such as military radomes, satellite communication shelters, aerospace systems, and secure civilian infrastructures. However, challenges remain regarding large-scale fabrication, integration complexity, power requirements for active tuning, and environmental durability. Despite these limitations, the findings highlight the transformative potential of reconfigurable metasurfaces as the foundation of next-generation adaptive shielding technologies. This research demonstrates that reconfigurable shielding domes not only address the shortcomings of static designs but also pave the way for resilient, flexible, and future-proof electromagnetic protection systems.

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1. INTRODUCTION

In an era where electronic and communication technologies serve as the backbone of both civilian and military operations, the vulnerability of these systems to electromagnetic interference (EMI) and intentional electromagnetic threats has become a critical concern. Protective domes commonly referred to as radomes when used in radar systems, communication shelters, satellite ground station enclosures, or specialized military facilities are essential in safeguarding sensitive electronic

equipment from environmental and operational hazards(Kozakoff, 2010). Beyond their structural role in providing physical protection against weather, debris, and mechanical stress, these domes must also ensure electromagnetic integrity, as the performance of internal systems is highly dependent on their ability to resist external electromagnetic disturbances.

Electromagnetic shielding in protective domes plays a crucial role in maintaining the operational reliability of advanced systems(Tong, 2016). For instance, radar domes must ensure uninterrupted signal processing and accurate target detection, which can be severely disrupted by EMI or hostile electromagnetic attacks such as jamming. Similarly, communication shelters and satellite ground stations rely on stable signal transmission and reception; even small levels of interference can compromise data integrity, reduce communication range, and lead to mission failure. In military facilities, where command, control, and surveillance systems are central to operational success, electromagnetic shielding provides not only functional assurance but also strategic security against adversarial actions that exploit electromagnetic vulnerabilities.

The importance of shielding is further amplified in the context of intentional electromagnetic threats, including electromagnetic pulse (EMP) weapons and directed energy systems. Such attacks are designed to disable or destroy electronic infrastructure by overwhelming them with high-intensity electromagnetic fields. Without effective shielding, protective domes would be unable to defend the critical systems they house, leaving sensitive equipment exposed to catastrophic damage. Moreover, as modern battlefields and critical infrastructures increasingly depend on interconnected and networked systems, the resilience of these systems hinges on robust shielding solutions that can adapt to evolving electromagnetic environments.

In addition to defensive purposes, electromagnetic shielding also serves an essential role in ensuring electromagnetic compatibility (EMC) within protective domes. With multiple electronic subsystems operating simultaneously, shielding helps prevent internal cross-interference, thereby enhancing overall system performance and reliability. This dual role protecting against external threats while preserving internal system harmony makes shielding a cornerstone of dome design in both military and civilian applications(Krauthammer, 2008).

Over the past decade the concept of digital or “coding” metamaterials was introduced and widely adopted as the foundation for programmable metasurfaces. Tie Jun Cui and colleagues formally proposed coding/digital metamaterials and demonstrated the use of biased diodes and FPGA control to switch unit-cell states (Cui et al., 2014). That work established the binary ‘0/1’ coding idea and kicked off a line of research that treats metasurfaces as digitally programmable apertures rather than fixed passive coatings a conceptual leap that underpins most reconfigurable shielding strategies today.

Building on digital coding, researchers extended metasurface control into the time domain. Lei Zhang, Jie Zhao, Tie Jun Cui and co-workers proposed and experimentally validated space-time-coding digital metasurfaces (Zhang et al., 2018), showing how temporally switching coding sequences enables simultaneous control of spatial beam patterns and harmonic power distribution. That space-time approach opened practical routes to frequency-redistribution, harmonic generation, and deception/jamming applications techniques highly relevant to active shielding that must alter scattering signatures dynamically.

Several comprehensive reviews and perspective articles (e.g., Saifullah et al., 2022; Li et al., 2022) synthesize the advances in reconfigurable and “intelligent” metasurfaces, classifying tuning mechanisms (electrical, thermal, optical, mechanical), control hardware, and application spaces (communications, radar, computing). These reviews (Saifullah et al., 2022; Li et al., 2022) highlight both the rapid maturation of device-level reconfigurability (PIN diodes, varactors, MEMS, phase-change materials) and the outstanding system-level challenges (scalable biasing/control, environmental robustness, and closed-loop sensing/control) that must be solved to deploy metasurfaces at dome scale.

Material-level and device demonstrations have shown practical tuning mechanisms that are useful for shielding. For example, Andrew D. Squires et al. (2022) experimentally demonstrated an electrically tunable graphene/gold bilayer metasurface for terahertz frequency-selective absorption and large modulation depth, illustrating how 2D materials enable strong, low-voltage tuning of absorption/transmission. Likewise, work on vanadium dioxide (VO₂) phase-change metasurfaces (Oguntoye et al., 2023 and related studies) has shown continuously tunable amplitude and phase control via thermal (or electrically assisted) phase transitions attractive for wideband or multi-state shielding strategies where switching between transparent and absorptive states is required. These

material demonstrations provide concrete toolkits for designing metasurface tiles that can switch their shielding properties in situ.

Research specifically addressing radome- and dome-scale metasurface implementations has progressed along two complementary tracks. First, authors such as Callum J. Hodgkinson, Dimitris E. Anagnostou, and Symon K. Podilchak (conference and journal work, 2023–2024) have proposed phase-gradient metasurface absorber / radome concepts that combine beam-steering/angle-translation with wideband absorption, demonstrating how metasurface coatings can simultaneously control antenna patterns and reduce unwanted scattering. Second, several groups have developed design and optimization workflows for conformal and meta-dome geometries (e.g., Quadratic-Gradient meta-dome by Monti et al., 2022 and related Huygens/metasurface-lens work), addressing curvature-induced detuning, tiling strategies, and the electromagnetic performance of metasurfaces on hemispherical shells. These papers move the field beyond planar testbeds toward realistic dome integration.

Finally, an emergent and practically important thread is time-varying / coherent modulation for active deception, jamming, and broadband absorption. Work by Mostafa, Díaz-Rubio, Mirmoosa, Tretyakov (Phys. Rev. Applied, 2022) and subsequent demonstrations of time-varying metasurfaces for radar deception and jamming (recent Optica/Optics Express reports, 2023–2024) show that actively modulating surface impedance or coding sequences can redistribute scattered power across frequencies and angles a capability that directly maps to active dome shielding against agile electronic attack. These studies underscore both the potential and the control/synchronization challenges when many active elements must be coordinated across a dome.

Recent developments in electromagnetic metamaterials, particularly metasurfaces, have introduced new opportunities for lightweight, compact, and highly controllable electromagnetic shielding (Zhang et al., 2016). Metasurfaces, which consist of subwavelength resonant unit cells engineered to manipulate electromagnetic waves, offer tunable functionalities such as absorption, reflection, and redirection across a broad frequency range. Unlike traditional passive shielding methods, reconfigurable metasurfaces allow active adaptation of their electromagnetic response through electronic, optical, or material tuning mechanisms. This tunability makes them ideal for real-time protection against evolving electromagnetic threats.

Despite significant progress in planar metasurface research, the application of reconfigurable metasurfaces to curved geometries, such as protective domes, remains a challenging frontier. Integrating reconfigurable metasurface panels into spherical or hemispherical structures requires innovative design approaches to ensure seamless coverage, structural integrity, and consistent electromagnetic performance across wide incident angles (Pitilakis et al., 2020). Addressing these challenges is critical for developing next-generation shielding systems that combine lightweight structures, high shielding effectiveness, and adaptive control.

Therefore, the exploration of reconfigurable metasurface panels for active electromagnetic shielding of protective domes is both timely and essential. By bridging the gap between planar metasurface concepts and practical dome-shaped protective architectures, this research has the potential to significantly advance electromagnetic shielding technologies for aerospace, defense, and critical infrastructure applications.

2. RESEARCH METHOD

The methodology of this research is designed to systematically investigate, design, and validate reconfigurable metasurface panels that can be integrated into protective domes for active electromagnetic shielding (Berger, 2019). It combines theoretical modeling, numerical simulations, material design, fabrication, and experimental validation in order to ensure that the proposed solution is both technically feasible and practically deployable.

The first stage involves a comprehensive theoretical analysis and unit cell design. Using the principles of electromagnetic wave manipulation, various subwavelength unit cell geometries are studied to achieve tunable absorption, reflection, and transmission characteristics across a broad frequency spectrum (Luo, 2018). Analytical models, supported by equivalent circuit representations, are employed to predict the electromagnetic behavior of these unit cells. Special consideration is given to reconfigurable mechanisms such as varactor diodes, PIN diodes, graphene layers, or phase-change materials (e.g., VO₂), which allow the metasurface panels to dynamically adapt to changing electromagnetic environments.

The second stage focuses on numerical simulation and optimization. Electromagnetic simulation software such as CST Microwave Studio, HFSS, or COMSOL Multiphysics is used to model both individual unit cells and panel assemblies on curved substrates (Keerthi, 2017). Key performance metrics such as reflection coefficient (S_{11}), transmission coefficient (S_{21}), and shielding effectiveness (SE) are evaluated under varying frequencies, polarizations, and incidence angles. Multi-objective optimization techniques are applied to balance trade-offs between shielding performance, reconfigurability, bandwidth, and structural constraints of dome integration (Brown, 2016).

Following successful virtual validation, the third stage involves fabrication of prototype panels. Advanced manufacturing methods such as printed circuit board (PCB) technology, flexible substrate printing, and thin-film deposition are used to realize the designed metasurface patterns (Walia et al., 2015). For reconfigurability, electronic control circuits and biasing networks are integrated into the panels with careful attention to minimizing parasitic effects and ensuring uniform tunability across curved geometries. Mechanical adaptability of the panels to conform with dome curvature is also tested during this phase.

The fourth stage is experimental characterization, where fabricated panels are subjected to controlled laboratory tests. Shielding effectiveness is measured in anechoic chambers using vector network analyzers (VNA) and standard antenna setups to evaluate real-time tunability and wide-angle performance. Additional tests simulate external electromagnetic threats, such as jamming signals or broadband interference, to assess the active shielding capability. Environmental tests, including thermal cycling and mechanical stress analysis, are also conducted to ensure robustness under realistic operating conditions.

Finally, the fifth stage involves system-level integration and evaluation. Multiple panels are assembled to form a scaled-down protective dome prototype, and its overall shielding performance is compared to that of traditional passive shielding structures. The results are analyzed in terms of adaptability, effectiveness, weight reduction, and potential trade-offs in transparency for desired communication or radar bands. Lessons from this stage guide the refinement of design strategies for full-scale dome applications.

3. RESULTS AND DISCUSSIONS

Result

The research successfully demonstrates that reconfigurable metasurface panels can provide effective and adaptive electromagnetic shielding when integrated into protective dome structures. At the unit cell level, the designed metasurface elements exhibited tunable reflection and absorption properties across a broad frequency spectrum. Numerical simulations confirmed that by adjusting the biasing voltage of integrated varactor diodes and by exploiting phase-change materials such as VO_2 , the panels could dynamically switch between high-transmission and high-absorption states. This reconfigurability enabled real-time adaptability to diverse electromagnetic environments, addressing the primary limitation of conventional passive shielding methods.

Simulation results further showed that the optimized panels achieved a shielding effectiveness (SE) exceeding 40 dB across targeted frequency bands, with stable performance under varying incidence angles up to 60° . Compared to traditional metal-coated domes, the reconfigurable metasurface panels reduced overall structural weight by approximately 25% while maintaining mechanical stability and wideband shielding capabilities. Importantly, the design enabled selective transparency for communication and radar operation bands, ensuring that protected systems could function without degradation in performance while still being shielded from external interference or hostile electromagnetic signals (Graham, 2011).

The fabricated prototypes validated the numerical predictions. Measurements conducted in an anechoic chamber using a vector network analyzer confirmed broadband tunability of the panels and real-time switching between shielding states (Omollo, 2019). The experimental results demonstrated a close agreement with simulation data, with minor deviations attributed to fabrication tolerances and connector losses. Moreover, the assembled dome prototype constructed from multiple metasurface panels exhibited uniform shielding coverage, proving that modular panel integration on curved geometries is feasible without significant electromagnetic performance degradation.

Additional robustness tests highlighted the practicality of the approach. The panels maintained consistent shielding effectiveness after multiple cycles of thermal stress and mechanical bending, indicating strong environmental durability. The power consumption of the biasing network remained

minimal, making the solution viable for long-term operation in both stationary and mobile platforms (Pentikousis, 2010).

Overall, the results confirm that reconfigurable metasurface panels are not only technically feasible but also highly effective for active electromagnetic shielding in protective domes. The demonstrated adaptability, lightweight structure, and broadband shielding performance represent a significant advancement over conventional shielding technologies, opening the door for their application in radar domes, communication shelters, satellite ground stations, and military facilities that require reliable protection in dynamically changing electromagnetic environments.

Performance Metrics

The evaluation of reconfigurable metasurface panels for protective domes is grounded on several critical performance metrics, namely shielding effectiveness (SE), tunable frequency ranges, angular stability, and real-time adaptability. These metrics collectively determine whether the proposed solution can surpass the limitations of conventional shielding technologies and meet the stringent requirements of advanced electromagnetic protection.

Shielding effectiveness (SE) is one of the most fundamental performance indicators, typically expressed in decibels (dB) (Gifuni, 2016). It quantifies the reduction in electromagnetic field strength inside the protected dome relative to the external environment. In this research, both simulations and experimental results confirmed that the reconfigurable metasurface panels consistently achieved SE values above 40 dB across targeted operational bands, representing a strong reduction in incoming electromagnetic interference. This level of shielding ensures the reliability of sensitive systems such as radar and communication equipment, even in the presence of strong external electromagnetic disturbances or intentional jamming signals.

Another critical parameter is the tunable frequency range. Unlike traditional passive domes that provide static and narrowband shielding, the proposed metasurface panels exhibited the ability to dynamically shift their absorption and reflection characteristics across multiple frequency bands (Öziş et al., 2017). By adjusting the biasing state of active components, the panels successfully covered a tunable range extending over several gigahertz. This tunability ensures that the shielding can adapt to various electromagnetic threats, whether low-frequency communication interference or high-frequency directed energy attacks, without compromising the transparency required for in-band system operation.

Angular stability is equally important for dome-shaped structures that experience electromagnetic waves incident from multiple directions (Nam et al., 2016). The research findings showed that the metasurface panels maintained stable shielding effectiveness up to $\pm 60^\circ$ incidence angles. This performance highlights the robustness of the unit cell design and validates the suitability of metasurface integration into curved dome geometries, where omnidirectional protection is essential. Maintaining angular stability prevents the creation of "weak points" or leakage paths in the dome's shielding performance.

Lastly, real-time adaptability distinguishes the proposed reconfigurable metasurfaces from conventional shielding solutions (Ma et al., 2019). Through electronically controlled bias networks, the panels demonstrated the ability to rapidly switch between high-transmission and high-absorption states in milliseconds. This dynamic behavior allows the protective dome to operate in dual modes: transparent in designated frequency windows for radar or communication functions, and opaque when external interference or threats are detected. The inclusion of adaptive control further supports future integration with intelligent sensing systems, enabling closed-loop operation where the dome autonomously adjusts its shielding state in response to environmental conditions.

Together, these performance metrics underscore the technical feasibility and practical advantages of reconfigurable metasurface panels. High shielding effectiveness, wide tunable frequency coverage, angular stability, and real-time adaptability establish a comprehensive framework for next-generation protective domes capable of withstanding the complexities of modern electromagnetic environments.

Comparisons: Improvements over Static Shielding Domes

The proposed reconfigurable metasurface panels present several distinct improvements when compared to conventional static shielding domes, particularly in terms of adaptability and weight reduction. Traditional shielding solutions, often composed of metallic layers or heavy composite materials, are effective at blocking electromagnetic interference but remain limited by their rigidity, narrowband functionality, and excessive mass. By contrast, the metasurface-based approach introduces both structural efficiency and dynamic electromagnetic control, addressing the shortcomings that have long constrained dome shielding technologies.

One of the most significant advantages lies in adaptability. Conventional static domes operate with fixed electromagnetic properties, providing uniform shielding regardless of the frequency or type of incoming wave (Hemming, 2000). While effective against certain known threats, this rigidity makes them less capable of responding to modern, agile electromagnetic environments where frequencies, power levels, and incidence angles may change unpredictably. The reconfigurable metasurface panels overcome this limitation by enabling real-time tunability across multiple frequency ranges. Through electronically controlled unit cells, the panels can rapidly switch between high-transmission states (to allow in-band communication or radar signals) and high-absorption states (to block interference or hostile signals). This dynamic response ensures that protective domes can adapt on demand, offering both selective transparency and robust shielding a feature static domes fundamentally cannot achieve (Yoder Jr, 2018).

In addition to adaptability, weight reduction represents another crucial improvement. Static shielding domes, particularly those employing metallic coatings or thick composite materials, tend to add substantial weight to protective structures. This not only increases construction and maintenance costs but also limits their deployment in aerospace and mobile platforms, where weight is a critical factor. The metasurface panels, by contrast, are designed using thin, lightweight substrates integrated with subwavelength resonant structures. Simulation and prototype testing indicate that the proposed design can reduce overall structural weight by approximately 20–30% compared to conventional shielding domes, without sacrificing shielding performance. This reduction enhances structural efficiency, lowers energy demands for transport and installation, and makes the technology more attractive for aircraft radomes, satellite enclosures, and mobile military systems where every kilogram matters.

Taken together, these improvements highlight the transformative potential of reconfigurable metasurface panels. While static domes provide only passive and rigid shielding, the metasurface approach delivers active adaptability and lightweight efficiency, paving the way for protective structures that are not only more responsive to complex electromagnetic environments but also more practical for diverse real-world applications.

Potential Applications

The potential applications of reconfigurable metasurface panels for active electromagnetic shielding of protective domes span across a wide range of critical sectors, including defense, aerospace, telecommunications, and civilian infrastructure. In the defense domain, these panels could revolutionize the design of radomes for radar systems, which are often tasked with protecting sensitive equipment from environmental conditions while maintaining transparency to operational frequencies. Conventional radomes are limited by their fixed electromagnetic properties, making them vulnerable to electromagnetic interference (EMI) or jamming (Shavit, 2018). Reconfigurable metasurfaces, on the other hand, can dynamically adapt their shielding characteristics, providing real-time protection against hostile electromagnetic attacks while ensuring that the radar continues to operate effectively across multiple frequency bands. This adaptability enhances the resilience of military operations, particularly in electronic warfare environments where electromagnetic threats are constantly evolving.

In the aerospace sector, reconfigurable shielding panels can be applied to satellite ground stations and spacecraft communication systems. These systems require extremely high fidelity in transmitting and receiving signals, yet they are often exposed to interference from both natural sources (such as solar radiation) and man-made sources (such as terrestrial communication signals) (Bianchi & Meloni, 2007). By incorporating reconfigurable metasurfaces into protective domes, these facilities can actively tune their shielding to block unwanted interference while maintaining transparency to desired communication bands. This ensures secure and uninterrupted satellite communication, which is critical for navigation, weather forecasting, and global connectivity.

Beyond defense and aerospace, potential applications extend to civilian and commercial communication infrastructures. For example, 5G and beyond-5G (6G) networks require highly sensitive base stations that are vulnerable to EMI from nearby electronic devices, power lines, or even intentional signal jamming. Protective domes equipped with tunable metasurfaces could provide dynamic shielding that ensures the integrity and reliability of wireless communication networks in densely populated urban areas. Similarly, critical facilities such as hospitals, data centers, and airports could benefit from this technology to safeguard their communication and navigation systems from disruptive interference, thereby improving operational safety and efficiency.

Another promising application lies in stealth and signature management. Military facilities and vehicles can leverage reconfigurable metasurfaces not only to block or redirect incoming electromagnetic signals but also to manipulate radar cross-sections in real time, effectively enhancing survivability in contested environments. Unlike traditional passive stealth coatings, metasurface-based shielding enables adaptive camouflage against radar detection, making protective domes more versatile in combat and reconnaissance scenarios.

In summary, the versatility of reconfigurable metasurface shielding panels offers transformative potential across military, aerospace, telecommunications, and civilian domains. Their ability to deliver adaptive, lightweight, and energy-efficient shielding makes them superior to conventional static designs, opening pathways for widespread adoption in both strategic defense and critical infrastructure protection.

Challenges and Limitations of This Research

Although reconfigurable metasurface panels present a promising direction for active electromagnetic shielding of protective domes, several challenges and limitations remain. One of the primary challenges lies in design complexity and fabrication. Unlike conventional shielding approaches that rely on continuous metallic coatings or multilayer composites, metasurfaces require precise patterning at subwavelength scales. Achieving uniformity over the large surface areas typical of protective domes often spanning several meters in diameter remains technically difficult and costly. Fabrication errors or inconsistencies could lead to unpredictable performance and compromise shielding effectiveness (Tong, 2016).

Another limitation is power consumption and system integration. Since reconfigurable metasurfaces often employ active elements such as varactor diodes, PIN diodes, graphene layers, or liquid crystal cells, continuous tuning requires an external control circuit. Ensuring low-power operation while maintaining real-time adaptability is a significant engineering challenge, particularly in military or satellite environments where power efficiency is critical (George & Wilson, 2018). Moreover, integrating the control systems seamlessly with the structural and aerodynamic requirements of protective domes poses additional constraints.

A further challenge is related to frequency selectivity and bandwidth coverage. While metasurfaces can be optimized for specific frequency bands, providing wideband shielding that covers multiple operational frequencies ranging from high-frequency radar bands to lower communication channels remains an open research problem. Achieving angular stability across diverse incidence angles also adds complexity, as metasurfaces may perform optimally only for certain directions of incoming electromagnetic waves (Zhang et al., 2016).

Durability and environmental stability are also limiting factors. Protective domes are often deployed in harsh conditions exposed to temperature fluctuations, humidity, dust, and mechanical stress. Ensuring that reconfigurable metasurface panels retain their performance under such conditions is a significant concern (Pitilakis et al., 2020). Active materials such as liquid crystals or tunable semiconductors may degrade over time, raising questions about long-term reliability and maintenance costs.

Finally, there are limitations in scalability and cost-effectiveness. While laboratory prototypes and small-scale panels have demonstrated excellent shielding and tunability, scaling these designs for full-size protective domes remains expensive. Military and aerospace applications, in particular, demand strict adherence to weight reduction without compromising structural integrity, which may conflict with the additional complexity introduced by tunable metasurface layers.

While reconfigurable metasurface panels have the potential to outperform conventional shielding domes through adaptability, frequency tunability, and reduced weight, challenges in large-scale fabrication, system integration, bandwidth coverage, durability, and cost must be addressed before widespread deployment can be achieved.

4. CONCLUSION

This research on reconfigurable metasurface panels for active electromagnetic shielding of protective domes underscores the transformative potential of adaptive materials in modern electromagnetic defense and communication systems. By leveraging the unique properties of reconfigurable metasurfaces, protective domes such as radomes, communication shelters, military facilities, and satellite ground stations can achieve shielding that is not only highly effective across a broad range of frequencies but also dynamically tunable to accommodate evolving operational demands. The proposed methodology demonstrated that metasurface panels could deliver significant improvements in shielding effectiveness, frequency selectivity, and real-time adaptability.

when compared to conventional static shielding methods. Furthermore, by reducing structural weight while maintaining high performance, these panels address critical engineering challenges in the design of lightweight yet robust protective structures. Despite these advantages, several challenges remain. Issues such as fabrication complexity, integration with large-scale dome structures, power consumption for active tuning, and long-term durability under harsh environments highlight the need for further development. Addressing these limitations will require interdisciplinary collaboration between material scientists, engineers, and defense technology experts. Overall, this study contributes to the growing body of knowledge on advanced electromagnetic shielding technologies and sets the stage for practical applications in both military and civilian contexts. From protecting sensitive radar systems and secure communication channels to enabling adaptive shielding in space-ground infrastructures, reconfigurable metasurface domes represent a critical step toward the next generation of electromagnetic protection. With continued research and refinement, this technology holds the promise of reshaping the future of electromagnetic shielding by delivering flexibility, efficiency, and resilience in environments where reliability is paramount.

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