Guest Editorial Special Cluster on Functionalized Metasurface-Based Covers and Unconventional Domes for Dynamic Antenna Systems

I. Introduction to Special Cluster

DOMES for antenna systems typically consist of single- or multilayered dielectric sheets whose main objective is to protect antenna arrays from the influence of outside environment [1]. The rapid growth in the use of electromagnetic spectrum and the need of integration of several functionalities within a single-antenna system has led to even more challenging design of the dome itself. Indeed, the design of an antenna dome is mainly driven by the minimization of its impact on the performance of the antenna system when pointing towards broadside direction, scanning in elevation and/or azimuth or, more in general, during any dynamic change of the radiated beam, leading to domes as electromagnetically transparent as possible in the operative angular and frequency bandwidth [2]. However, the presence of an antenna cover and the inevitable interaction with the radiated electromagnetic field may represent an interesting opportunity for increasing the dynamic performance of the antenna system, making the cover functionalized to realize a specific function.

In this scenario, metasurfaces have demonstrated to exhibit the capability to mold the phase-front, amplitude profile, and frequency of the interacting field, thanks to their engineerable surface properties in space and time domains [3], [4], [5], [6]. Such artificial surfaces can be used to build antenna domes with prescribed electromagnetic behaviors and even with new features such as the property of being tunable or switchable, thus resulting in a new class of devices: metasurface-enhanced domes or "metadomes." A metadome therefore is designed not only for protecting the antenna system from the environment, but also for engineering new radiating and electrical performance of the antenna without the need to redesign the antenna system.

The objective of this Special Cluster is to collect the recent advancements in this field and provide an overview of the potential applications of this technology in the next generation antenna devices, with emphasis on metamaterial-based enhancements enabling real-time control of their radiation characteristics.

TABLE I
Overview of the Letters in the Special Cluster

No.	Authors	Functionality	Ref.
1	S. Yu, N. Kou	Spatial filtering	[A1]
2	H. Li et al.	Beam steering	[A2]
3	R. Shi, S. Yu, and N.Kou	Frequency filtering/absorption	[A3]
4	E.B. Whiting et al.	Directivity enhancing	[A4]
5	S. Pawar et al.	Mutual coupling reduction	[A5]
6	Ramaccia et al.	Grating lobe reduction	[A6]
7	S.M.Young, A.Grbic	Scan loss reduction	[A7]
8	C.J. Hodgkinson et al.	Frequency filtering/absorption	[A8]
9	F. Dicandia, S. Genovesi	Polarization conversion	[A9]
10	M. Phaneuf, P Mojabi	Space-time modulated imaging	[A10]
11	A. Fallah et al.	Beam steering	[A11]
12	A.Paraskevopoulos et al.	Aperture Magnification	[A12]

II. Contributions

Overall, this Special Cluster has received 22 submissions, of which 12 peer-reviewed letters are selected into this issue after a rigorous review process. The 12 letters are from 46 authors of various academic institutions and industries worldwide.

Each of the 12 letters of this cluster presents a different engineered dome or metasurface-based cover for antenna systems able to implement a specific functionality. Table I provides a list of these letters, along with the authorship and investigated functionality. In the following, we shall briefly introduce these letters.

Yu and Kou [A1] propose a cover consisting of a cascade of artificial surfaces for achieving angular selectivity of electromagnetic waves. An odd-mode resonant frequency selective surface (FSS) is designed for obtaining varying frequency responses under different incident angles and polarizations. An experimental verification demonstrates the perfect transmission under TE polarization when a plane wave is impinging at 30° with respect to the normal direction, validating the feasibility of the design method.

Li et al. [A2] present an active metasurface lens loaded with parallel-plate waveguide (PPW) able to improve the beam steering range and the sidelobe level (SLL). A linear PPW lens array operating around 5.75 GHz is fabricated and measured, showing

Date of current version 28 October 2022.
Digital Object Identifier 10.1109/LAWP.2022.3207255

that the scanning coverage of lens antenna can reach $\pm 60°$, and the SLL are below -15.7 dB within the $\pm 50°$ field-of-view.

Shi et al. [A3] present an artificial antenna cover exhibiting absorption properties in a wide frequency band (3–15 GHz), except for a narrow frequency band where it is transparent for the antenna system. The authors propose to use the proposed cover in radar applications to enhance the anti-interference and stealth performance of the antenna systems.

Whiting et al. [A4] propose a new method of designing freeform GRIN lenses to be used in front an aperture antenna using adjoint sensitivities to rapidly find the optimal solutions within feasible material bounds that achieve the desired performance goals.

Pawar et al. [A5] present the design of elliptical metasurface cloaks to use with subwavelength spaced slot antennas for curbing the adverse effects of mutual coupling between them. It is demonstrated through simulation results that by enclosing each radiating edge of the individual slots with these uniquely designed metasurfaces, the slot antennas are decoupled in the near field, without affecting the far-field radiation properties of the slots.

Ramaccia et al. [A6] propose an approach based on an electrically thin metasurface-based dome for the reduction of the grating lobes, raising during angular scanning in antenna arrays. A simple design procedure of the metasurface dome is described, together with the antenna performance, evaluated through a proper set of numerical experiments.

Young and Grbic [A7] present a metadome for an antenna array consisting of an alignment of high-permittivity pillars of varying diameter and height embedded in a lower permittivity slab. The unit cells of the metadome can provide a 490° transmission phase range with zero reflection and low loss. Full wave simulations of a representative scan loss-reducing dome antenna agree well with analytic calculations that assume an ideal phase sheet.

Hodgkinson et al. [A8] report the design and test of an artificial antenna cover exhibiting absorption properties in a wide frequency band (1–11 GHz) and a transmission window around 5.5 GHz. The cover offers wideband absorption, low insertion losses, and polarization insensitivity to the incident TM and TE fields.

Dicandia and Genovesi [A9] present a novel wideband linear-to-circular polarization converting metasurface composed by a cascade of two identical fully metallic FSSs separated by an air gap, able to operate over a 3 dB axial-ratio fractional bandwidth of 25% for a normally impinging plane wave. The metasurface provides a prominent robustness to oblique incidence, and it is therefore suitable to be employed in radomes and dichroics.

Phaneuf and Mojabi [A10] propose to use space-time metasurfaces as microwave imaging system enclosures, able to be reconfigured to implement different boundary conditions in real-time, such as open space and perfect electric conductor conditions.

Fallah et al. [A11] propose and study a beam-steering structure based on the interaction of antenna radiation with an electron sheet with swiftly moving electrons with a constant velocity. Such an electron-sheet metasurface, while uniform and homogeneous in its composition, exhibits nonlocal response that is dependent on the tangential component of the wave vector impinging on it, enabling the synthesis of asymmetric radiation patterns.

Finally, Paraskevopoulos et al. [A12] propose a cover for aperture antennas made of a doublet of inhomogeneous lenses, one divergent and one convergent, for aperture magnification. It is useful for reusing already available medium-gain arrays and bring them to a high gain, occupying a reduced volume as compared to traditional lenses or multireflector systems.

In closing, the guest editors wish to express their gratitude to Prof. C. Fumeaux, the editor-in-chief of the IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, for his constant presence and support. A special thanks goes to Dr. C. Sideri, the Editorial Assistant, for her professionalism and prompt assistance. The guest editors would like to thank the authors and the reviewers for their effort in this issue. We wish this Special Cluster will inspire new ideas and applications for functionalized artificial covers and metadome for antenna systems, and new ways of exploiting the intriguing properties of artificial electromagnetic structures that have not been explored yet.

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APPENDIX
RELATED ARTICLES

[A1] S. Yu and N. Kou, "Angular selectivity based on odd mode resonance of frequency selective surface," *IEEE Antennas Wireless Propag. Lett.*, early access, May 10, 2022, doi: 10.1109/LAWP.2022.3173949.

[A2] H. Li, Y. Fan, Y. Zhuang, T. Zhou, and T. A. Denidni, "Experimental validation of an active PPW-loaded metasurfaces lens for wide-angle beam steering," *IEEE Antennas Wireless Propag. Lett.*, early access, Apr. 22, 2022, doi: 10.1109/LAWP.2022.3168864.

[A3] R. Shi, S. Yu, and N. Kou, "A miniaturized frequency-selective rasorber with absorption bands on two sides of passband for antenna dome," *IEEE Antennas Wireless Propag. Lett.*, early access, Jul. 4, 2022, doi: 10.1109/LAWP.2022.3187958.

[A4] E. B. Whiting et al., "Adjoint sensitivity optimization of three-dimensional directivity-enhancing, size-reducing GRIN lenses," *IEEE Antennas Wireless Propag. Lett.*, early access, Jun. 14, 2022, doi: 10.1109/LAWP.2022.3182900.

[A5] S. Pawar, H. G. Skinner, S.-Y. Suh, and A. B. Yakovlev, "Cloaking of slot antennas at C-band frequencies using elliptical metasurface cloaks," *IEEE Antennas Wireless Propag. Lett.*, early access, Jul. 22, 2022, doi: 10.1109/LAWP.2022.3193038.

[A6] D. Ramaccia et al., "Metasurface dome for above-the-horizon grating lobes reduction in 5G-NR systems," *IEEE Antennas Wireless Propag. Lett.*, early access, Aug. 4, 2022, doi: 10.1109/LAWP.2022.3196324.

[A7] S. M. Young and A. Grbic, "Dielectric Huygens' metasurface dome antennas," *IEEE Antennas Wireless Propag. Lett.*, early access, Jun. 20, 2022, doi: 10.1109/LAWP.2022.3184595.

[A8] C. J. Hodgkinson, D. E. Anagnostou, and S. K. Podilchak, "Jaumann-like rasorber offering angular stability with wideband absorption and low insertion loss," *IEEE Antennas Wireless Propag. Lett.*, early access, Sep. 1, 2022, doi: 10.1109/LAWP.2022.3203510.

[A9] F. A. Dicandia and S. Genovesi, "Linear-to-Circular polarization transmission converter exploiting meandered metallic slots," *IEEE Antennas Wireless Propag. Lett.*, early access, Jul. 4, 2022, doi: 10.1109/LAWP.2022.3188063.

[A10] M. Phaneuf and P. Mojabi, "On the use of reconfigurable space-time metasurface enclosures for microwave imaging," *IEEE Antennas Wireless Propag. Lett.*, early access, Jul. 13, 2022, doi: 10.1109/LAWP.2022.3190250.

[A11] A. Fallah, M. Camacho, and N. Engheta, "Electron-sheet metasurfaces for reconfigurable beam patterns," *IEEE Antennas Wireless Propag. Lett.*, early access, Aug. 15, 2022, doi: 10.1109/LAWP.2022.3198576.

[A12] A. Paraskevopoulos, I. Gashi, M. Albani, and S. Maci, "Analytical formulas for refractive indices of a telescopic GRIN lens for aperture magnification," *IEEE Antennas Wireless Propag. Lett.*, early access, Sep. 6, 2022, doi: 10.1109/LAWP.2022.3203914.

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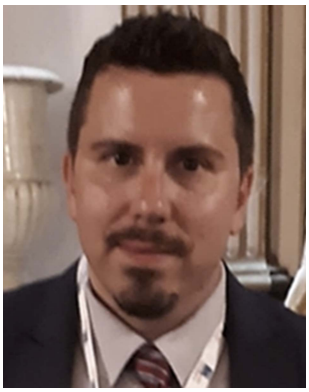
[3] M. Barbuto et al., "Metasurfaces 3.0: A new paradigm for enabling smart electromagnetic environments," *IEEE Trans. Antennas Propag.*, early access, Dec. 1, 2021, doi: 10.1109/TAP.2021.3130153.

[4] M. Barbuto et al., "Intelligence enabled by 2D metastructures in antennas and wireless propagation systems," *IEEE Open J. Antennas Propag.*, vol. 3, pp. 135–153, 2022.

[5] E. Martini and S. Maci, "Theory, analysis, and design of metasurfaces for smart radio environments," *Proc. IEEE*, vol. 110, no. 9, pp. 1227–1243, Sep. 2022, doi: 10.1109/JPROC.2022.3171921.

[6] Q. Ma, Q. Xiao, Q. R. Hong, X. Gao, V. Galdi, and T. J. Cui, "Digital coding metasurfaces: From theory to applications," *IEEE Antennas Propag. Mag.*, vol. 64, no. 4, pp. 96–109, Aug. 2022, doi: 10.1109/MAP.2022.3169397.



Davide Ramaccia (Senior Member, IEEE) received the B.S. and M.S. degrees (summa cum laude) in electronic and ICT engineering and the Ph.D. degree in electronic engineering from Roma Tre University, Rome, Italy, in 2007, 2009, and 2013, respectively.

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Dr. Ramaccia was the recipient of a number of awards and recognitions, including The Electromagnetics Academy Young Scientist Award in 2019; seven Outstanding Reviewer Award by the IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION from 2013 to 2021; the IET prizes for the Best Poster on Microwave Metamaterials in 2013; and the IET Award for the Best Poster on the Metamaterial Application in antenna field in 2011. He is currently the General Secretary of the Virtual Institute for Artificial Electromagnetic Materials and Metamaterials (METAMORPHOSE VI, the International Metamaterials Society) and has been an Elected Member of the Board of Directors of the same association for three consecutive terms since 2014. He was also a guest co-editor of three special issues on metamaterials and metasurfaces and a Lead Guest Editor for the Special Cluster on Metadome for Antenna Systems of IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS in 2022. He has been the General Chair and a local organizer of the 39th and 42nd EUPROMETA Doctoral School on Metamaterials held in Rome, in 2019 and 2021, respectively. He has been a Technical Program Coordinator (Track "Electromagnetics and Materials") for the 2016 IEEE Antennas and Propagation Symposium. He was elected as a Secretary of the Project Management Board of the H2020 CSA Project Nanoarchitectonics from 2017 to 2018. He serves as an Associate Editor for IEEE ACCESS since 2019; a Scientific Moderator for IEEE TechRxiv since 2019; and a technical reviewer for the major international journals related to electromagnetic field theory and metamaterials.

Filiberto Bilotti (Fellow, IEEE) received the Laurea and Ph.D. degrees in electronic engineering from Roma Tre University, Rome, Italy, in 1998 and 2002, respectively.

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Prof. Bilotti was the recipient of a number of awards and recognitions, including the elevation to the IEEE Fellow Grade for contributions to metamaterials for electromagnetic and antenna applications in 2017; the Outstanding Associate Editor of the IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION in 2016; the NATO SET Panel Excellence Award, in 2016; the Finmeccanica Group Innovation Prize in 2014; the Finmeccanica Corporate Innovation Prize in 2014; the IET Best Poster Paper Award (Metamaterials 2013 and Metamaterials 2011); and the Raj Mittra Travel Grant Senior Researcher Award, in 2007. He has been serving the scientific community, by playing leading roles in the management of scientific societies, in the editorial board of international journals, and in the organization of conferences and courses. In particular, he was a founding member of the Virtual Institute for Artificial Electromagnetic Materials and Metamaterials–METAMORPHOSE VI in 2007. He was elected as a member of the Board of Directors of the same society for two terms from 2007 to 2013; and as the President for two terms from 2013 to

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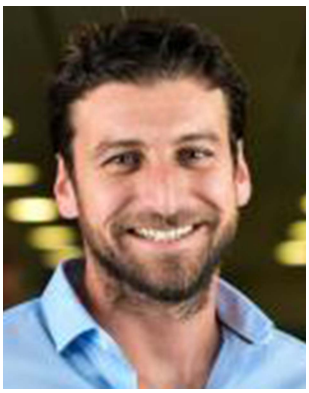

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Dr. Epstein was a recipient of the Young Scientist Best Paper Award in the URSI Commission B International Symposium on Electromagnetic Theory (EMTS2013), held in Hiroshima, Japan, in May 2013. In 2020, he was chosen by the American Physical Society to be listed as an APS Outstanding Referee of the Physical Review journal family (a lifetime award). Since 2018, he has been serving as an Associate Editor for the IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION.

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Dr. Cui has served as a Technical Program Committee (TPC) Member for the International Congress on Advanced Electromagnetic Materials in Microwaves and Optics (Metamaterials 2014, 2016, 2018, and 2019). He received the Natural Science Award (First Class) from the Ministry of Education, China, in 2011, and the National Natural Science Awards of China (Second Class) in 2014 and 2018. His research has been selected as one of the most exciting peer-reviewed optics research "Optics in 2016" by *Optics and Photonics News Magazine* (OSA), Ten Breakthroughs of China Science in 2010, "Best of 2010" in *New Journal of Physics*, and Research Highlights in a series of journals. His work has been widely reported by *Nature News, MIT Technology Review, Scientific American, Discover*, and *New Scientists*. He has presented more than 30 keynote and plenary talks in academic conferences, symposiums, or workshops. He has served as the General Co-Chair for the International Workshops on Metamaterials (META 2008

and META 2012), and the TPC Co-Chair for Asia-Pacific Microwave Conference (APMC 2005) and Progress in Electromagnetic Research Symposium (PIERS 2004). He was an Associate Editor of IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, a Guest Editor of *Science China Information Sciences* and *Science Bulletin*, and a Guest Editor in *Research*. Currently he is the Chief Editor of Metamaterial Short Books in Cambridge University Press, the Editor of *Materials Today Electronics*, the Associate Editor of *Research*, and the Editorial Board Members of *National Science Review, eLight, PhotoniX, Advanced Optical Materials, Small Structure, Advanced Photonics Research*, and *Journal of Physics: Photonics*. He is the Academician of Chinese Academy of Science.

Enrica Martini (Senior Member, IEEE) was born in Spilimbergo (PN), Italy, in 1973. In 1998, she received the Laurea degree (cum laude) in telecommunication engineering from the University of Florence, Florence, Italy, where she worked under a one-year research grant from the Alenia Aerospazio Company, Rome, Italy, until 1999. In 2002, she received the Ph.D. degree in informatics and telecommunications from the University of Florence and the Ph.D. degree in electronics from the University of Nice-Sophia Antipolis, under joint supervision.

In 2002, she was appointed Research Associate at the University of Siena, Siena, Italy. In 2005, she received the Hans Christian Ørsted Postdoctoral Fellowship from the Technical University of Denmark, Lyngby, Denmark, and she joined the Electromagnetic Systems Section of the Ørsted•DTU Department until 2007. From 2007 to 2017, she was a Postdoctoral Fellow at the University of Siena. From 2016 to 2018, she was the CEO of the start-up Wave Up Srl, Siena, Italy, that she co-founded in 2012. She is currently an Associate Professor with the University of Siena. Her research interests include metasurfaces, metamaterial characterization, electromagnetic scattering, antenna measurements, finite element methods, and tropospheric propagation.

Dr. Martini was a co-recipient of the 2016 Schelkunoff Transactions Prize Paper Award, the Best Paper Award in Antenna Design and Applications at the 11th European Conference on Antennas and Propagation in 2017, the Best Poster Award at the Metamaterials Congress in 2019, and the Best Paper Award in Electromagnetics at the 15th European Conference on Antennas and Propagation in 2021.

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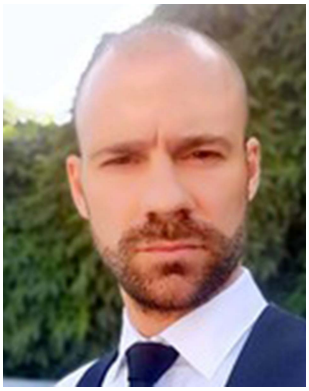

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