TABLE 1. Feeding network performance comparison.

	Frequency (GHz)	Size	Amplitude Variation (dB)	Phase Distortion (deg.)	Efficiency (%)	Feeding Mechanism
[2]	11.5	1.93λ	$\pm$10	$\pm$20	50	Slotted Waveguide
[6]	76	6.5λ	$\pm$3	$\pm$30	50	Coupling Windows
[7]	9.35	5.67λ	-	-	81	Multiple Reflector System and Twin Pin Feeder with Leaky PRS ($\beta > \alpha$)
(this work)	15	2.5λ	$< \pm 1.5$	$< \pm 5$	>90	Leaky SIW T-Junction and Single-input Microstrip Feed ($\beta \approx \alpha$)

different from zero ($H_y \neq 0$). On the other hand, inside the PPW, there are no components in the direction of propagation ($E_y = 0$, $H_y \approx 0$) as expected for a TEM mode.

The normalized amplitude distribution and the phase are further depicted in Fig. 7, where it can be observed that the amplitude is uniform along most of the launcher aperture and starts to decay by about 5 dB when approaching the PEC sections at the end of the T-junction arms. On the other hand, the phase maintains small variations of 5° or less along the entire aperture while a maximum variation of about 1.5 dB is observed. It should also be mentioned that our aperture profile provides a more uniform distribution when compared to [13], since in that work phase and magnitude variations of more than 25° and 2 dB were observed, respectively. Some comparisons between the proposed structure and previous feeding networks for slot based planar antennas found in the literature has also been included in Table 1. This comparison shows the improvement with respect to previous alternatives to feed slot arrays in terms of compactness and efficient propagation.

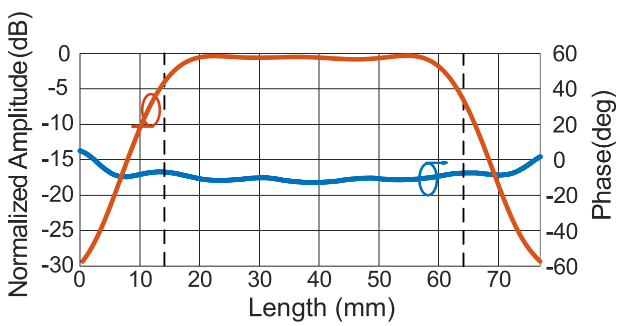

FIGURE 7. The normalized amplitude (left) in dB and the phase (right) in a transverse plane within the end-to-end for the dominant component E_z. The two dashed black lines define the ends of the PRS wall.

Following these developments and modal characterization, an end-to-end test device using two launchers has been designed using the commercial full-wave simulation tool CST Microwave Studio [22]. See Fig. 8 where the simulated electric fields are depicted and show uniform propagation within the PPW region.

Depending on the desired feed system requirements, it is also possible to obtain a similar uniform field distribution but for a wider aperture by means of introducing some

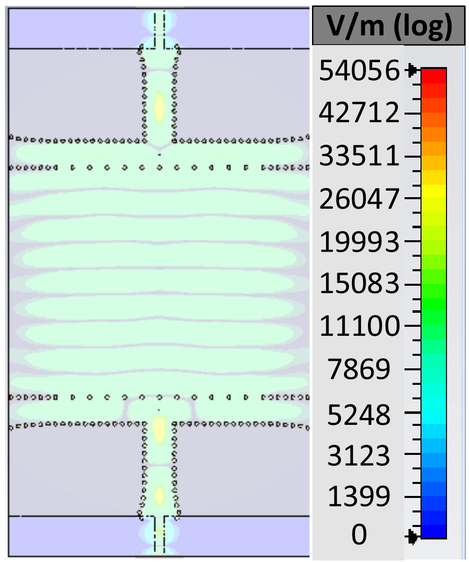

FIGURE 8. Simulated electric fields within the examined PCB test circuit using two launchers. A collimated or uniform TEM field profile can be observed inside the PPW region.

asymmetry in the feed. This can allow for the leakage rate to be tailored as desired without affecting the pointing angle as in [23]. Such a tapered LW distribution could allow for uniform feeding in larger arrays while maintaining the desired parallel-plate propagation at broadside. Future work can include the use of this tapered leakage when considering slot array feeding.

III. MEASUREMENT RESULTS AND DISCUSSION

As a proof of concept, an end-to-end structure has been manufactured on a ROGERS RT5880 substrate with a thickness h of 0.79 mm and a rated relative permittivity $\varepsilon_r = 2.2$ at 10 GHz. This substrate was selected due to its capability to support a unimodal propagation. A photograph of the realized prototype is reported in Fig. 9 while measurements are shown in Fig. 10. It should be mentioned that in real antenna applications for example, a second launcher would not be included. Therefore measurements and simulations are used to demonstrate that the power is actually launched into the PPW and is able to propagate without significant losses, confirming its capability to feed any element placed

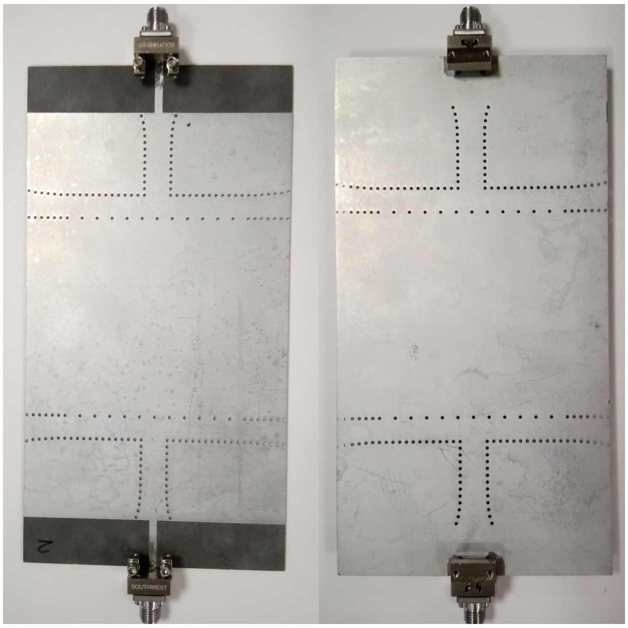

FIGURE 9. The manufactured prototype, top conducting layer on left (a) and bottom layer on the right (b), to work at 15 GHz on Rogers RT5880 with $\varepsilon_r = 2.2$ (rated) for the relative dielectric constant.

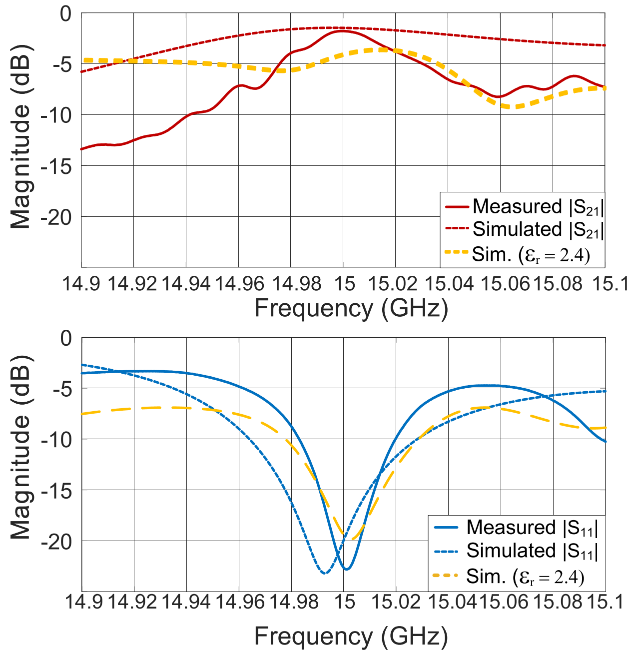

FIGURE 10. Measured S-parameters for the structure under test (solid lines) compared to simulations (dashed lines) using the rated values for the dielectric $\varepsilon_r = 2.2$ at 10 GHz. The difference between the measurements and simulations can be attributed to the practical variation of the relative permittivity of the substrate (see yellow dashed lines). Regardless of these practicalities the launcher is still operating as expected, showing proof of concept.

within the PPW. The relevant parameters defined for this PPW launcher to achieve a design frequency of 15 GHz are as follows: $W = 6.8$ mm, $W' = 10.2$ mm, $W_o = 2.35$ mm, $P = 4.5$ mm and $d = 1$ mm.

The two launchers were placed several wavelengths apart for practical demonstration purposes. This introduced some conductor and dielectric losses which slightly increased the port-to-port insertion losses, but still the launcher is operating as expected as shown in Fig. 10. The measured $|S_{21}|$ for the test structure is about -1.3 dB at the design frequency of 15 GHz and $|S_{11}| < -20$ dB. The electromagnetic coupling between the two launchers is not of concern because the complete end-to-end structure was simulated in CST [22] and no significant losses were found, as shown in Fig. 10 for $\varepsilon_r = 2.2$. This is important because the launchers are not in the respective far-field regions for each wave-guiding structure, which we consider to be $32\lambda_g$ following $R = 2D^2/\lambda_g$ [24] (where $\lambda_g = \frac{1}{f\sqrt{\varepsilon_r \varepsilon_0 \mu_0}}$ and ε_0 and μ_0 are the free-space permittivity and permeability, respectively, and D is the length of the leaky aperture). Also, the measurements are in good agreement with the simulations as well as the center frequency for the structure designed using LW theory and the developed TEN circuit model.

Higher losses for the measured structure at the design frequency can be explained by the importance of the substrate relative dielectric constant as well as the fabrication tolerances for via placement and via diameters. More specifically, the via drilling processes defines the exact via placement and its diameters and small variations from any nominal value can result in minor performance variations and small frequency shifts away from the original design frequency. For example, in our simulation model we considered a $\pm 5\%$ variation in the diameters of the all vias within the transition structure and about a 0.5% frequency shift in the minimum of $|S_{11}|$ was observed (results not reported for brevity). Also, for any minor variation in ε_r (see Fig. 10) port matching can be maintained, however the maximum value for $|S_{21}|$ can be shifted in frequency because the originally designed $\alpha \approx \beta$ condition is no longer preserved, and, at the original frequency. This can be observed in Fig. 10 when considering a variation of the relative permittivity in the material of $\varepsilon_r = 2.4$ since good port matching is still obtained at 15.0 GHz ($|S_{11}| < -15.0$ dB) while $|S_{21}|$ is less than -4.0 dB at about 15.02 GHz as observed for the simulations. Despite these practicalities, the measured performance is still in good agreement with the full-wave simulations.

The structure is inherently narrow band due to the $\alpha \approx \beta$ condition at the design frequency. This can be observed in Fig. 10 for both the measurements and the simulations as $|S_{11}| < -10$ dB from about 14.98 GHz to 15.02 GHz. Techniques exist to enhance the bandwidth of such LW apertures and can be applied to both radiating leaky-wave antennas and non-radiating structures as in this work. For example, in [25] a double-cavity leaky-wave antenna with an improved operational frequency range was made possible by two stacked PRS layers.

IV. CONCLUSIONS

In this paper, design guidelines and measured results for a novel PPW TEM mode launcher for feeding planar circuits and low-cost antenna systems has been presented. This SIW to PPW transition is compact and maintains a low profile for simple fabrication and offers 50-Ω microstrip feeding. By proper design of the structure, uniform and bound propagation at broadside (with respect to the leaky SIW sidewall) can be achieved within the PPW region. Due to the practical substrate variations and SIW technology fabrication tolerances, the measurements of the demonstrator circuit are not exactly as per the full-wave simulations. However, measurements of this end-to-end test structure still suggest that the two launchers operate at about 15 GHz, as per design, and follow the developed LW theory and waveguide dispersion analysis.

It should also be mentioned that our proposed PPW TEM planar launcher can be re-designed when using different permittivity substrates and when considering operation at higher millimeter-wave frequencies. Also, the relatively narrow band behavior of the structure could be improved by employing a double layer of PRSs. This can create two cavities where the modes can couple as studied in [25] increasing the possible frequency range of the structure. Our proposed PPW launcher could lead to other kinds of SIW launchers, such as surface-wave launchers when considering TM_0 surface-wave propagation on grounded dielectric slabs as briefly examined in [26] and for end-fire radiation, new planar antennas, or to other wave guiding structures and other new transition circuits.

ACKNOWLEDGMENT

The authors would like to indicate that the work is only the authors' views, and that the Horizon 2020 Agency is not responsible for any information contained in the communication.

REFERENCES

[1] J. Volakis, *Antenna Engineering Handbook*, 4th ed. New York, NY, USA: McGraw-Hill, 2007.
[2] J. Hirokawa, M. Ando, and N. Goto, "Waveguide-fed parallel plate slot array antenna," *IEEE Trans. Antennas Propag.*, vol. 40, no. 2, pp. 218–223, Feb. 1992.
[3] M. Ettorre, R. Sauleau, and L. Le Coq, "Multi-beam multi-layer leaky-wave SIW pillbox antenna for millimeter-wave applications," *IEEE Trans. Antennas Propag.*, vol. 59, no. 4, pp. 1093–1100, Apr. 2011.
[4] F. Xu and K. Wu, "Guided-wave and leakage characteristics of substrate integrated waveguide," *IEEE Trans. Microw. Theory Techn.*, vol. 53, no. 1, pp. 66–73, Jan. 2005.
[5] K. Sakakibara, Y. Kimura, A. Akiyama, J. Hirokawa, M. Ando, and N. Goto, "Alternating phase-fed waveguide slot arrays with a single-layer multiple-way power divider," *IEE Proc.-Microwaves, Antennas Propag.*, vol. 144, no. 6, pp. 425–430, Dec. 1997.
[6] J. Hirokawa and M. Ando, "Single-layer feed waveguide consisting of posts for plane TEM wave excitation in parallel plates," *IEEE Trans. Antennas Propag.*, vol. 46, no. 5, pp. 625–630, May 1998.
[7] M. Ettorre, A. Neto, G. Gerini, and S. Maci, "Leaky-wave slot array antenna fed by a dual reflector system," *IEEE Trans. Antennas Propag.*, vol. 56, no. 10, pp. 3143–3149, Oct. 2008.
[8] E. Gandini, M. Ettorre, R. Sauleau, and A. Neto, "Mutual coupling reduction of fabry–perot siw feeds using a double partially reflecting pin-made grid configuration," *IEEE Antennas Wireless Propag. Lett.*, vol. 10, pp. 647–650, 2011.
[9] S. Germain, D. Deslandes, and K. Wu, "Development of substrate integrated waveguide power dividers," in *Proc. Can. Conf. Elect. Comput. Eng.*, vol. 3, May 2003, pp. 1921–1924.
[10] H. Boutayeb, T. A. Denidni, K. Mahdjoubi, A.-C. Tarot, A.-R. Sebak, and L. Talbi, "Analysis and design of a cylindrical EBG-based directive antenna," *IEEE Trans. Antennas Propag.*, vol. 54, no. 1, pp. 211–219, Jan. 2006.
[11] D. Deslandes and H. Wu, "Substrate integrated waveguide leaky-wave antenna: Concept and design considerations," in *Proc. Asia–Pacific Microw. Conf.*, vol. 1, Dec. 2005, pp. 346–349.
[12] A. J. Martinez-Ros, J. L. Gómez-Tornero, and G. Goussetis, "Planar leaky-wave antenna with flexible control of the complex propagation constant," *IEEE Trans. Antennas Propag.*, vol. 60, no. 3, pp. 1625–1630, Mar. 2012.
[13] J. L. G. Tornero, A. M. Ros, M. A. Martinez, A. M. Sala, G. Goussetis, and S. K. Podilchak, "A simple parallel-plate wave launcher in substrate integrated waveguide technology," in *Proc. IEEE Int. Symp. Antennas Propag. USNC/URSI Nat. Radio Sci. Meeting*, Jul. 2015, pp. 480–481.
[14] E. D. Caballero, A. B. Martinez, H. E. Gonzalez, O. M. Belda, and V. B. Esbert, "A novel transition from microstrip to a substrate integrated waveguide with higher characteristic impedance," in *IEEE MTT-S Int. Microw. Symp. Dig. (MTT)*, Jun. 2013, pp. 1–4.
[15] D. M. Pozar, *Microwave Engineering*, 4th ed. New York, NY, USA: Wiley, 2011.
[16] A. R. Akbarzadeh and Z. Shen, "Waveguide power dividers using multiple posts," *Microw. Opt. Technol. Lett.*, vol. 50, no. 4, pp. 981–984, 2008.
[17] J. Hirokawa, K. Sakurai, M. Ando, and N. Goto, "An analysis of a waveguide T junction with an inductive post," *IEEE Trans. Microw. Theory Techn.*, vol. 39, no. 3, pp. 563–566, Mar. 1991.
[18] A. J. Martinez-Ros, J. L. Gómez-Tornero, and F. Quesada-Pereira, "Efficient analysis and design of novel SIW leaky-wave antenna," *IEEE Antennas Wireless Propag. Lett.*, vol. 12, pp. 496–499, 2013.
[19] P. Burghignoli, G. Lovat, and D. R. Jackson, "Analysis and optimization of leaky-wave radiation at broadside from a class of 1-D periodic structures," *IEEE Trans. Antennas Propag.*, vol. 54, no. 9, pp. 2593–2604, Sep. 2006.
[20] A. P. Feresidis and J. C. Vardaxoglou, "High gain planar antenna using optimised partially reflective surfaces," *IEE Proc.-Microw., Antennas Propag.*, vol. 148, no. 6, pp. 345–350, Dec. 2001.
[21] N. Marcuvitz, *Waveguide Handbook*. New York, NY, USA: McGraw-Hill, 1951.
[22] *CST Microwave Studio*. Accessed: Jun. 20, 2017. [Online]. Available: https://www.cst.com
[23] J. L. Gómez-Tornero, G. Goussetis, A. P. Feresidis, and A. A. Melcón, "Control of leaky-mode propagation and radiation properties in hybrid dielectric-waveguide printed-circuit technology: Experimental results," *IEEE Trans. Antennas Propag.*, vol. 54, no. 11, pp. 3383–3390, Nov. 2006.
[24] C. Balanis, *Antenna Theory: Analysis and Design*. Hoboken, NJ, USA: Wiley, 2012.
[25] C. Mateo-Segura, A. P. Feresidis, and G. Goussetis, "Bandwidth enhancement of 2-D leaky-wave antennas with double-layer periodic surfaces," *IEEE Trans. Antennas Propag.*, vol. 62, no. 2, pp. 586–593, Feb. 2014.
[26] V. G. G. Buendia, S. K. Podilchak, G. Goussetis, and J. L. Gómez-Tornero, "A TM_0 surface wave launcher by microstrip and substrate integrated waveguide technology," in *Proc. 11th Eur. Conf. Antennas Propag. (EUCAP)*, Mar. 2017, pp. 3859–3862.

VICTORIA GÓMEZ-GUILLAMÓN BUENDÍA (S'18) was born in Murcia, Spain, in 1990. She received the Telecommunications Engineer degree from the Universidad Politecnica de Cartagena, Cartagena, Spain, in 2015. She is currently pursuing the Ph.D. degree with Heriot-Watt University, Edinburgh, U.K., where she joined, in 2015, as an International Research Student under a COST short-term scientific mission and was involved in the development of an in-flight wireless communication system for aircraft. Her current research interests include the analysis and design of planar leaky-wave antennas and surface-wave launchers for microwave frequencies in different planar technologies, such as microstrip, parallel-plate waveguides, substrate integrated waveguides, dielectric, and substrate integrated image guides.

SYMON K. PODILCHAK (S'03–M'05) received the B.A.Sc. degree in engineering science from the University of Toronto, Toronto, ON, Canada, in 2005, the M.A.Sc. degree in electrical engineering from The Royal Military College of Canada, Kingston, ON, Canada, in 2008, and the Ph.D. degree in electrical engineering from Queen's University, Kingston, in 2013, where he was an Assistant Professor, from 2013 to 2015. He then joined Heriot-Watt University, Edinburgh, U.K., in 2015, as an Assistant Professor and became an Associate Professor, in 2017. His research is currently supported by the H2020 Marie Sklodowska-Curie European Research Fellowship. He received the Outstanding Dissertation Award from Queen's University.

He is a registered Professional Engineer and has had industrial experience as a Computer Programmer. He has designed 24- and 77-GHz automotive radar systems with Samsung and Magna Electronics. Recent industrial experience also includes the design of high-frequency surface-wave radar systems, professional software design and implementation for measurements in anechoic chambers for the Canadian Department of National Defence, and the SLOWPOKE Nuclear Reactor Facility. He has also designed new compact multiple-input multiple-output antennas for wide-band military communications, highly compact circularly polarized antennas for microsatellites with COM DEV International, and new wireless power transmission systems for Samsung. His research interests include surface waves, leaky-wave antennas, metasurfaces, UWB antennas, phased arrays, and CMOS integrated circuits.

Dr. Podilchak was a recipient of many best paper awards and scholarships, most notably the Research Fellowships from the IEEE Antennas and Propagation Society and the IEEE Microwave Theory and Techniques Society. He also received the Postgraduate Fellowship from the Natural Sciences and Engineering Research Council of Canada and four Young Scientist Awards from the International Union of Radio Science. He received the Student Paper Awards at the IEEE International Symposium on Antennas and Propagation, in 2011 and 2013, the Best Paper Prize for Antenna Design at the European Conference on Antennas and Propagation for his work on CubeSat antennas, in 2012, and the European Microwave Prize for his research on surface waves and leaky-wave antennas, in 2016. In 2017, he received the Visiting Professorship Award at La Sapienza University of Rome, Rome. In 2014, the IEEE Antennas and Propagation Society recognized him as an Outstanding Reviewer for the IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION. He was also the Founder and the First Chairman of the IEEE Antennas and Propagation Society and the IEEE Microwave Theory and Techniques Society and a Joint Chapter of the IEEE Kingston Section, Canada. In recognition of these services, the IEEE presented him with the Outstanding Volunteer Award, in 2015. He currently serves as an Associate Editor for the *IET Electronic Letters*.

DAVIDE COMITE (M'15) received the master's degree *(cum laude)* in telecommunications engineering and the Ph.D. degree in electromagnetics and mathematical models for engineering from La Sapienza University of Rome, Rome, Italy, in 2011 and 2015, respectively, where he is currently a Postdoctoral Researcher. He was a Visiting Ph.D. Student with the Institute of Electronics and Telecommunications of Rennes, University of Rennes 1, France, in 2014, and a Postdoctoral Researcher with the Center of Advanced Communications, Villanova University, Villanova, PA, USA, in 2015.

His scientific interests involve the design of dual-polarized leaky-wave antennas, 2-D periodic leaky-wave antennas, and the generation of non-diffracting waves and pulses. He is also interested in the study of the scattering from isotropic and anisotropic natural surfaces and the characterization of the GNSS reflectometry over the land. His activity also regards microwave imaging and objects detection performed through GPR, operating both in down-looking and forward-looking configurations, and the modeling of the radar signature in forward scatter radar systems. He was a recipient of the Marconi Junior Prize awarded by Fondazione Guglielmo Marconi, in 2012, to a young student author of a master's degree thesis particularly relevant and important in ICT. He received an honourable mention in the frame of the Minerva Award 2017, assigned by La Sapienza University of Rome and Fondazione Sapienza to postdoctoral researchers who developed distinguished research activities. As a co-author, he received the Best Student Paper Award at the SPIE Remote Sensing and Security + Defence International Symposia, in 2017, and the Best Paper Award for the Electromagnetics and Antenna Theory Section at the 12th European Conference on Antennas and Propagation, in 2018.

PAOLO BACCARELLI (M'01) received the Laurea degree in electronic engineering and the Ph.D. degree in applied electromagnetics from the La Sapienza University of Rome, Rome, Italy, in 1996 and 2000, respectively, where he joined the Department of Electronic Engineering, in 1996, and has been an Assistant Professor, since 2010. In 1999, he was a Visiting Researcher with the University of Houston, Houston, TX, USA. He has been an Associate Professor with the Department of Engineering, Roma Tre University, Rome, since 2017. In 2017, he received the National Scientific Qualification for the role of Full Professor of electromagnetic fields in Italian universities.

He has co-authored about 230 papers in international journals, conference proceedings, and book chapters. His research interests include the analysis and design of planar antennas and arrays, leakage phenomena in uniform and periodic structures, numerical methods for integral equations and periodic structures, propagation and radiation in anisotropic media, metamaterials, graphene, and electromagnetic band-gap structures. He was a recipient of the Giorgio Barzilai Laurea Prize (1994–1995) presented by the former IEEE Central and South Italy Section. He is in the editorial boards of international journals and acts as a reviewer for more than 20 IEEE, IET, OSA, and AGU journals. He was a Secretary of the 2009-European Microwave Week and has been a member of the TPCs of several international conferences.

PAOLO BURGHIGNOLI (S'97–M'01–SM'08) was born in Rome, Italy, in 1973. He received the Laurea degree *(cum laude)* in electronic engineering and the Ph.D. degree in applied electromagnetics from the La Sapienza University of Rome, Rome, in 1997 and 2001, respectively.

In 1997, he joined the Department of Information Engineering, Electronics and Telecommunications, La Sapienza University of Rome. In 2004, he was a Visiting Research Assistant Professor with the University of Houston, Houston, TX, USA. From 2010 to 2015, he was an Assistant Professor with the La Sapienza University of Rome, where he has been an Associate Professor, since 2015. His scientific interests include the analysis and design of planar antennas and arrays, leakage phenomena in uniform and periodic structures, numerical methods for integral equations and periodic structures, propagation and radiation in metamaterials, electromagnetic shielding, and graphene electromagnetics. In 2017, he received the National Scientific Qualification for the role of Full Professor of electromagnetic fields in Italian universities.

He has co-authored the Fast Breaking Papers, in 2007, in EE and CS, about metamaterials (paper that had the highest percentage increase in citations in Essential Science Indicators). He was a recipient of the Giorgio Barzilai Laurea Prize (1996–1997) presented by the former IEEE Central and South Italy Section, the 2003 IEEE MTT-S Graduate Fellowship, and the 2005 Raj Mittra Travel Grant for Junior Researchers presented at the IEEE AP-S Symposium on Antennas and Propagation, Washington, DC, USA. He is an Associate Editor of the *IET Electronics Letters* and the *Hindawi International Journal of Antennas and Propagation*.

JOSÉ LUIS GÓMEZ TORNERO (SM'01–M'06–SM'14) was born in Murcia, Spain, in 1977. He received the Telecommunications Engineer degree from the Technical University of Valencia, Valencia, Spain, in 2001, and the Ph.D. degree from the Universidad Politecnica de Cartagena (UPCT), Cartagena, Spain, in 2005. In 2000, he joined the Radio Frequency Division, Industry Alcatel Espacio, Madrid, Spain. In 2001, he joined UPCT, where he has been an Associate Professor, since 2008. He was a Vice Dean for students and lectures affairs as a member of the Telecommunication Engineering Faculty. He has been a Visiting Researcher/Professor with the University of Loughborough, Loughborough, U.K., Heriot-Watt University, Edinburgh, U.K., the Queen's University of Belfast, Belfast, U.K., and the CSIRO-ICT Centre, Sydney, NSW, Australia. In 2010, he was appointed as a CSIRO Distinguished Visiting Scientist by the CSIRO ICT Centre.

He has co-authored more than 50 peer-reviewed journal papers and more than 100 conference papers. His current research interests include the analysis and design of leaky-wave devices and their applications and the innovation in the area of higher education. His research work has received various awards, including the EPSON-Ibérica Foundation Award, in 2004, and the Vodafone Foundation Award, in 2005, to the best Ph.D. thesis in the area of advanced mobile communications technologies and the Hispasat Prize, in 2014, and the Hisdesat Prize, in 2015, to the best Ph.D. thesis in satellite communication technologies. He was also a co-recipient of the 2010 IEEE Engineering Education Conference Award, the 2011 EuCAP Best Student Paper Prize, the 2012 EuCAP Best Antenna Theory Paper Prize, the 2012 and 2013 Spanish URSI Prizes for the best student paper, the 2013 APS Best Student Paper Finalist, and the 2018 iWAT Best Poster Award.

GEORGE GOUSSETIS (S'99–M'02–SM'12) received the Diploma degree in electrical and computer engineering from the National Technical University of Athens, Athens, Greece, in 1998, the B.Sc. degree (Hons.) in physics from University College London, London, U.K., in 2002, and the Ph.D. degree from the University of Westminster, London, in 2002. In 1998, he joined Space Engineering, Rome, Italy, as an RF Engineer. In 1999, he joined the Wireless Communications Research Group, University of Westminster, as a Research Assistant. From 2002 to 2006, he was a Senior Research Fellow with Loughborough University, Loughborough, U.K. He was a Lecturer (Assistant Professor) with Heriot-Watt University, Edinburgh, U.K., from 2006 to 2009, and a Reader (Associate Professor) with Queen's University Belfast, Belfast, U.K., from 2009 to 2013. In 2013, he joined Heriot-Watt University as a Reader and was promoted to a Professor, in 2014.

He has authored or co-authored over 200 peer-reviewed papers, five book chapters, and one book. He holds two patents. His current research interests include the modeling and design of microwave filters, frequency-selective surfaces and periodic structures, leaky-wave antennas, microwave sensing and curing, and numerical techniques for electromagnetics. He was a co-recipient of the 2011 European Space Agency Young Engineer of the Year Prize, the 2011 EuCAP Best Student Paper Prize, the 2012 EuCAP Best Antenna Theory Paper Prize, and the 2016 Bell Labs Prize. He held the Research Fellowship with the Onassis Foundation, in 2001, and the U.K. Royal Academy of Engineering, from 2006 to 2011, and the European Marie-Curie experienced Researcher Fellowship, from 2011 to 2012.