Antenna Booster Technology: From R&D to Ignion

Jaume Anguera and Aurora Andújar

EDITOR'S NOTE

In this installment of "Industry Activities," we have the pleasure of reading a contribution by Dr. Jaume Anguera, CTO at Ignion and Aurora Andújar, founder and director of engineering at Ignion. In this article, insight is provided into the thought process, creation, and development of a universally adaptable small antenna technology. The importance of collaboration, whether it be among researchers from around the world, within small and large companies, or between industry and academia, is also highlighted. I would like to thank Dr. Jiang Zhu from Google for arranging for this article.

Rod Waterhouse

The purpose of this article is to illustrate how research ignites big assets; from products, patents, technology, and even the creation of new companies. Using authors' experiences, it will be shown how an antenna engineering challenge was addressed and how it ended up with a new antenna technology to bring new solutions to the Internet of Things (IoT) space. The different milestones discussed in the article will also inspire and encourage young researchers to pursue R&D career paths. The paths include plenty of hard work and ups and downs but also a very rewarding experience that, in the end, enables stunning advances in technology for humanity.

A PROBLEM TO BE SOLVED

After reading and becoming inspired by the fascinating journeys of C.J. Reddy [1] and R.W. Schlub [2], we are going to travel along a new experience where research is the catalyzer of big things. Let us begin this journey in 2003, when I earned my Ph.D. degree from Universitat Politècnica of Catalunya, Barcelona, Spain, in telecommunication engineering in the field of small and multiband antennas. Most of the research was carried out at the technology company Fractus in Barcelona. Just after finishing my Ph.D. degree, I was assigned to the Fractus branch office in Seoul, South Korea, to head up the research team. One of my main tasks was to provide training, education, and development of the team's core competency and to provide an R&D vision to address the rapidly growing mobile device market. Besides growing as a researcher, I had a precious opportunity to learn from the Korean people and their culture, thus complementing my Western vision of facing challenges [3]. From 2003 to 2006, Fractus secured major contracts with companies such as Samsung and LG. While in South Korea, I had the challenge of presenting our antenna technology to mobile design experts to demonstrate the benefits we could offer their mobile phone designs as we were able to make antennas small and multiband. After many presentations given at IEEE Antennas and Propagation symposiums, I was confident enough to perform well.

By that time, cellular communications had matured with 2G, and the mobile industry was moving forward to adopt 3G frequency bands once the licensing concessions were granted in 2000–2001. And we were there, at the right time and place and in one of the more advanced countries, as far as the mobile phone industry was concerned.

After previous research at Fractus in the field of small and multiband antennas, in our Korean R&D branch office, we were designing antenna products for Korean mobile phone makers. Our small and multiband antenna products had great performance and as a result, our Korean team won many projects (Figure 1). Those products were based on printed inverted-F and monopole antennas where the antenna geometry was customized not only to be small and multiband but also to adapt to the

Digital Object Identifier 10.1109/MAP.2021.3085163
Date of current version: 5 August 2021

stringent requirements of limited space within a mobile phone. After many long days and nights, we achieved the specs in terms of many parameters, such as impedance matching, efficiency, total radiated power, sensitivity, synthetic aperture radar, repeatability, mechanical robustness, competitive cost, and others. As engineers, we were proud that our antenna designs were adopted by the mobile industry.

However, after one winning project, a new project started with a novel challenge to design an original small and multiband antenna. Even in some designs, although the number of frequency bands was the same, a change on the mechanics of the mobile phone implied a new antenna geometry, which required new electromagnetic simulations, a fabrication of new prototypes, an adjustment of those prototypes in the lab, and the manufacturing and qualification of the new product. From a business perspective, a customized antenna design was very artisan, and the process was not efficient because a different customized antenna was needed for every different device. At that time, the following question arose in our brains: "Can we invent a new antenna technology to be used for any device and for any frequency band?"

THE SOLUTION: ANTENNA BOOSTER TECHNOLOGY

Returning to Barcelona in 2006 from my time spent in Korea, it was the right moment to accelerate research and find an answer to the big question of inventing a new antenna concept capable of working for any band and device size without the need for customizing a new antenna geometry and so on.

After a deep dive into research, we ended up with a new technology that we named *ground plane booster* or *antenna booster technology*. In essence, the novel idea relies on the use of a very simple and small nonresonant antenna component, an antenna booster that, when strategically placed on the ground plane of a wireless device, boosts radiation modes on such a ground plane, making it an effective radiating means for transmitting and receiving electromagnetic waves. Because the ground planes of wireless devices are comparable to their wavelength, enough bandwidth and efficiency can be obtained when properly exciting the radiating modes in the ground plane, thanks to an antenna booster. Here is where the name *ground plane booster* comes from as the booster is, in fact, a boosting element of currents in the ground plane. Actually, from a commercial perspective, the technology is called *virtual antenna*, which refers to the fact that the main radiator in the ground plane and the antenna booster are merely a feeding component of currents in the ground plane. A parallelism can be found in a rectangular waveguide excited by a voltage probe, that is, a short monopole, which is not considered an antenna but rather the feeding mechanism used to excite modes inside a waveguide.

The first booster prototyped in the lab measured 5 mm × 5 mm × 5 mm, representing only $\lambda/70$ at 824 MHz, being very small in terms of the wavelength. With the addition of a single matching network with six lumped components, we showed that it was possible to achieve multiband performance [4], with a volume 10-times smaller than that of a typical printed inverted-F antenna-type antenna with a similar performance [5].

Due to the novelty of the idea, we filed two patents in 2008, which were granted some years later [7], [8] (see Figure 2). We did not stop there, we continued conducting research, with new patents and papers published in prestigious scientific journals and at conferences, including many of IEEE's [5], [9], [10]. Once the physics principles were understood, it was the right time to translate the research into a real product. In 2013, the first commercially available antenna booster was born: the *CUBE mXTEND* antenna booster. Named in honor of the first antenna booster prototype developed in the lab five years prior, it featured dimensions of 5 mm × 5 mm × 5 mm (see Figure 3).

The antenna booster addressed the need for one antenna for any band and for any device. It was no longer necessary to customize a different antenna for a new device or for new bands. With an antenna booster, it is possible to operate from 0.4 up to 10.4 GHz, due to the correct selection of the antenna booster, its location of the ground plane of an IoT device, and with the design of a matching network. In fact, the design of IoT devices embedding antenna boosters looks more like a microwave problem than it does an antenna problem where the antenna booster is treated as an impedance box. Moreover, the frequency of operation is not determined by the antenna but by the

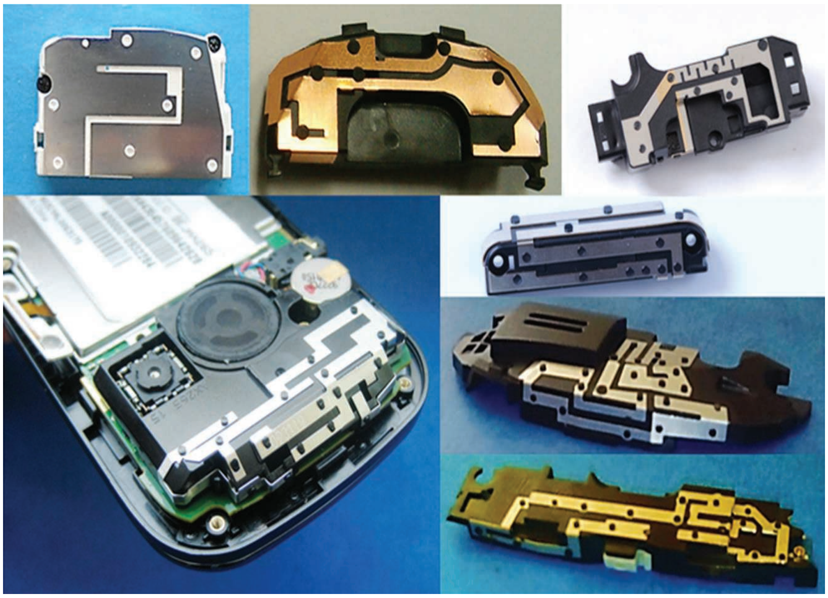

FIGURE 1. Several of the small and multiband antennas developed at our Korean branch office around 2003, operating at 2G and 3G as well as in GPS.

designers, who can freely shape the frequency band to operate, from single- to multiband, with the design of a matching network [11] (see Figure 4). In addition, the design of the matching network can be easily addressed by matching the network synthesis tools [5], [12]. Therefore, this design procedure is faster and simpler than designing a complex antenna geometry from scratch. And because they are off the shelf and surface-mount-device compatible, antenna boosters are ready to use, eliminating the need for manual-intervention assembly on a printed circuit board, thus making it convenient for mass production.

Antenna booster technology was growing, with many IoT devices adopting the technology worldwide. And the team grew as well, from researchers developing new antenna booster products, antenna engineers helping IoT device makers to embed antenna boosters, operations, and a sales team to bring it to the market. As a result, in 2015, a new company, Ignion, was founded, with headquarters in Barcelona, Spain, and with branch offices in Shanghai, China, and Tampa, Florida, United States. The mission of Ignion is to accelerate the IoT and empower the ecosystem with off-the-shelf antenna booster solutions. Since then, many big players in the IoT field, such as Nordic Semiconductor, Sierra Wireless, Sequans, Cavli Wireless, and The Things Industries, have been using antenna booster technology in their devices to bring connectivity in a reliable and efficient way (Figure 5).

Another aspect of research within the company that is worth discussing refers to the different dynamics compared to those of other departments that are more short-term oriented. In effect, an R&D department has its outcomes in the medium and long term. The example of antenna booster technology is an

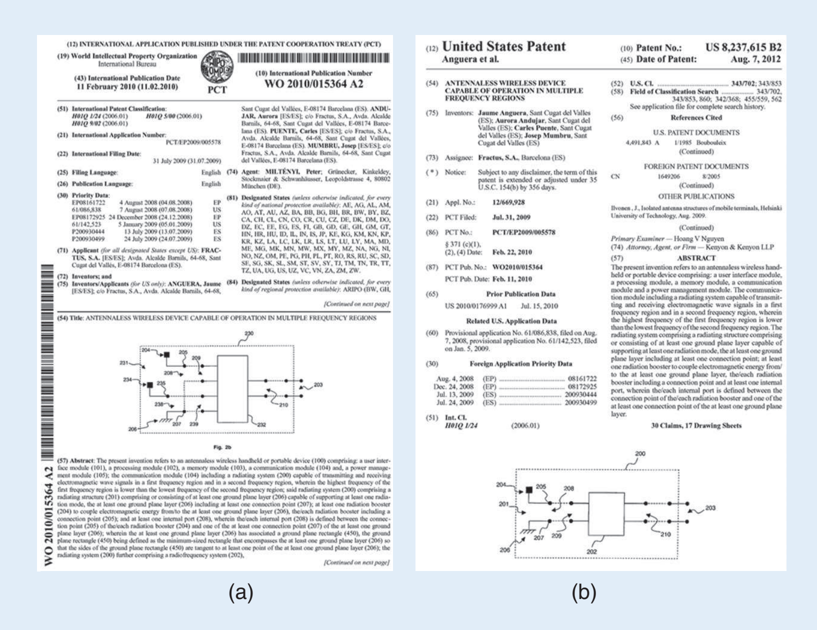

FIGURE 2. (a) The first publication of antenna boosters for multiband operation [6] and (b) the first patent awarded by the U.S. Patent Office [7].

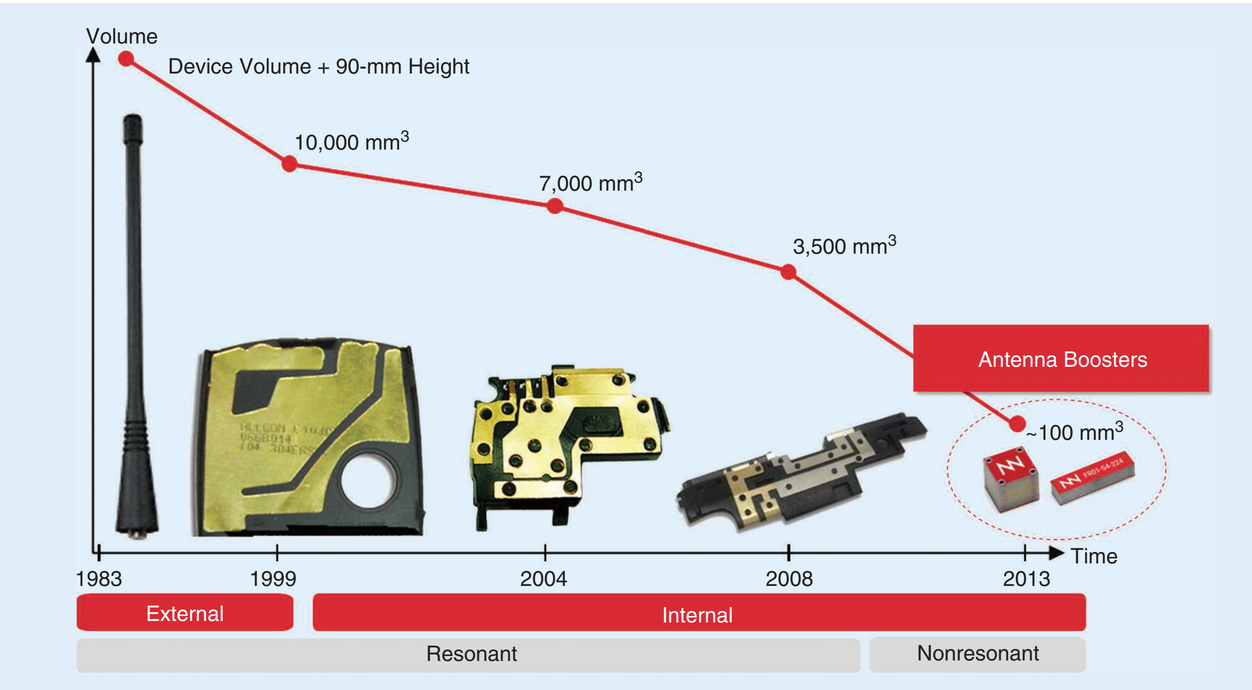

FIGURE 3. From external monopole antennas to the internal customized antennas relying on complex geometries, to the miniature, multiband, off-the-shelf antenna boosters.

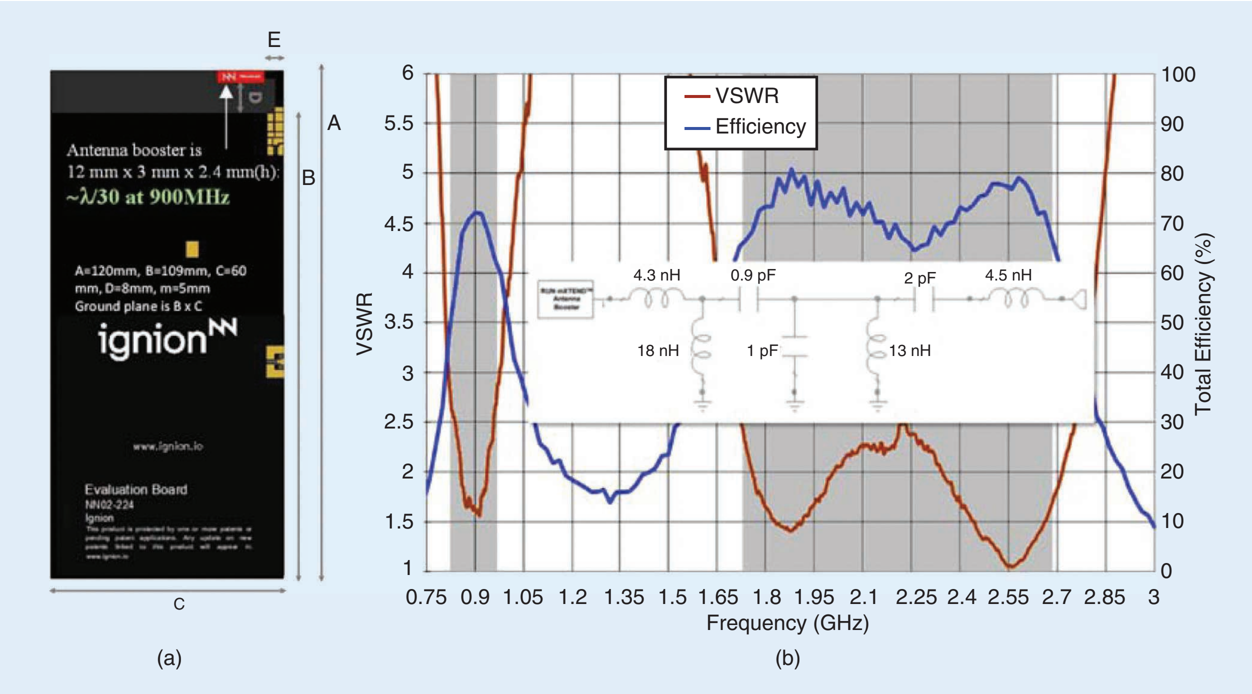

FIGURE 4. (a) An antenna booster that measures 12 mm × 3 mm × 2.4 mm. (b) The booster provides operation in the 824–960 and 1,710–2,690 MHz ranges, respectively. VSWR: voltage standing-wave ratio.

apt case where, thanks to our research, we ended up with a new technology that is different from the technology we had. This process, from the first step in forms of electromagnetic simulations to the first commercially available product of this new technology, lasted seven years (2007–2013). In this regard, to keep research current, public funding provides a mechanism to make the research engine running smart. Our research team has been awarded by both national and European funding organizations to bring the technology to the next level [13], [14].

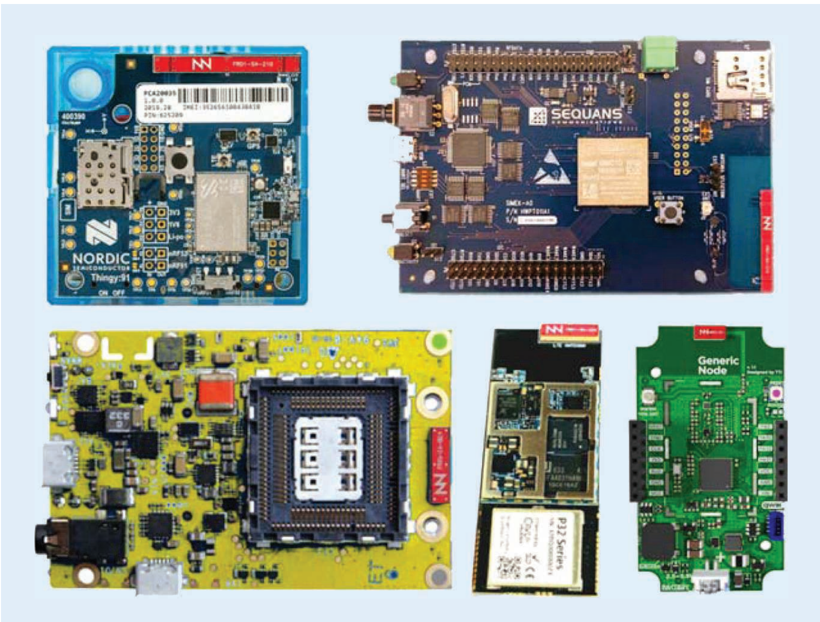

FIGURE 5. The IoT devices with cellular connectivity and geolocalization embedding antenna booster technology (the red color component at the edges).

DISSEMINATION OF ANTENNA BOOSTER TECHNOLOGY

Since 1999, I have been applying the lessons from my industry activities, first at Fractus and then with Ignion since 2017, into teaching. In this environment, students are engaged to research at the industry-academic level, where 84 students have thus far been involved in developing their thesis, achieving the most from it thanks to the lab facilities made available by Ignion and Universitat Ramon Lull, both in Barcelona.

Aside from the basic antenna fundamentals that every telecommunication/electrical/electronics engineer should know, the students highly appreciate a dose of industry trends to link the theory learned at the academic level to the applications found in the wireless industry. In this regard, at the master of telecommunication engineering level at Universitat Ramon LLull, antenna booster technology is already a part of the academic program. In addition, students compete in a contest to develop a design project that embeds an antenna booster in an IoT device

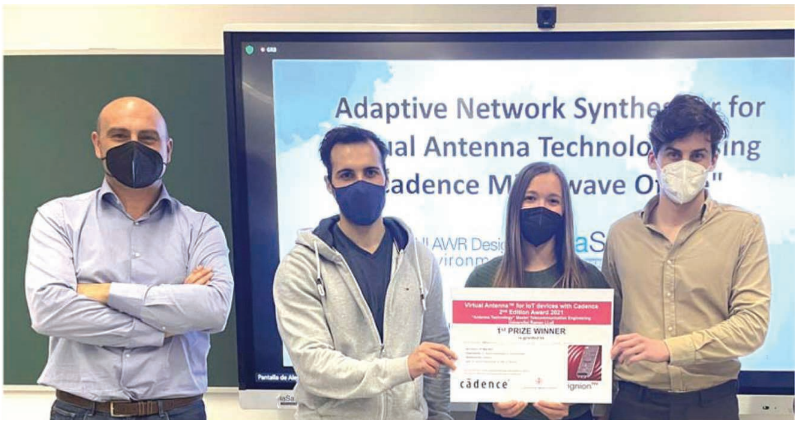

FIGURE 6. The COVID-19 pandemic did not prevent the celebration of the second edition award of Antenna Boosters for IoT, using Microwave Office software. From left: Dr. Jaume Anguera, José L. Pina, Nuria Ramos, and Alejandro Fernández.

using a Microwave Office simulator by Cadence (Figure 6). Not only are the students involved with world-class antenna booster technology, they get to interact with advanced simulation tools. Finally, the winners have the chance to present their project in Cadence via a live conference, likely their first such opportunity to display their results in front of a large audience of experts.

As far as dissemination at both the industry and academic levels is concerned, from 2018 to 2021, more than 37 conferences, webinars, and workshops were given [15]. Finally, in 2021, I was appointed an IEEE Antennas and Propagation Distinguished Lecturer, and antenna booster technology is one of the topics for the lecture. The COVID-19 pandemic does not impede us from sharing our knowledge with peers worldwide, and we hope that we can soon meet in person with colleagues all around the world.

CONCLUSIONS

Research results take the form of new products for a company and new patents for licensing to third parties. In the present case, the invention of antenna booster technology has enough entity and practical application in the IoT space that a new company was created.

Due to medium- and short-term outputs, funding is an important engine to develop research with the best human resources and equipment. We have also shown that industry research complements academic content, further motivates students and engages them in developing applied research in the field of small and multiband antennas, and facilitates their transition from students to engineers.

We hope that this journey will be useful for our IEEE community of engineers to shape the future for a better-connected society and the benefit of mankind.

ACKNOWLEDGMENTS

Antenna booster technology has received funding from the European Commission (Horizon 2020); Centro para el Desarrollo Tecnológico Industrial Ministry of Science, Innovation, and Universities; and the Spanish Ministry of Industry, Energy, and Tourism.

AUTHOR INFORMATION

Jaume Anguera (jaume.anguera@ignion.io) is the founder of and CTO at Ignion. He is also an associate professor at Universitat Ramon LLull, Barcelona, Spain. He is an IEEE Antennas and Propagation Distinguished Lecturer. He holds more than 150 patents and is the author of more than 250 journal and conference papers. He is a Fellow of IEEE.

Aurora Andújar (aurora.andujar@ignion.io) is the founder and director of engineering at Ignion. She has invented more than 45 patents and is the author of more than 110 journal and conference papers.

REFERENCES

[1] C. J. Reddy, "Career path: From researcher to entrepreneur and beyond," *IEEE Antennas Propag. Mag.*, vol. 63, no. 2, pp. 111–116, Apr. 2021. doi: 10.1109/MAP.2021.3054881.

[2] R. W. Schlub, "Career considerations: Antenna design for complex consumer products at scale," *IEEE Antennas Propag. Mag.*, vol. 62, no. 6, pp. 94–96, Dec. 2020. doi: 10.1109/MAP.2020.3027282.

[3] J. Anguera, "¿Es posible viajar al pasado y al futuro y simultáneamente vivir el presente?: Experiencias en Corea del Sur," 13 Apr. 2020. [Online]. Available: https://www.amazon.es/posible-viajar-pasado-simult%C3%A1neamente-presente/dp/1983292443

[4] J. Anguera, C. Picher, A. Bujalance, and A. Andújar, "Ground plane booster antenna technology for smartphones and tablets," *Microw. Opt. Technol. Lett.*, vol. 58, no. 6, pp. 1289–1294, June 2016. doi: 10.1002/mop.29788.

[5] J. Anguera, A. Andújar, G. Mestre, J. Rahola, and J. Juntunen, "Design of multiband antenna systems for wireless devices using antenna boosters," *IEEE Microw. Mag.*, vol. 20, no. 12, pp. 102–114, Dec. 2019. doi: 10.1109/MMM.2019.2941662.

[6] J. Anguera, A. Andújar, C. Puente, and J. Mumbrú, "Antennaless wireless device capable of operation in multiple frequency regions," Patent WO2010/015364, Feb. 2010.

[7] J. Anguera, A. Andújar, C. Puente, and J. Mumbrú, "Antennaless wireless device capable of operation in multiple frequency regions," U.S. Patent 8 237 615 B2, 2012.

[8] J. Anguera, A. Andújar, C. Puente, and J. Mumbrú, "Antennaless Wireless device," U.S. Patent US8 203 492 B2, 2012.

[9] A. Andújar, J. Anguera, and C. Puente, "Ground plane boosters as a compact antenna technology for wireless handheld devices," *IEEE Trans. Antennas Propag.*, vol. 59, no. 5, pp. 1668–1677, May 2011. doi: 10.1109/TAP.2011.2122299.

[10] J. Anguera, A. Andújar, and C. García, "Multiband and small coplanar antenna system for wireless handheld devices," *IEEE Trans. Antennas Propag.*, vol. 61, no. 7, pp. 3782–3789, July 2013. doi: 10.1109/TAP.2013.2253297.

[11] J. Anguera, N. Toporcer, and A. Andújar, "Slim booster bars for electronic devices," U.S. Patent 9 960 478 B2, 2018.

[12] J. Anguera, C. Puente, A. Andújar, R. M. Mateos, D. Vye and M. Lien, "Antenna library for IoT devices with antenna boosters," in *Proc. 50th European Microwave Conf. (EuMC)*, 2021, pp. 1147–1150. doi: 10.23919/EuMC48046.2021.9338246.

[13] "Virtual antenna technology: The next generation antenna for wireless devices," European Commission, Brussels, Belgium, Grant Agreement no. 674491, 2017. [Online]. Available: https://cordis.europa.eu/project/id/674491

[14] "Virtual antenna technology for GNSS, Bluetooth and 5G compact solutions," Granting Institution: CDTI (Centro para el Desarrollo Tecnológico e Industrial) – Spanish Ministry of Science, Innovation and Universities, 2019.

[15] J. Anguera, "Virtual antenna: Design of wireless devices embedding antenna boosters," IEEE Microwave and Theory Society Webinar, July 2020. [Online]. Available: https://resourcecenter.mtt.ieee.org/education/webinars/MTTWEB0620.html