

Infrared Antennas and Resonant Structures

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Preface

It was May 1996 when we were walking in Alcobendas, Madrid, to find a place to enjoy a coffee. Once we got updated on personal matters, we were ready to jump into the scientific and technical issues that always light a spark with us. The topic that day was the capability of very tiny pieces of metal, deposited on a dielectric substrate, to resonate at optical frequency in the manner of the old-fashioned antenna. A research stay at the ETHZ in Switzerland showed that, besides the exotic application of optical frequency multiplication for time standard measurements, antennas could move upward in the frequency domain and get into the optical regime with awesome capabilities yet to be explored.

This was probably the first conversation on optical antennas that we had. Since that walk, significant advances have been made in this field, and in some of them, the efforts made at the Infrared System Lab of CREOL (University of Central Florida), at the Applied Optics Complutense Group (Universidad Complutense de Madrid), and at the Physics and Optical Science Department (University of North Carolina at Charlotte) have contributed to a better understanding and application of this area.

Optical antennas, infrared antennas, antenna-coupled detectors, plasmonic antennas, nano-antennas, resonant optics, meta-surfaces... are all different names representing the same idea: how the electromagnetic interaction of light and a wise combination of material and geometry may provide new elements and devices that did not previously exist. However, naming the devices we were studying was not our main concern, nor was the visibility of our findings. The Infrared System lab has been primarily devoted to complying with the sponsors' requirements and supporting the students graduating from the lab. These 20 years of activity in this field have been mainly focused on the practical application of antenna-coupled devices and resonant structures.

At times we have been tempted to present this topic as a mere translation of the radiofrequency and microwave antenna principles to optical frequencies. Although optical antennas inherited some basic ideas from their lower-frequency counterparts, there are couple of very substantial differences. First of all, materials, especially metals, that behave as ideal conductors in the radiofrequency regime become dispersive at optical frequency. Charge carriers

are not able to follow the incident electric field, and new phenomena, sometimes degrading device performance, are at play. Secondly, the size of the elements able to resonate at optical bands is in the range of tens and hundreds of nanometers. We are then in the nanoworld with all that goes with it. Meso-optics and nano-photonics are the two areas that aid in understanding this technology, where the systems are moving closer and closer to the quantum realm. Besides, fabrication technologies in the nanoscale are complex, hard to master, and extremely expensive. Therefore, computational electromagnetism plays a decisive role in sorting out the best possible design that finally goes to the nanofabrication lab. These labs mainly involve electron-beam lithography, focused ion beam, and all of the auxiliary techniques for the precise deposition of materials. These techniques, although well established and capable, produce geometries departing from the specification to some extent, with the result of a loss of performance. The fabricated devices are tested using dedicated characterization setups, and the measured discrepancies require further refinement of the models and simulations.

The purpose of this book is to document the advances in technology achieved by our research groups over the period of approximately 1995–2016 in the area of infrared antennas and frequency-selective surfaces. Our approach was primarily experimental and consisted of three main thrusts: design, fabrication, and testing. The goal was always to have operational devices to measure, and the comparison between the designed-for and measured performance “closed the loop,” giving additional insight and guidance for device optimization. This volume summarizes a large part of our activity in antenna-coupled detectors, optical antennas, and resonant structures, including frequency-selective surfaces, resonant polarization elements, and reflectarrays. Our main goal is to show the reader the practical issues related to the design, modeling, fabrication, and testing of these devices.

Our over-riding principle was to implement and demonstrate radio-frequency technology at infrared frequencies, using electron-beam lithography. Translation of longer-wavelength designs to infrared by wavelength-ratio scaling of dimensions provides a starting point, but modifications are needed because of the non-ideal properties of the metals in the infrared, and because of the effect of the substrate refractive index.

The two main types of devices were antenna-coupled sensors that had an electrical connection for signal readout, and frequency-selective surfaces that were purely passive devices without electrical connection. Owing to the practical difficulties of establishing connections between the antenna structure and the sensor, the passive devices were always easier to work with. We did not pursue antenna-coupled emitters, so antenna-coupled devices were always seen from a sensor perspective. We were not typically concerned with field enhancement for its own sake, but rather for the response of the sensor.

The authors want to recognize those persons who over the years have contributed to making possible the type of applied research that is described here: Mohamed Abdel-Rahman, Jeffrey Bean, Christos Christodoulou, Iulian Codreanu, Kevin Coffey, Alexander Cuadrado, Jeffrey D'Archangel, Aristide Dogariu, Mahmoud Elshorbagy, José Miguel Ezquerro, Louis Florence, William Folks, Bill Franklin, Chi Fu, Christophe Fumeaux, James Ginn, José Antonio Gómez-Pedrero, Francisco Javier González, Michael Gritz, Robert Hudgins, Edward Kinzel, Fritz Kneubühl, Dale Kotter, Peter Krenz, Brian Lail, Nuria Llombart, José Manuel López-Alonso, Donald Malocha, Tasneem Mandviwala, Juan Carlos Martínez-Antón, Christopher Middlebrook, Charles Middleton, Brian Monacelli, Camilo Moreno, Daniel Mullaly, Ben Munk, Robert Olmon, Robert Peale, Wolfgang Porod, James Potter, Menelaos Poutous, Irina Puscasu, Markus Raschke, José María Rico-García, Jason Schaefer, William Schaich, David Shelton, Manuel Silva-López, Brian Slovick, Jeff Tharp, Eric Tucker, Sam Walsworth, Arthur Weeks, Scott Williams, and Guy Zummo.

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Javier Alda
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