كلية العلوم و التقنيات فاس

Faculté des Sciences et Techniques de Fès

جامعة سيدي محمد بن عبد الله

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Centre d'Etudes Doctorales : Sciences et Techniques de l'Ingénieur

AVIS DE SOUTENANCE

THESE DE DOCTORAT

Présentée par

Mr: MOHAMED EL BAKKALI

Discipline : Physique

Spécialité : Télécommunications

Sujet de la thèse : Planar Antennas with Parasitic Elements and Metasurface Superstrate Structure for 3U CubeSats.

Formation Doctorale : Sciences de l'ingénieur Sciences Physiques, Mathématiques et Informatique.

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Etablissement : Faculté des Sciences et Techniques de Fès.

Titre de la thèse : Planar Antennas with Parasitic Elements and Metasurface Superstrate Structure for 3U CubeSats.

Nom du candidat : MOHAMED EL BAKKALI
Spécialité : Télécommunications

Résumé de la thèse

The rapid progress of both science and technology in areas such as telecommunications, microelectronics, and modern materials have led to a dramatically change in the modern understanding of small spacecrafts as big opportunities for scientific research and space industries. Miniaturization of mass, volume and power consumption of a spacecraft for space missions such as Earth observation, remote sensing, and scientific research in general has led to the rapid growth of a new generation of small satellites called cube satellites (CubeSats). CubeSats allow universities, small companies, or small countries to gain experience in space technology, and to be involved in space research and exploration by cost-effective missions. The basic CubeSat configuration is a modern small satellite that has a cubic shape and standard size of about one liter, i.e.; 1U CubeSat. Three 1U CubeSats could be stacked to form a 3U CubeSat which is the most common type for universities such us the University of Wollongong (Australia) which is currently developing its first 3U CubeSat for targeting space technologies.

However, connecting the CubeSat with ground stations at the earth to uplink tele-commands, downlink telemetry and payload data is the major challenge after a successful lunch mission. Therefore, CubeSats need suitable antennas to transfer data with the earth station and accomplish other downlink tasks. This means that the CubeSat antenna should be suitable for the CubeSat-ground station links. This will be realized if the antenna is high gain at the target operating frequencies. However, the gain is proportional to the full size and then compels antenna engineers to compromise link quality for compliance with the size and weight requirements of a standard CubeSat structure. Conforming to these requirements and maintaining good antenna performance at the CubeSat operating frequency, represent the major CubeSat RF and mechanical challenge for both Low-Earth orbit (LEO) and deep-space missions.

To date, the scientific community proposed large antennas which request deployment after a successful launch operation. Traditionally, reflectarray and deployable antennas are used for CubeSats by NASA at very high frequencies (Ku and Ka bands) while dipole antennas are preferred at low frequencies. Deployment of these antennas may fail on satellite launch and hence increases the likelihood of mission failure. One idea to overcome the deployment issue is to use planar antennas (patch antennas, patch antenna arrays, and slot antennas). They have low cost, lightweight, are easily integrated with electronic devices, and are mechanically robust, while they have low gains and their performances are unknown on CubeSats. It is possible to introduce amplifiers for gain improvement, but the power consumption would increase dramatically. Power is a very limited resource on CubeSats, due to the limited amount of batteries and solar panels that can be carried on board. Hence, equipping a CubeSat with an amplifier is not the optimal solution for high data rate and long communication distances.

This PhD thesis, therefore, is the first comprehensive study that introduces planar antennas with passive elements for CubeSats. Passive elements are extruded from metamaterial

engineering and their effectiveness is defined through the electromagnetic coupling between radiating elements. They can improve the antenna performances without needing more power and space on the CubeSat body. In this study, parasitic elements (PEs) and metasurface superstrate structure (MSS) as the present passive elements for the purpose of making the proposed antenna designs suitable for 3U CubeSat missions without increasing their physical sizes and power consumption.

Through this PhD thesis it is proved that the 1D-EBGs created by PEs and MSS (1) translate the resonant frequency and (2) change the radiation direction. This means that the way of defining the PEs and MSS's unit cells beside/atop the source antenna must be chosen for maximizing energy in the main direction and achieving good RL at the target operating frequencies. The presented approaches show that the inter-elements distance (horizontal translation) affects resonant frequency and then the impedance bandwidth while radiating element dimensions define energy radiated by the main lobe and so determine the antenna gain at an operating frequency. In addition to that, the air-gap distance between the source antenna and an MSS (vertical translation) changes the antenna gain and the radiation pattern shape. These are the dominant behaviours in parasitic and metasurface designs while the proposed approaches focus also on minimizing side and back lobes, and miniaturizing as maximum as possible the antenna full size. For that, QNM and GAO are used in designing the proposed antennas.

This PhD thesis presents three very compact antenna designs for CubeSats. These antennas are printed on sizes smaller than 12×12 mm^2 and achieve peak gains bigger than 5.50 dBi at the target operating frequencies. In these designs, the antennas gains are improved at the required operating frequencies using only PEs or MSS and without increasing the antennas power, full lengths, and full widths. In addition to that, this study presents the antenna design that achieves the highest gain at S-band with suitability for all CubeSat configurations. It is an S-band MSS slot antenna fed by a CPW stripe line, and achieves high gain of 10.70 dBi with high RL and good impedance matching at 2450 MHz (S-band) since it is etched on a square area of 90 mm × 90 mm. The other proposed antennas are also small size, lightweight, and are suitable for the 3U CubeSat configuration which is the targeted satellite structure in this PhD thesis.

The present PhD thesis, therefore, is the first study that introduces PEs and MSS as good techniques for improving the radiating performances of patch and slot antennas to be suitable for CubeSat-to-Earth or CubeSat-to-CubeSat communications at lower and medium frequencies.