Resonant cavity antennas technology

Subjects: Engineering, Electrical & Electronic
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Resonant cavity antennas (RCAs) are suitable candidates to achieve high directivity with a low-cost and easy fabrication process. The stable functionality of the RCAs over different frequency bands, as well as, their pattern reconfigurability make them an attractive antenna structure for the next-generation wireless communication systems, i.e., fifth-generation (5G). The variety of designs and analytical techniques regarding the main radiator and partially reflective surface (PRS) configurations allow dramatic progress and advances in the area of RCAs. Adding different functionalities in a single structure by using additional layers is one appealing feature of the RCA structures, which has opened the various fields of studies toward 5G applications. This paper reviews the recent advances on the RCAs along with the analytical methods, and various capabilities that make them suitable to be used in 5G communication systems.

Keywords: resonant cavity antennas ; Millimeter-wave ; fifth-generation (5G) ; partially reflective surface ; Fabry–Pérot Cavity (FPC) structures ; Reconfigurability

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1. History of Resonant cavity antennas

RCAs were first introduced in 1956 by Trentini [1], who demonstrated how placing a partially reflective surface (PRS) above a waveguide aperture antenna structure can increase the antenna directivity, significantly. Since then, further studies have been carried out in this area leading to introducing several PRS configurations with different functionalities in combination with various radiating elements inside the structure. In [2][3], Alexopoulos et showed that using full dielectric PRS layers above the antennas can provide a remarkable directivity improvement. Then, in [4][5], Jackson and Oliner conducted more studies on RCAs with multi-layer dielectric PRS. In [6], James et al. added an extra discussion to Terentini study and used a three-layer PRS to increase the gain of an aperture antenna. The conventional RC structures have utilized thick full dielectric or multi-layer PRS structures. By emerging electromagnetic bandgap (EBG), metamaterial (MTM), and frequency selective surface (FSS) structures, the trend of studies changed to the design of metallo-dielectric PRS layers to take advantage of fewer layers, thinner layers, more degrees of freedom, and layers with flexible properties.

In the literature, RCAs have associated with different terminologies such as electromagnetic bandgap (EBG) [7][8], RC structures [9], 2-D leaky-wave (LW) structures [10][11], PRS [12], and Fabry–Pérot Cavity (FPC) structures [13]. RCA structures consist of a PRS in parallel with a perfect electric/magnetic conductor or an impedance surface, which establish a cavity, fed by a main radiating element inside the cavity to excite the entire structure [1]. Open-ended waveguide, patch antenna, stacked antenna, dielectric resonant antenna (DRA), dipole antenna, and crossed bowtie dipole can be used as the main radiating element inside the cavity. The PRS layer might have different configurations as will be discussed later. It can be a full dielectric structure or a periodic structure composed of an array of metallic unit cells. Due to having a cavity with reflective surfaces, multiple reflections of electromagnetic waves happen. A proper cavity thickness (the distance between the PRS and the ground plane) can superimpose in-phase transmitted waves, which enhances the antenna gain significantly. The phase and magnitude of the PRS reflection behavior have a remarkable impact on the performance of the RCAs in terms of gain, bandwidth, beam angle and aperture efficiency. Therefore, designing the PRS structures has an imperative role in the design of the RCAs to achieve the desired performance.

2. Application of Resonant cavity antennas

The demand for high traffic capacity and speed in wireless communication systems led to the fifth-generation (5G) technologies [14]. The upcoming 5G technologies provide a multitude of advantages including high data rate, high reliability, and low power consumption. More importantly, it brings newborn technologies to have smart cities and factories based on the industry 4.0 [15]. The millimeter-wave (MMW) frequency band has attracted significant attention among academic and industrial sectors, since it has enormous unlicensed bandwidth in comparison with other frequency bands [16]. Thus, MMW band can take an integral role in 5G communication systems. The MMW spectrum brings about compact structures and a higher data rate. However, many concerns are remained, which should be addressed in future communication technologies. One of these concerns is the high cost and complexity of fabrication processes within the MMW band. Another concern is the high energy loss of the MMW spectrum in comparison with the other frequency bands, which can be addressed by increasing the antenna gain.

New research directions have been done to find effective solutions to address the aforementioned concerns over the MMW frequency band. Different antenna types with a variety of configurations have been proposed to compensate for the high loss and propagation issues such as interference of the MMW spectrum. Directional antennas with medium to high gain characteristics are excellent candidates to compensate the high loss of the MMW spectrum compared to the conventional planar antennas. Antenna structures such as reflectors [17] or waveguide horns [18][19] and even array antennas [20] and dielectric lenses [21] are conventional structures, which have potential to achieve high-gain and wideband characteristic. However, they have some issues such as being bulky, heavy, and complicated and having lossy feeding networks, which in turn draws attention to other possible alternative solutions. In fact, designing a proper antenna that meets the requirements of the upcoming 5G communication systems in a simple, efficient, low-profile structure is of prime importance, which has been the subject of many researches.

There are different types of antennas, such as corrugated antennas [22][23][24], cavity-backed antennas [25][26], and SIW aperture antennas [27][28] that meet the requirement of having a high gain for 5G applications. Recently, much attention has been focused on the design of multi-functional antennas, which have a combination of characteristics in one single structure for different applications. In fact, having a high-gain antenna with features such as beam steering and circular polarization while being multi-frequency band, compact, and wideband is desired. Such structures are highly required for the next communication systems, since they lead to lower cost, compact size and even lower power consumption. It is still challenging to obtain multiple functionalities in just one antenna structure.

Recently, resonant cavity antennas have been attracting a growing attention due to their planar configuration, low fabrication difficulty, high-gain characteristic, and their capability of integration with other systems. Therefore, the RCAs with the capabilities of reconfigurability, polarization conversion, being wideband, or multi-band, while keeping high gain features have been investigated in a variety of studies. This type of antennas, which are a promising candidate to be used in the future 5G communication systems over the MMW frequency band, will be reviewed in this paper. An example of their potential is the capability to be used in 5G wireless multiple-input-multiple-output (MIMO) systems due to having a low loss and compact structure with a high-gain characteristic. Besides, RCA structures can achieve steerable radiation patterns with a great radiation performance, which is an essential key for the future 5G base stations and mobile devices. Additionally, the RCAs can offer tilted radiation beam towards a desired direction, which is the demand of mobile communication base stations. Another potential use of the RCAs is in the wireless sensor network (WSN) for future 5G systems due to the requirement of using an efficient antenna with multi-function features to enrich the communication between the nodes [29][30][31][32][33].

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