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Circularly Dielectric Resonator Antenna for Satellite Communication: A Review

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ABSTRACT: With the advancements in wireless communication, dielectric resonator antenna (DRA) can efficiently come up as the suitable substitution in comparison to the other conventional conducting antennas. In the past decades, several works have been reported for exploring the field of DRA for the upcoming futuristic technologies. Therefore, this thesis deals with the concepts related to the advancement in designing and development of DRA. The work done in this thesis mainly explores various research issues related to DRA that includes (i) obtaining circularly polarized (CP) response, miniaturization and tuning of small frequency-ratio in dual-band DRA using the single-feeding technique, (ii) exploring the multi-input-multi-output (MIMO) configuration in DRA with the achievement of wideband response and study of various MIMO performance parameters using multi-port feeding technique, and (iii) obtaining CP generation technique in nano-DRA (NDRA) for THz and optical frequency communication range.

KEYWORDS: Dielectric Resonator Antenna, Micro strip Antenna, Circular

I. INTRODUCTION

The theoretical development of dielectric resonator (DR) in the context of microwave devices like filters, oscillators and resonators has been stated in the late back 1939 by Ritchmyer [1]. The DR consists of the non-metallic resonator made up of high quality factor (Q-factor) dielectric material used for the designing of microwave circuit elements. This study demonstrated the concept of DR radiation in open environment. In 1962, Okaya and Barash studied the first and second-order approximations of the resonant frequencies for investigating modes of oscillations inside the DR. This study investigates the band-pass and band-reject filters using DR in the form of crystal [2]. Later, extensive theoretical and experimental analysis of high Q-factor DR as the filters was explored [3]. In 1968, Sager and Tisi reported the Eigen modes and forced resonant modes of the spherical DR in their study [4]. This investigation was carried out with the two practical aims of using a high Q-factor DR for waveguide applications and the other included matching with the low-impedance short dipole antenna. It was found that in both the cases, discrete resonances occurs for the different ratios of radius to wavelength of the sphere. Bladel in 1975, presented the detailed theory for the evaluation of confined and non-confined modes inside the high-permittivity DR. In 1980, Kobayashi and Tanaka studied the resonant modes of the dielectric rod resonator and generalized the modes as leaky and trapped states [5]. Initially, the DRs were shielding inside the metallic cavities in order to maintain the high Q-factor. Thus, DRs were utilized for the conventional applications like filters and oscillators. However, the use of DR as the radiator in antenna designs was not addressed until then apart from the proof of radiations in open environment for a long time. The first experimental investigation of the cylindrical DR cavity antenna was reported. Subsequently, they had investigated the rectangular and hemispherical DR in 1983 and 1984, respectively as the radiating element of the antenna [6]. Apart from this, various shapes of the DR were analysed including the ring-shaped, triangular, and spherical along with the study of radiation characteristics and different applications. A broadband two-cylindrical stacked dielectric resonator antenna (DRA) was reported with the coaxial feeding technique [7]. The use of different shaped DRAs with proper excitation techniques have been explored by many researchers over the decades. A cylindrical DRA was reported with the microstrip transmission line excitation for investigating the coupling behaviour and radiation characteristics [8]. A Coplanar waveguide feeding mechanism was reported in a cylindrical DRA. A hemispherical DRA was reported with the coaxial feeding technique for the study of input impedance [9]. A stacked annular ring was reported using the axisymmetric coaxial probe excitation [18]. In 1991, Martin et al. reported an aperture-coupled cylindrical DRA [10]. The aperture-coupled excitation technique consists of the slot in metallic ground plane through which field leaked in the DR structure to define the specific modes. In 1996, Antar and Fan have theoretically investigated the aperture coupled feeding technique in a rectangular DRA [11].

II. LITERATURE REVIEW

Qi-Bo Yan et al. [1], for satellite communication, a duplex dual circularly polarized (CP) antenna is proposed in this paper. Right-hand circular polarization (RHCP) is used for the downlink, which operates between 11.3 and 12.3 GHz, and left-hand circular polarization (LHCP) is used for the uplink, which operates between 14 and 14.5 GHz. For circular polarization, the sequential rotation (SR) method is used, and the CP axial ratio (AR) of the operating bands is below 3 dB. In the uplink, the elevation angle of the 3-dB AR of the center frequency is greater than 45° , and in the downlink, it is greater than 48° . In addition, this structure utilizes an electromagnetic band gap (EBG) structure for decoupling, resulting in uplink isolation of more than -36.16 dB. Lastly, the scan angle is greater than 23° when 90° phase difference in $\phi=0^\circ$ direction is entered when calculating the beam direction patterns of a 1616 array using HFSS array factor calculation.

D. Wu et al. [2], for full-duplex applications, a high isolation circularly polarized (CP) antenna is presented in this paper. The proposed receiving wire is made out of a consecutively pivoted cluster (SRA) of four double spellbound radio wire components and two quadrature taking care of organizations. To produce identical right-handed CP (RHCP) for both transmit (TX) and receive (RX) channels, the four TX/RX ports of the STAR antenna are excited with equal amplitude and relative phase values of 0° , -90° , -180° , and -270° , respectively. Over the 2.4-2.5 GHz band, the proposed antenna maintains identical TX/RX radiation patterns and has a TX/RX isolation of more than 40.8 dB, according to measurements.

W. Wang et al. [3], in this letter, a low-profile, low-frequency ratio dual-band dual circularly polarized (CP) patch antenna with a square patch, coupling lines, and a dual-feed network with a dispersive delay line is proposed. Noticing that this antenna was constructed on a single-layer substrate, which results in its low-profile performance. In terms of the coupling scheme, dual-band radiation performance is achieved by expanding the bandwidth of impedance matching. The circular polarization can be controlled by the phase difference that corresponds to two orthogonal signals that transmit along two paths of the dual-feed network. This assumes that the magnitudes of the signals are equal. The requirements of quadrature phases are met thanks to the dispersive delay line, which allows for the presentation of circular polarizations in both directions at two operating frequencies. In the meantime, achieving a low frequency ratio is not difficult. The single-layer antenna with a profile of 0.0060 is designed, fabricated, and measured to demonstrate the proposed design. Right-handed CP characteristic is achieved by adjusting the phase difference between two orthogonal signals to 90° at the lower operating frequency of 1.9 GHz; left-handed CP characteristic is achieved by adjusting the phase difference between two paths to 90° at the higher operating frequency of 2.4 GHz. The measured results and the simulated ones are found to be fairly consistent.

C. Cheng et al. [4], a four-fed dual circular polarization microstrip patch antenna that is fed by two Wilkinson power dividers and two ring bridges is designed to address the issue of circularly polarized antennas' limited axial ratio bandwidth. When the feeding network is fed by different ports, the output signal has a phase shift in the opposite direction, allowing it to radiate circular polarized waves that are either left-handed or right-handed. Simple structure and dependable performance are two of the characteristics of the dual circular polarization feed network. To load T-shaped branches, four triangular patches with opposite vertices are utilized. The antenna's compact structure is realized by the radiation patch's back-fed structure. The measured center frequency point S11 of the prototype antenna is less than -15 dB, the left-handed circular polarization in port Pin1 is less than 2 dB, and the right-handed circular polarization in port Pin2 is less than 1.5 dB. The prototype antenna has a wider axial ratio bandwidth than an equivalent-sized antenna of the same type. The simulated and tested radiation pattern demonstrates that the four-fed structure enhances radiation pattern symmetry and axial ratio.

Q. Han et al. [5], open four triangular grooves on four sides of the radiation patch to adjust the size of the resonance point and the resonance bandwidth in order to create a multi-band circularly polarized microstrip antenna for ISM (2.4GHz to 5.8GHz) and WiMAX (3.3GHz to 3.6GHz). The results of the simulation indicate that the antenna has a return loss below -10 dB in the frequency bands of 2.38 GHz to 2.52 GHz, 3.37 GHz to 3.45 GHz, and 5.6 GHz to 5.9 GHz. The antenna satisfies the multi-frequency and miniaturization design requirements.

C. Mao et al. [6], for transmitting and receiving (Tx/Rx) purposes in X-band satellite communication systems, a novel self-diplexing aperture-shared dual-band dual-sense circularly polarized (CP) antenna array is proposed. The antenna can transmit right-handed CP (RHCP) signals in the high band while simultaneously receiving left-handed CP (LHCP) signals in the low band. As the first component of the array, a high-isolation dual-port cavity-fed linearly polarized

(LP) patch antenna is developed. A slotted patch, a substrate integrated cavity (SIC) loaded in a U-slot, and two groups of split-ring resonators make up the element. Utilizing two feeding networks that are separated by a ground plane and rotated in a sequential manner, the LHCP and RHCP operations are carried out. In the middle of the patches, narrow slots have been etched out to reduce the radiators' mutual coupling. Importantly, the array's compact footprint is made possible by sharing patches at various bands (i.e., a common aperture). This helps to reduce undesirable grating lobes because interelement spacing is reduced. A manufactured prototype's measured results show an impedance bandwidth of 7.2-7.75 GHz (7.85-8.4), a 3 dB axial ratio (AR) bandwidth of 7.4-7.7 GHz (7.95-8.32 GHz), and a gain of 14 dBic (14.2 dBic) in the low band (high band). These values are in good agreement with the simulations. In both bands, the sidelobe levels are below -15 dB and the channel isolation is greater than 27 dB. The low-profile dual-band, dual-sense CP antenna array that has been demonstrated may be an excellent option for satellite communication.

J. Li et al. [7], we present a shared-radiator, dual-band, dual-sense circularly polarized (CP) microstrip antenna with filtering and duplexing capabilities. The proposed antenna's left-handed CP (LHCP) and right-handed CP (RHCP) characteristics are respectively realized at various bands for a single patch thanks to the presence of a coupling network that consists of a hairpin resonator, a straight slot, and a U-slot for each band. This provides two paths with an inherent phase difference of either 90° or -90° for the input signal to couple to the patch. This kind of dual-band, dual-sense CP patch antenna is highly integrated and performs better than other modern-day traditional CP antennas. Additionally, the dual-band patch antenna has a low profile of 0.044 λ , making it possible to reduce the volume, complexity, and cost of RF front-ends by integrating the filtering and duplexing functions seamlessly into the device. The fundamentals of achieving the dual-sense CP, duplexing, and filtering functions are demonstrated using topologies based on resonators. An antenna that works in the C-band is prototyped and tested as a proof-of-concept. An LHCP radiation characteristic for the low-band operation and an RHCP radiation characteristic for the high-band operation, respectively, are shown to be in good agreement with the simulated results. In addition, the antenna has excellent out-of-band rejection and frequency selectivity. The impedance and 3-dB axial-ratio (AR) bandwidths at the low band are 4.7% and 1.1%, respectively. The impedance and AR bandwidths are approximately 7.3% and 3.2% at the high-band. A feeding method for a wideband circularly polarized (CP) patch antenna based on the 90° phase difference between tapped line and parallel coupled line in a feeding network is proposed.

Q. Wu et al. [8], the isolation between the two channels or bands is greater than 24 dB. A direct coupling element with a phase delay of 0° and a J-inverter coupling element with a phase delay of 90° are both referred to as the parallel coupled line. For wideband equal magnitude, two orthogonal modes are excited by two identical $/2$ resonators in the design. In the meantime, the feeding lines are tapped and coupled to the two resonators. The tapped and coupled lines are able to automatically provide the 90° phase difference required for CP radiation without the need for a phase shifter or additional delay lines. The theoretical axial ratio (AR) is calculated using the magnitude and phase of the voltage at the radiation conductance, and the entire structure is modeled as an equivalent three-port network. This proposed patch antenna has the potential to attain a substantial AR bandwidth due to the emergence of two minima in AR response. Finally, a fabricated CP patch antenna prototype with a profile of 0.042 λ and a 3 dB AR fractional bandwidth of 7.07% confirms the theoretical performance.

III. PROBLEM FORMULATION

Due to rapid growth in wireless communication, the research on low profile, multiband and dual polarized antennas are extremely focused. Different types of antennas are available to fulfill all these requirements, such as microstrip antenna, slot antenna, and dielectric resonator antenna (DRA). Out of these antennas, DRA is one of the most noticeable radiators due to its integral potentials such as no metallic loss and high radiation efficiency [1]. In order to develop multiband characteristics in DRA, several techniques have been developed such as higher order mode generation (HE_{m11} and HE_{m13} mode) in cylinder-shaped DRA [2]. Different shapes of DRA have also been studied to obtain multiband characteristics such as pentagon, stair rectangular DRA [3, 4]. There are various higher order modes such as HE_{216} mode which is quite easily generated in CDRA due to its low quality factor. These modes are not advantageous in the case of antenna because it affects the radiation characteristics of other fundamental modes. Similarly, it is not easy to generate higher order modes (which is useful in the case of antenna) with the help of a simple feed structure [5, 6]. In order to avoid these difficulties, the concept of hybrid DRA comes into existence, which represents combination of DRA with other resonating structures [7, 8]. Similarly, Khalily et al. presented a hybrid CDRA (split half CDRA with fork shape monopole) for multiband applications [9]. Cylindrical DRA along with parasitic slots on ground plane was proposed by Sharma and Gangwar. Recently, dual-polarized antennas are the most favorable topic of the researchers due to their several advantages such as orientation insensitive, getting more information by radar from targets, etc.

IV. METHODOLOGY

Dielectric constant of the substrate gives mechanical strength to the microstrip patch antenna. In order to predict the resonant frequency, resonant resistance and other antenna parameter, the propagation constant for a wave in the microstrip substrate must be accurately known. This can be done by accurately estimating the dielectric constant of the substrate materials, and the temperature tolerance of the permittivity.

There is no one ideal substrate; the choice rather depends on the application. Substrate choice and evaluation is an essential part of the design procedure. Many substrate properties may be involved in these considerations; dielectric constant and loss tangent and their variation with temperature and frequency, thermal coefficient and temperature range. Low frequency application requires high dielectric constants to keep the size small. For high power application of microstrip patch antenna, a thick cladding is desirable. Microstrip patch antennas used low dielectric substrates.

In this project, we have used RT duroid 5880 substrate with dielectric constant 2.5 and this substrate has following features

- High thermal conductivity
- Low loss tangent
- Thermally stable low profile and reverse treated copper foil
- Advanced filler system

USB Microstrip Antenna

In the recent rapid research of ultra-wideband (UWB) technology, the UWB antenna is one of the most essential components for an UWB system. Many applications such as local network, imaging radar, and communication employ UWB technology. Therefore, developments of UWB antennas become important and complex for system and antenna designers. In conventional UWB systems, the antenna radiates in the preferred direction with high gain performance and operates over a broad impedance-matched bandwidth. One of the examples would be log-periodic antennas; they have broadband impedance matching and reasonable gain in the desired direction. However, due to their dispersive properties on broadband waveform radiation, extra compensations and complexities are required. Another type of broadband antenna would be the TEM horn.

To have lower dispersive rating, bi-conical antennas are a good choice for broadband systems. Bi-conical antennas have a broadband impedance match and tend to generate non-dispersive waveforms. However, when applying UWB systems to portable devices, conventional UWB antennas are not suitable. This is mainly due to their bulky size and directional properties. Monopole and dipole antennas are good options for portable UWB devices. They have great features such as broadband impedance matching, small size and omni-directional radiation. However, from a system design point of view, fabrication may not be easy because those antennas require a perpendicular ground plane. Therefore, planar or printed-circuit board (PCB) antennas are much more suitable in terms of manufacturing complexities. Also, when designing UWB antennas, designers must make new considerations based on new UWB standards.

V. CONCLUSION

Dielectric Resonator Antennas (DRAs) has some attractive characteristics like high radiation efficiency, small size, high power handling capacity, wide operational bandwidth, low losses and easy to integrate with existing technologies as compared to other antennas. In addition, their main parameters like resonance frequency, excited modes, radiation pattern and gain are designed by their dielectric constant, geometry, feeding and coupling mechanism etc. These flexibility and other inbuilt properties declare them as suitable candidate for Ultra Wideband technology. However, still academic and researchers are facing challenges in two main areas: first, in determination of accurate resonance frequency of Rectangular Dielectric Resonator Antenna and second, further widening the bandwidth of Dielectric Resonator Antenna to meet the requirement of ultra wideband technology.

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