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Dielectric resonator antennas: An application oriented survey

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Abstract
This survey article outlines a comprehensive investigation of research carried out on dielectric resonator antennas (DRAs) in the last three and half decades, in an application-oriented approach. DRAs have created a remarkable position in antenna engineering for their adept characteristics like high efficiency, low loss, wide bandwidth, compact size, 3-dimensional modeling flexibility, etc. The use of DRAs for different commercial and defense applications associated with the wireless communication is highlighted in this article. To make a smooth and effective survey article, all the application-oriented DRAs available in the open literature are classified in five different categories like microwave bands, specific frequency, technology, millimeter-wave, and miscellaneous types. The ultimate aims of this review article are as follows: (i) highlights the usability of DRAs for different commercial and defense applications, (ii) helpful for the antenna industries/manufacturers to find out the best DRA for any specific application as per their requirement, and (iii) points out research gap in some application domains which will be quite helpful for future antenna researchers. In the authors' opinion, this survey may be helpful to DRA researchers as such a survey process is not available in the open literature.

KEYWORDS
antenna survey, antenna review, dielectric resonator, different applications, DRA, DR-antenna

1 | INTRODUCTION

The dielectric resonator antenna commonly known as DRA or sometime DR-antenna has brought remarkable attention around the globe in recent years. In 1939, the concept of the dielectric resonator as a high Q-factor material has come into existence by Richtmyer[1] but it was used as an effective electromagnetic radiator in 1983.[2] Since then, it has grown up rapidly because of several notable advantages like wide bandwidth, low loss, 3-dimensional design flexibility, high efficiency, and large power handling capability over the traditional antennas.[3–6] The 3-dimensional design flexibility depends on the respective fundamental shapes' controlling parameters like radius for hemispherical shape, height to radius ratio for cylindrical shape, and depth/width ratio as well as length/width ratio for rectangular shapes.[4] To fulfill different electrical and physical requirements, several other shapes shown in Figure 1, are also being used now-a-days.

Invention is very much important from a research point of view but cognitively it is incomplete without real field application. For this purpose to be well perceived, researchers always try to materialize their idea, which is well reflected in DRAs history. Though the invention of DRAs was in the early 1980s but the rapid development and application started in 2000s. As per the current trends of commercialization, the use of DRAs has been successfully analyzed and realized for numerous applications like: for different microwave bands, specific frequencies, different technologies, millimeter waves, etc. As far as the literature on review articles of DR antennas is concerned, then it is very much limited[7–11] to the best of the authors' knowledge. Mongia and Bhartia[7] have reviewed different modes and radiation characteristics of multiple DR shapes like cylindrical, ring type cylindrical, spherical, and rectangular. They have also derived respective expressions for radiation Q-factor, resonant frequencies, and fields for a cylindrical dielectric

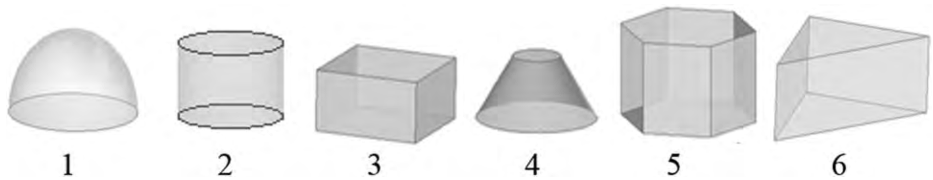

FIGURE 1 Different geometrical shapes of DR antennas. (1: Hemispherical, 2: Cylindrical, 3: Rectangular, 4: Conical, 5: Hexagonal, 6: Triangular)

resonator. Antar and Guha[8] have reviewed the new composite and hybrid DRA structures and their salient features. Moreover, they have discussed the challenges in DRA studies from the perspective of the state-of-the-art developments and technologies like micromachining and integrated with MICs. Petosa and Ittipiboon[9] have reviewed last three decades research and development in DRAs based on performance characteristics like bandwidth, compactness, circular polarization, increased directivity as well as design characteristics like reconfigurable, array, etc. Leung et al.[10] have mainly highlighted the basic characteristics of DRAs with recent developments like high gain, circular polarization, higher order mode, dual operation, transparent and decorative DRA designs in reference to some data available in open literature. Soren et al.[11] have presented a comprehensive review of the research carried out on dielectric resonator antennas (DRAs) over the last three decades in terms of broadband, ultra-wideband, and multiband.

Hence, different ways of reviewing the DRAs have been proposed[7–11] in last two decades but an application oriented survey/review has not been carried out by anyone and in authors' opinion this type of survey/review article is equally important to the antenna researchers as well as antenna designers before designing any DRA for any specific application. This has encouraged the authors to bring the novel researches carried on DRAs with the application-oriented approach in a compressed manner with a perspective of to pay honor to novel researchers as well as to show the research gap to the current innovators to meet out the same. Further, this application oriented review is providing a comprehensive details on DRAs' research in perspective of different applications based on: specific microwave frequency band (C-band, X-band, Ku-band, Ka-band, wide-band, dual-band, multi-band, etc.), specific frequency (2.4 GHz, 5.8 GHz, 60 GHz, 94 GHz, etc.), specific technology (WLAN, WiMax, Wi-Fi, Bluetooth, Mobile Device, Radar Communication, RFID, etc.), millimeter wave (different bands between 30 GHz-and-300 GHz), and several miscellaneous applications (Medical, BAN, LTE, Bean Scanning, Cognitive Radio, etc.).

This survey article is summarized as follow: Section 2 gives the introduction to DR as an antenna. Section 3 describes DRAs applications based on microwave bands followed by frequency based applications in Section 4. The technology based applications are described in Section 5 while DRAs for millimeter wave communication are discussed in Section 6. Some miscellaneous DRA applications not yet covered are highlighted in Section 7. A summary of this survey process is then highlighted in Section 8. Finally, the conclusion followed by references is discussed in Section 9.

2 | DIELECTRIC RESONATOR AND ANTENNA

The gradual development of modern communication systems from microwave-to-millimeter wave had given a chance to Long et al.[2] to investigate dielectric resonator (DR) as a radiator, as a better solution to avoid unnecessary radiation loss, conduction loss, and lower efficiency of conventional microstrip/waveguide antennas at higher frequencies. In course of time, the applications of DRs are not limited to only millimeter but are widely used in microwave and radio frequency ranges also now-a-days. This is because of its several attractive physical characteristics, like 3D-design flexibility, variable Q-factor, light weight, low cost, ease of excitation, etc., as well as several improved performances in terms of bandwidth, gain, etc., as discussed in the previous section.

Initially, the dielectric resonator was invented in the form of a high Q-factor element specifically used for filters and oscillators.[1] Because of the high Q-factor, the amount of energy stored was much more than the amount of energy lost, which made it to be used as an energy storage device. Once the Q-factor is low, the working is vice versa, that is, the energy radiated is much higher than the energy stored.[1] As per Long et al.,[2] when a DR (of low Q-factor) is placed on a metallic ground surface with unshielded surroundings and an excitation is applied to it, then the discontinuity of the relative permittivity at the resonator surfaces plays an important role. It enables the radio waves bounce back and forth in between the resonator boundary and called as standing electromagnetic wave, means it resonates as well as create chances of reflection but cannot radiate. It is well known that the resonator walls happen to be transparent to radio waves. Once, the resonator is excited at proper resonating mode, the radio waves start penetrating the resonator boundary and radiate into space. The desired resonating mode can be achieved by proper positioning of dielectric resonator, ground plane, feed, and slot. Moreover, the field distribution inside the resonator as well as the radiation pattern in the space, are distinct depending upon the resonating mode at which the resonator is excited. These modes are mainly divided into three different modes, like transverse electric (TE), transverse magnetic (TM), and hybrid electromagnetic (HEM) modes.[3,4] Generally, for rectangular DRAs, the fundamental modes are considered to be TE^{x}_{111}, TE^{y}_{111}, and TE^{z}_{111}, respectively. For hemispherical DRAs, these are considered as TE_{111} and TM_{101}. Similarly, for cylindrical DRAs, these modes are considered as TE_{01}, TM_{01}, and HE_{11}/EH_{11}.[3,4]

The DRA usually offers better performances as well as geometrical flexibility than conventional patch/waveguide antennas. As per Refs. 3 and 4, the concrete reasons are as follows: (i) microstrip antenna radiates through narrow slot (s) or two-dimensional surface while the DR-antenna radiates through whole three-dimensional surfaces which lead to wider bandwidth. Recently this is further deeply analyzed and proved by Guha and Kumar[12] with different types of feeding mechanism, (ii) with the proper choice of low loss dielectric material radiation efficiency can be improved (>95%) due to the absence of surface waves, (iii) the threat of conduction loss is negligible as the DRA is made up of dielectric material and null presence of perfect conducting material, (iv) wide range of permittivity (ε_r = 2-100) and comparatively more controlling parameters (as described in Section 1) as 3-dimensional geometry control the operation range, and (v) several feeding mechanism (coaxial probes, microstrip lines, slots, dielectric image guides, and coplanar waveguide lines) can be used for excitation. These unique characteristics have supported DR to be a better alternative in modern wireless communication systems. The researchers have been working on improving the performance of DR-antennas in terms of bandwidth enhancement,[13–15] gain improvement,[16–18] circular polarization,[19,20] directivity improvement,[21,22] mutual coupling reduction,[23,24] mode explorations,[25,26] etc. This article is, however, proposed for surveying of DR-antennas for the application-oriented research.

3 | DRAS APPLICATIONS BASED ON MICROWAVE BANDS

Microwave engineering is considered to be one of the matured disciplines in the technical world which took birth around 50 years back.[27] The development of microwave was totally application oriented, that is, for the use of radar during the World War II. The electromagnetic spectrum is a certain range of frequency which is licensed to some operators for technical applications and a small section of this spectrum is known as a band. As per the openly available literature, the DRAs have been utilized to cover different microwave bands for specific applications. Apart from allocated IEEE standard bands, there are some other bands like UWB, wide-band, dual-band, and triple-band which are also discussed in this section in the context of DRA applications. These bands are described in Table 1.

TABLE 1 Microwave bands covered by DRAs

Sl. No.	Band	Ref.	Sl. No.	Band	Ref.
1.	C	28,29	5.	W	40,41
2.	X	30–34	6.	UWB	42–50
3.	Ku	35–38	7.	Wide-band	51–71
4.	Ka	39	8.	Dual-/multi-band	72–83

3.1 | C band and X band

Kumar and Gupta[28] have used the air-gap slot for bandwidth enhancement up to 31% with 7.2 dB gain in a compact rectangular shaped DR-antenna for C-band communication purpose. A dual-band DRA with 4% and 6% impedance bandwidth, respectively for C-band and X-band applications is then followed by Batra et al.[29] Chair et al.[30] have designed a microstrip fed dual-polarized two stepped stair-shaped DR-antenna for X-band applications. A broad-band hybrid DRA covering X-band has been reported by Coulibaly et al.[31] Like this, for X-band application, a stepped patch fed low profile DRA centered at 10.16 GHz,[32] nine element DR-antenna array covering X-band between 6.3 GHz-and-11.2 GHz[33] and three elements dual-segment wide-band triangular DRA for X-band[34] have been testified respectively.

3.2 | Ku-band, Ka-band, and W-band

Guraliuc et al.[35,36] have proposed a less complex layout for tuning of a DRA[35] and slot-coupled rectangular DRA operating for Ku-band,[36] respectively. After this, dual-band DR-antenna centered at 13 and 10.55 GHz with linear and circular polarization,[37] right hand circularly polarized (17.24% AR bandwidth) centered at 13 GHz wideband DR-antenna[38] have been developed. A parasitic DR-antenna with pyramidal horn excitation operating at 38 GHz has been developed by Othman et al.[39] followed by a CPW fed hybrid DRA operating between 93.7 GHz-and-110 GHz by Haraz et al.[40] applicable for W-band communication. Rahman et al.[41] have characterized an aperture coupled DRA for W-band applications.

3.3 *UWB*

Ge and Esselle[42] have developed a coaxial-probe-fed DRA for UWB range (3.1 GHz-to-10.7 GHz) applications, followed by a compact DRA structure for UWB applications like digital video broadcasting-handheld (DVB-H) and GSM by Huitema et al.[43] A hybrid monopole-fed DRA for 1.5 GHz-to-12 GHz operation,[44] and monopole-like radiation DR-antenna covering 1.9 GHz-to-9.5 GHz and rejecting 5.15 GHz-to-5.825 GHz have been reported by Jazi and Denidni.[45] Hemachandra et al.[46] have discussed UWB (6.32 GHz-to-24.865 GHz) range covering rectangular hybrid DRA. Like this; L-shaped parasitic strip and printed monopole excited DR-antenna covering UWB band with WLAN (5.8 GHz) rejection has been proposed in Ref. 47. Elmegri et al.[48] have designed a small DRA with T-shaped feeding network operating between 3.1 GHz-and-5.5 GHz.[48] A compact UWB DRA for 23% BW between 9.97 GHz-and-12.558 GHz with band notch centered at 10.57 GHz has also been designed.[49] Abedian et al.[50] have proposed a novel UWB U-shaped microstrip feed line excited DRA with more than 122% impedance bandwidth with avoiding interference problem for 3.22 GHz-to-4.06 GHz (WiMAX) and 4.84 GHz-to-5.96 GHz (WLAN) bands.

3.4 | Wide band

A stepped rectangular DR-antenna for 61.5% bandwidth has been modeled by Pliakostathis and Mirshekar-Syahkal.[51] Like this, stacked elliptical shaped DR-antenna for the improved bandwidth of 61.5% by Sharkawy et al.,[52] microstrip-fed cylindrical DRA impedance bandwidth of 26% by Bijumon et al.[53] have been reported in open literature. Huang and Kishk[54] have designed multi-layered coaxial-probe-fed DRA for 66% BW wide-band applications followed by more than 48% impedance bandwidth in a pyramidal shaped DR-antenna by Almpanis et al.[55] A coplanar waveguide (CPW) fed three sides metal coated rectangular DRA for broadband application with 47% impedance bandwidth has been modeled by Chang and Kiang.[56] Huang et al.[57] have developed aperture coupled DRA with fork-like feed-line to obtain 10.6% impedance bandwidth for broadband applications. Apart from this, H-shaped DRA operating between 3.61 GHz-and-6.85 GHz for wideband applications,[58] U-slot fed hybrid DRA for 30% bandwidth covering the 5.2 GHz/5.8 GHz wireless application,[59] slot coupled DR-antenna covering 2.63 GHz-to-5.86 GHz for wideband applications[60] and super shaped DR based on plastic material for wideband application with broadside radiation pattern,[61] have been developed.

A co-axial fed half-split multilayer stacked cylindrical DR-antenna with 60% impedance bandwidth for wideband applications (C-band applications) and low-profile multi-frequency band DRA with 135.7% bandwidth for broadband mobile wireless applications like DCS, UMTS, PCS, Bluetooth, and IEEE 802.11a/b/g wireless standards has been discussed in Refs. 62 and [63], respectively. A microstrip-fed circularly polarized DRA for wireless applications has been developed by Hedi et al.[64] An inverted trapezoidal patch excited compact T-shaped DRA for broadband applications like; OFDM-UWB systems between 3.81 GHz-and-8.39 GHz, that is, 75.1% BW has been reported by Gao et al.[65] However, Chaudhary et al.[66] have characterized ($Zr_{0.8}Sn_{0.2}$) TiO_4–epoxy composite in a rectangular DRA for wideband applications ranging between 6.0 GHz-and-11.5 GHz. The stacking concept has been applied by Ge et al.[67] to form a compact DRA for broadband applications covering 3.1 GHz-to-10.6 GHz FCC band. After this, again Chaudhary et al.[68] have developed a two layered half-split cylinder shaped DRA in an embedded form operating in 5.55 GHz-to-12.08 GHz range for wideband applications. Mukherjee et al.[69] have investigated a hemispherical (cup shaped) DRA for wideband application over 83% bandwidth centered at 2.3 GHz. Panigrahi et al.,[70] have removed the central portion of a DRA and used U-shaped feeding mechanism for covering 46.7% wideband, that is, 3.9 GHz-to-6.20 GHz. A PBG loaded DRA has been modeled by Mukherjee et al.[71] for 38% wide bandwidth applications resonating at 1.78 GHz.

3.5 | Dual-band/multi-band

The antenna operating in dual-band is quite an important radiator in application point of view. The literature based on dual-band applications have been discussed here. Two ring slots have been actualized on the ground plane (one of them is fed by a gap source) to excite a DRA for dual band realization.[72] After this a dual band has been obtained by Deng et al.[73] in a rectangular shaped DRA while the slot was kept in the middle between the edge and the center of the resonator. Wang et al.[74] have discussed a dual-band dielectric resonator antenna that can be applicable to 2.4 and 5.2 GHz WLAN applications. Ding et al.[75] have placed an L-shaped feed inside the cavity to produce dual-band WLAN systems, followed by a high Q-factor microstrip-fed rectangular cavity based dielectric resonator antenna for dual function applications by Hady et al.,[76] and a CPW fed dielectric resonator antenna by Omar et al.[77] for dual band applications. However, a slot and DR-integration antenna has been investigated for covering 4.5% and 5.5% bandwidth with 7.1 dBi and 6.3 dBi gain, respectively by Batra and Sharma.[78] Leung et al.[79] have investigated an omnidirectional (both linearly polarized and circularly polarized) rectangular glass DRA with a LED for both antenna as well as light source, while in Ref. 80 again they have discussed another dual band hemispherical glass DRA for WLAN and WiMAX applications as well as a

TABLE 2 Different DRA shapes with coupling techniques used for microwave band based applications

DRA shape	Coupling used	Ref.
Cylindrical DRA	Microstrip feed with rectangular/circular/elliptical slot, aperture feed, Printed/probe monopole, CPW feed with slot, hexagonal patch with elliptic slot, Co-axial probe.	14,37,38,40,41,45,49,53,54,57,60,63,76,83
Rectangular DRA	Parallel-slot, single-slot with microstrip feed, aperture coupled, Slot with CPW, straight probe, L-probe, Monopole and F shaped/T-shaped microstrip feed.	28,29,31–33,35,36,39,42,46,48,50,51,56,66,67,73,75,77–79,81.
Hemispherical DRA	Probe feed with EBG and microstrip feed with slot.	71,80
Conical DRA	Monopole/Microstrip feed with inclined slot	44,64
Super shaped/L or H or T Shape/ Pyramid shaped DRA	Co-axial probe, microstrip feed, trapezoidal patch/ inverted trapezoidal patch.	43,47,55,58,61,65,68,74.
Triangular/Modified Triangular DRA	Probe, inverted trapezoidal patch	34,82
Stacked Elliptical DRA	Co-axial probe	52

light source. Bala et al.[81] have developed a metamaterial based dielectric resonator antenna resonating at 5.5 GHz and 5.8 GHz with 6.24 dBi and 6.04 dBi gain and applicable for WiMAX and WLAN applications, followed by a Sierpinski fractal structure DRA by Liu et al.[82] for covering WLAN (2.4 GHz-to-2.484 GHz) and WiMAX (3.4 GHz-to-3.69 GHz) bands. For the purpose of triple band applications, Chaudhary et al.[83] have proposed some novel structures like; triple band cylindrical shaped DR-antenna resonating at 4.93, 6.46, and 7.41 GHz.

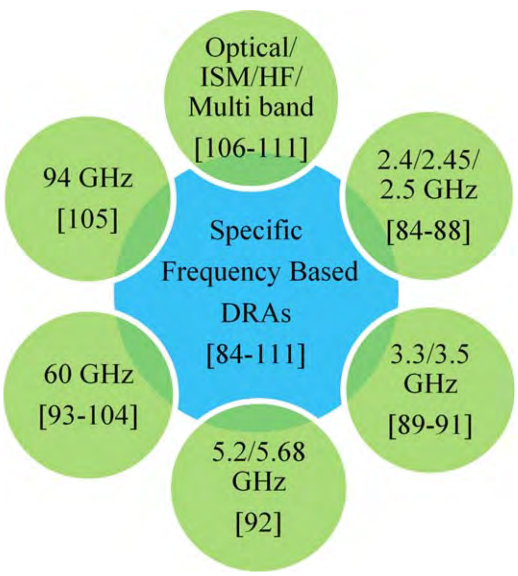

FIGURE 2 Application oriented frequencies covered by DRAs

The DRA geometrical survey with different coupling techniques used for different applications based on microwave bands has been carried out in this section and this is summarized in Table 2.

4 | SPECIFIC FREQUENCY BASED APPLICATIONS

Electromagnetic radiator or antenna is all about frequency and the operation of an antenna in any frequency range totally depends on upon its geometrical modeling. For the dedicated wireless system, it becomes necessary to design an antenna only for a specific frequency rather than a range of frequency. The objective of this section is to highlight research carried out on DRAs only for a specific frequency.[84–111] All the specific frequency based articles are arranged here in a chronological manner. A compressive overview of these specific frequencies covered by DRAs is illustrated in Figure 2, whereas the detail is further illustrated in this section.

4.1 | 2 GHz-to-6 GHz

In 2006, Wang et al.[84] have revealed a miniaturized broadband DR-antenna for 2.4 GHz application. Kumar et al.[85] have designed microstrip-fed half-CDRA for 2.4 GHz WLAN (2.4 GHz-to-2.484 GHz) with a peak gain of 3.6 dBi, followed by metal plate above a DR-antenna for significant reduction of resonant frequency at 2.4 GHz by Makwana and Vinoy.[86] Baba et al.[87] have proposed a dielectric image line excited cylindrical shaped DR-antenna for operating at 2.45 GHz, followed by a microstrip fed high dielectric constant barium titanate ($BaTiO_3$) made DR-antenna by Ain et al.[88] to resonate at 2.5 GHz. A $BiYWO_6$ based compact shaped cylindrical DRA has been utilized by Rocha et al.[89] for 3.3 GHz practical applications. Ain et al.[90] have developed microstrip line fed rectangular DRA operating at 3.5 GHz. After that, a hybrid feeding technique based DRA has been explored operating for 3.5 GHz LTE base station covering 3.35 GHz-to-3.85 GHz by Zhang et al.[91] Abumazwed and Sebak[92] have used a U-shaped slot feeding network for a compact DRA covering WLAN (5.2 GHz/5.8 GHz) with 39% impedance bandwidth.

4.2 | At 60 GHz and 94 GHz

Oh et al.[93] have introduced micromachining technology CPW-fed DR-antenna for broadband characteristics between 54 GHz-and-71.5 GHz with 3.6 dBi gain at 60 GHz. Then, a half-mode substrate integrated waveguide (HMSIW) feeding mechanism has been used by Lai et al.[94] for a DRA having 24.2% impedance bandwidth operating at 60 GHz with a 3 dB axial ratio bandwidth of 4.0%. After that, higher-order modes of a rectangular DRA have been used for the enhancement of gain at 60 GHz by Petosa and Thirakoune.[95] In 2011 Guzman et al.[96] have developed a DR-antenna of 6.4 GHz bandwidth and 5.4 dBi gain and can be applicable for 60 GHz integrated systems. Chorfi et al.[97] have developed cylindrical DR-antenna mounted on a conformal ground plane operating at 60 GHz with 7.9% impedance bandwidth and 5.4 dBi gain. The use of silicon integrated DRA as a trans-receiver at 60 GHz has been reported by Guzman et al.[98] Again Guzman et al.[99] have modeled a chip integrated slot coupled DRA for front end solution at 60 GHz. A power amplifier excited DRA (known as System-in-package) has been modeled by Muhammad et al.[100] for high data rate transfer at 60 GHz.

After this an on-chip $Ca_5Nb_2TiO_{12}$ rectangular shaped DR-antenna for 60 GHz radio wireless applications by Freundorfer et al.[101] Then Wang et al. have reported a new DR-antenna passive repeater end fire 6 × 6 array at 60 GHz with end-fire radiation characteristics and notch characteristic in Refs. 102 and [103], respectively. The Ferro A6-M material has been utilized by Jimenez et al.[104] for designing of a rectangular DR-antenna for 60 GHz application. Saleem et al.[105] have developed a sensor based on cylindrical DRA for 94 GHz detection with 40% radiation efficiency.

4.3 | Optical/ISM/HF/multi-frequency

A transparent conformal strip-fed dual function DRA made of Borosilicate Crown glass (Pyrex) has been proposed for optical applications by Lim et al.[106] Zou et al.[107] have modeled a highly efficient (around 80%) and scalability metal-backed DR-antennas for optical applications. Morsy and Gorla[108] have proposed a novel miniaturized design covering 34% impedance bandwidth resonating at 2.45 GHz and can be useful for ISM applications.

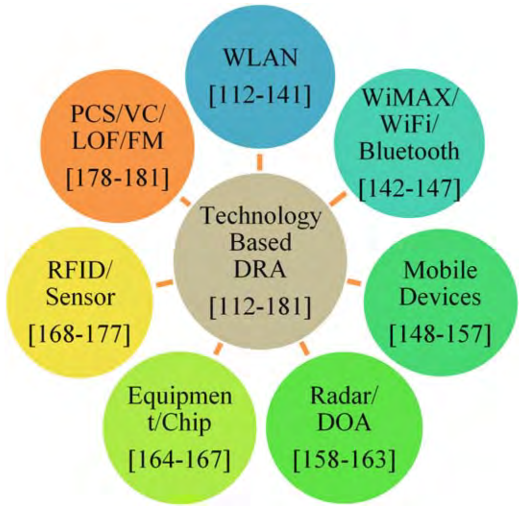

FIGURE 3 Application dedicated systems covered by DRAs

The requirement of multi-band and multi-frequency operated DRAs is also equally important for modern wireless communication systems. But unfortunately, the literature on this is very much limited.[109–111] The multi-eccentric ring slot coupled DRA has been proposed by Denidni et al.[109] for multi-frequency application. Hamsakutty et al.[110] have designed a probe be fed hexagonal DRA for resonating at 1.92, 2.57, and 3.25 GHz, simultaneously. A printed fork-like stepped monopole antenna has been used for exciting two new modified hemicylindrical type dielectric resonator for 1.54 GHz-3.25 GHz, 3.3 GHz-3.6 GHz, 3.8 GHz-4.4 GHz, and 4.8 GHz-6.2 GHz by Khalily et al.[111]

5 | TECHNOLOGY BASED APPLICATIONS

Today's rapidly developing world is mainly based on technology. Starting from day-to-day commercial life to several defense/military applications, everything is pillared upon technology. For the ease of communication, different wireless master devices have come up in the market with improved characteristics dedicated to specific client devices. For the media of electromagnetic radiation, DRA has been proposed and perceived as an effective radiator for different master/client devices like Hiper LAN, WLAN, Wi-Fi, WiMAX, mobile devices, etc., which are being sequentially discussed in this section.[112–181] An inclusive compressed sketch of DRA devices for modern communication technologies is shown in Figure 3.

5.1 | WLAN

WLAN is quite prominent for linking between two or more devices by adopting wireless distribution method. With respect to the articles referenced here, the use of DRA for this purpose is fairly interesting. For the purpose of a smooth and easier understanding, the articles are discussed chronologically. In 2002, a high permittivity DRA loaded with narrow conducting strips for broadband circularly DRA has been proposed by Hsiao et al.[112] for WLAN applications. Cormos et al.[113] have also modeled a new DRA with 12% impedance bandwidth for WLAN applications. A 50 Ω-microstrip line excited rectangular DRA with 21% impedance bandwidth has been designed by Mridula et al.[114] for WLAN applications at 5.45 GHz. Gao et al.[115] have used the CPW feeding mechanism for a rectangular DRA for 5.5 GHz WLAN application with 5 dBi gain and 23.3% impedance bandwidth. A 5 GHz-to-6 GHz WLAN DRA with 20% impedance bandwidth has been reported by Rashidian et al.[116] Also Alipour et al.[117] have proposed a compact DR-antenna for both WLAN and HIPERLAN (High-Performance Radio LAN) within reasonable gain and bandwidth, followed by two segments rectangular DRA[118] with 19% and 17.5% impedance bandwidth to WLAN system specification. Kumar et al.,[119] have discussed a compact half-cylindrical type 2.4 GHz WLAN dielectric resonator antenna.

Different shapes of DR-antennas like; hexagonal shape with 5.4 dB gain at 2.4 GHz,[120] a novel integrated hybrid DR-antenna structure for System-in-Package (SiP) application has been developed for WLAN (5 GHz) with 20.4% impedance bandwidth and 6 dBi gain,[121] cylindrical Barium Strontium Titanate (BST) at 5.0 GHz,[122] have been made for WLAN applications. After this, a small shaped high permittivity rectangular DRA for 5 GHz WLAN and circularly polarized cylindrical DRA for DPS L1 excited at 1.575 GHz and for WLAN excited around 2.45 GHz has been reported in Refs. 123 and [124], respectively. Mahender et al.[125] have then reported an inverted U-shaped DR-antenna covering 5.10 GHz-to-5.97 GHz for WLAN, followed by a stacked triangular DRA for enhanced bandwidth covering 4.0 GHz-to-6.02 GHz with 6.36-to-7.98 dBi gain for WLAN applications by Kumari et al.[126] A Barium Strontium Titanate-COC composite rectangular DR-antenna with 2 dB gain for 2.4 GHz WLAN wrist application has been proposed by Palukuru et al.[127]

After this, Wang et al.[128] have developed a dual-feed dual-polarized mechanism in a DRA for 5.2 GHz WLAN applications with F/B ratio of 10 and 18 dB for port-1 and port-2, respectively. A triple-band DRA with three segments thin dielectric resonating at 2.4, 3.5, and 5.8 GHz for WLAN and WiMAX applications has been reported by Bemani et al.[129] An M-shaped conformal patch fed DRA has been modeled by Parmar et al.[120] for WLAN 5.15 GHz-to-5.3 GHz and high-performance radio LAN followed by a compact size isosceles trapezoidal shaped DRA with 7.22 dBi gain broadband radiation pattern for 2.4 GHz WLAN applications by Gopakumar and Mathew.[131] The use of hybrid type triangular shaped DR-antenna covering 2.3445 GHz-to-2.9709 GHz with 6.12 dB gain for WLAN purpose and co-planar waveguide inductive slot fed DRA for 5.8 GHz WLAN have been noticed in Refs. 132 and [133], respectively. However, high aspect ratio two segment DRA for 5.8 GHz WLAN applications,[134] stacked CDRA fed by coplanar waveguide for covering entire WLAN bands, that is, 4.96 GHz-to-6.07 GHz,[135] hybrid-high permittivity DR-antenna for 2.4 GHz/5.2 GHz/5.8GHz of WLAN and 2.5 GHz/3.5 GHz/5.5 GHz of WiMAX[136] have been observed during this survey process. A low profile rectangular DRA dedicated to WLAN operating between 4.86 GHz-and-5.40 GHz has been proposed by Zhang et al.,[137] followed by a quarter volume DRA (QVCDRA) with reconfigurable type radiation pattern with three port operating between 4.75 GHz-and-5.54 GHz for WLAN by Liu *et al*.[138] and a coaxial probe fed rectangular asymmetric DRA covering 5.2, 5.5, and 5.8 GHz WLAN/WiMAX by Kumar and Gupta.[139] Dhara et al.[140] have discussed a CPW fed inductive slot coupled DR-antenna covering IEEE 802.11a, Hiper LAN and UNII bands with realized gain of 5.5 dBi over entire band. Recently in 2016, Sharma et al.[141]have proposed a MIMO DRA for LTE2500/WLAN/WiMax applications. Different DRAs for respective WLAN operation ranges are listed in Table 3.

TABLE 3 DRAs dedicated for WLAN applications

Operating Range	Ref.
2-3 GHz	119,120,124,127,129,131,132,136
3-4 GHz	129
4-5 GHz	126
5-6 GHz	112–118,121–123,125,126,128–130,133–141

5.2 | WiMAX/Wi-Fi/bluetooth

WiMAX is quite similar to Wi-Fi and commonly used for 30-40 Mbps data transmission for various purposes as an alternative to cable and DSL. The DRAs specifically dedicated to both WLAN and WiMAX have already been discussed in the previous section. The DRAs mainly designed for WiMAX/Wi-Fi/Bluetooth communication purpose are discussed here. Chang et al.[142] have developed a sectorial beam DR-antenna with bent ground plane covering 3.4 GHz-to-3.7 GHz WiMAX band. A 5.4% impedance bandwidth low profile high permittivity DRA for WiMAX application

TABLE 4 DRAs dedicated for mobile device applications

Key features	Dedicated applications	Ref.
180 circular sector DRA + 2 PMC wall	GSM900, that is, 890 −915.8 MHz	148
BW enhancement and Size reduction	IMT-2000 handset	149
Small size broadband	Mobile communication band	150
SAR value increased to 2 W/kg over 10 g of tissue as per IEEE	UMTS (1920-2170 MHz)	151
Quarter wavelength resonant mode excited	GSM and DCS/PCS/UMTS operations	152
Compact aperture coupled DRA	Portable communication applications	153
Behave like a monopole	Wi-Fi + WiMAX + DVB-H band (790 −862 MHz)	154
Slot coupled DRA	For DVB-H/GSM850/900 (470-960 MHz band) and for DCS/PCS	155
Human torso mounted annular CDRA	3.7% BW at 2.45 GHz and 52.6% efficiency	156
Dual resonant DRA	Mobile phone applications	157

has been designed by Chen et al.[143] Gangwar et al.[144] have designed a fractal rectangular shaped curve DRA for WiMAX,[144] followed by a 3.5 GHz operating mushroom shaped DRA for WiMAX by Kumari and Behera.[145] Ricci et al.[146] have proposed an innovative conformal DR-antenna for Wi-Fi application purpose. Moon and Park[147] have used advance meander line technique to design a small size ceramic DRA covering 2.4 GHz-to-2.48 GHz and can be applicable for Bluetooth applications.

5.3 | Mobile devices

Mobile devices have been so popular from the day of their invention and also getting updated by each passing days. The antenna is the utmost priority in mobile devices from communication/electromagnetic transmission point of view. DRA has also participated in that race and done so smooth, notable contribution to this technically interesting area with an evidence of 10 articles[148–157] referenced here and shown in Table 4.

Asgary et al.[148] have modeled an 180 circular sector DRA by deriving TE- and TM-mode using approximate theory 2 PMC walls for telephone handset of GSM900, that is, 890 MHz-to-915.8 MHz (VSWR < 2.5) system with reduced radiation toward head area. Kim et al.[149] have used bandwidth enhancement, size reduction, and resonant frequency tuning technique, to develop two geometries of about 2 dBi gain and Omni-directional radiation pattern for IMT-2000 mobile handsets. Pliakostathis et al.[150] have introduced a small size broadband coaxial probe fed new DRA for mobile communication band. Zainud-Deen et al.[151] have developed a DR-antenna where the SAR value increased from 1.6 W/kg averaged over any 1 g of tissue to 2 W/kg over any 10 g of tissue by the new IEEE standard for safety levels with respect to human exposure to radio-frequency radiation. Lin et al.[152] have designed a DRA where feeding couple excites the quarter-wavelength resonant modes at about 925, 1762, and 1953 MHz covering GSM and DCS/PCS/UMTS operations, respectively. An aperture coupled differentially fed DR-antenna has been modeled by Ee et al.[153] as an attractive and potential alternative radiator in portable communication applications. Huitema et al.[154] have developed a monopole behaving DRA covering the Wi-Fi and WiMAX bands for mobile handheld devices. Guo et al.[155] have reported a slot coupled DRA for achieving 470-960 MHz band for DVB-H/GSM850/900 operation and 1710-1990 MHz band for DCS/PCS operation. Chandran et al.[156] have designed human torso mounted annular CDRA (wearable antenna) covering 3.7% impedance bandwidth centered at 2.45 GHz, with the on-body efficiency of 52.6%. Kivekas et al.[157] have reported a dual-resonant DRA for mobile phone applications.

5.4 | Radar/DOA

Detection of object details, that is, velocity, angle, and range by using radio waves is commonly known as radio detection and ranging (RADAR) which is used for military and civil aviation purposes. As per the data available in the open

TABLE 5 DRAs dedicated for RFID/sensor applications

DRA shape	Dedicated sensing for	Ref.
Inverted F-shaped DRA	255 and 835 MHz	168
RDRA	160 MHz (2.37-2.53 GHz)	169
DRR/Hollow Cylinder	2.45 and 5.8 GHz	170
Half Cylindrical	European UHF, 857-885 MHz	171
L-Shaped DRA	2.4 and 5.8 GHz for HIS	172
Hollow cylindrical DRA	Covering 4 −15 GHz for EMI Sensor	173
Cylindrical DRA	Harmonic control in Ku band at 14.25 GHz.	174
Half cylindrical and Half conical	Ultra-wide (2-18 GHz) spectrum sensing	175
Half split cylindrical	Chip-less tag based DRA temperature sensor (20°C-370°C) at 3 GHz	176
($Zr_{0.8}Sn_{0.2}TiO_4$, ZST) made cylindrical DRA	Temp. sensing upto 700°C at 2.37 GHz	177

literature,[158–163] DR-antenna has much impact and role in this field which is being discussed in this section.

A waveguide slot-fed DRA has been analyzed by Eshrah et al.[158] for radar applications. A harmonic radar system with temperature detection accuracy of 0.5°K for distances up to 2 m and a maximum reading range of 3.75 m has been achieved in the scenario working at 22°C and 91°C by Bernd Kubina et al.[159] DOA (Direction of arrival) receiver using rectangular DRAs as receiving elements at 2.37 GHz has been developed by Wu et al.[160] The sum/difference hybrid ring design configuration for exciting $HEM_{11\delta}$ mode at 2.3 GHz has been developed by Hady et al.[161] For target tracking and mechanical direction finding, cylindrical DR-antenna has been designed by Salman et al.[162] Zakariya et al.[163] have done an experimental study on a microstrip fed cylindrical DRA at 5.8 GHz for improving radiation pattern, tuning frequencies, gain, and impedance bandwidth.

5.5 | Equipment/chip

Lambrecht et al.[164] have intentionally demonstrated a simple DRA as well as dual-polarized arrays to have more information for using as a base station radiator. Bijumon et al.[165] have designed two novel integrated DRA designs suitable for millimeter wave on-chip applications with 0.96 dB gain, 28.16% radiation efficiency and 3.2 dB gain, 54% radiation efficiency. A novel integrated DRA on high conducting silicon substrate has been designed for 1 dBi gain and 45% radiation efficiency with 2725 MHz impedance bandwidth at 27.78 GHz by Bijumon et al.[166] Nezhad-Ahmadi et al.[167] have modeled a high radiation efficiency on-chip antenna with 1 dBi gain at 35 GHz and bandwidth of 4.15 GHz (12%).

5.6 | RFID/sensor

The use of DRA for RFID as well as a sensing device or sensor is quite effective as per the articles referenced.[168–177] The dedicated applications are further highlighted in Table 5.

Tseng et al.[168] have developed an inverted F-shaped DRA for applicable in RFID in 255 MHz (2.300 GHz-to-2.555 GHz) and 835 MHz (5.595 MHz-to-6.430 MHz), followed by a rectangular DRA for RFID application covering 160 MHz (2.37 GHz-to-2.53 GHz) by Thamae et al.[169] and curved type dual-band DR-antenna covering 2.45 GHz and 5.8 GHz by Zauind-Deen et al.[170] After this, a high permittivity DR-antenna has been modeled by Raggad et al.[171] for covering European UHF RFID applications working between 857 MHz-and-885 MHz. Makwana and Ghodgaonkar[172] have placed a patch on DRA to resonate at 2.4 GHz and 5.8 GHz for RFID tag human identification system (HIS) in a wrist watch. Ghosh et al.[173] have designed a DRA loaded T-shaped monopole antenna with a bandwidth of 110% variation of antenna factor from 38 to 46 dB/m within frequency range 4 GHz-to-15 GHz using as an EMI sensor. The harmonic control technique for the DR in Ku band at 14.25 GHz has been defined by Lucci et al.[174] Niroo-Jazi et al.[175] have developed an ultra-wide (2 GHz-to-18 GHz) spectrum sensing DRA. Kubina et al.[176] have presented a chip-less tag based DRA for the wireless high-temperature sensor (20°C-to-370°C) with resonance frequency near 3 GHz with a temperature sensitivity of 307 KHz/°K. Boccard *et al*.[177] have developed a temperature sensor up to 700°C using DRA operating at 2.37 GHz and composed of zirconium tin titanate ($Zr_{0.8}Sn_{0.2}TiO_4$, ZST).

TABLE 6 DRAs for mm-wave applications

DRA shape	Coupling type	Ref.
CDRA	Microstrip feed/CPW feed	183,185,186,198,199
CDRA + Superstrate	Microstrip feed	192,195
CDRA + EBG	Microstrip feed	200,202
Hollow CDRA	Microstrip feed + Patch	189
RDRA	Microstrip feed/SIW/CPW	188,190,191,193, 196,197,213
Stack RDRA	CPW feed	194
T-Shape DRA	E-shape slot	187
Cup shape DRA	Microstrip feed	201
SI-DRA	SIW feed	203–205

5.7 | PCS/VC/LOF/FM

DRAs have also been developed at CRC for different operating band between 1 GHz-to-40 GHz for PCS applications by Cuhaci et al.[178] Leung et al.[179] have modeled dual purpose glass DRA for operating as a wireless video system at 2.4 GHz as well as a lighting lamp. Lee et al.[180] have studied a small DRA using aperture coupling. Abbasi and Langley,[181] have introduced a coaxial probe fed high permittivity ($\varepsilon_r = 194$) DR-antenna placed over a metal ground plane/AMC for FM range applications (88 MHz-to-108 MHz) resonating at 96.5 MHz.

6 | DRAs FOR MILLIMETER-WAVE COMMUNICATION

The word millimeter-wave is nothing but millimeter-wave length which defines a region in the electromagnetic spectrum that falls within the range of wavelengths from 10 to 1 mm (0.4-0.04 inches). This is longer than infrared waves but shorter than microwaves (radio waves). Sometimes, it is also known as EHF as it ranges in between 30 GHz-and-300 GHz.[182] The literature shows many successful implementations of DRAs for millimeter wave communication. As the DRA is an effective radiator in high frequency because of low loss, it has drawn keen attention to the researchers working in this specific area. The collected literature[183–205] is sequentially discussed in this section and the overall summary of this section is illustrated in Table 6. However, as per volume of articles, these are differentiated as work done prior to 2010 as well as 2010 onward.

6.1 | Prior to 2010

Several authors have reported several novel structures for the application of millimeter wave bands. Kranenburg and Long[183] have designed a microstrip fed CDRA operating in millimeter wave band while a multi-pole gap-coupled low cost. A low loss DRA for the millimeter-wave band at 38 GHz have been investigated by Lee and Lee.[184] Sakuma et al.[185] have reported the analysis and measurement of CPW fed cylindrical shaped DRA in millimeter wave bands resonating at 31.18 GHz. Like this; on-ship high gain cylindrical DRA on a conducting type silicon operating at 59.96 GHz[186] and E-shaped slot coupled DRA covering 41.1 GHz-to-49.5 GHz with 5.8 dBi-to-6.6 dBi gain[187] have been developed for millimeter wave frequency applications. Again, a slot coupled low permittivity DRA with enhanced bandwidth performing between 57 GHz-to-65 GHz,[188] high-gain and low-cost hybrid ring-shaped DRA covering 57 GHz-to-65 GHz band[189] and planar waveguide with integrated waveguide (SIW) technology fed low profile rectangular DRA[190] have been developed for millimeter wave frequency applications.

6.2 | 2010 onward

Compact and low-cost SIW-DRA with more than 95% radiation efficiency[191] and hybrid high gain DRA with superstrate for obtaining better than 11 dB gain over the ISM frequency bandwidth (57 GHz-to-65 GHz)[192] have been designed for millimeter wave communication. Polymer-based DR-antenna with 3.5 times more bandwidth than ceramic antenna[193] and stacked DRA fed by CPW targeting ISM band with 24% impedance bandwidth at 62.16 GHz[194] have been developed for millimeter wave applications, respectively. A microstrip-fed high gain hybrid DRA with a bandwidth of 12.69% centered at 59.55 GHz[195] and T-slot-stub coplanar waveguide fed DR-antenna[196] have been developed for millimeter wave applications. A CPW-fed slot miniaturized DRA,[197] on-chip DRA to operate 60 GHz band covering wireless personal network (WPAN),[198] high gain rectangular shaped DR-antenna with superstrate covering entire ISM band at 60 GHz and to recover the leaked energy due to the oxygen absorption at 60 GHz[199] have been designed for millimeter wave applications. The UC-EBG fed aperture coupled DRA[200] has been designed for millimeter applications followed by low-profile cube-shaped DRA operating at 60 GHz,[201] EBG DRA with reduced back radiation[202] and DRA for system in package millimeter wave transmitter purpose over 14% impedance bandwidth covering (56.5 GHz-to-65 GHz).[203] An SIW fed low profile DR-antenna has been used in PCB process[204] followed by substrate integrated DR-antenna using two-layer PCB applicable for millimeter-wave applications with 12% impedance BW near 35 GHz.[205]

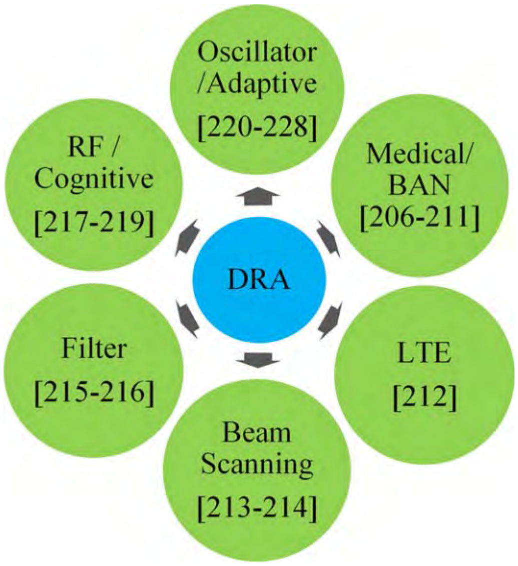

FIGURE 4 Some miscellaneous applications covered by DRAs

7 | MISCELLANEOUS APPLICATIONS

The maximum available literature have been categorized in four separate sections like; DRA for microwave band applications,[28–83] specific frequency based DRA application,[84–111] technology-based DRA application,[112–181] millimeter-wave-based DRA application,[183–205] respectively. But some articles are still not covered in these sections and felt by the authors to be discussed in a separate section from their application, novelty, and importance point of view. Therefore the literature[206–228] is being discussed in this section. An illustrative idea of these DRA utilized applications is briefed in Figure 4.

7.1 | Medical, BAN, LTE, beam scanning

A compact stair-shaped DR-antenna with quarter-wavelength choke with greater than 40% return loss centered at 6.5GHz has been demonstrated by Huang and Kishk[206] for breast cancer detection purpose. Iqbal et al.[207] have designed a small footprint DRA for biomedical communication purpose covering $S_{11} < -10$ dB 74% bandwidth ranging between 3.4 GHz-and-7.2 GHz. Almpanis et al.[208] have reported inverted truncated annular conical DR-antenna for body area network (BAN) application between 3.4 GHz-to-5.0 GHz. Mashhadi et al.[209] have designed a broadband DRA for implementation as a textile wearable antenna in BAN. A wearable textile dielectric resonator antenna for body area network has been proposed by Mashhadi et al.,[210] followed by a coaxial probe fed DR-antenna covering 74% bandwidth (4.4 GHz-to-9.7 GHz) for on-body applications by Iqbal et al.[211] A multiband DRA for operating at LTE band-VI (828 MHz-880 MHz), GSM 1800/1900 and UMTS 2100 has been designed by Khan et al.[212] Michishita et al.[213] have designed a low loss dielectric metamaterial lens antenna for wide angle beam scanning. Kamada et al.[214] have reported a DR NRI lens antenna for wide beam scanning purpose.

7.2 | Filter, RF, cognitive, oscillator, adaptive

Lim and Leung[215] have brought the concept of DRA Filter i.e. used DR as antenna and filtering device simultaneously. Kazemi et al.[216] have used new excitation scheme with $TE_{01\delta}$ mode DRs for microwave filters around 9 GHz. A wide-band DR-antenna for RF energy harvesting, ranging between 1.84 GHz-and-2.445 GHz covering GSM, UMTS, WLAN has been developed by Mrnka et al.[217] Messaoudene et al.[218] have experimented patch antenna integrated with a DR-antenna operating in the narrowband region (i.e., 5.23 GHz-to-6.11 GHz) for cognitive radio applications. Wang et al.[219] have designed UWB and NB antenna providing VSWR bandwidth for 2.4 GHz-to-12 GHz and 2.3 GHz-to-4.5 GHz, respectively, which can be applicable for cognitive radio.

A combination of microstrip-fed DR-antenna and oscillator (DRAO) at 1.85 GHz has been developed first time by Lim and Leung.[220] Again they have explained the function of a DRA as a resonator as well as an oscillator at 1.85 GHz applicable for a personal communication system (PCS).[221] Fayad and Record[222] have designed a hemispherical DRA using mixed dielectric with beam agility where the radiation direction of the antenna may be controlled by a dielectric discontinuity in the radome. Some researchers have also discussed some DRAs for wireless application purpose only and these are being discussed here. Leung and Luk[223] have reported a broadside TM_{101} mode excited aperture-coupled circular DR-antenna with 4.5 dB peak gain for low profile applications. Petosa et al.[224] have discussed some advancements like bandwidth, CP, gain, with a different coupling mechanism for wireless applications. Wu[225] has studied the

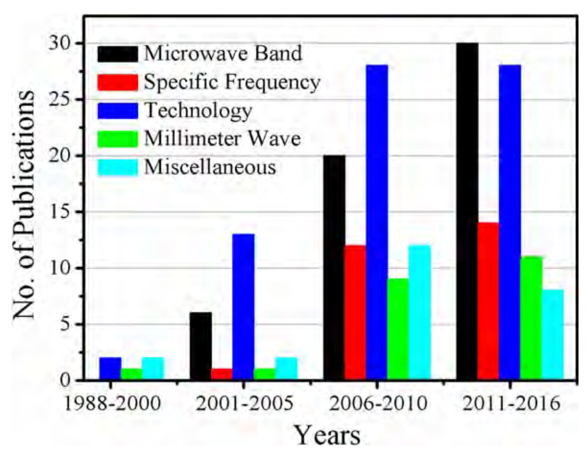

FIGURE 5 Yearly publications of application-oriented DRAs

TABLE 7 Overall organization of application oriented DRAs survey

Dielectric resonator antenna applications				
Microwave band	**Specific frequency**	**Technology**	**Millimeter wave**	**miscellaneous**
C-Band [28,29]	Particular frequency [84–105]	WLAN [112–141]	[183–205]	BAN/Medical [206–211]
		WiMAX [142–145]		
X-Band [30–34]		Wi-Fi/Bluetooth [146,147]		LTE [212]
Ku-Band [35–38]		Mobile Devices [148–157]		Beam scanning [213,214]
Ka-Band [39]	Optical & ISM[106–108]	Radar/DOA [158–163]		
W-Band [40,41]		Equipment/Chip [164,167]		Filter [215,216]
UWB [42–50]		RFID [168–172]		
Wideband [51–71]	Multiple-Frequency/ Multiple-Band[109–111]	Sensor [173–177]		RF/Cognitive [217–219]
		PCS Applications [178,179]		
Dual and Triple Band [72–83]		Low Operating Freq. [180]		Oscillator/Adaptive/ Others [220–228]
		FM Range [181]		

applications of cylindrical and rectangular DR-antenna theoretically and experimentally. Guha and Antar[226] have reported some challenges with a respective solution in novel DRA geometries for wireless communication. The directivity of patch antenna has been increased from 4.67 (6.69 dBi) to 11.94 (10.8 dBi) by placing metamaterial DR slab above the patch antenna by Kim and Gopinath.[227] Ahmed and Sebak[228] have developed a UWB (ultra-wide band) DR-antenna for short-range wireless applications.

8 | SUMMARY OF THE SURVEY

In this application oriented survey article, the literature on DRAs has been characterized into different sections covering 200+ research articles. For the ease of smooth and adept understanding, all the articles have been arranged in different sections as per their applications, respectively. For ease of summarization, the authors have figured out the number of publications of each 5 years from last three decades as described in Figure 5. It is concluded here that in the early stage of DRAs development up to 2000s, an application-oriented research on DRAs was very much limited. However, this application-oriented research has increased rapidly (∼360%) during 2001-2005.

During 2006-2010 and 2011-2016, the number of application based DRAs are nearly equal and sounds good for almost all type of applications. Further, the sequence of articles in each section/subsections is in ascending order of their year of publication. The overall survey process on DRAs for different applications is finally summarized in Table 7.

On summarizing this survey process, several observations have been made. The use of dielectric resonator antennas for specific band and frequency applications are found quite promising in all aspect. The increasing number of publications for wideband, UWB, and dual/multi-band characteristics is again proving the improved bandwidth characteristics of DR-antennas. The DR-antennas for millimeter-wave applications indirectly repeats low loss and high-efficiency characteristics. However, with little engineered DR-geometries, the gain, radiation pattern, etc., can also be improved for millimeter wave applications. But the DR-antennas dedicated for specific technology like: WLAN, Wi-Fi, Bluetooth, etc., gives the glimpse of null modification as they must have been satisfying the requisite characteristics. The outcome of this survey article may be summarized as follows: (i) highlights the novelty of DRAs in terms of different commercial and defense applications, (ii) may help the antenna industries/manufacturers to choose the right one for any specific application as per their requirement, and (iii) shows the research gap in different application domains which might be very much helpful for the future researchers.

9 | CONCLUSION

This survey article has highlighted the advancement of dielectric resonator antennas from an application point of view. The novel perspective intention of this survey work is to show a path for the betterment of modern sophisticated technical world with the proposed application oriented DRA models as well as to encourage the researchers for further miniaturization of the existing structures. This article perhaps works as a thrust for current antenna designers to find out the gap before introducing a new model.

From this surveying process, it is clear that the dielectric resonator antenna has touched several applications starting from commercial day-to-day life up to important defense needs. The data sheets outlined here give a common idea of the extreme use of DRA for microwave and technology based applications with a sufficient number of millimeter wave and specific frequency based applications. As per the current trend and status of application-oriented dielectric resonator antennas, the prediction of a wide control of modern communication systems in near future by DR-antennas cannot be ignored.

DRAs have covered the wide range of applications. It is a known fact that the satellite communication, radar communication, mobile (PCS) communication, and biomedical communication are very much demandable area of wireless communication in the 21st century. The flexibility of using DR-antennas in those dedicated key areas can be considered as the milestones in DRAs research history. In a future perspective point of view the authors' recommendations are as follows: (i) The use of flexible type of DRAs for biomedical, BAN has not yet been done so far, which could be a favorable directive for future researchers, (ii) Characterization of DRAs for demandable communication links like: satellite, radar, mobile, etc., could be further enhanced, and (iii) In view of modern compact communication devices the miniaturization of the existing ones would be much valuable.

Although the authors have tried at their level best to outline all the important and novel contribution of the DRA researchers for real field application based DRAs modeling across the globe, still the authors apologize to the researcher community if any important and novel contribution is skipped unknowingly and unintentionally during this survey process.

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