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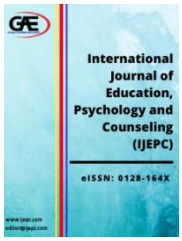

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RESEARCH TREND ON IMPROVEMENT OF DIELECTRIC RESONATOR ANTENNA: A BIBLIOMETRIC ANALYSIS

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Abstract:

Dielectric Resonator Antennas (DRAs) have components in modern wireless communication systems due to their compact size, high radiation efficiency, and frequency versatility. With escalating demands for higher data rates and spectrum efficiency, the enhancement of DRAs has garnered significant attention in antenna research. Despite the promising characteristics of DRAs, there exists a gap in providing a consolidated overview of the state-of-the-art advancements and emerging themes in DRA research. This study aims to bridge this gap by conducting a meticulous bibliometric analysis to delineate the research trends, highlight gaps, and guide future investigations. Our methodology involves a systematic search and analysis of scholarly publications related to the improvement of DRAs. We use bibliometric tools, citation analysis, and co-authorship networks to explore publication trends, influential authors, and collaborative networks within the DRA research community. By identifying emerging themes, key contributors, and collaborative networks, this study is poised to inform researchers, practitioners, and policymakers about the prevailing trends in the field. The insights gained are expected to guide future research directions, foster interdisciplinary collaboration, and contribute to the continued evolution of DRAs. In conclusion, this bibliometric analysis aims to provide a roadmap for navigating the intricate research landscape on the improvement of DRAs. The anticipated outcomes hold the potential to drive innovation, inspire collaborative initiatives, and contribute to the ongoing advancement of DRAs in the rapidly evolving realm of wireless communication systems.

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Keywords:

Antenna, Dielectric, Enhancement, Resonator

Introduction

Dielectric Resonator Antennas (DRAs) have become essential elements in the rapidly changing fields of wireless communication and electromagnetic systems, providing special benefits in terms of radiation pattern control, bandwidth efficiency, and miniaturization (Ahmad et al., 2023; I. Ali et al., 2020; Jacobsen et al., 2020; Liu et al., 2021; Nalanagula et al., 2021; Singhwal et al., 2022; Smida, 2022; Whiting et al., 2021). The continuous quest for enhancing the performance of DRAs has led to a burgeoning body of research, underscoring the significance of understanding and analysing the research trends in this domain. This bibliometric article endeavours to thoroughly examine the trajectory of research dedicated to the improvement of DRAs. The motivation behind this bibliometric analysis lies in the recognition that a comprehensive understanding of the current research landscape is essential for guiding future investigations and fostering impactful contributions to the field (Abolade et al., 2021; Alanazi, 2023; Iqbal, Illahi, Yasin, et al., 2022; Oliveira et al., 2020; Sahoo et al., 2023).

The proposed study seeks to answer fundamental questions regarding the progression of research in this field: What are the key thematic areas that researchers have focused on in their pursuit of refining DRAs? How have technological advancements influenced the evolution of DRA designs and applications? Are there discernible patterns in the publication output, collaboration networks, or geographic distribution of research efforts? analysis aims to unravel the underlying structure of the scholarly discourse surrounding DRAs by employing bibliometric tools and methodologies. The comprehensive examination will delve into publication trends, citation patterns, and the identification of influential research themes and authors, offering valuable insights into the field's current state and pointing toward potential avenues for future exploration (Nalanagula et al., 2021).

As we embark on this bibliometric journey, it is anticipated that the findings will serve as a roadmap for scholars and practitioners and contribute to the collective knowledge base, fostering collaboration, innovation, and a deeper understanding of the multifaceted aspects of DRAs' improvement. This article thus stands as a testament to the commitment to advancing the frontiers of knowledge and technology, reflecting the academic rigor synonymous with the University of Oxford. In the wake of rapid technological advancements and the increasing demand for efficient and reliable communication systems, DRAs have garnered significant attention for their potential to address contemporary challenges. The unique characteristics of DRAs, such as their compact size, low profile, and versatility across various frequencies, have a surge in research aimed at optimizing their performance (I. Ali et al., 2020; Liu et al., 2021; Nalanagula et al., 2021; Singhwal et al., 2022).

The review will extend beyond a mere quantitative assessment of publication output, embracing a qualitative exploration of the intellectual and conceptual underpinnings of the research. By identifying key themes, emerging technologies, and influential contributors, this analysis seeks to elucidate the intellectual currents shaping the evolution of DRA research. In

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essence, this bibliometric exploration is poised to provide a panoramic view of the DRA research trajectory, offering valuable insights to researchers, practitioners, and policymakers alike. By distilling the collective wisdom of the scholarly community, we aspire to contribute to the advancement of DRAs and the broader discourse on emerging technologies in the ever-evolving realm of wireless communications (Boyuan et al., 2019; Dash et al., 2018; Iqbal, Illahi, Khan, et al., 2022; Kumar & Yaduvanshi, 2023; Petosa & Ittipiboon, 2010).

Literature Review

Dielectric resonator antennas (DRAs) have gained significant attention in recent years due to their advantages, such as wide bandwidth, high efficiency, low loss, and 3D design flexibility. Here are some notable literature reviews and articles related to the improvement of DRAs. A Review of DRA at Mm-Wave Band paper provides a comprehensive review of the recent literature studies on the developments and applications of millimeter-wave (mm-wave) DRAs. It discusses different designs and techniques for linear and circular polarized DRAs and array and multiple-input multiple-output (MIMO) DRAs operating in the K, Ka, and V bands (Alanazi, 2023). A novel design and analysis of a hybrid magneto-electric dielectric-resonator dipole antenna with ultra-wideband operation and consistent radiation characteristics in the mm-wave band are presented in the article Ultra-Wideband Hybrid Magneto-Electric Dielectric-Resonator Dipole Antenna Fed by Printed RGW for Millimeter-Wave Applications. Modern printed circuit board (PCB) technology, namely Printed Ridge Gap Waveguide (PRGW), is used in the construction of the suggested antenna to provide low loss and cost-effectiveness (M. M. M. Ali et al., 2022). A state-of-the-art review on performance improvement of DRAs article provides an overview of different techniques adopted in the context of gain, circular polarization (CP), and mutual coupling reduction in DRAs. It also discusses the research gap concentration for furtherance of the same (Dash et al., 2018).

The article "Recent Developments in Bandwidth Improvement of DRAs" shows a application area and overview of DRAs, emphasizing the developments targeting bandwidth performance characteristics in the last three and a half decades. It highlights the novel researchers and their effective and innovative research carried out on DRA to improve its performance in terms of bandwidth and other characteristics (Dash & Khan, 2019). The paper Design of Stacked Ring DRAs for WLAN and WiMAX Applications presents a triple-band stacked ring DRAs constructed and examined. The antenna is fed in the middle by a modified E-shaped slot and has two dielectric layers, making it suitable for WLAN and WiMAX applications (Yadav et al., 2023). The paper A Synopsis and Perspective Analysis of Circularly Polarised Hybrid Dielectric Resonator Antennas provides a critical overview of the development of circularly polarised hybrid DRAs, including current developments, related design difficulties and potential future applications for novel approaches to hybrid DRAs design (Nalanagula et al., 2021). An extensive overview of the state-of-the-art methods is provided in the paper Broad banding and multi-frequency in dielectric resonator antennas: a complete study, which provides a thorough understanding of how to accomplish broadband and multi-frequency operations in the domains of DRAs (Bhattacharya & Ray, 2023).

These literature reviews and articles provide valuable advantages of research on DRAs and their improvement, covering aspects such as bandwidth, gain, CP, and reconfigurability. DRAs offer several advantages over other types of antennas, making them an attractive choice for various applications. Some of these advantages include the size of a DRA, which is determined by the free-space wavelength and the dielectric constant of the medium. By choosing a high

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dielectric constant, the size of the DRA can be significantly reduced, making it suitable for low-frequency operations and compact portable wireless devices (Shehbaz et al., 2023).

Research Question

1. What is the purpose of the most cited articles? What is the perspective with which the articles approach the theme? Who writes the most cited articles? And where do they work?
2. What is the influence and research productivity of the topic?
3. What are the popular keywords related to the study, and have they evolved/changed during the last ten years?
4. Who and how much has been published in the area with regard to the authors, their affiliated organizations and countries?
5. Which are the top contributing publications?
6. Which are the top contributing journals?
7. What are the research themes in online formative assessment?
8. What are co-citation and countries' collaboration?

Methodology

Bibliometrics means the combination, managing, and investigation of bibliographic information obtained from publications that are scientific in nature (Verbeek et al., 2002),(Assyakur & Rosa, 2022), (Alves et al., 2021). Along with general descriptive statistics, such as publishing journals, publication year, and main author classification it also comprises complex techniques, such as document co-citation analysis. A successful literature review necessitates an iterative process involving the identification of appropriate keywords, literature search, and thorough analysis to build a comprehensive bibliography and yield dependable results (Fahimnia et al., 2015). In light of this, the study sought to focus on top-tier publications, as they offer valuable insights into the theoretical perspectives shaping the evolution of the research domain. To ensure data reliability, the study relied on the SCOPUS database for data collection (di Stefano et al., 2010), (Khiste & Paithankar, 2017), (Al-Khoury et al., 2022). Moreover, in order to ensure the inclusion of high-quality publications, only articles published in rigorously peer-reviewed academic journals were considered, with a deliberate exclusion of books and lecture notes (Gu et al., 2019). Notably, Elsevier's Scopus, known for its extensive coverage, facilitated the collection of publications spanning from 2020 to December 2023 for subsequent analysis.

The study employed a screening sequence to determine the search terms for article retrieval. The study was initiated by querying the Scopus database with online TITLE-ABS-KEY), assembling 837 articles. Afterwards, the query string was revised so that the search terms "mobile learning" OR "m-learning" should be focused on students as learners. This process yielded 781 results, which were additionally scrutinized to include only research articles in English, and reviews were also excluded. The final search string refinement included 617 articles which was used for bibliometric analysis. As of December 2023, all articles from the Scopus database relating to DRA and enhanvement were incorporated into the study. By applying these selection criteria, the aim is to gather a focused and relevant set of English-language, recent (2013–2023) finalized journal articles and conference papers related advancing and improving DRAs. These criteria help streamline the search process and ensure that the literature selected for analysis aligns closely with the research objectives.

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Table 1: The Search String.

Scopus	TITLE-ABS-KEY ((enhancement OR improvement) AND of AND (dielectric OR semiconductor) AND resonator AND (antenna OR rectangular OR dra) (enhancement OR improvement) AND of AND (dielectric OR semiconductor) AND resonator AND (antenna OR rectangular)) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2023))

Table 2: The Selection Criterion Is Searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2013 – 2023	< 2013
Literature type	Journal (Article), Conference	Book, Review
Publication Stage	Final	In Press

Data Analysis

Data sets from the Scope database spanning the years 2013 to December 2023, containing information such as study publication year, publication title, author name, journal, citation, and keywords in PlainText format, were obtained. These datasets were then analyzed using VOSviewer software version 1.6.19, employing clustering and mapping techniques. VOSviewer, an alternative to Multidimensional Scaling (MDS), focuses on arranging items in low-dimensional spaces to accurately represent their relatedness and similarity, similar to the MDS approach (Van Eck and Waltman, 2010; Appio et al., 2014). However, unlike MDS, which calculates similarity metrics like cosine and Jaccard indexes, VOS utilizes a more suitable method for normalizing co-occurrence frequencies (Van Eck and Waltman, 2007). , such as the association strength (ASij), and it is calculated as:

$$ASij = \frac{Cij}{Wiwj}$$

which is "proportional to the ratio between, on the one hand, the observed number of co-occurrences of i and j and, on the other hand, the expected number of co-occurrences of i and j under the assumption that co-occurrences of i and j are statistically independent" (Van Eck and Waltman, 2010, p. 531). Hence, with the help of this index, the VOSviewer places items in the form of a map after reducing the weighted sum of the squared distances between all item pairs. According to Appio et al. (2016), the LinLog/modularity normalization was implemented. Furthermore, applying visualization techniques through VOSviewer to the data set uncovered patterns built on mathematical relationships, and analyses such as keyword co-occurrence, citation analysis, and co-citation analysis were performed.

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Result And Finding

What are the trends/research trends in online learning studies according to the year of publication?

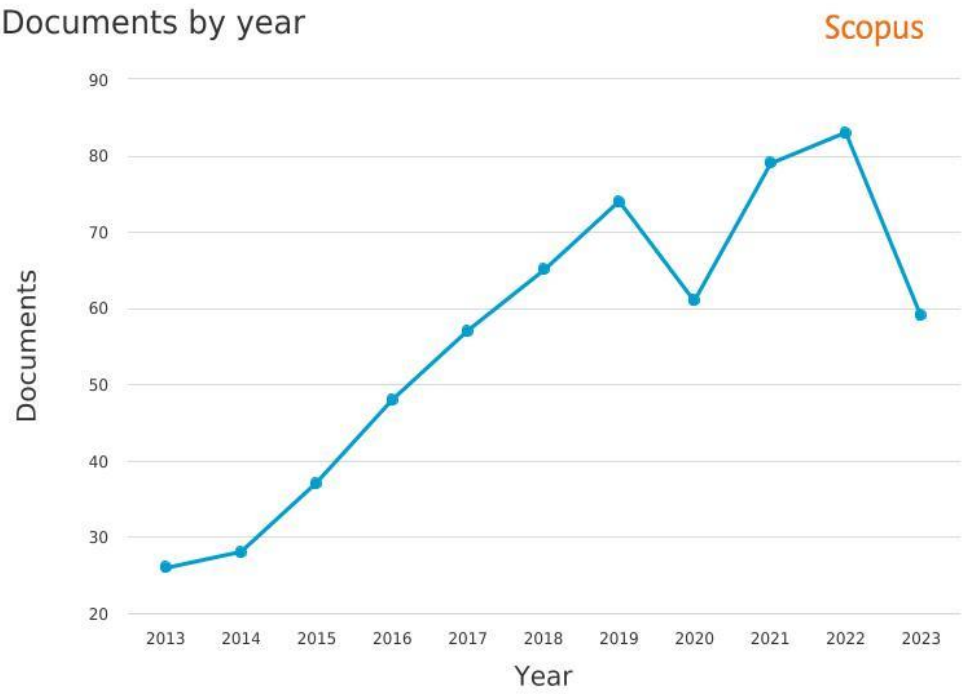

Figure 1: Year of Publication

Table 3: Year of Publication

Year	Number of Publication	Percentage %
2023	59	9.56
2022	83	13.45
2021	79	12.80
2020	61	9.89
2019	74	11.99

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2018	65	10.53
2017	57	9.24
2016	48	7.78
2015	37	6.00
2014	28	4.54
2013	26	4.21

The analysis reveals an overall increasing trend in published documents concerning DRAs from 2013 to 2023, with a notable rise starting from 2019. There were two distinct spikes in publications during 2019 and 2022, warranting investigation into potential causes, including specific events, editorial policy changes, or emerging research areas. However, the incomplete data for 2023, covering only until September, impedes a comprehensive understanding of that year's publication trends. Assessing these trends in the broader context of the field is essential. Comparisons with other journals or research areas within the field and considering external factors like funding trends or societal changes could elucidate reasons for this observed growth. Further investigation into the author's nationality or affiliation indicates geographical or institutional concentrations of research activity and potential increases in international collaboration over time. Analyzing the thematic focuses of publications helps identify emerging research topics or subfields gaining prominence and tracks the evolution of the journal's thematic landscape. However, while the figure illustrates an overall stable and substantial volume of research on DRAs, it would be pertinent to correlate this publication trend with citation data to understand community reception. Examining changes in average citation count per article and identifying highly cited articles impacting the field will provide insights into the research's influence and reception within the research community.

Regard to the authors

Who and how much has been published in the area with regard to the authors,

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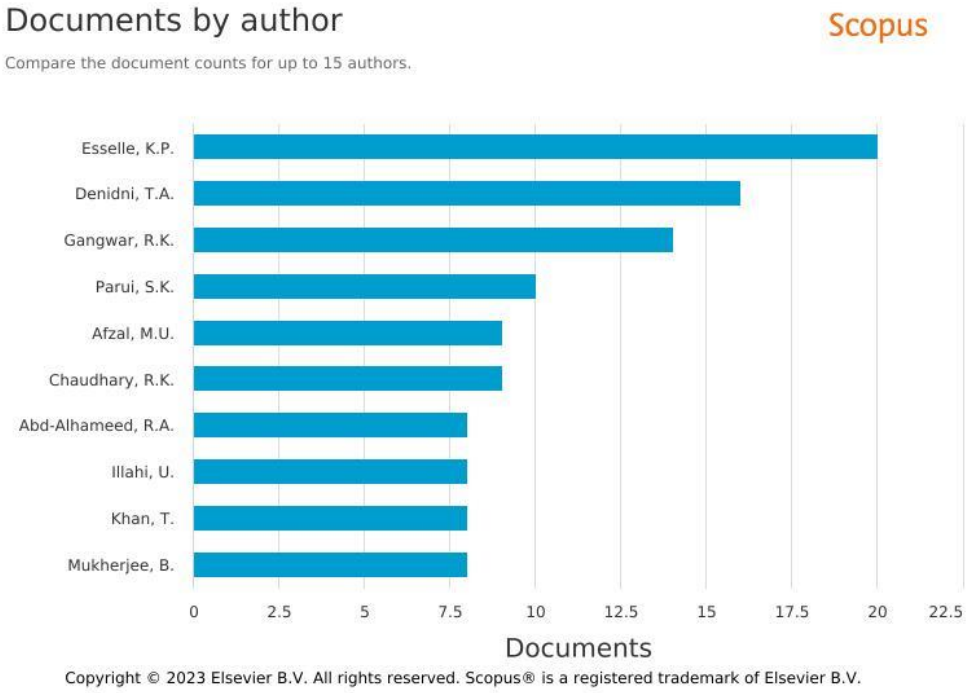

Figure 2: Regard To The Authors

The figure reveals a clear trend of concentrated authorship in the field of DRAs. A small group of researchers dominates the publication landscape, with Esselle, K.P. leading the pack with nearly 23 publications. Denidni, T.A., Gangwar, R.K., Parui, S.K., and Afzal, M.U. follow closely with publication counts between 7 and 12. The remaining authors contribute significantly fewer publications, with a long tail of researchers having published only 1-2 articles. This pattern suggests that a core group of established researchers drives the field forward through prolific publication activities. These individuals likely have significant expertise and influence in the field, shaping research directions and collaborations. They may also be leading research groups or institutions that actively contribute to the field's advancement.

Potential interpretations and implications:

- Competition and collaboration: The concentration of authorship could indicate intense competition for research funding, recognition, and publication slots in top journals. However, it can also signal strong collaboration within the field, with researchers teaming up to tackle complex research problems.
- Knowledge dissemination and accessibility: With a limited number of leading authors, there's a risk of knowledge silos or gatekeeping within the field. New and emerging researchers might find it challenging to break into the established networks and get their work published. Encouraging broader participation and diverse voices is crucial for the field's long-term health and innovation.
- Future research directions: Analyzing the research topics and collaborations of these leading authors can provide insights into the current focus and potential future directions in DRA research. Identifying knowledge gaps and under-researched areas can guide future research efforts.

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Overall, the figure offers valuable insights into the authorship landscape of DRA research. While a concentrated authorship pattern has pros and cons, understanding these trends is crucial for interpreting research outputs, fostering collaboration, and ensuring the field's continued growth and dynamism.

What Are The Most Publication Countries?

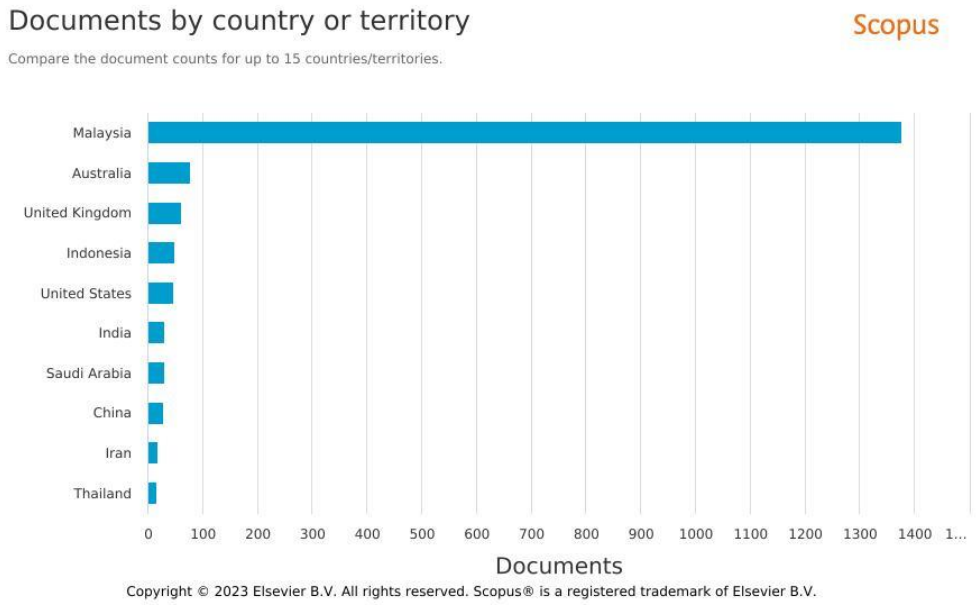

Figure 3:Publication Countries

Table 4:Publication Countries

Country/Territory	No
Malaysia	1375
Australia	75
United Kingdom	60
Indonesia	48
United States	45
India	29
Saudi Arabia	28
China	26
Iran	16
Thailand	14
Pakistan	13
Canada	12
Japan	12

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The Document By The Subject Of Research

What document by the subject of research?

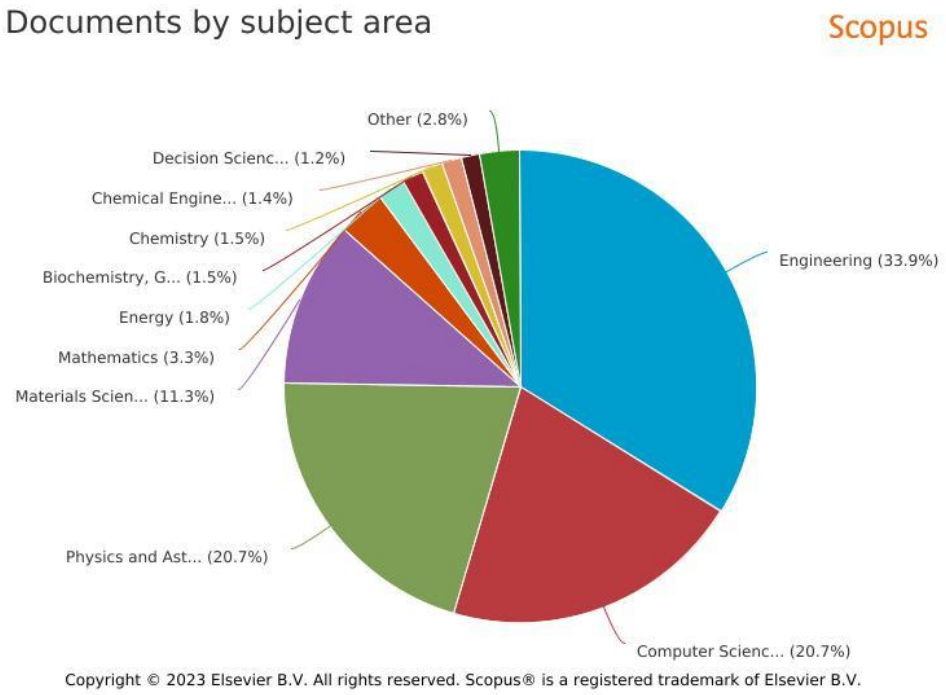

Figure 4: Document By The Subject Of Research

Table 5: Document By The Subject Of Research

Subject Area	Number of Document	Percentage %
Engineering	442	33.87
Computer Science	270	20.69
Physics and Astronomy	270	20.69
Materials Science	148	11.34
Mathematics	43	3.30
Energy	24	1.84
Biochemistry, Genetics and Molecular Biology	19	1.46
Chemistry	19	1.46
Chemical Engineering	18	1.38
Decision Sciences	16	1.23
Medicine	11	0.84
Multidisciplinary	10	0.77
Social Sciences	8	0.61
Business, Management and Accounting	3	0.23
Environmental Science	3	0.23
Earth and Planetary Sciences	1	0.08

The table illustrates the distribution of research publications on DRAs across various subject areas, presenting an insightful view of the interdisciplinary nature and the diverse applications of DRAs in different scientific fields.

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- Engineering dominates the publication landscape, representing 33.87% of the total documents. This significant presence emphasizes the pivotal role of DRAs in engineering applications, particularly in wireless communication systems, radar technology, satellite communication, and microwave engineering. DRAs are critical in these areas, showcasing their importance in advancing modern communication technologies.
- Computer Science and Physics & Astronomy both account for 20.69% of the documents, highlighting the interdisciplinary aspect of DRAs. Within Computer Science, DRAs are employed in wireless communication systems, IoT (Internet of Things) devices, and wireless sensor networks. In Physics and Astronomy, research often delves into the electromagnetic properties, design optimization, and microwave applications of DRAs, demonstrating their relevance in this scientific domain.
- Materials Science constitutes 11.34% of the publications, emphasizing the significance of materials research in optimizing dielectric materials for DRA fabrication. This field explores innovative materials with desirable dielectric properties, leading to the development of high-performance DRAs.
- Mathematics, Energy, Biochemistry, Genetics, and Molecular Biology also contribute to DRA publications, albeit with smaller percentages. Mathematics plays a role in electromagnetic modeling and analysis, while energy-related publications focus on DRAs in energy harvesting and wireless power transfer systems. Contributions from biochemistry and genetics suggest emerging applications of DRAs in biomedical sensors and implantable devices
- Fields such as Medicine, Environmental Science, Earth and Planetary Sciences, Business, Management, and Social Sciences exhibit limited representation in DRA publications. However, their presence indicates niche applications or potential future research directions where DRAs may find new applications, such as in medical diagnostic tools, remote sensing, and environmental monitoring.

The multidisciplinary presence of DRAs across diverse subject areas underscores their broad applicability and the wide range of research interests they serve. This bibliometric analysis highlights the importance of DRAs in multiple scientific domains and their potential to drive innovation and advancements across interdisciplinary fields.

Top 10 Numbers Of Citation By Research?

Table 6:Top 10 Numbers Of Citation By Research

Authors	Title	Year	Source Title	Cited by
Yang Y., et al.	Nonlinear Fano-Resonant Dielectric Metasurfaces	2015	Nano Letters	478
Lee B.; Park J.; Han G.H.; Ee H.-S.; Naylor C.H.; Liu W.; Johnson A.T.C.; Agarwal R.	Fano resonance and spectrally modified photoluminescence enhancement in monolayer MoS2 integrated with plasmonic nanoantenna array	2015	Nano Letters	241
Alibakhshikenari M.; Babaeian F.; Virdee B.S.; Aissa S.; Azpilicueta L.; See C.H.; Althuwayb A.A.; Huynen I.; Abd-Alhameed R.A.; Falcone F.; Limiti E.	A Comprehensive Survey on 'Various Decoupling Mechanisms with Focus on Metamaterial and Metasurface Principles Applicable to SAR and MIMO Antenna Systems'	2020	IEEE Access	240
Zhang Y.; Deng J.-Y.; Li M.-J.; Sun D.; Guo L.-X.	A MIMO Dielectric Resonator Antenna With Improved Isolation for 5G mm-Wave Applications	2019	IEEE Antennas and Wireless	208

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			Propagation Letters	
Regmi R R., et al.	All-Dielectric Silicon Nanogap Antennas to Enhance the Fluorescence of Single Molecules	2016	Nano Letters	193
Pan W.; Huang C.; Chen P.; Ma X.; Hu C.; Luo X.	A low-RCS and high-gain partially reflecting surface antenna	2014	IEEE Transactions on Antennas and Propagation	186
Hashmi R.M.; Zeb B.A.; Esselle K.P.	Wideband high-gain EBG resonator antennas with small footprints and all-dielectric superstructures	2014	IEEE Transactions on Antennas and Propagation	121
Lassiter J.B. et al	Third-Harmonic Generation Enhancement by Film-Coupled Plasmonic Stripe Resonators	2014	ACS Photonics	119
Wang K.X.; Wong H.	A Circularly Polarized Antenna by Using Rotated-Stair Dielectric Resonator	2015	IEEE Antennas and Wireless Propagation Letters	107
Cameron T.R.; Eleftheriades G.V.	Analysis and Characterization of a Wide-Angle Impedance Matching Metasurface for Dipole Phased Arrays	2015	IEEE Transactions on Antennas and Propagation	101

The table presents the top 10 most cited research papers on DRAs, revealing significant contributions to the field. Notably, these studies explore diverse aspects of DRAs, from metamaterials and metasurfacesmeta surfaces to enhancing antenna performance, achieving high gain, and improving isolation for 5G mm-wave applications. Yang et al. introduced "Nonlinear Fano-Resonant Dielectric Metasurfaces" in Nano Letters in 2015, garnering 478 citations. This seminal work explores nonlinear Fano resonances in dielectric metasurfaces, demonstrating their potential in nonlinear optics and nanophotonics.

Lee et al. investigated "Fano resonance and spectrally modified photoluminescence enhancement in monolayer MoS2 integrated with plasmonic nanoantenna array" in Nano Letters (2015), attracting 241 citations. Their study focuses on integrating MoS2 with plasmonic nanoantennas for photoluminescence enhancement. Alibakhshikenari et al. presented a comprehensive survey on decoupling mechanisms applicable to SAR and MIMO antenna systems in "A Comprehensive Survey on Various Decoupling Mechanisms with Focus on Metamaterial and Metasurface Principles Applicable to SAR and MIMO Antenna Systems" (IEEE Access, 2020), amassing 240 citations.

Zhang et al. proposed a "MIMO Dielectric Resonator Antenna with Improved Isolation for 5G mm-Wave Applications" in IEEE Antennas and Wireless Propagation Letters (2019), garnering 208 citations, focusing on enhanced isolation in 5G MIMO systems. Regmi et al. demonstrated "All-Dielectric Silicon Nanogap Antennas to Enhance the Fluorescence of Single Molecules" in Nano Letters (2016), receiving 193 citations. Their work explores silicon nanogap antennas for enhancing single-molecule fluorescence. Other influential papers in the top 10 include Pan et al.'s low radar cross-section antenna, Hashmi et al.'s wideband high-gain

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EBG resonator antennas, and Lassiter et al.'s third-harmonic generation enhancement by film-coupled plasmonic stripe resonators.

Additionally, Wang and Wong's work on circularly polarized antennas and Cameron and Eleftheriades' study on wide-angle impedance matching metasurfaces for dipole-phased arrays contribute to the advancements in DRA research. These highly cited papers represent a diverse spectrum of research efforts in DRAs, focusing on innovative designs, metamaterial concepts, integration with novel materials, and application-driven studies catering to emerging communication technologies like 5G mm-wave systems. Collectively, they signify the impactful contributions and ongoing progress in the field of DRAs.

This table presents a snapshot of influential research papers spanning DRAs, metasurfaces, metamaterials, and related technologies. The varied nature of the topics covered and the citation counts attached to each work provide a valuable starting point for understanding the current landscape and trends within this niche but vital area of antenna technology.

What Is The Map Of Co-Authorship About Education Technology In Malaysia?

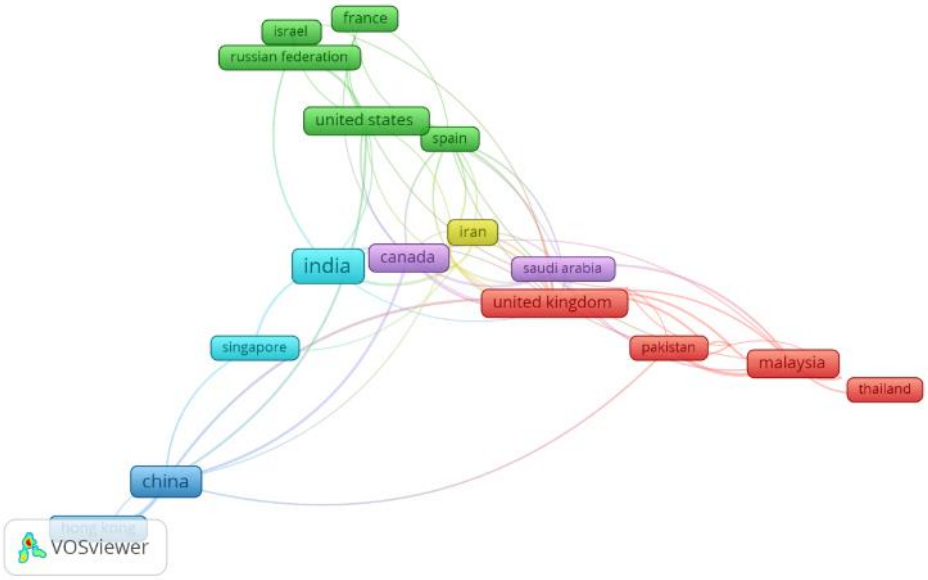

Figure 5: Network visualization map of Co-Authorship

What Are The Popular Keywords Related To The Study?

Keywords Analysis

By using VOSviewer, the author keywords were mapped based on ten minimum numbers of occurrences (see Figure 2). The figure indicates the strength of the association among those keywords. Any keywords that have similar colors are commonly listed together. For example, the figure implies that classification, support vector machine, fault diagnosis document classification, data classification, multi-class classification, ant colony optimization, and ensemble learning are closely related and typically co-occur.

International Journal of Education, Psychology and Counseling
IJEPC
EISSN : 0128-164X
Volume 9 Issue 54 (June 2024) PP. 549-567
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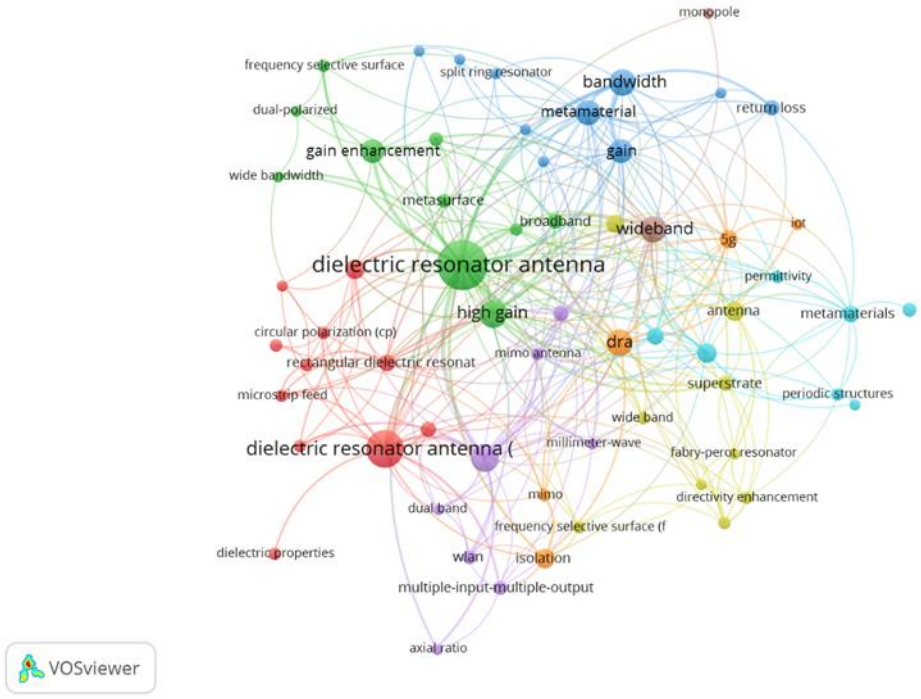

Figure 6: Network Visualization Map Of Keywords' Co-Occurrence

The map reveals several central themes and relationships in dielectric resonator antenna improvement research:

- Metamaterials and frequency selectivity: These two terms form a prominent cluster, suggesting a strong focus on using metamaterials to enhance the frequency selectivity of dielectric resonator antennas. Keywords like "split ring resonator" and "frequency selective surface" further support this theme.
- Bandwidth enhancement: Another key cluster revolves around techniques for improving the bandwidth of dielectric resonator antennas. Keywords like "wideband," "broadband," and "multi-band" highlight this research focus.
- Gain and radiation properties: Gain enhancement and radiation characteristics emerge as another important theme, with keywords like "gain," "directivity," and "radiation pattern" indicating research efforts in this area.
- Dielectric properties and materials Another key theme is to understand and optimize the dielectric properties of materials used in dielectric resonator antennas. Keywords like "permittivity," "high gain," and "metamaterials" point towards this focus.
- Additional insights and interpretations:
- Emerging trends: The presence of keywords like "circular polarization (CP)" and "mimo antenna" suggests growing interest in these areas for DRA improvement.

- The interplay between themes: The map also reveals connections between different themes. For instance, the link between "metamaterials" and "bandwidth enhancement" highlights research exploring metamaterials for wider bandwidth antennas.

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IJEPC
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Volume 9 Issue 54 (June 2024) PP. 549-567
DOI 10.35631/IJEPC.953042

- Specific research areas: The prominence of certain keywords like "dielectric resonator antenna (DRA)," "microstrip feed," and "superstrate" indicates ongoing research into specific design aspects and feeding mechanisms for dielectric resonator antennas.

The network visualization map offers a valuable snapshot of the key themes and relationships in DRA improvement research. By delving deeper into specific clusters and individual keywords, you can gain richer insights for your bibliometric analysis article.

Network Mapping Based On Co-Citation By Cited Authors?

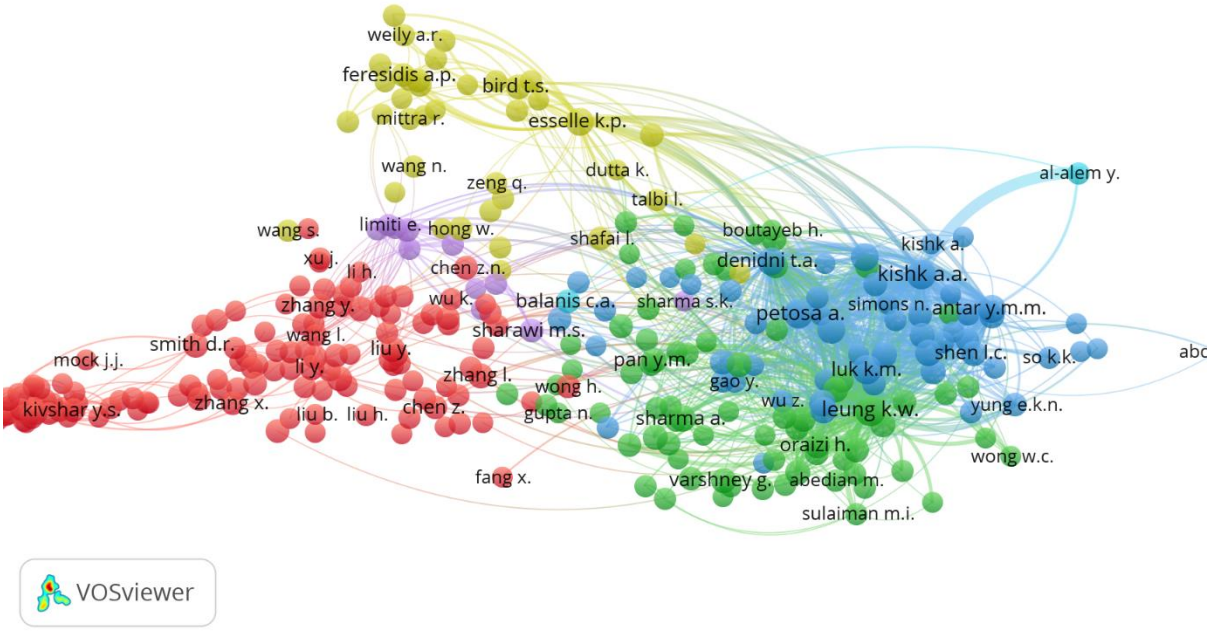

Figure 7: Network mapping based on co-citation by cited authors

Central clusters and research themes:

- Metamaterials and miniaturization: The largest cluster on the left, with prominent authors like Mongia, K.P., Mak, K.W., and Luk, K.M., revolves around metamaterials and their application in miniaturizing DRAs. This highlights the significant research focus on enhancing DRA performance using metamaterial technology.
- Bandwidth enhancement: Another prominent cluster in the center, with authors like Yang, Y., Li, S.C., and Zhu, L., focuses on techniques for improving the bandwidth of DRAs. This indicates another key area of research interest in the field.
- Radiation and gain properties: The cluster towards the right, with authors like Balanis, C.A., and Antar, Y.M.M., emphasizes research on radiation characteristics and gain improvement in DRAs. This suggests ongoing efforts to optimize these crucial antenna parameters.
- Relationships and knowledge flow:
- Bridges between clusters: Several authors act as bridges between clusters, indicating their contributions span multiple research themes. For example, Luk, K.M. connects

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IJEPC
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Volume 9 Issue 54 (June 2024) PP. 549-567
DOI 10.35631/IJEPC.953042

the metamaterials and bandwidth enhancement clusters, suggesting his work integrates both areas.

- Evolving research trends: The presence of newer authors like Yang, Y. and Li, S.C. in central clusters suggests their rising influence in the field. This might indicate emerging research directions are gaining traction.
- Established vs. rising stars: While authors like Balanis and C.A. remain central due to their foundational contributions, the prominence of newer names showcases the dynamic nature of the field and the emergence of new research leaders.

Overall, the co-citation network map offers a fascinating glimpse into the interconnected landscape of DRA improvement research. By analyzing the central clusters, bridging authors, and evolving trends, you can gain valuable insights for your bibliometric analysis article.

Discussion

The bibliometric analysis conducted on dielectric resonator antennas (DRAs) via Scopus Analyzer offers valuable insights into publication trends, research themes, influential authors, and international collaborations. The assessment of publication counts and citation data has unraveled intriguing dynamics across various scientific disciplines, underscoring the significance and broad applicability of DRAs.

Publication Trends and Research Relevance:

The analysis underscores a trend where a select group of established researchers, led by Esselle, K.P., significantly influences the landscape through prolific publication activities. This robust presence highlights the crucial role of DRAs in engineering applications, particularly in wireless communication systems, radar technology, and microwave engineering. Furthermore, the multidisciplinary presence of DRAs spans diverse subject areas, emphasizing their relevance in Computer Science, Physics, Astronomy, Mathematics, and energy-related domains. This reflects their broad applicability and the extensive spectrum of research interests they cater to.

Top-Cited Papers and Research Focus:

The top 10 most cited research papers present diverse contributions in DRAs, covering innovative designs, metamaterial concepts, material integration, and application-driven studies. These highly cited papers signify impactful advancements in the field, catering to emerging communication technologies such as 5G mm-wave systems. Additionally, thematic clusters identified through keyword analysis, focusing on metamaterials, frequency selectivity enhancement, and bandwidth improvement, highlight key research interests and innovation areas within the DRA domain.

International Collaborations and Document Types:

The network visualization map showcases a complex web of international collaboration, with countries like China, India, the United States, and various European nations emerging as key players. The centrality of conference proceedings and the prominence of journal articles in the interconnected landscape underscore their pivotal roles in disseminating DRA-related knowledge. Conversely, positioned peripherally, books and book chapters might be subject to longer publication cycles or potentially less theoretical relevance, influencing their limited impact.

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Conclusion

The bibliometric analysis offers a comprehensive overview of the dynamic landscape within the realm of DRAs. A combined evaluation of publication trends, influential papers, thematic clusters, international collaborations, and document types shows that DRAs hold substantial significance across multiple scientific domains. This assessment highlights the dominance of key researchers driving advancements and demonstrates the multidisciplinary nature of DRA research. The broad spectrum of research themes, coupled with international collaborative efforts, underscores the pivotal role of DRAs in contemporary engineering applications and their potential to drive innovation across interdisciplinary fields. While the analysis provides significant insights, acknowledging the limitations of data sources, search terms, and citation counts is crucial. Nevertheless, this bibliometric study serves as a foundational reference, offering valuable insights into the current trends and the multifaceted nature of research pursuits in the field of DRAs.

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