A Study On Calcium Copper Titanate (CCTO) For Improvement Of Dielectric Semiconductor

Hasanah Safein Shafie[1,2], Julie Juliewatty Mohamed[1*], Ainor Izmira Mahmood[2], Md Fadzil Ain[3], Nor Fadzilah Mohamed[1], Mohamed Johari Abu[1],

[1] Faculty of Bioengineering And Technology (FBKT), Universiti Malaysia Kelantan (UMK), Jeli Campus, 02600 Jeli, Kelantan, Malaysia
[2] Department of Mathemetics Science And Computer (JMSK), Politeknik Kota Bharu, 16450 Ketereh, Kelantan, Malaysia
[3] Faculty of Electronic Engineering Technology, UniCITI Alam Campus, Universiti Sains Malaysia, 02100 Padang Besar, Perlis, Malaysia

Corresponding email: [1]hasanah@pkb.edu,my,

Abstract This study critically examines the utilization of Calcium Copper Titanate (CCTO) for enhancing dielectric semiconductor. Against the backdrop of growing demand for efficient wireless communication systems, the integration of advanced dielectric materials like CCTO has garnered significant action. The problem addressed is the need for improved antenna performance, including enhanced bandwidth, permittivity, and radiation efficiency. The methodology involves a experimental method on CCTO's dielectric properties, its impact on DRA characteristics, and its potential for realizing compact and high-performance antennas. By doping proses from diverse sources, this review aims to provide a comprehensive overview of the current state of research, identify trends, challenges, and gaps, and offer insights into future research directions. Expected outcomes include a deeper understanding of CCTO's influence on DRA enhancement, a synthesis of diverse findings, and the identification of key factors influencing the performance of CCTO-enhanced DRAs.
Keywords: CCTO, Dielectric, Semiconductor, Enhancement,

INTRODUCTION

The release of the unlicensed 60GHz band and the development of 5G technologies aimed at increasing data rate on wireless communication network by a factor of 100 [1] will impose stinging specifications (large bandwidth, high gain, small size, and temperature independent performance) on the design of the radio frequency (RF) electronics. Various front-end antenna solutions relying on monopoles, dipoles, and patch antennas have been proposed for millimeter-wave applications.

An up-to-date literature overview on relevant approaches for controlling circuital characteristics and radiation properties of dielectric resonator antennas (DRAs) is presented. The main advantages of DRAs are discussed in detail, while reviewing the most effective techniques for antenna feeding as well as for size reduction. Furthermore, advanced design solutions for enhancing the realized gain of individual DRAs are investigated. In this way, guidance is provided to radio frequency (RF) front-end designers in the selection of different antenna topologies useful to achieve the required antenna performance in terms of frequency response, gain, and polarization. Particular attention is put in the analysis of the progress which is being made in the application of DRA technology at millimeter-wave frequencies. The goal of this research can be achieved with the following objectives which is to improve the dielectric properties of CCTO in reduce the loss, also to design and fabricate the CCTO antenna and to characterize the CCTO Antenna through resonant frequency)

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For the future application in microelectronic device, the films states are more suitable compared with bulk materials state. The existing deposition techniques of CCTO film state had been said to produce product that have very high dielectric constant but also have high dielectric loss (tan δ) especially at high frequencies. Previous report had showed that it can possess tan δ of 0.15 at room temperature [7, 8]. Dielectric loss makes more energy dissipate in the form of heat in unit time when an electric fields act on it. The electronic devices that have high dielectric losses can affect circuit performance due to dissipation of heat in the circuit.

Electroceramic calcium copper titanates (CaCu3Ti4O12, CCTO), with high dielectric permittivities (ε) of approximately 100000 to 1000000, respectively, for single crystal and bulk materials, are produced for a number of well-established and emerging applications such as resonator, capacitor, and sensor. These applications take advantage of the unique properties achieved through the structure and properties of CCTO

The most two popular radiating dielectric resonators are the cylindrical and the rectangular ones. They will be reviewed in this section. Design equations to calculate the relevant resonant frequencies are given. More complex dielectric resonators, such as the spherical/hemispherical, cross-shaped, and super shaped (see Figure 1) ones, will be also discussed in this section.

Cylindrical DRAs have been studied extensively in literature. The antenna consists of a cylindrical dielectric resonator (DR) with height h, radius a, and dielectric constant ϵr.The DR is placed on top of a ground plane and fed by a coaxial connector. The main advantages of the cylindrical DRA consist in the ease of fabrication and the ability to excite different modes. The Ceramic Antenna Features for Circular Polarization Antenna for range through 900 MHz ISM dimension is as small as Teflon antenna. Usually these feature using high quality factor dielectric to provide highly stabilized performance.

These antennas are characterized by small size, low weight, and low cost and can be easily integrated on chip. However, unless advanced design solutions based on the integration of suitable dielectric superstrates or lensing structures are adopted, these antennas typically suffer from reduced radiation efficiency and narrow impedance bandwidth due to the effect of lossy silicon substrate materials. On the other hand, dielectric resonator antennas (DRAs) are promising candidates to replace traditional radiating elements at high frequencies, especially for applications at millimetre waves and beyond. In this work amine functionalized material of glass have been designed with dielectric gradients. The glass was characterized with suitable characterization tools and the dielectric behaviours were measured through impedance measurement. The dielectric study has shown significantly high dielectric properties at sintered temperature 1000°C (6 h). So, it can conclude that this series of glass with a different dielectric constant can be used for designing various electronic devices

The energy storage density for dielectric capacitors grows linearly with the dielectric constant and quadratically with breakdown strength [5], thus the glass ceramic materials possess the potential to achieve a much higher energ storage density. However, high dielectric loss and low breakdown (~1.02.0 kV/cm) voltage limit further applications of CCTO (Jianying et al., 2013).

The use of a dielectric resonator as a resonant antenna was proposed in 1983. Due to the absence of metallic loss, the dielectric resonator antenna (DRA) is highly efficient when operated at millimetre wave frequencies. With the use of high dielectric constant material, the DRA can also be used as a small and low profile antenna when operated at low microwave frequencies. Low-cost dielectric materials are now easily available commercially: encouraging more antenna engineers to design communication systems with DRAs. Although DRAs are show promise in practical applications, surprisingly, there is no research summary in reference form on DRAs available.(2016. Lim, Eng Hock,Pan, Yong Mei,Leung, Kwok Wa) Handbook of Antenna Technologies. This is mainly attributed to the fact that DRAs do not suffer from conduction losses and are characterized by high radiation efficiency when excited properly.

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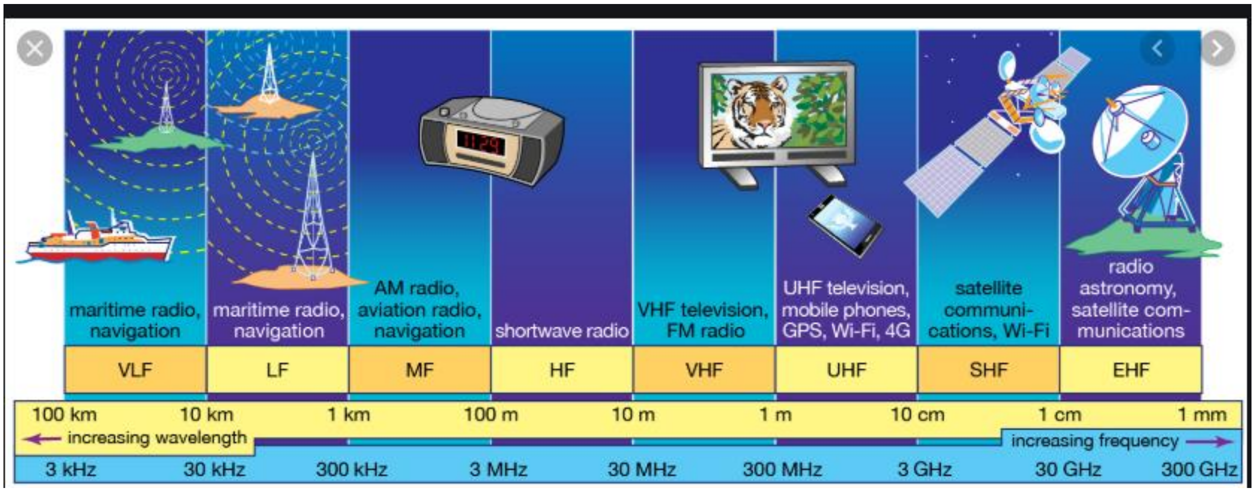

FIGURE 1. Spectrum Navigationin frequency wavelength

By using a suitable excitation technique, any dielectric structure can become a radiator at defined frequencies. It is to be noticed that, for a given resonant frequency, the size of the dielectric resonator is inversely proportional to the relative permittivity of the constitutive material.

The lowest dielectric constant material adopted in DRA design is reported in [2–4], where commodity plastics with relative dielectric constant smaller than 3 have been utilized for the realization of super shaped DRAs. The basic principle of operation of dielectric resonators is similar to that of the cavity resonators [5] and is thoroughly discussed in literature. The most two popular radiating dielectric resonators are the cylindrical and the rectangular ones.
More complex dielectric resonators, such as the spherical/hemispherical, cross-shaped, and super shaped will be also discuss.

The antenna consists of a cylindrical dielectric resonator (DR) with height *h*, radius , and dielectric constant .The DR is placed on top of a ground plane and fed by a coaxial connector.
The cylindrical DRA consist in the ease of fabrication and the ability to excite different modes. Resonant frequency is the oscillation of a system at its natural or unforced resonance. Resonance occurs when a system is able to store and easily transfer energy between different storage modes, such as Kinetic energy or Potential energy as you would find with a simple pendulum. Resonance describes the phenomenon of increased amplitude that occurs when the frequency of a periodically applied force is equal or close to a natural frequency of the system on which it acts.

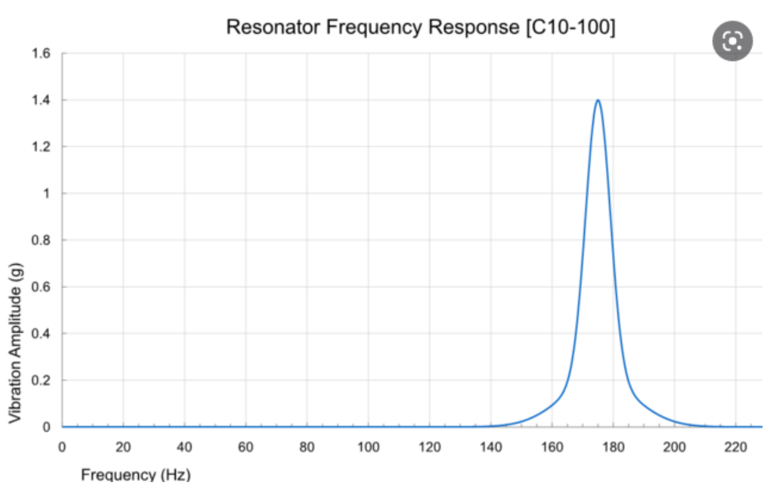

FIGURE 2. Resonator Frequency Response

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Significant of Study

- The antenna made from CCTO ceramic will be more efficient compared to other electroceramic materials, due its very high dielectric constant behaviour.
- The CCTO has a potential to be used as DRA antenna
- Dielectric loss in CCTO must be designed at lowest value to become a good antenna.

The objectives of study is to characterize The CCTO Antenna in scecific Resonant Frequency. The study also is going to identify the dielectric Properties Of CCTO in reduce the loss of enhancement antenne

Materials and Methods

Calcium copper titanate (CCTO) has the chemical formula of CaCu3Ti4O12, a novel electroceramic material with high dielectric permittivity (ε), of approximately 100,000 for single crystal and 10,000 for bulk material at room temperature. In addition, CCTO shows moderate dielectric loss (tan δ ~ 0.15) at a broad frequency region (up to 106 Hz), high positive temperature coefficient of resonant frequency (τ f ~ +9.13 ppm K−1), and phase transition stability against temperatures of a wide range (100–400 K).

The dielectric materials, which known as insulating materials can be in the form of solid, liquid or gases. Solid dielectrics are the most commonly used in electrical engineering because these materials are very good insulators. solid dielectrics are mica, glass, rubber and ceramics. There are good examples of ceramic in dielectric materials, which is Calcium Copper Titanium Oxide (CCTO), Aluminium Oxide (Al_2O_3), Aluminium Nitride (AlN), Silicon Carbide (SiC), Fused Silica (SiO_2) and NiO. NiO is one of the dielectric materials. NiO is a very important material extensively used in catalysis, battery cathodes, gas sensors, electrochromic films, and magnetic materials

In these applications, it is still needed for synthesizing high quality and ultra-fine powders with required characteristics in terms of their size, morphology, optical properties, magnetic properties and so on . NiO is good in insulation, but it needs to be enhance its properties especially in dielectric. In this study, the solid-state or ceramic method is used to synthesis and characterize the TiO_2 doped NiO. By having various amount of TiO_2 added to the NiO, the improvement in phase composition, microstructure, density and dielectric properties will be seen.

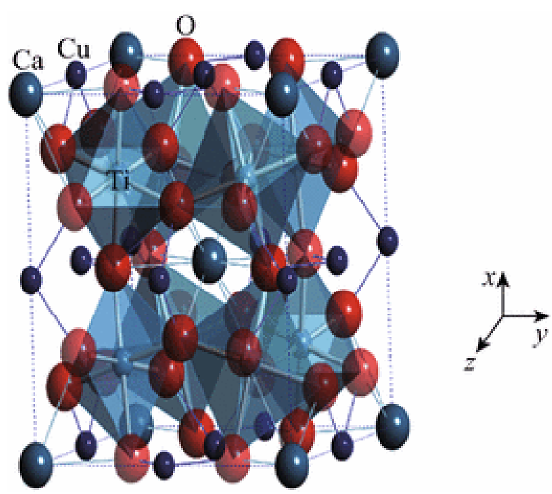

FIGURE 3. Structure and Dielectric Properties

A crystalline structure of $CaCu_3Ti_4O_{12}$. *Large white blue atoms* are Ca, *medium-sized dark blue atoms* are Cu, *red atoms* are O, and atoms in the *octahedra centers* are Ti [43].

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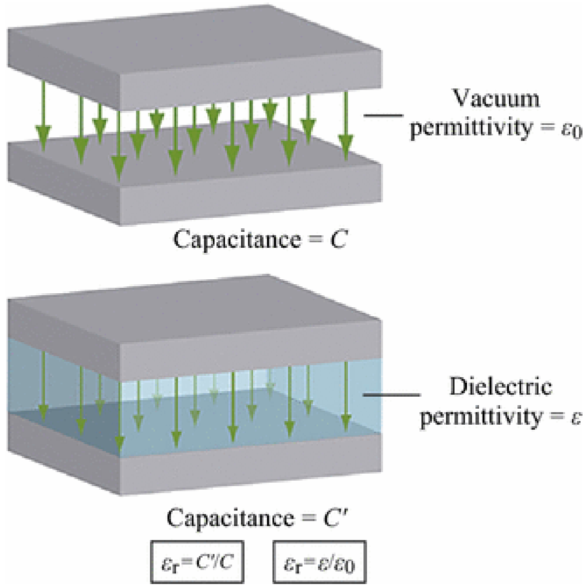

Figure 4: Dielectric permittivity concept

Two main features are needed for any dielectric material in practical applications: high ε_r and low tan δ.

TABLE 1: Summary of CCTO APD drive element design measurement results for input impedance and return loss simulation results.

Parameter	**Simulasi**	**Simulasi DIR CCTO APD**	**Simulasi + 2 DIR CCTO APD**	**Simulasi** 3 DIR CCTO APD	**Simulasi** 4 DIR CCTO APD
Resonant Frequency,	3.553 GHz	3.534 GHz	3.542 GHz	**3.549 GHz**	3.533 GHz
Return Loss	-35.16 dB	-38.29 dB	-33.6 dB	**-35.37 dB**	-43.74 dB
Bandwidth	180 MHz	190 MHz	170 MHz	**190 MHz**	190 MHz
HPBW(E-plane)	83.4^0	75.6^0	66.1^0	**58.6^0**	51.4^0
HPBW(H-plane)	180.1^0	65.5^0	43.6^0	**35^0**	28.8^0
Side Lobe Level (E-plane)	-2.1 dB	-3.5 dB	-7.5 dB	**-6.5 dB**	-7.0 dB
Side Lobe Level (H-plane)	Tiada	-3.5 dB	-4.5 dB	**-4.6 dB**	-5.2 dB
Directionality	5.636 dBi	7.706 dBi	9.169 dBi	**9.773 dBi**	10.69 dBi
Impedans	4.459 dB	6.380 dB	7.84 dB	**8.27 dB**	9.21 dB

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The size of the DRA is proportional to $\lambda 0/\sqrt{\epsilon r}$ with $\lambda 0 = c/f\ 0$ being the free-space wavelength at the resonant frequency $f0$ and where ϵr denotes the relative permittivity of the material forming the radiating structure. As compared to traditional metallic antennas whose size is proportional to $\lambda 0$, DRAs are characterized by a smaller form factor especially when a material with high dielectric constant (ϵr) is selected for the design.

Due to the absence of conducting material, the DRAs are characterized by high radiation efficiency when a low-loss dielectric material is chosen. This characteristic makes them very suitable for applications at very high frequencies, such as in the range from 30GHz to 300GHz. As a matter of fact, at these frequencies, traditional metallic antennas suffer from higher conductor losses.

The goal of this research can be achieved with the following methods of literature studies, Practical On Site, sampling and Lab Testing. DRAs can be characterized by a large impedance bandwidth if the dimensions of the resonator and the material dielectric constant are chosen properly. Its can be excited using different techniques which is helpful in different applications and for array integration. The gain, bandwidth, and polarization characteristics of a DRA can be easily controlled using different design techniques.

The main target of this study summarizing the most relevant techniques to control circuital characteristics and radiation properties of DRAs. In this way, guidance will be provided to RF frontend designers to achieve the required antenna performance in terms of gain, bandwidth, and polarization. Different geometries of radiating resonators will be discussed first, turning then our attention to advantages and disadvantages of different feeding techniques proposed so far in the literature. Various methodologies that have been used to enhance the impedance bandwidth and the antenna gain will be explored. Furthermore, different techniques to achieve circular polarization are summarized. Finally, the most recent implementation of DRAs on chip and off chip will be presented.

Therefore, the use of materials with high dielectric constant can result in a narrowband antenna behavior. By using a suitable excitation technique, any dielectric structure can become a radiator at defined frequencies. It is to be noticed that, for a given resonant frequency, the size of the dielectric resonator is inversely proportional to the relative permittivity of the constitutive material. The lowest dielectric constant material adopted in DRA design is reported where commodity plastics with relative dielectric constant smaller than 3 have been utilized for the realization of super shaped DRAs. The basic principle of operation of dielectric resonators is similar to that of the cavity resonators and is thoroughly discussed in literature. The most two popular radiating dielectric resonators are the cylindrical and the rectangular ones. They will be reviewed in this section. Design equations to calculate the relevant resonant frequencies are given. More complex dielectric resonators, such as the spherical/hemispherical, cross shaped, and super shaped (see Figure 1) ones, will be also discussed in this section.

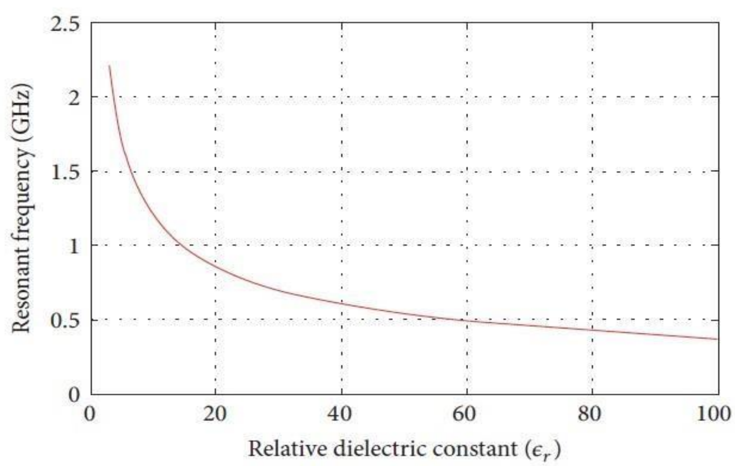

FIGURE 5: Resonant frequency of a cylindrical DRA with radius a = 2.5 cm and height h = 5 cm as a function of the relative dielectric constant**.**

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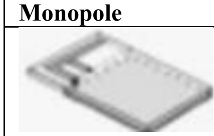
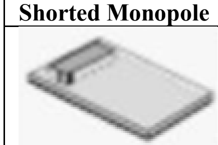
Figure 4 shows the effect of the relative dielectric constant (ϵr) on the resonant frequency. It can be noticed that the resonant frequency of the fundamental mode decreases by increasing the dielectric constant of the DRA. This behavior is the most important characteristic of the DRA since it allows decreasing the size of the DRA by increasing its dielectric constant. It is to be noted that the impedance bandwidth is inversely proportional to the relative permittivity of the DR.

FIGURE 6 shows the Ceramic Antenna Features for Circular Polarization Antenna

TABLE 2 show the effect of frequency resonant, bandwidth and pattern of Circular Polarization Antenna

	Effect on Frequency Resonant	**Effect on Bandwidth**	**Effect on Pattern**
 **Monopole**	Large (>15 %)	Large	Large
 **Shorted Monopole**	Large (<15 %)	Large	Large
 **PIFA**	Small (~5%)	Large	Large

The antenna covers the 60GHzunlicensed frequency band (from 57GHz to 65GHz) with a nearly flat gain of about 12 dBi. A similar concept has been recently proposed in [60] where the resonances of a circular patch and a ring-shaped DRA are combined together in order to achieve a broadband behaviour while improving the antenna gain. An impedance matching bandwidth of 12% (from 57GHz to 64GHz) has been predicted numerically for such radiating structures. The simulated antenna gain is 16.5 dBi, this being reported as the largest gain level featured by a single-element DRA.

The characteristics of the considered antenna are listed in Table 6. A class of linearly and circularly polarized cylindrical DRAs fed by substrate integrated waveguides is presentet. The proposed DRAs are designed in such a way as to resonate at 60GHz. Theme as urged impedance bandwidths are 24% and 4.5% for the linearly and circularly polarized DRA s, respectively. The performance characteristics of the linearly polarized DRA are summarized in Table 6.

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CONCLUSIONS

The results of dielectric properties of CCTO always vary when different techniques had been used. It is hope that after using plasma spray method, it can give a better result in term of microstructure and dielectric properties of CCTO. Recent developments in millimeter-wave DRA technology have been presented and discussed in detail in this survey.Furthermore, useful design guidelines have been provided to RF front-end designers in order to control circuital characteristics and radiation properties of this class of antennas. Different feeding techniques for DRAs have been first introduced, while outlining the relevant advantages and disadvantages. Furthermore, design approaches useful to achieve size reduction of DRAs have been discussed in detail. By using high permittivity materials or by placing conducting plates along specific symmetry planes of the resonator body, one can make DRAs considerably smaller. On the other hand, the gain of a DRA can be increased either by exciting therelevant higher-order modes (electrically large DRAs), or by integrating horn-like structures. Particular attention has been put on hybrid design techniques which rely on the combination of DRAs and radiating patch/slot antennas. In this way, the antenna impedance bandwidth can be easily tuned in such a way as to synthesize a dual-band rather than wide-band frequency response. Circular polarization of the electromagnetic field radiated by DRAs can be achieved by using various design methodologies.

In this respect, the cross-shaped feeding slot-based approach provides different benefits in terms of high coupling to the DR and additional degrees of freedom to control the polarization purity (axial ratio) of the DRA, in combination with ease of manufacturing and integration. Finally, advances in the application of DRA technology at millimeter-wave frequencies have been presented, and the most recent implementation of onchip DRAs and off-chip DRAs has been reviewed. It has been shown that DRAs realized on silicon substrates with standard CMOS process can be characterized by good efficiency and gain, thus proving the good potential of dielectric resonator antennas for said applications. Expected outcomes include a deeper understanding of CCTO's influence on DRA enhancement, a synthesis of diverse findings, and the identification of key factors influencing the performance of CCTO-enhanced DRAs. The review's conclusion will consolidate the observed outcomes, highlighting the progress made, challenges encountered, and potential avenues for further exploration in this burgeoning field of research, thus providing valuable guidance for researchers and practitioners in advancing dielectric material integration for enhanced antenna technologies.

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