A compact perovskite-based DRAs with multi-band and wideband characteristics for 5G and emerging 6G applications.

Abstract

The rapid evolution of fifth-generation (5G) wireless systems and the anticipated transition toward sixth-generation (6G) communication networks demand compact, high-efficiency, multi-band, and wideband antenna solutions capable of supporting ultra-high data rates, low latency, massive device connectivity, and enhanced spectral efficiency. Conventional metallic antennas suffer from conductor losses, surface wave excitation, electromagnetic interference (EMI), and limited miniaturization potential at microwave and millimeter-wave frequencies. Whereas, dielectric resonator antennas (DRAs) have emerged as a promising alternative due to their compact size, light weight, high gain, high bandwidth, high radiation efficiency, flexible excitation techniques, and high-permittivity ceramic materials. The present work focuses on the design, fabrication, and performance evaluation of a compact perovskite-based DRA exhibiting multi-band and wideband characteristics suitable for sub-6 GHz 5G and prospective 6G frequency regimes.

Perovskite oxide ceramics, particularly titanate-based compounds such as $BaTiO_3$, $SrTiO_3$, and $CaTiO_3$, etc., and related compositions, are known for their exceptionally high dielectric constant, tunable permittivity, low dielectric loss, and thermal stability. These properties make them highly attractive for antenna miniaturization and bandwidth engineering. In this study, perovskite ceramics are synthesized using the combustion method followed by high-temperature sintering to achieve dense microstructures with controlled grain morphology. Structural confirmation is performed using X-ray diffraction (XRD) analysis to verify phase purity and crystallinity. Microstructural examination through Field emission scanning electron microscopy (FESEM) ensures uniform grain distribution and reduced porosity. Fourier Transform Infrared (FTIR) spectroscopy further confirmed the characteristic stretching and bending vibrations in the 400–4000 cm^{-1} region, validating successful perovskite phase formation. The resonant frequency and return loss (S_{11}) of the fabricated DRA prototype are measured using a vector network analyzer (VNA) over the microwave frequency range and simulated through CST software to validate their suitability for antenna applications.

The proposed antenna employs a cylindrical dielectric resonator configuration excited using a slot-coupled microstrip feed mechanism. The use of high dielectric constant perovskite material enables substantial size reduction. The 5G operates mainly from 600 MHz to 40 GHz with bandwidth up to ~400 MHz, while 6G is expected to operate above 100 GHz (sub-THz to THz range) with bandwidths greater than 10 GHz, enabling ultra-high data rates. The antenna

exhibits a wide impedance bandwidth exceeding that of conventional single-mode DRAs, with return loss values below–15 dB across multiple bands. The realized gain ranges between 3.5–6 dBi depending on the excited mode, while radiation efficiency remains above 75%, confirming the low-loss nature of the optimized ceramic composition. Experimental validation is performed by fabricating the prototype and characterizing it using a calibrated vector network analyzer. Measured S_{11} characteristics show close agreement with simulated results, with minor deviations attributed to fabrication tolerances and dielectric constant variation during sintering. The radiation patterns measured in the far-field region confirm broadside radiation with stable pattern characteristics across operating bands. Cross-polarization levels remain within acceptable limits, ensuring reliable performance for practical wireless deployments. The antenna maintains stable performance under temperature variations, highlighting the thermal robustness of perovskite ceramics for real-time communication systems.

The multi-band response achieved in this work enables simultaneous support for diverse wireless services such as enhanced mobile broadband (eMBB), massive machine-type communication (mMTC), and ultra-reliable low-latency communication (URLLC). The wideband behavior further ensures improved channel capacity and reduced signal distortion. Unlike conventional metallic antennas, the dielectric-based structure mitigates surface current-related interference and reduces electromagnetic coupling in compact electronic environments. This advantage becomes particularly significant in dense 5G small-cell deployments and future 6G integrated sensing-communication platforms. From a materials engineering perspective, the study highlights the critical role of dielectric constant tailoring through compositional modification and sintering optimization. By controlling grain growth and densification, dielectric loss can be minimized while preserving the high permittivity required for miniaturization. The synergy between material design and electromagnetic simulation provides a pathway for the systematic development of next-generation functional antenna ceramics.

In conclusion, the proposed compact perovskite-based DRAs demonstrate promising multi-band and wideband characteristics suitable for 5G and emerging 6G applications. The integration of high-permittivity perovskite ceramics with optimized DRA geometry results in reduced antenna size, enhanced bandwidth, stable radiation patterns, and high efficiency. The outcomes of this work establish strong DRAs for future wireless communication systems, including smart devices, IoT networks, satellite-assisted 6G links, and AI-enabled communication platforms.

Success/Completion criteria:

- To design and fabricate a successful compact perovskite-based DRA with significant size reduction compared to conventional antennas.
- Achievement of stable multi-band or wideband operation covering targeted fractional bandwidth of at least 15–20% (with $|S_{11}| \leq -10$ dB) 5G and emerging 6G frequency bands.
- Attainment of high radiation efficiency (~ 90%) and acceptable gain with consistent radiation patterns across operating bands.
- Demonstration of suitable dielectric properties of the synthesized perovskite material, high permittivity (ε_r) and low dielectric loss ($\tan \delta$) for effective antenna performance.
- Good agreement between CST simulation and experimental VNA measurements, confirming practical feasibility and performance reliability.

Preconditions intellectual property:

- High-density, low-loss perovskite ceramics with stable dielectric constant must be successfully synthesized and characterized for operation in 5G and emerging 6G frequency ranges.
- Accurate measurement of dielectric constant (εr) and dielectric loss ($\tan\delta$) in the GHz region is required to validate material suitability for multi-band and wideband DRA applications.
- Novel perovskite material composition, compact DRA structure, and multi-band excitation techniques should be protected through patent filing prior to publication to secure intellectual property and commercialization potential.