# 3D Printed RF Antenna

## Contents



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## 1. Summary

In this project, the feasibility of fabricating a radio-frequency (RF) antenna via 3D printing was investigated, with particular emphasis on a metasurface-based approach. Interest in employing additive manufacturing for RF applications has grown substantially in recent years, owing to its potential for producing complex, lightweight components and reducing production costs. Nevertheless, only a handful of 3D-printable materials have been developed for microwave-frequency use.
Beam steering—i.e., controlling the direction of the radiated beam—often proves both complex and expensive when achieved through purely electronic means, while mechanical alternatives tend to be bulky and heavy. In this context, the use of 3D printing to realize Risley prisms offers an innovative, lightweight, and potentially low-cost solution for dynamically directing the beam. This technique exploits local control over the shape, size, and arrangement of sub-wavelength dielectric structures to create a gradient refractive index and thereby modulate the phase of the wavefront. Originally developed in the optical domain, it has since been successfully adapted to microwave frequencies, greatly expanding its range of applications (Fig. 1).

## 2. Objectives

The complex geometries required—combining microstructures and macrostructures—are difficult to produce using traditional methods such as milling or sintering. Additive manufacturing, on the other hand, enables the fabrication of these intricate three-dimensional forms without mechanical post-processing, thereby simplifying the workflow and reducing costs. Consequently, the objective of this work, leveraging Granta EduPack, is to identify a material that exhibits a high dielectric constant, low loss tangent, high thermal conductivity, and compatibility with an FDM process. Finally, the performance of conventional materials is compared with an alternative proposed by Zetamix, consisting of a cyclic olefin copolymer (COC) loaded with titanium dioxide ($TiO_2$).

## 3. Problem statement

In the framework of this research, driven by the ongoing technological evolution of electronic devices, there is a growing need for advanced polymeric materials that marry superior dielectric performance with robust processability. In particular, applications such as the RF antennas examined in this study, together with printed-circuit-board substrates, sensors, and microelectronic components, require materials that exhibit:

- A high relative permittivity ($\varepsilon_r$) to ensure effective storage and transmission of electromagnetic fields.
- A low dissipation factor (tan δ) to minimize dielectric losses under alternating fields.
- Adequate thermal stability—characterized by a high glass-transition temperature (Tg)—to withstand critical operating conditions.
- Compatibility with production techniques such as extrusion and additive manufacturing, thereby facilitating industrial uptake.

Achieving all these characteristics simultaneously in a single polymer is exceptionally rare. Manual selection—relying on disparate tables or technical references—is both inefficient and susceptible to oversight. Therefore, this work adopts a systematic, computer-aided methodology (via Granta EduPack) to screen and rank candidate polymers against these criteria. Such an approach enables rapid, objective, and reproducible identification of optimal solutions from an extensive materials database, ensuring alignment with the project's metasurface-based RF-antenna objectives.

## 4. Proposed solution

To address the challenge of selecting polymeric materials suitable for applications with stringent dielectric requirements, Ansys Granta EduPack 2025 was employed, using the MaterialUniverse database filtered to Level 3 Polymer. The adopted strategy involved a multi-stage selection process, with progressively more stringent criteria:

**Stage 1 – Initial filtering based on key requirements**

The following constraints were imposed (Fig. 2):

- Glass transition temperature ($T_g$) ≥ 100 °C, to ensure thermal stability of the material in electronic applications.
- Relative dielectric constant ($\varepsilon_r \geq 2$), in order to guarantee adequate insulating properties.
- Dissipation factor (tan δ) ≤ 0.005, to minimize dielectric loss.
- Extrudability rating of "Acceptable" or "Excellent," since the objective is to produce a filament suitable for the FDM process.

**Stage 2 – Adding new records**

Utilizing tools such as 'Add New Record' and 'Synthesizer', key materials such as Zetamix Epsilon, ABS-$BaTiO_3$, and COP-$TiO_2$ were added to the system, as they were not previously included in the existing database (Fig. 3).

**Stage 3 – Ashby chart: relative permittivity vs. dissipation factor**

An Ashby chart is generated with $\varepsilon_r$ on the x-axis and tan δ on the y-axis. The objective here is to evaluate the balance between the ability to store electric field energy and dielectric loss (Fig. 4).

**Stage 4 – Definition of Ka-band "box" selection**

To focus the selection on materials suitable for operation in the Ka-band (approximately 26.5 – 40 GHz), an additional refinement level is introduced based on $\varepsilon_r$ and tan δ values typical of polymers optimized for those frequencies. It is well established that, in the Ka-band, achieving a favorable trade-off between transmission and loss requires choosing materials with moderate permittivity and very low tan δ (Fig. 5).

Numerical criteria for the Ka-band selection box:

- $2{,}5 \leq \varepsilon_r \leq 3{,}2$
- $\tan \delta \leq 0{,}003$

## 5. Results and conclusions

The materials screening identified several polymers with potential for use in Ka-band metasurface-based RF antennas, especially those compatible with FDM 3D printing and exhibiting favorable dielectric properties.

Among the noteworthy findings:

- ABS (Acrylonitrile Butadiene Styrene), while not ideal on its own due to moderate dielectric losses, becomes significantly more promising when combined with high-permittivity ceramic fillers such as barium titanate ($BaTiO_3$).
- The COC–$TiO_2$ composite, marketed under the Zetamix Epsilon® tradename by Nanoe, emerged as a particularly strong candidate. It combines a moderate relative permittivity ($\varepsilon_r$) with an exceptionally low dissipation factor, and is specifically engineered for high-frequency applications.

In conclusion, to illustrate the benefits of using high-permittivity, low-loss materials in RF applications, a simulation study was reviewed [4]. Two sub-wavelength diffractive prisms (Ø 250 mm) were modeled in **CST Microwave Studio 2018** to compare performance:

- One prism was made from **ABS**
- The second used **COC–$TiO_2$**

As shown in (Fig. 6), the geometries were identical aside from the material. At **30 GHz**, the high-permittivity prism showed:

- **50% thickness reduction** (11 mm vs. 22 mm)
- **1 dB higher directivity** (34.8 dBi vs. 33.8 dBi), as shown in (Fig. 7)

These results highlight the growing potential of additive manufacturing to produce complex RF structures and to modify the dielectric properties of base materials through filler integration, in order to meet the required performance criteria.

## 6. References

[1] Thi Quynh Van Hoang, Matthieu Bertrand, Erika Vandelle, Brigitte Loiseaux. Low-Profile Highly Directive 2D-Beam-Steering Antenna in Ka-band with 3D-printed All-dielectric Sub-wavelength Deflectors. 2022 52nd European Microwave Conference (EuMC), Sep 2022, Milan, Italy. ⟨10.23919/EuMC54642.2022.9924439⟩. ⟨hal-03839508v2⟩

[2] High Permittivity, Low Loss, and Printable Thermoplastic Composite Material for RF and Microwave Applications

[3] https://zetamix.fr/en/produit/zetamix-%C9%9B-filament/ (data sheet)

[4] R. Czarny *et al.*, "High Permittivity, Low Loss, and Printable Thermoplastic Composite Material for RF and Microwave Applications," *2018 IEEE Conference on Antenna Measurements & Applications (CAMA)*, V□sterås, Sweden, 2018, pp. 1-4, doi: 10.1109/CAMA.2018.8530660.

# 7. Appendix

*Figure 1 3D-Printed Beam steering system*

| Attribute | Constraints |
|---|---|
| Glass temperature (°C) | ≥ 100 |
| AND Dielectric constant (relative permittivity) | ≥ 2 |
| AND Dissipation factor (dielectric loss tangent) | ≤ 0,005 |
| AND Polymer extrusion | Acceptable, Excellent |

*Figure 2 Constraints*

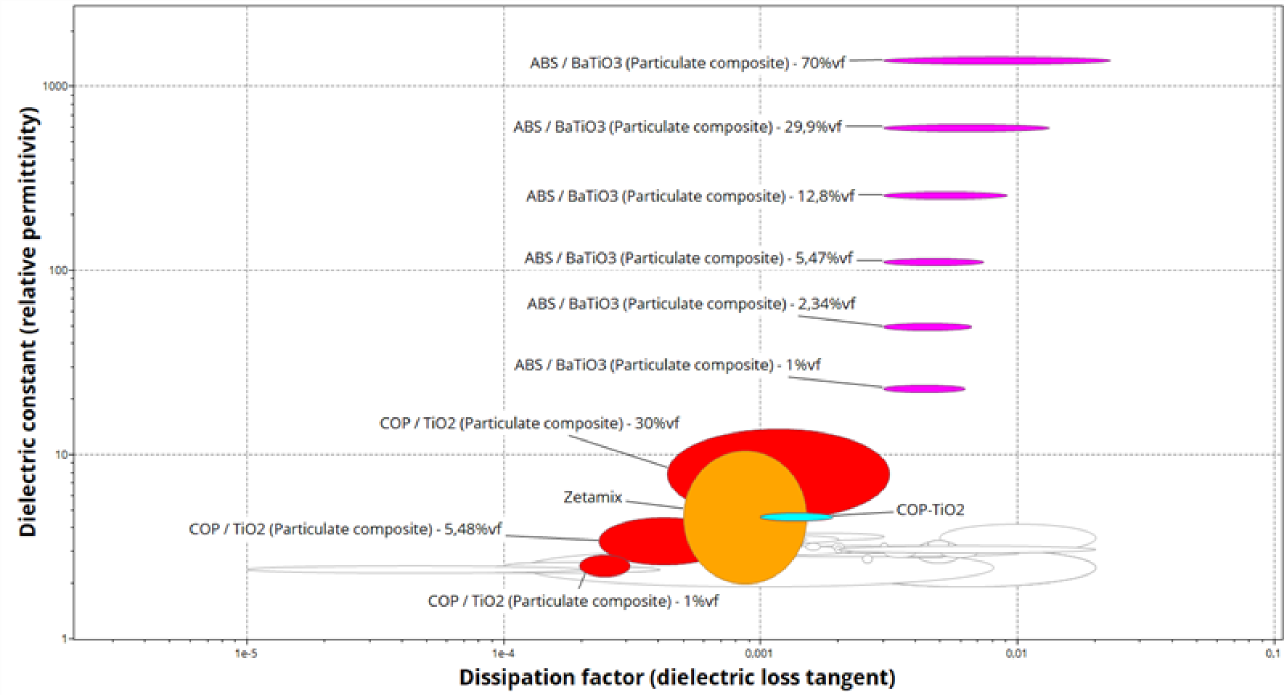



*Figure 3 Materials added (New records and synthesizer)*

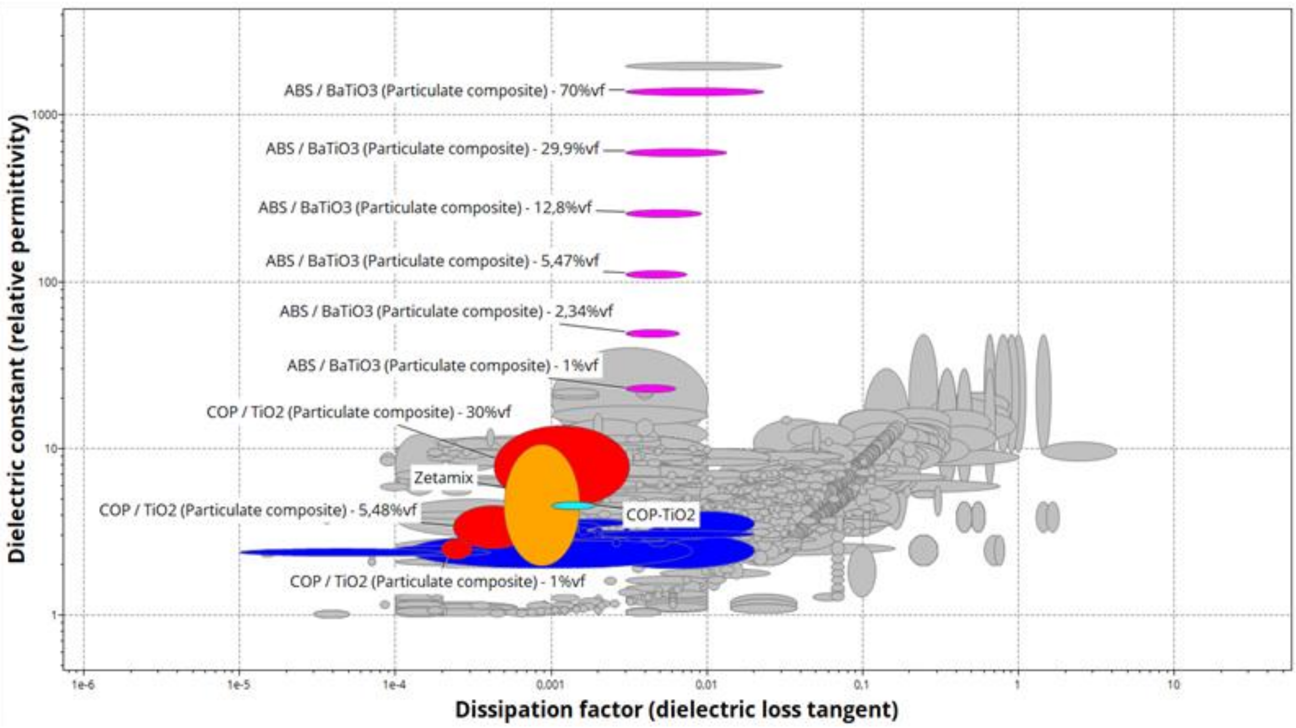



*Figure 4 Ashby chart: relative permittivity vs. dissipation factor*

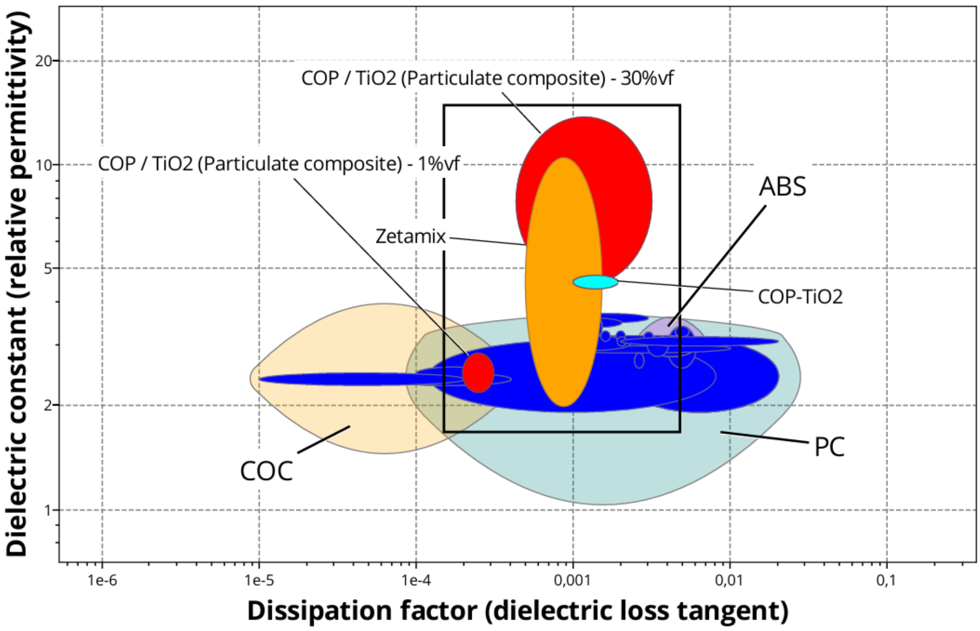
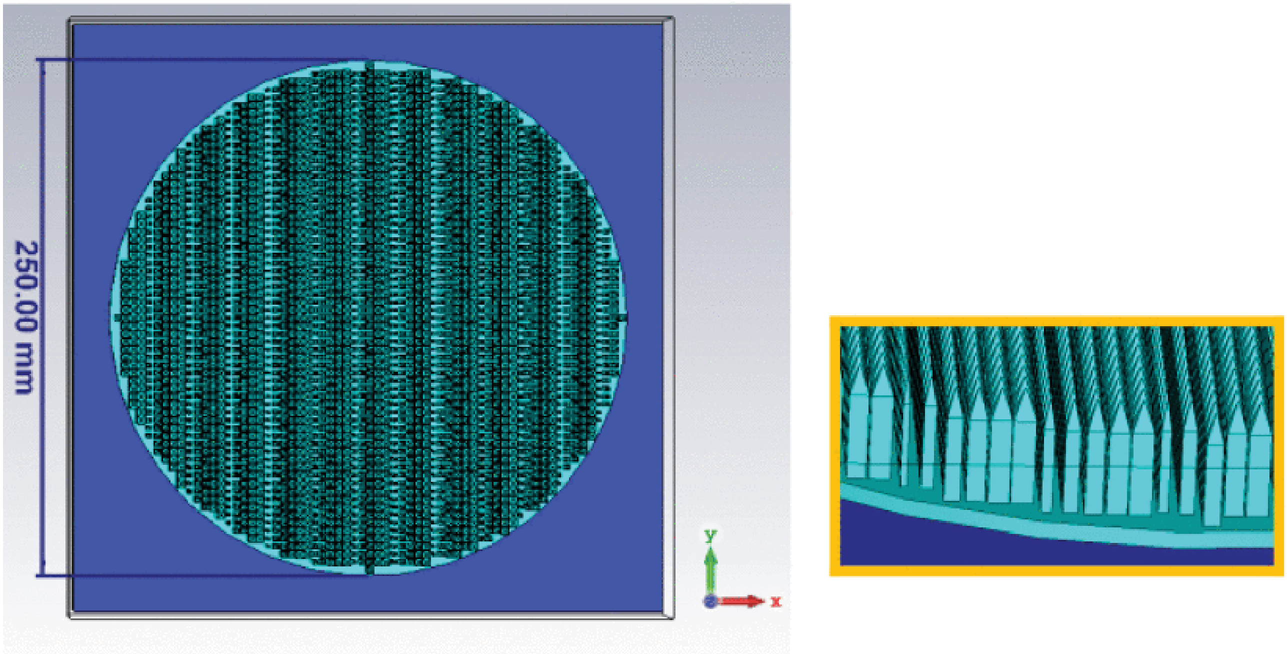



*Figure 5 Selection Box*




(a) (b)

*Figure 6 (a) entire component; (b) zoom in the pillars*

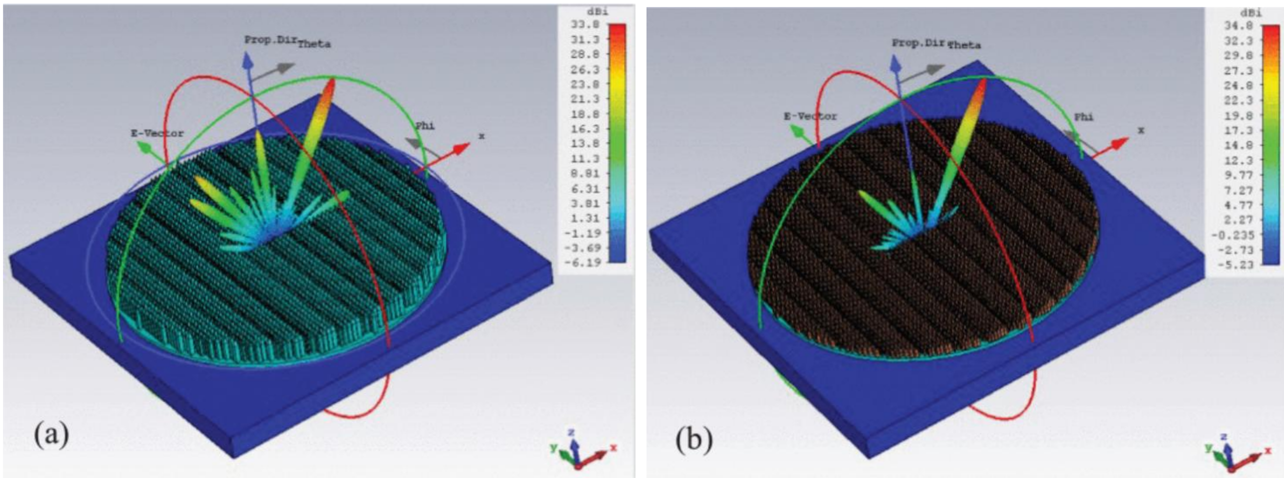



*Figure 7 CST simulation results: 3D radiation pattern: (a) Component in ABS (b) Component in COC-TiO2*