

6G-INTEGRATION-05-E5: Broadband detector



6G-INTEGRATION

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Executive Summary

This document provides a detailed description of the solution implemented by UC3M for the 6G-Integration project, aimed at developing an ultrawideband broadband detector.

The development of broadband receivers is closely aligned with the objectives of 3GPP Release 17 ("Rel17"), which introduces standardized support for Non-Terrestrial Networks (NTNs) within the 5G framework. These networks, encompassing Low Earth Orbit (LEO) satellites and High-Altitude Platform Stations (HAPS) platforms, demand highly flexible and adaptive receiver architectures capable of operating across wide frequency ranges to address the diverse spectrum allocations, dynamic channel conditions, and Doppler effects inherent to NTN scenarios. Broadband receivers enable critical functionalities such as carrier aggregation across disparate bands, efficient spectrum utilization, and dynamic adaptation to varying propagation environments. As such, they are key enablers for the implementation of Rel17 NTN features and form a foundational technology for the evolution toward beyond 5G (B5G) and 6G, where integration of terrestrial and non-terrestrial systems and exploitation of higher frequency bands will be essential.

UC3M's proposal is based on a high-sensitivity THz photon counting receiver operating in the 75-110 GHz band. The receiver is based on a Whispering Gallery Mode Resonator (WGMR) and a dielectric rod waveguide (DRW) antenna for efficient coupling of THz power to the resonator.

This report focuses on the development of the broadband DRW antenna. Both the design process and the experimental validation of a manufactured prototype are presented.

Resumen ejecutivo

Este documento ofrece una descripción detallada de la solución implementada por la UC3M en el marco del proyecto 6G-Integration, cuyo objetivo es el desarrollo de un detector de banda ultraancha.

El desarrollo de receptores de banda ancha está estrechamente alineado con los objetivos de la Release 17 del 3GPP ("Rel17"), que introduce el soporte estandarizado para las Redes No Terrestres (NTN) dentro del ecosistema 5G. Estas redes, que incluyen satélites en órbita baja (LEO) y plataformas de gran altitud (HAPS), requieren arquitecturas de receptor altamente flexibles y adaptativas, capaces de operar en rangos de frecuencia amplios para abordar la diversidad en la asignación espectral, las condiciones dinámicas del canal y los efectos Doppler propios de los escenarios NTN. Los receptores de banda ancha permiten funcionalidades clave como la agregación de portadoras en bandas no contiguas, el uso eficiente del espectro y la adaptación dinámica a entornos de propagación variables. Por tanto, constituyen una tecnología habilitadora esencial para la implementación de las funcionalidades NTN definidas en Rel17, y sientan las bases para la evolución hacia B5G y 6G, donde la integración de redes terrestres y no terrestres, así como el aprovechamiento de bandas de frecuencia más altas, será fundamental.

La propuesta de la UC3M se basa en un receptor de conteo de fotones en terahercios (THz) de alta sensibilidad, operando en la banda de 75–110 GHz. El receptor emplea un resonador de modo galería de susurros (WGMR) y una antena de guía de onda de varilla dieléctrica (DRW) para lograr un acoplamiento eficiente de la potencia en THz al resonador.

Este informe se centra en el desarrollo de una antena DRW de banda ancha para este receptor, presentándose los detalles de diseño y validación experimental de un prototipo de esta en las siguientes secciones.

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Glossary

3GPP	3 rd Generation Partnership Project
5G	5 th Generation technology standard for cellular networks
6G	6 th Generation technology standard for cellular networks
B5G	Beyond 5G
DRW	Dielectric Rod Waveguide
DRWA	Dielectric Rod Waveguide Antenna
HAPS	High Altitude Platform Station
LEO	Low Earth Orbit
mmWave	Millimeter waves
NTN	Non-Terrestrial Network
Rel17	Release 17 of the 5G standard
UC3M	Universidad Carlos III de Madrid
WGMR	Whispering Gallery Mode Resonator
WR	Waveguide Rectangular

Introduction

The integration of terrestrial and non-terrestrial networks (NTNs) represents a fundamental step toward the realization of global, ubiquitous connectivity in future 5G and beyond-5G (B5G/6G) systems. 3GPP Release 17 (Rel17) marks a significant milestone by introducing standardized support for NTNs within the 5G architecture, enabling seamless interoperability between ground-based infrastructure and platforms such as Low Earth Orbit (LEO) satellites and High-Altitude Platform Stations (HAPS). This evolution brings about new challenges in terms of system design, particularly at the radio frequency front-end, where communication links must adapt to a wide variety of propagation environments, spectrum allocations, and mobility patterns.

In this context, the development of broadband receiver technologies is of critical importance. These receivers must operate across ultra-wide frequency bands to support flexible spectrum use, carrier aggregation, and the coexistence of multiple services and waveforms. Moreover, the unique conditions of NTN links—such as large Doppler shifts, long signal delays, and high path losses—demand receiver architectures with high sensitivity, low noise figures, and strong adaptability. Broadband receivers thus serve as key enablers for the successful implementation of NTN capabilities defined in Rel17, being essential for future evolutions of the 5G standard toward fully integrated terrestrial and non-terrestrial systems.

A high-sensitivity receiver in the range from 75 to 110 GHz has been developed at UC3M for ultra-wide band operation. Figure 1 shows the schematic of the proposed receiver, which is formed by a Dielectric Rod Waveguide Antenna (DRWA) and a Whispering Gallery Mode Resonator (WGMR) for efficient coupling of the THz power.

This document focuses on the design and micromachining of dielectric waveguides to illuminate the radiating part of the DRWA.

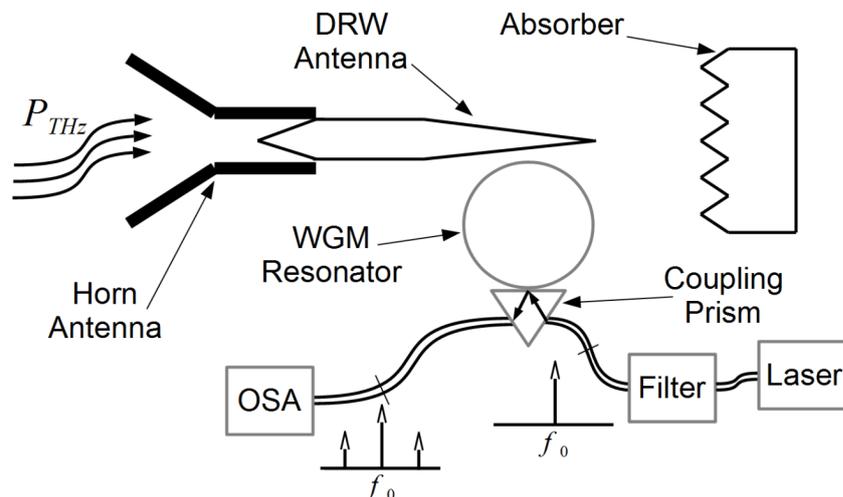
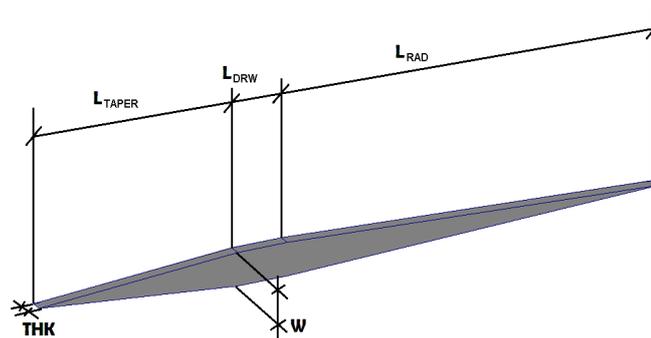


Figure 1 – Schematic of the proposed broadband receiver

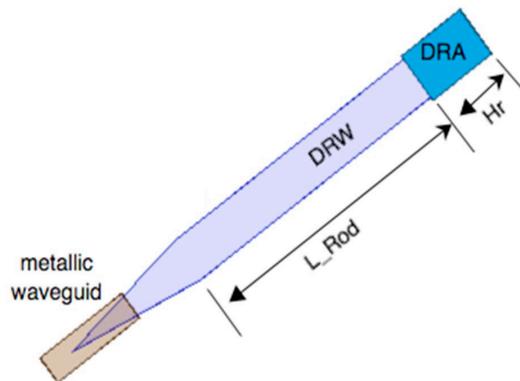
Dielectric rod waveguides

Figure 5 illustrates the schematic of a DRWA, where two additional tapers are added at both sides of the DRW to achieve both good matching in the operation band and proper radiation to the free space.

The tapered rectangular dielectric rod waveguide is made of Acrylonitrile Butadiene Styrene (ABS) with a relative permittivity of 4.5, and a metallic waveguide (WR-34) with fixed internal dimensions of $4.318\text{mm} \times 8.636\text{mm}$ is used for feeding. The DRA is made of Polylactic Acid (PLA) with a relative permittivity of 2.5. The matching can be done by varying the length of tapered section inside the metallic waveguide.



(a)



(b)

Figure 2 – Sketch of a Dielectric Rod Waveguide Antenna

(a) Perspective view, (b) Side view

The design procedure begins with a simulation of the transition in the DRW to optimize the size of the DRW. The optimal cross-section of the DRW is $6.65 \text{ mm} \times 6.4 \text{ mm}$, and the optimal length value of the tapered section for waveguide matching is 10.74 mm .

Figure 3 shows the E-field distribution obtained through full-wave simulations in Ansys High Frequency Structure Simulator (HFSS). These results show efficient feeding through the waveguide as the field is predominantly guided into the DRW, and single-mode propagation is achieved. This is consistent with the experimental reflection S-parameters shown in Figure 4, where an excellent match (below -10 dB) over the whole 5G mm-wave band (from 22 to 32 GHz) is observed.

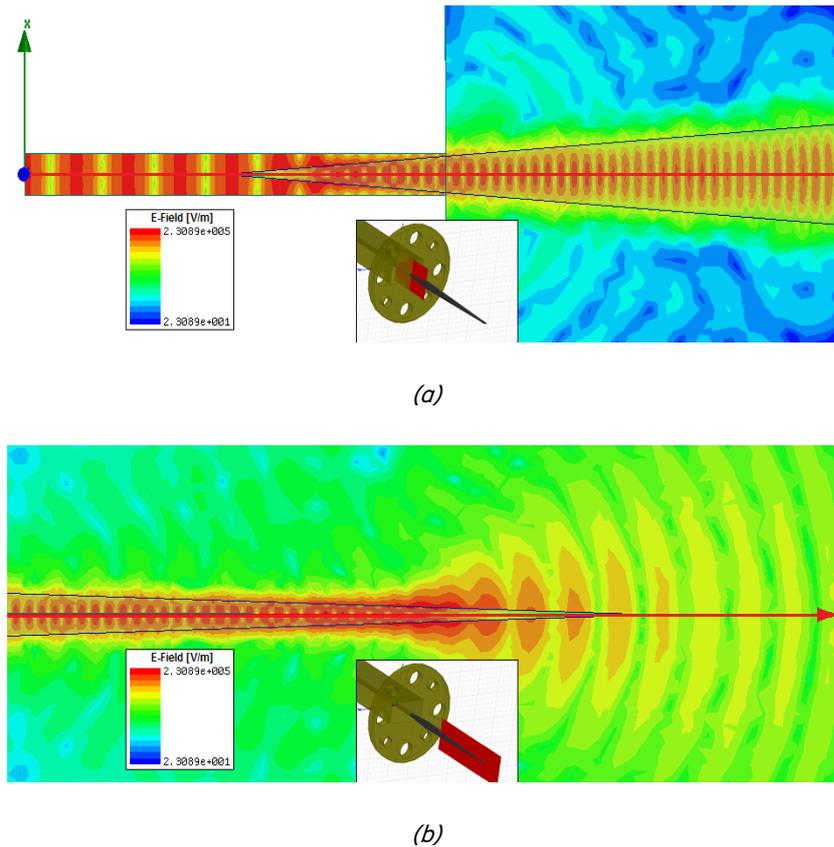


Figure 3 – Simulated E-field distribution $[\log(V/m)]$ on XZ plane in the DRW
 (a) Waveguide DRW transition, (b) radiation taper

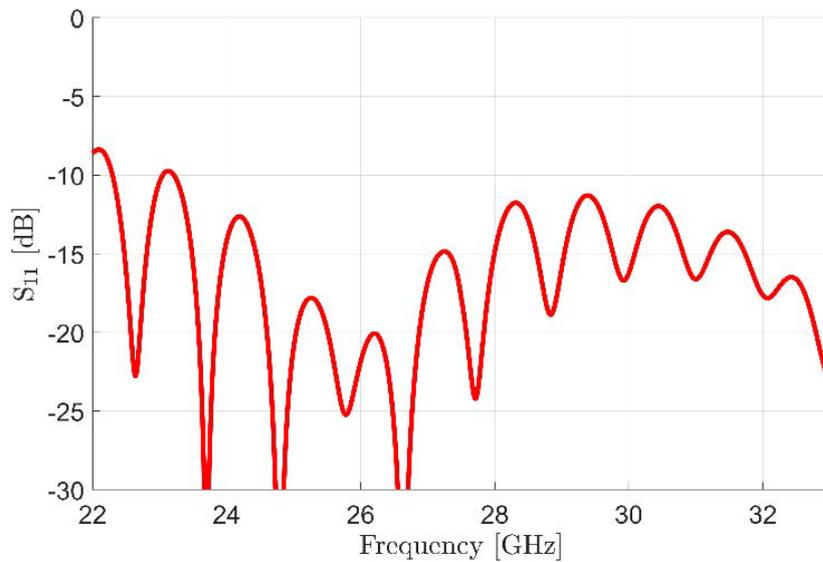
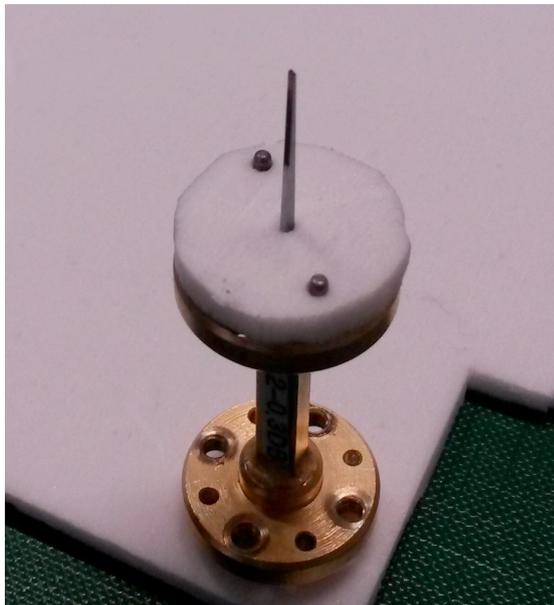


Figure 4 – Reflection S-parameters at the input of the DRWA

The manufactured prototype of the DRWA is presented in Figure 5. Proper alignment into the metal waveguide is achieved by gluing a low-density foam ring in a 2 mm long section of the DRW, while contact between metal and semiconductor is avoided using a Teflon strip. The optimum dimensions of the antenna are 7.75 mm × 7.75 mm × 10.77 mm.



(b)

Figure 5 – Manufactured prototype of the dielectric rod waveguide antenna in the mm-wave band.

Conclusion

This work evaluates the excitation of dielectric rod antennas using rectangular waveguides. Full-wave simulations show good impedance matching and efficient feeding, with single-mode guided propagation successfully achieved in the dielectric rod waveguide (DRW). A prototype of the DRW was fabricated, confirming the practicality and feasibility of the proposed design for mm-wave applications.

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