Environmentally Protected Transparent Microstrip Patch Antenna Using ITO-Kapton Layers for Sustainable CubeSat Communications

Amjad Alanazi, Haneen Alhussain, Amal Alanazi, Ruyuf Almuaither, Dana Alqumaizi, Tulin Alhazmi, Taef Bawazir.
Department of Electrical Engineering, College of Engineering, Princess Nourah bint Abdulrahman University, P.O. Box 84428, Riyadh 11671, Saudi Arabia

Abstract

Environmental degradation and RF performance constraints are critical challenges for CubeSat antennas operating in Low Earth Orbit (LEO). In this project, we propose a transparent microstrip patch antenna using Indium Tin Oxide (ITO) combined with a 0.05 mm Kapton protective layer for 1U CubeSats. The antenna targets Ku-band operation (12–18 GHz) to support high-data-rate communication while preserving solar panel efficiency. Three cases were simulated: Copper, ITO, and ITO + Kapton. Results show that the ITO + Kapton design achieves a gain of 6.15 dBi, a bandwidth of 2.7 GHz, and an effective optical transmittance of 93.02%, with an estimated operational lifetime exceeding two years — significantly outperforming conventional copper designs in LEO durability.

Introduction

- The congestion of traditional frequency bands and the growing need for higher data rates are driving a shift toward Ku, K, and Ka bands in CubeSat communications. However, designing efficient antennas for these high frequencies is challenging due to the strict size and power constraints of CubeSat platforms, and existing research in this area remains limited and lacks comprehensive, structured analysis. Beyond RF performance, antennas operating in Low Earth Orbit (LEO) must withstand harsh environmental conditions that degrade conventional copper-based designs within less than a year. This project addresses these challenges by proposing a transparent microstrip patch antenna using ITO on a 0.05 mm Kapton protective layer, targeting Ku-band operation (12–18 GHz) while preserving solar panel efficiency and extending the operational lifetime in LEO.

Methodology

The methodology focuses on a multi-layered design and simulation approach:
System Layering: Defining the electromagnetic properties of the Kapton coating and transparent antenna substrate.
EM Simulation: Analyzing the interaction between the antenna and the underlying solar panel to ensure minimal signal interference.
Optimization: Refining the transparency-to-conductivity ratio to achieve optimal gain without shadowing the solar cells.

- **Electromagnetic Boundary Analysis**

The antenna structure was analyzed as an electromagnetic boundary value problem (BVP) using Maxwell's equations. Boundary conditions were applied between the air, ITO conductive layer, and Kapton protective layer to study electromagnetic wave propagation, reflection, and transmission across the material interfaces.

$$\nabla^2 E + k^2 E = 0$$

$$E_{1t} = E_{2t}$$

The analysis was used to evaluate antenna performance parameters such as S11, radiation efficiency, and transparency under environmental protection constraints.

Table 1. System Model and Methodology Overview

Step	Description	Objective
System Layering	Defining the ITO + Kapton layers and CubeSat solar panel for the antenna.	Ensure proper multi-layer interaction without EM interference.
Simulation	Analyzing antenna-solar panel interaction using 3D and 2D simulations (S11, Gain, Radiation Pattern).	Ensure minimal signal interference and maintain antenna performance.
Optimization	Refining transparency-to-conductivity ratio of the antenna layers.	Achieve optimal gain while maintaining solar panel illumination.

Main Idea

The proposed solution introduces an innovative Transparent Antenna system integrated directly onto the solar panels of a CubeSat. By utilizing transparent conductive materials and a protective Kapton coating, this design solves the surface area constraints of small satellites. It allows sunlight to pass through to the solar cells for power generation while simultaneously maintaining high-performance radio frequency (RF) communication links. This integration maximizes space efficiency and enhances the overall reliability of LEO satellite missions.

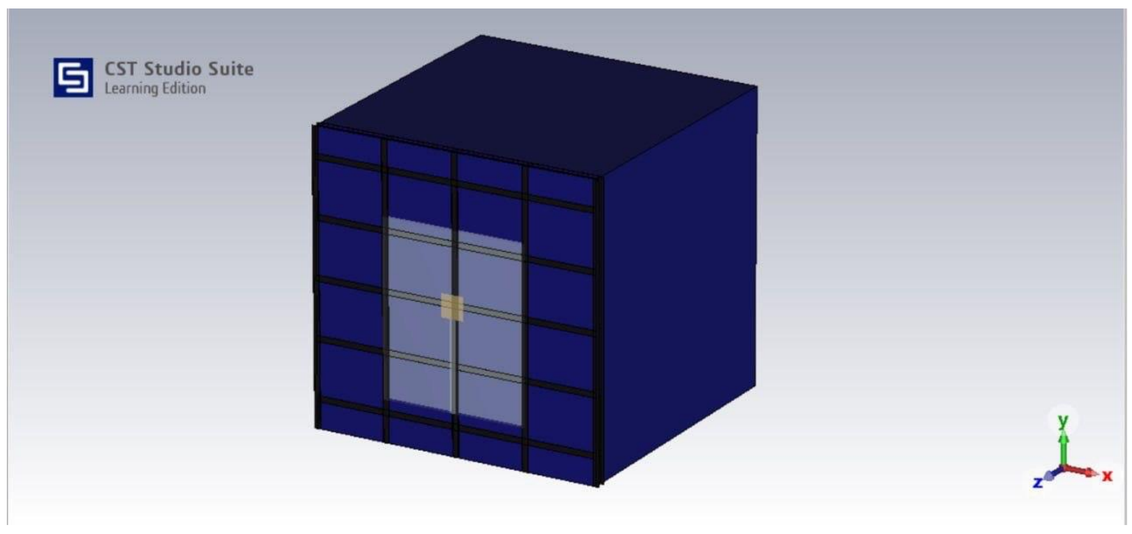


Figure 1. Visual representation of the patch antenna on a U1 CubeSats in CST Studio

Results

The simulated ITO + Kapton microstrip patch antenna for a 1U CubeSat resonates at 12 GHz with a gain of 6.15 dBi and radiation efficiency of 59.43%, while S11 reaches −16 dB. The bandwidth of 2.7 GHz meets Ku-band requirements. Optical analysis shows 93% effective transmittance, allowing efficient solar panel operation, and the estimated operational lifetime exceeds 2 years, outperforming copper antennas (<1 year). These results confirm a balanced design, combining efficient RF performance, high transparency, and long-term reliability, suitable for long-duration CubeSat missions.

Name	Best S11 (dB)	Gain (dBi) at 15GHz	Bandwidth (GHz)	T_eff (%)	Lifetime (years)
Copper	-35.0	6.42	4.8	75.0	0.8
ITO	-16.0	6.15	2.7	97.25	2.0
ITO + Kapton	-16.0	6.15	2.7	93.02	2.5

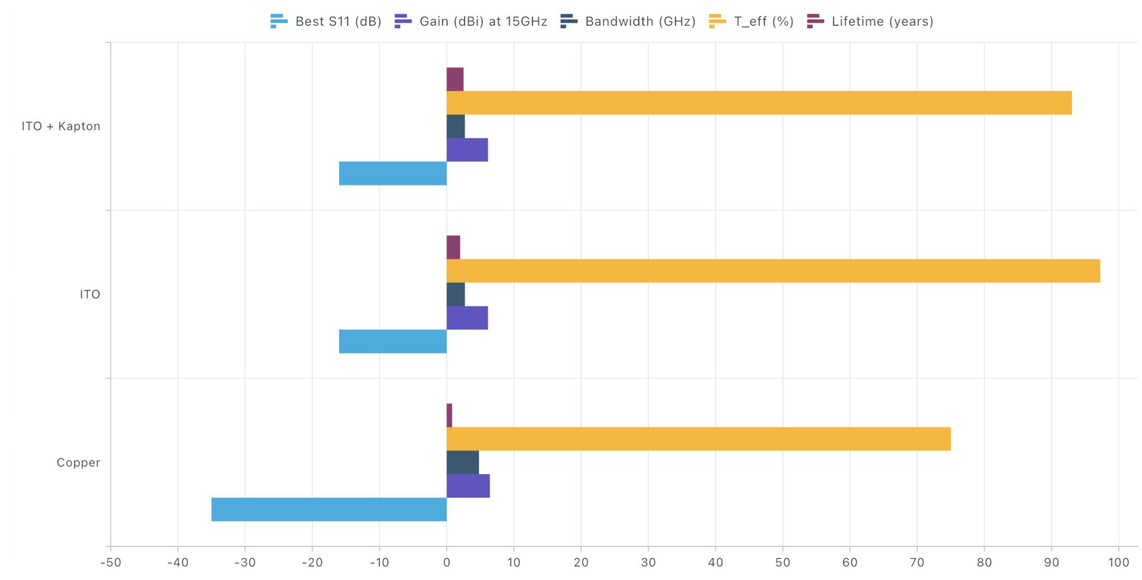


Figure 2. CubeSat Antenna Simulation Metrics and Estimated Lifetime.

Conclusions

This study demonstrates that transparent ITO + Kapton microstrip patch antennas are highly suitable for CubeSats in LEO, combining optical transparency (~93%) with efficient RF performance (gain ~6 dBi, radiation efficiency ~59%). These antennas enable integration with solar panels without significant power loss, making them ideal for small satellite platforms. Array configurations further improve gain (up to 22 dBi) and allow directional, high-data-rate communication. The research highlights a balance between electrical performance, optical transparency, and structural durability. Future work will focus on optimizing bandwidth, testing alternative transparent materials, and extending these designs for longer-duration missions and higher-frequency CubeSat applications.

© Poster Template by Genig