Simulation of and Antenna Design for a Reflector-based Broadband Axion Search

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Introduction

The axion is a theoretical particle that presents a solution to the Strong CP problem in the Standard Model and is a strong candidate for dark matter.

Axions convert to photons in the presence of a strong magnetic field. Searches for the axion capitalize on this property, but the unknown mass of the axion means the frequency of oscillation of the photons is also unknown. This work explores a broadband reflector-based experiment with a conical horn antenna and circular waveguide as a new potential search method for this particle.

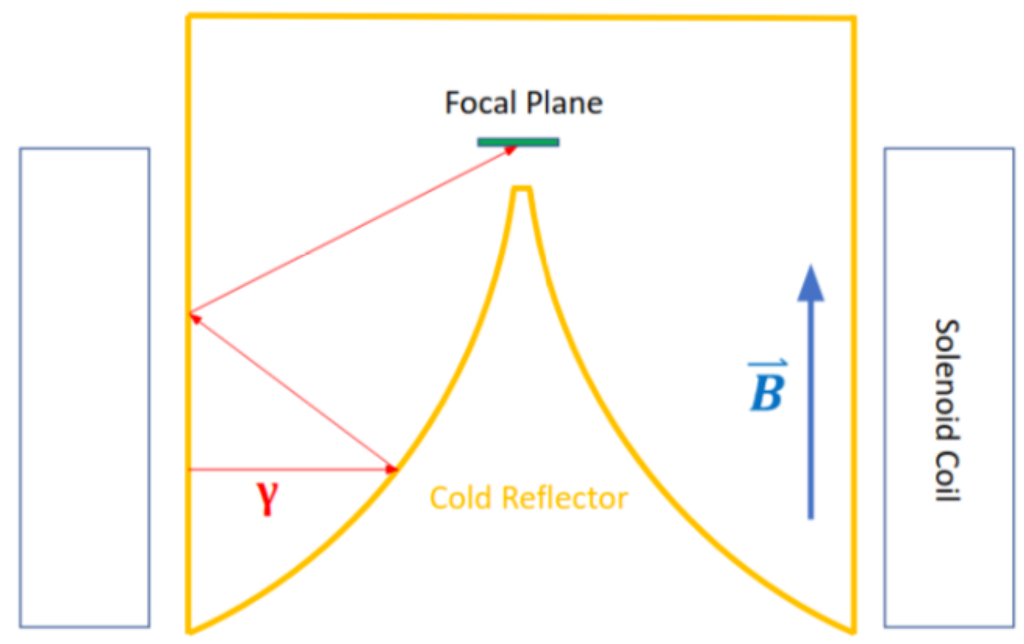

Fig 1. Schematic of the reflector-based experiment

Experiment

This experiment places a parabolic reflecting surface enclosed in a cylinder into a uniform magnetic field. Photons converted from axions are reflected and focused to a plane where an antenna will be used to receive this signal for measurement (Fig 1).

This work used COMSOL Multiphysics as a 2D axial symmetric model to simulate this experiment. Axions were modeled as a uniform volume of current density oriented in the z direction.

An antenna was designed to have a 20 dB gain at a signal frequency of 10 GHz for a TE_{11} mode excitation. The length and the size of the horn aperture were chosen to achieve this performance.

Methodology and Results

Project Goals:

- Characterize power in model
- Design and test an antenna

This project measured the power along the surface of a sphere with variable radius surrounding the focus. The expectation was for the net power flux through the sphere to be zero.

An antenna was designed, and the following were calculated to determine its efficiency:

- S11 parameters
- Power emitted from the waveguide
- Gain

Characterizing the power in this model revealed a flaw in the assumptions made by this test. The axion current has no spatial dependence, producing a standing wave as opposed to a transverse wave. This type of wave does not necessarily allow for a net power flux of zero.

The S11 reflection parameter graph for the antenna shows close matching at 14 GHz (Fig 2). The antenna was designed using parameters for antennas supporting a TE_{11} mode, but the orientation of the current causes a TM_{01} mode to propagate.

The transmitted power and S11 graphs do not seem to have consistency between them, which is puzzling. It is promising that the electric field strength at 9 GHz and 14 GHz (Figs 4,5) are consistent with the peaks in power, but the inefficiency of the antenna is disappointing.

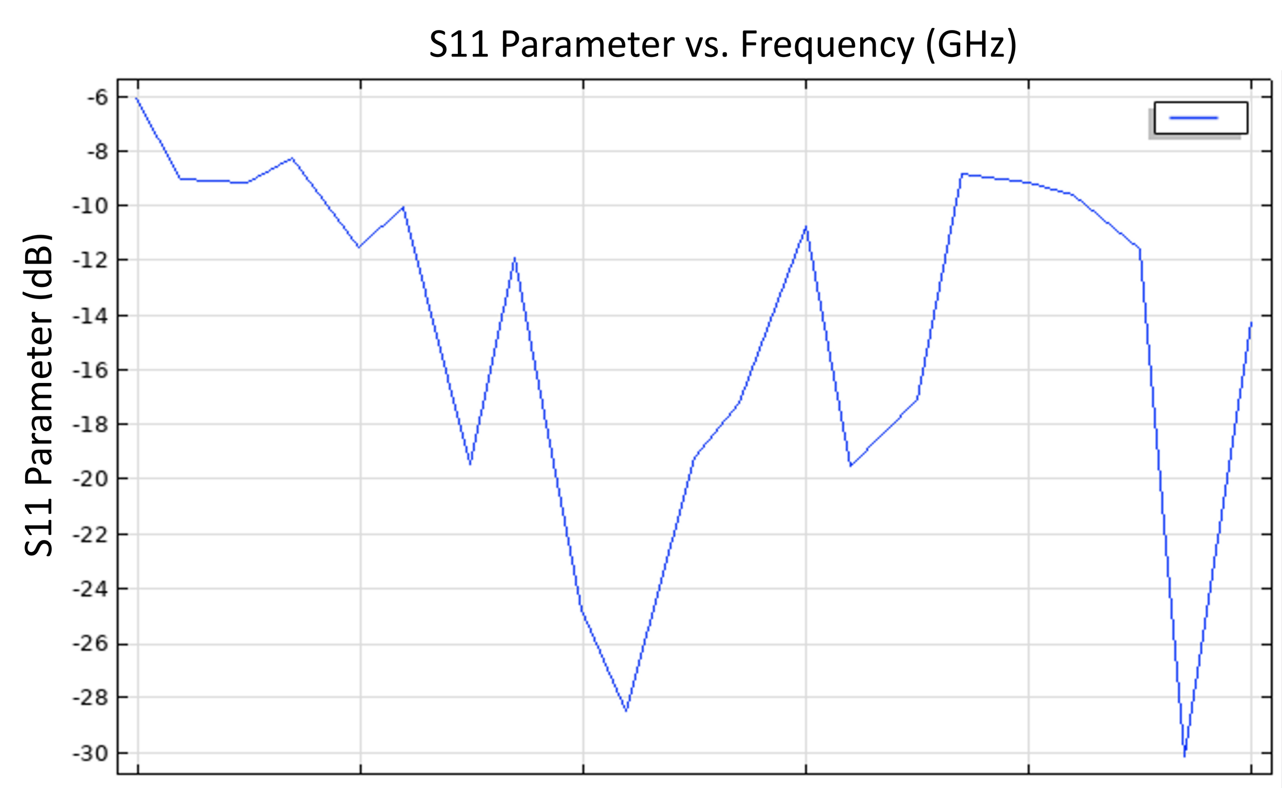

Fig 2. S11 reflection parameters of antenna

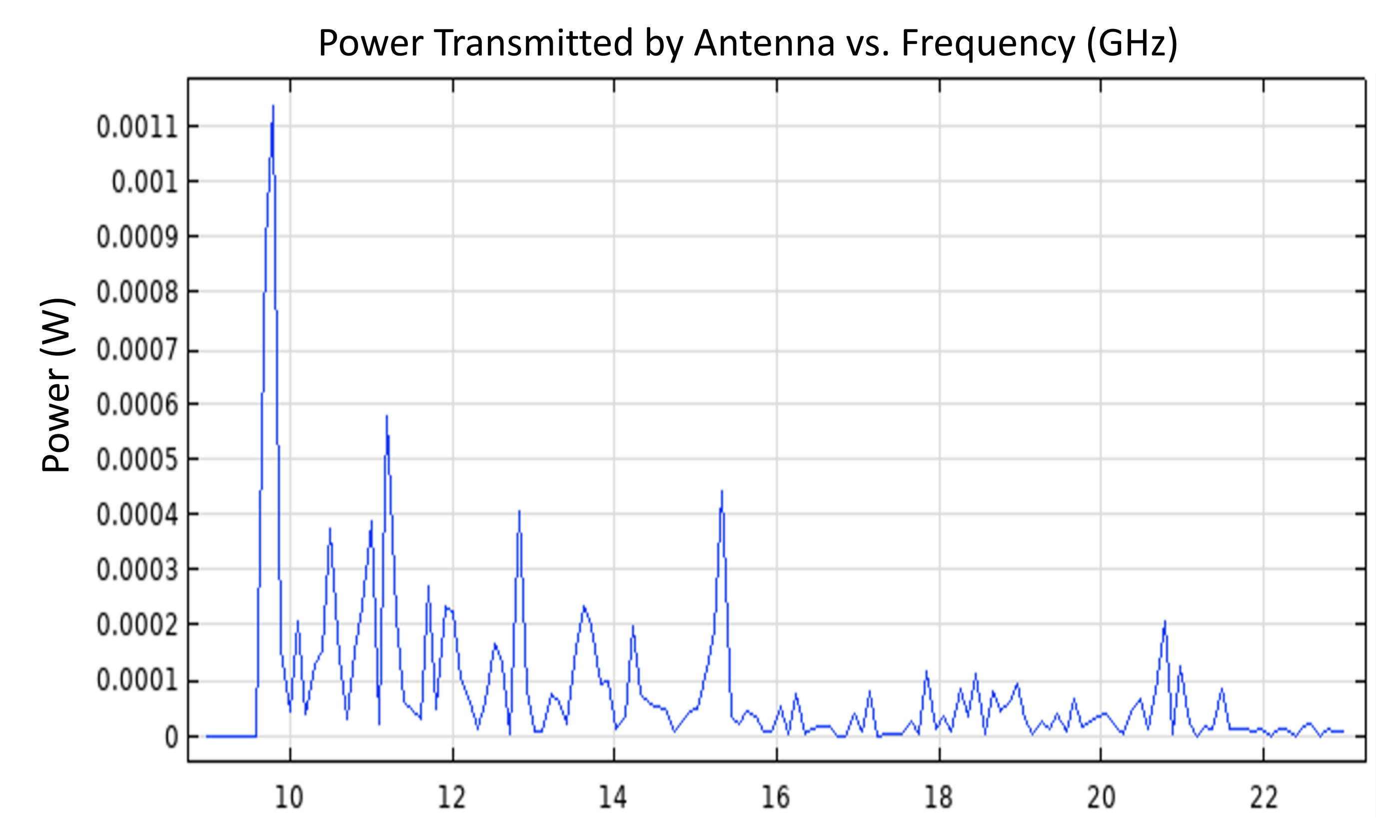

Fig 3. Power transmitted by antenna

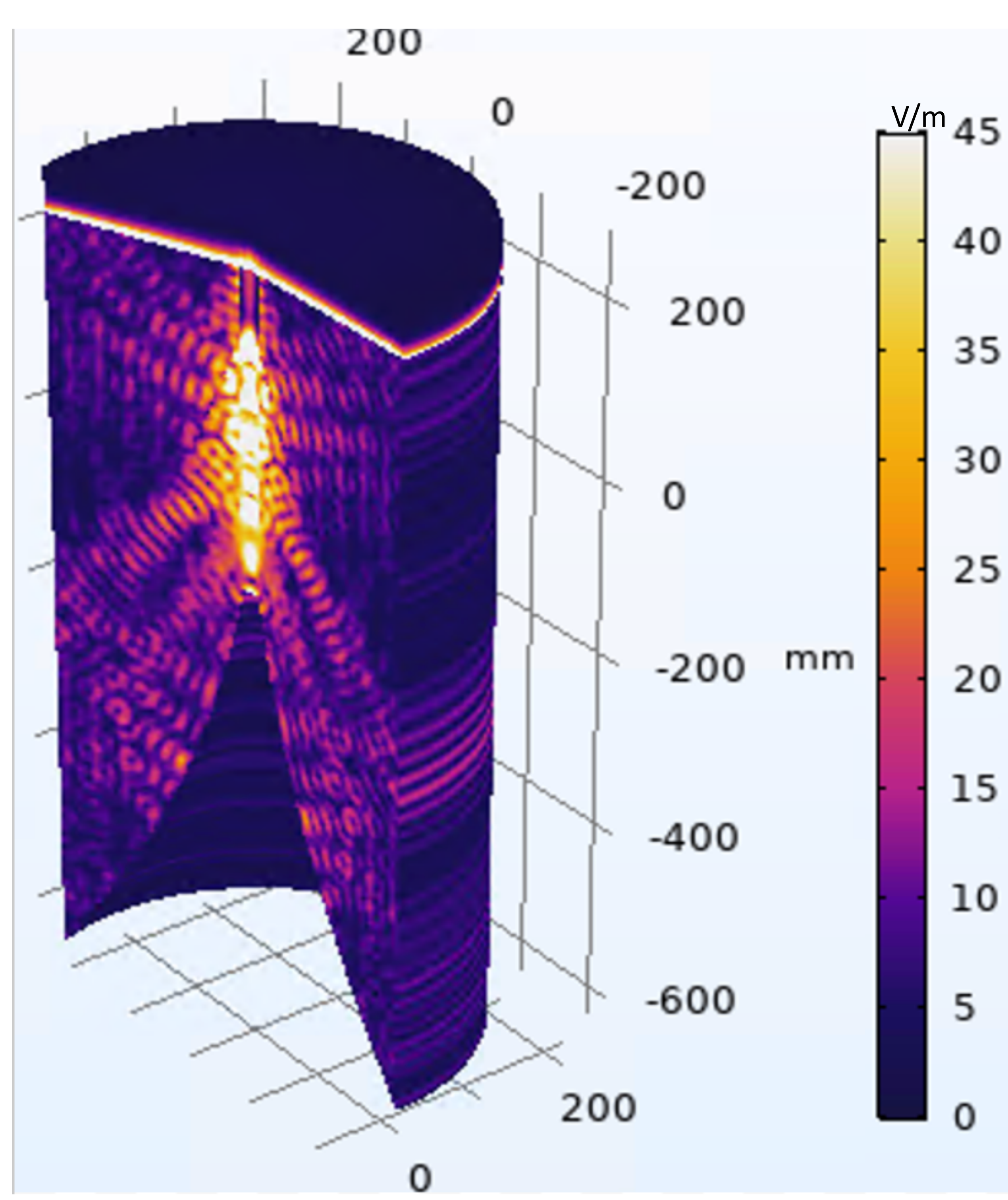

Fig 4. 3D plot of the normal electric field distribution at 9 GHz showing a strong electric field

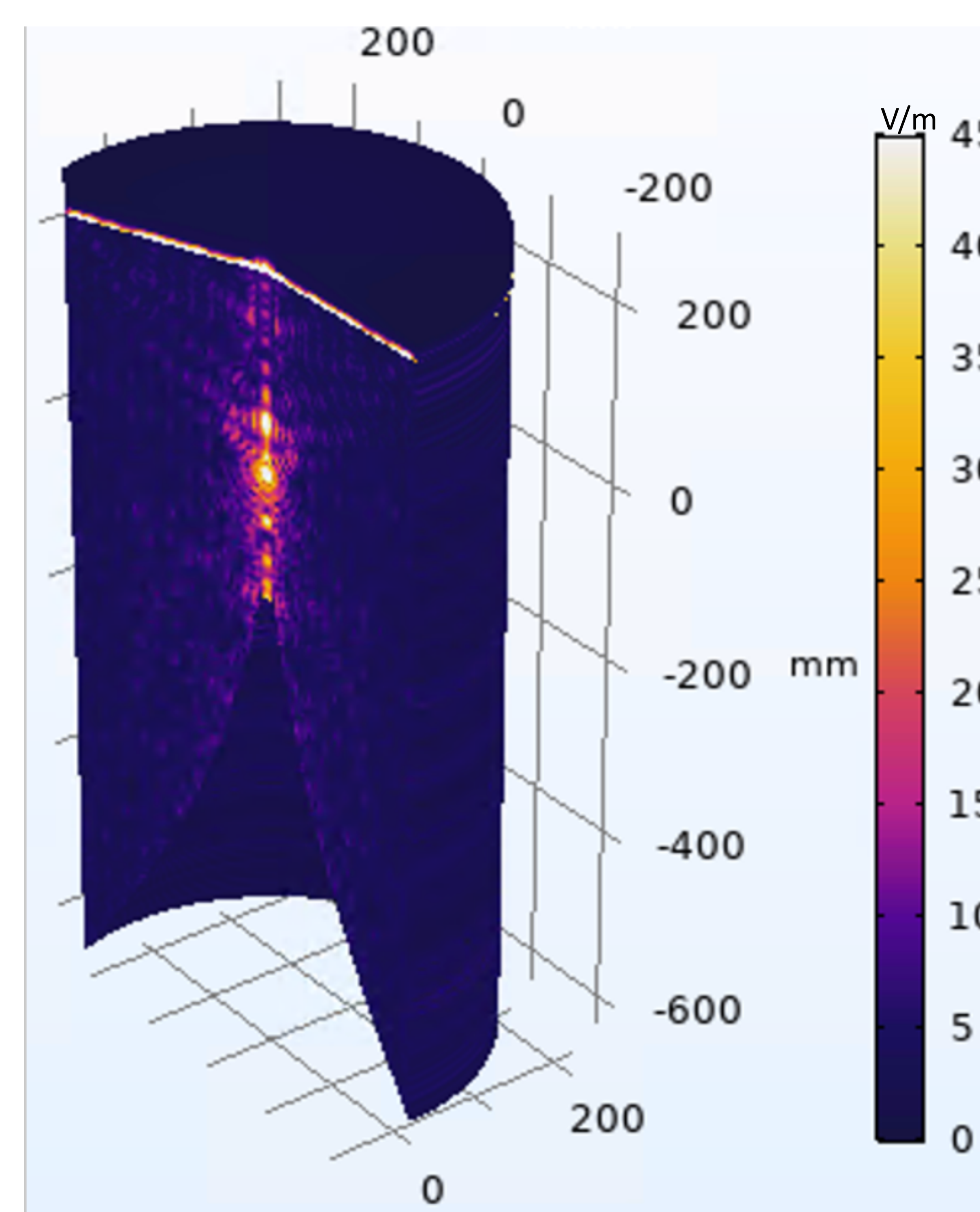

Fig 5. 3D plot of the normal electric field distribution at 14 GHz showing a weaker electric field than at 9 GHz

Conclusions

This model produces the expected electric field distribution with a clear maximum in field strength at the focus.

It is unclear as to why the antenna is so inefficient. The sharp, narrow resonances indicate that very little power is collected over a broadband frequency range (Fig 3). This indicates the antenna does not perform well over the range it was designed for.

In the future, more antenna designs should be tested. Examining how these results change as idealized boundary conditions change could also be insightful.

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