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Examination of Resonant Frequencies in Microwave Cavities

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Motivation

The **A**xion **D**ark **M**atter e**X**periment (**ADMX**) looks to detect dark matter axion particles by using microwave cavities to convert the axion's rest mass to a detectable photon. The photon frequency corresponds to the axion mass. Tuning elements in the cavities allow the resonant frequency to be changed but only certain modes couple to the axion. Interactions with additional modes cause unobservable regions. We investigated new methods to move around these regions.

Introduction

The axion is a particle predicted to solve the charge-parity (CP) problem. It can be observed with the reverse Primakoff effect using a magnetic field. It will emit a photon corresponding to its mass energy.

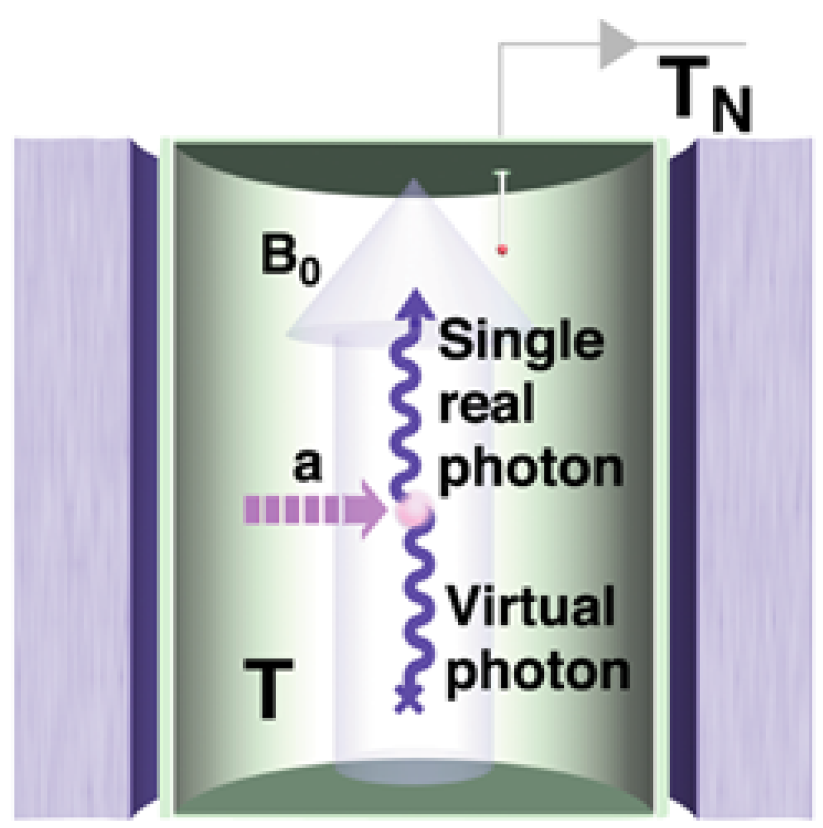

Figure 1: Model of cavity and axion interaction.

The resonant frequency of the cavity is tuned to match the photon's energy by adjusting the volume, done by rotating tuning rods inside. The addition of tuning rods adds transverse electric (TE) modes. [1]

$$TE_{mnp} = \frac{c}{2\pi\sqrt{\mu_r \epsilon_r}} \sqrt{\left(\frac{X_{mn}}{R}\right)^2 + \left(\frac{p\pi}{L}\right)^2} \quad (1)$$

The modes of interest are the transverse magnetic (TM) modes. [1]

$$TM_{mnp} = \frac{c}{2\pi\sqrt{\mu_r \epsilon_r}} \sqrt{\left(\frac{X'_{mn}}{R}\right)^2 + \left(\frac{p\pi}{L}\right)^2} \quad (2)$$

The interaction between modes is known as mode crossing and creates regions in the frequency range that cannot be observed.

Methods

The resonant frequencies for each experiment were measured by a network analyzer after being modelled in CST Microwave Studio.

Run	Material	Radius[in]	Variable
1	Cu	2	Alumina Rod
2	Al	0.435	None
3	Cu	0.435	None
4	Cu	0.435	0.5 mm Slit

Table 1: Experiments characterized by material, size, and variable changes.

Results

For Run 1, the insertion of the alumina rod shows shifts in TE peaks.

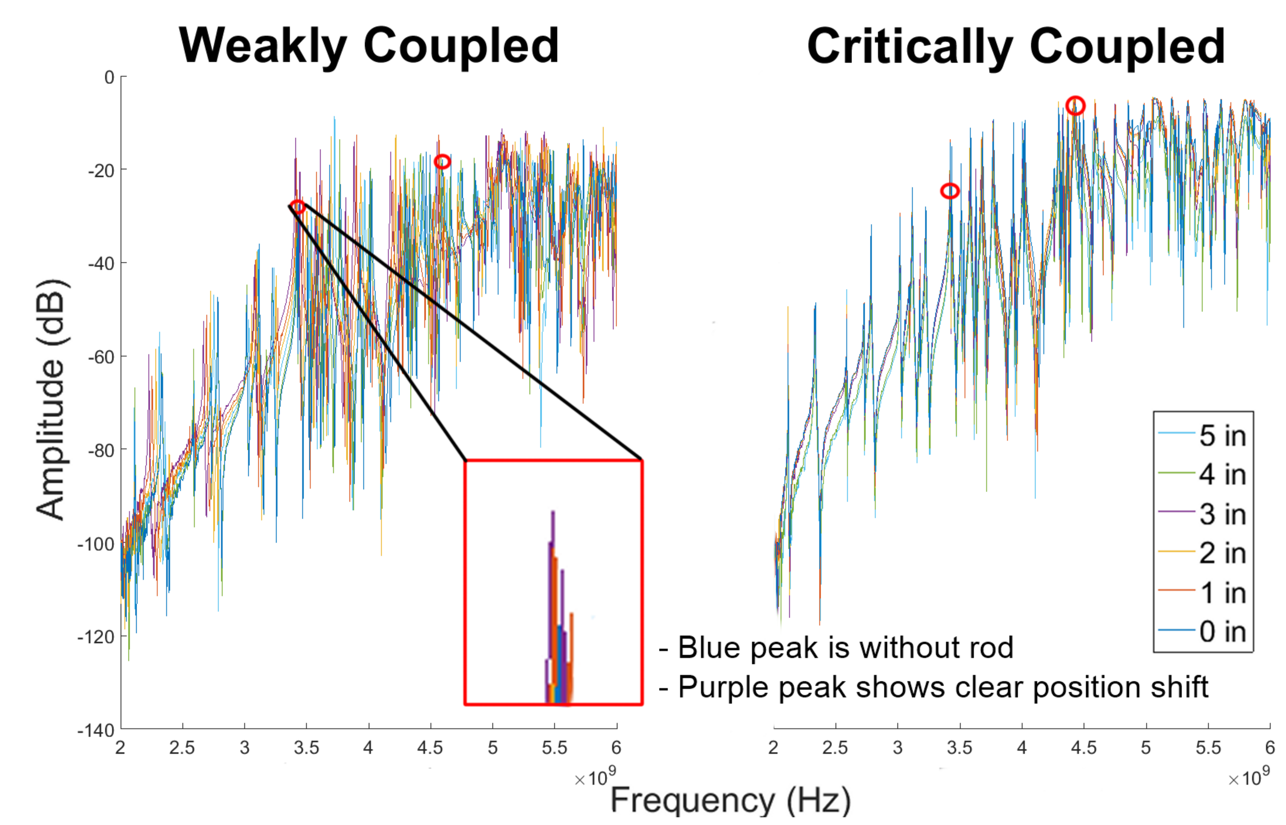

Figure 2: Comparison of dielectric rod in cavity at different depths. Red circles indicate the TE peaks with no rod insertion. Red box shows close-up of TE peak.

For Runs 2, 3, and 4, there are small shifts in peaks.

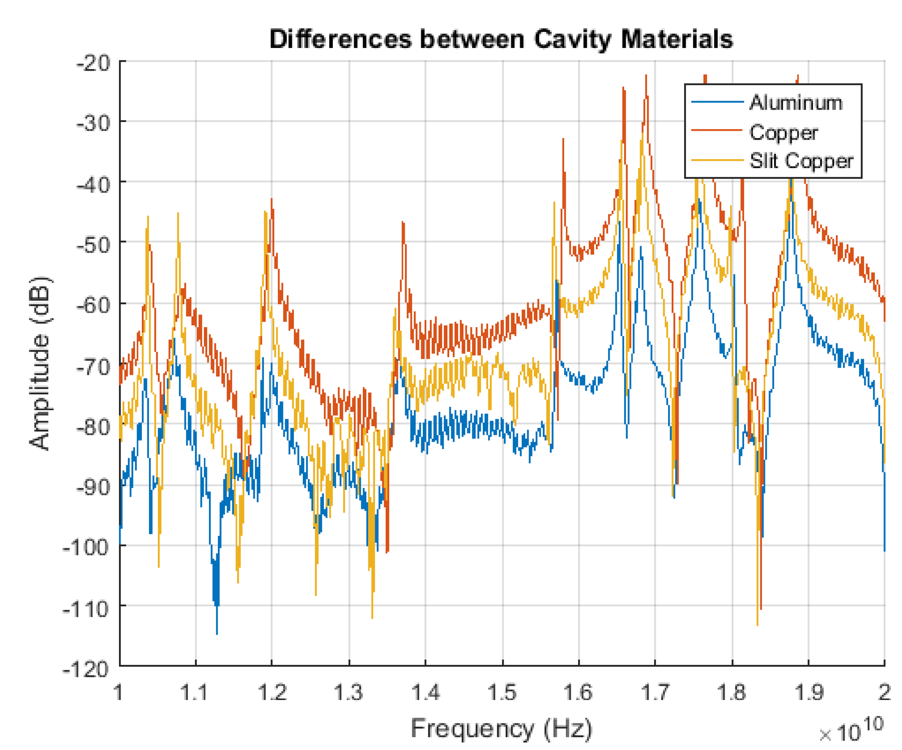

Figure 3: Comparison of materials for cavity construction.

Conclusion

There were shifts in the TE peak locations for each run. The most promising results came from inserting the **alumina rod** into the cavity. This gave us the most noticeable difference in TE peak shifting by about 0.05 GHz. Weakly coupled antennas also showed the most change. Position did not affect the results for critically coupled antennas but did for weakly coupled ones. Changing the cavity material slightly changed the mode locations and greatly changed the quality factor, while the slit did not have much of an effect.

Next Steps

More research will need to be done to determine additional methods to compensate for mode crossing. Additional steps include:

- Examining Eccosorb materials as possible absorbers
- Adding material in slit and vary insertion depth
- Using lattice structures instead of rods for absorbers

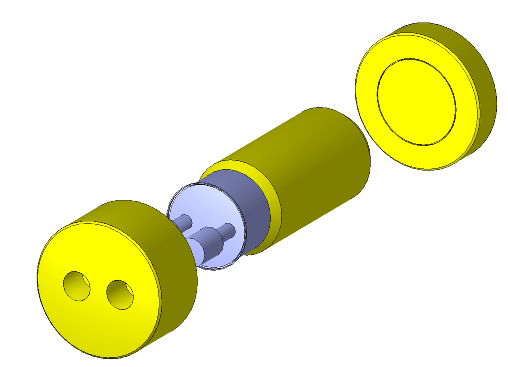

Figure 4: CST Microwave Studio model of cavity used in simulations.

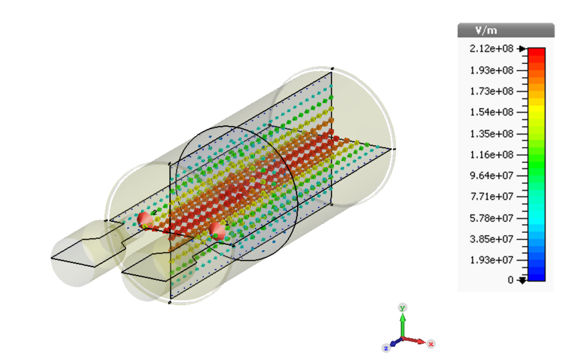

Figure 5: CST Microwave Studio model of electric field in cavity.

Acknowledgements

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[1] T. Wangler, RF linear accelerators, Wiley (2008)

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