8-11-2016

Examination of Resonant Modes in Microwave Cavities

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Examination of Resonant Frequencies in Microwave Cavities
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Motivation
The Axion Dark Matter eXperiment (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.

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]

\[
TE_{\text{mnp}} = \frac{c}{2\pi\sqrt{\mu_{\text{r}}\epsilon_{\text{r}}}} \left( \frac{X_{\text{mnp}}}{R_{\text{r}}} \right)^2 + \left( \frac{p\pi}{L} \right)^2
\]

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

\[
TM_{\text{mnp}} = \frac{c}{2\pi\sqrt{\mu_{\text{r}}\epsilon_{\text{r}}}} \left( \frac{X_{\text{mnp}}}{R_{\text{r}}} \right)^2 + \left( \frac{p\pi}{L} \right)^2
\]

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 modeled in CST Microwave Studio.

<table>
<thead>
<tr>
<th>Run</th>
<th>Material</th>
<th>Radius [in]</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cu</td>
<td>2</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>Al</td>
<td>0.435</td>
<td>None</td>
</tr>
<tr>
<td>3</td>
<td>Cu</td>
<td>0.435</td>
<td>0.5 mm Slit</td>
</tr>
<tr>
<td>4</td>
<td>Cu</td>
<td>0.435</td>
<td>0.5 mm Slit</td>
</tr>
</tbody>
</table>

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.

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

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

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

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

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

Acknowledgements
LLNL-POST-698959
Supported by DOE Grants DE-FG02-97ER41409, DE-FG02-96ER40956, DE-AC52-07NA27344, DE-AC03-76SF00098, the Heising-Simons Foundation, and the Lawrence Livermore National Laboratory LDRD program.