Effective Approximation of Electromagnetism for Axion Haloscope Searches

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An issue in haloscope condition

Under Haloscope condition $\vec{E}_{ext} = 0,\ \nabla \times \vec{B}_{ext} = 0,\ \rho_e = 0,\ \vec{J}_e = 0,\ \nabla\theta = 0$

$$\cancelto{0}{\nabla \times \vec{B}_{ext}} = \frac{1}{c^2}\cancelto{0}{\frac{\partial \vec{E}_{ext}}{\partial t}} - \frac{g_A}{c}\vec{B}_{ext}\frac{\partial\theta}{\partial t} \xrightarrow{\text{But!}} -\frac{g_A}{c}\vec{B}_{ext}\frac{\partial\theta}{\partial t} \neq 0$$

Problem

Forcing constraint by hand with E_a, B_a, as displacement current

$$\nabla \times \vec{B}_a = -\frac{g_A}{c}\vec{B}_{ext}\frac{\partial\theta}{\partial t} = \frac{1}{c^2}\frac{\partial \vec{E}_a}{\partial t} \longrightarrow \vec{E}_a = -cg_A\theta B_0\hat{z},\ \vec{B}_a = -\frac{g_A}{2c}rB_0\dot{\theta}\hat{\phi}.$$

Solutions of E_a, B_a do not satisfy Faraday's Law

Solution

Applying effective approximation into E.M field, and rebuilding M.E. for reacted fields

Effective Approximation

Approximation

$$E = \sum_{n=0}^{\infty} (g_A)^n E_n = E_0 + g_A E_1 + \cancel{\ldots}$$
$$= E_0 + E_r$$

$$B = \sum_{n=0}^{\infty} (g_A)^n B_n = B_0 + g_A B_1 + \cancel{\ldots}$$
$$= B_0 + B_r$$

Maxwell's equations for reacted fields

$$\nabla \cdot \overrightarrow{E}_r = 0, \ \nabla \cdot \overrightarrow{B}_r = 0$$

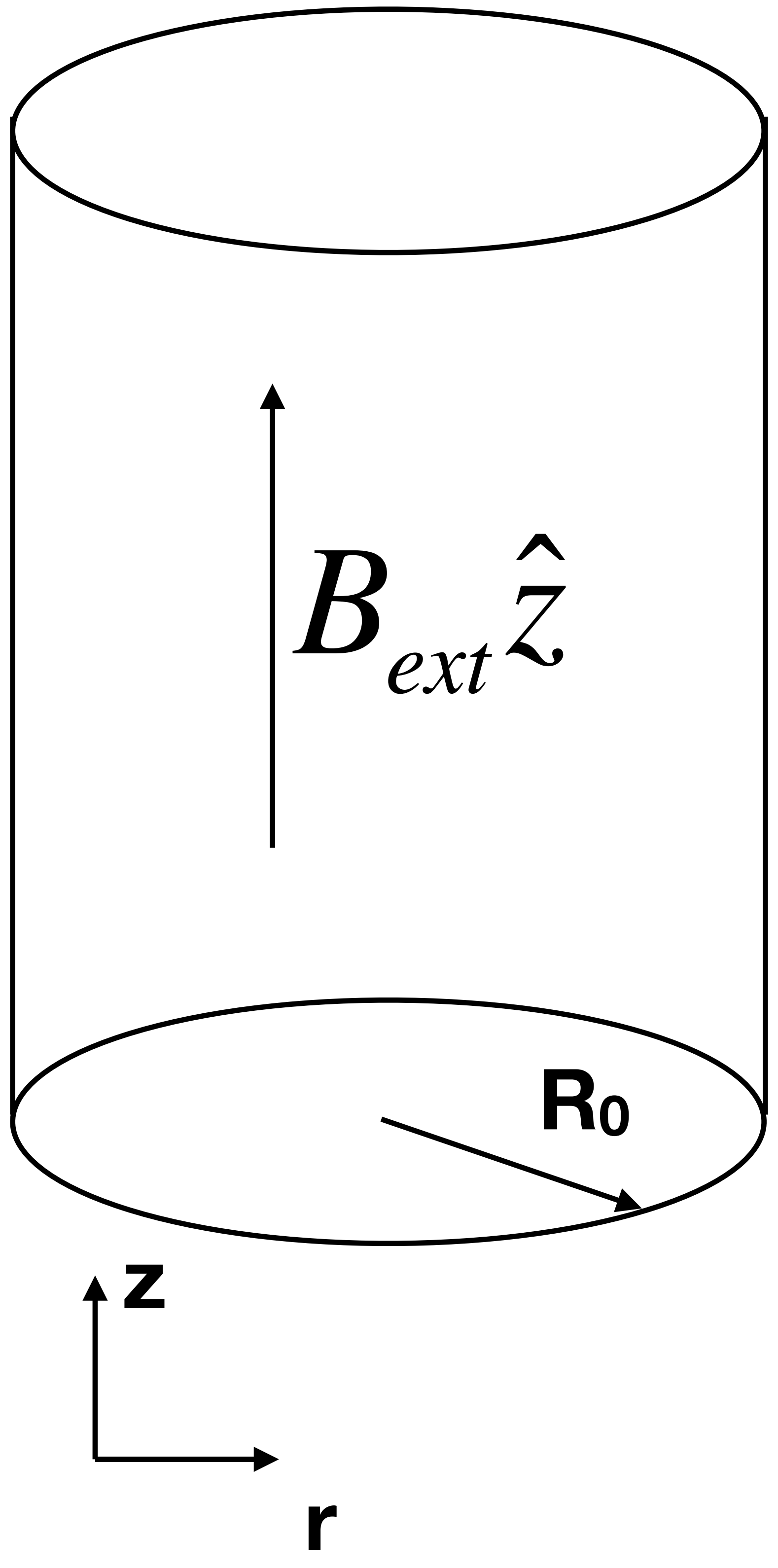
$$\nabla \times \overrightarrow{E}_r = -\frac{\partial}{\partial t}\overrightarrow{B}_r$$

$$\nabla \times \overrightarrow{B}_r = \frac{\partial}{c^2 \partial t}\overrightarrow{E}_r \boxed{- g_A \overrightarrow{B}_0 \frac{\partial \theta}{c \partial t}}$$

- **Axion-photon coupling is small, therefore it perturbs the classical electromagnetism.**
- **The first order terms of g_A from the inverse Primakoff effect comprises a set of equations for the reacted fields.**
- **The red boxed term does not appear in the classical electromagnetism.**

Results

Field solutions for cylindrical cavity



$$\vec{E}_r = \vec{E}_{special} + \vec{E}_{resonant}$$

$$\vec{B}_r = \vec{B}_{resonant}$$

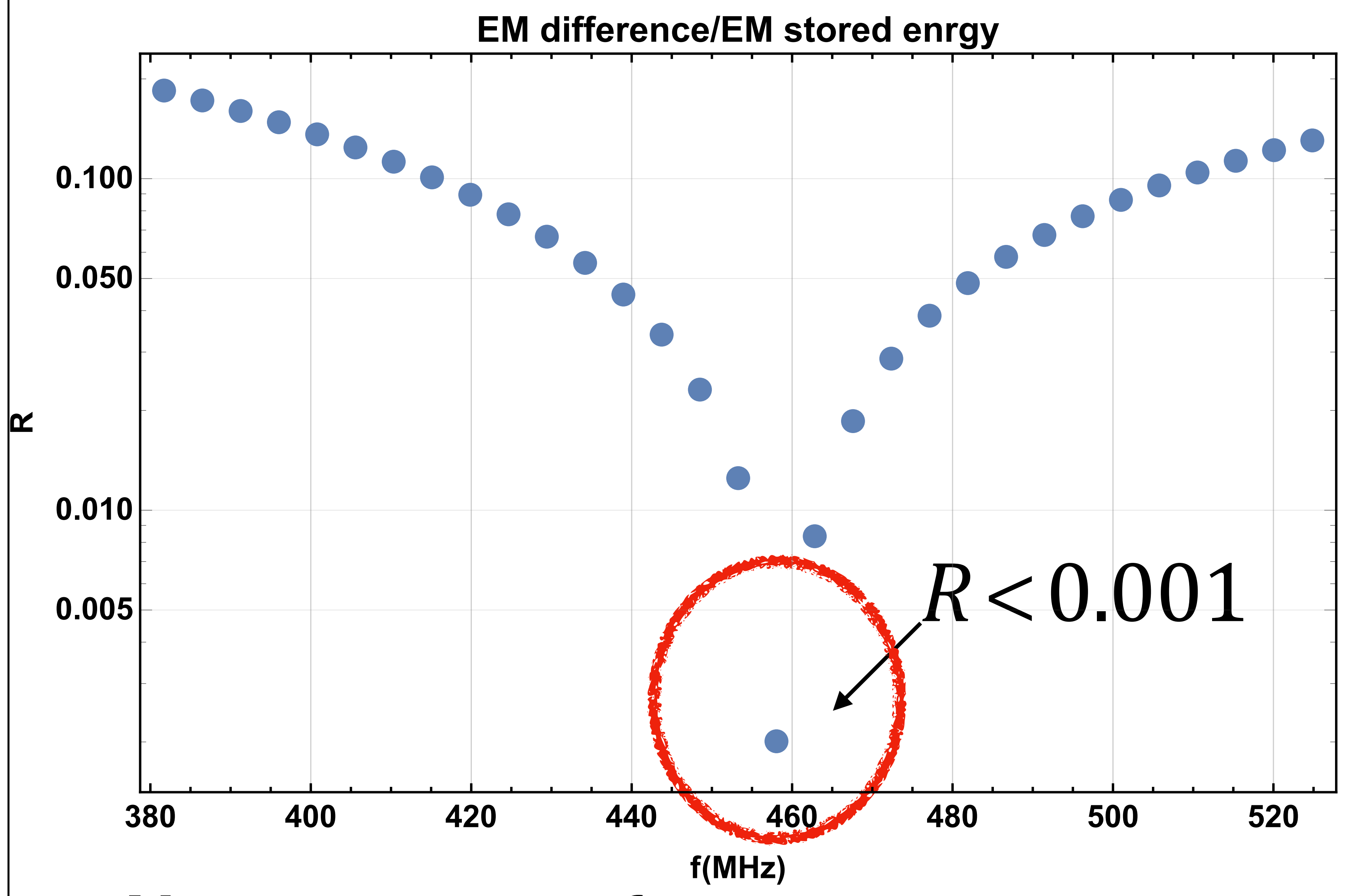
$$\vec{E}_r = c g_A \theta_0 B_0 e^{-i\omega_a t}\left(1 - \frac{J_0(kr)}{J_0(kR_0)}\right)\hat{z}$$

$$\vec{B}_r = i g_A \theta_0 B_0 e^{-i\omega_a t}\left(\frac{J_1(kr)}{J_0(kR_0)}\right)\hat{\theta}$$

- **Boundary conditions define the amplitude of the fields**
- **Free parameter ‘k’**

Difference in stored energies

$$\int(\vec{E}_r \cdot \vec{E}_r^* - c^2 \vec{B}_r \cdot \vec{B}_r^*)dV = c g_A \theta \int \vec{B}_0 \cdot \vec{E}_r^* dV \neq 0$$



$$R = \frac{|U_E - U_B|}{U_E + U_B}$$

- **Near resonant frequency, we can approximate**

$$U_t = U_E + U_B \simeq 2U_E$$

Thank you!
More information on Poster Session!!!