Calculation of g01 coupling costant trought HFSS simulation

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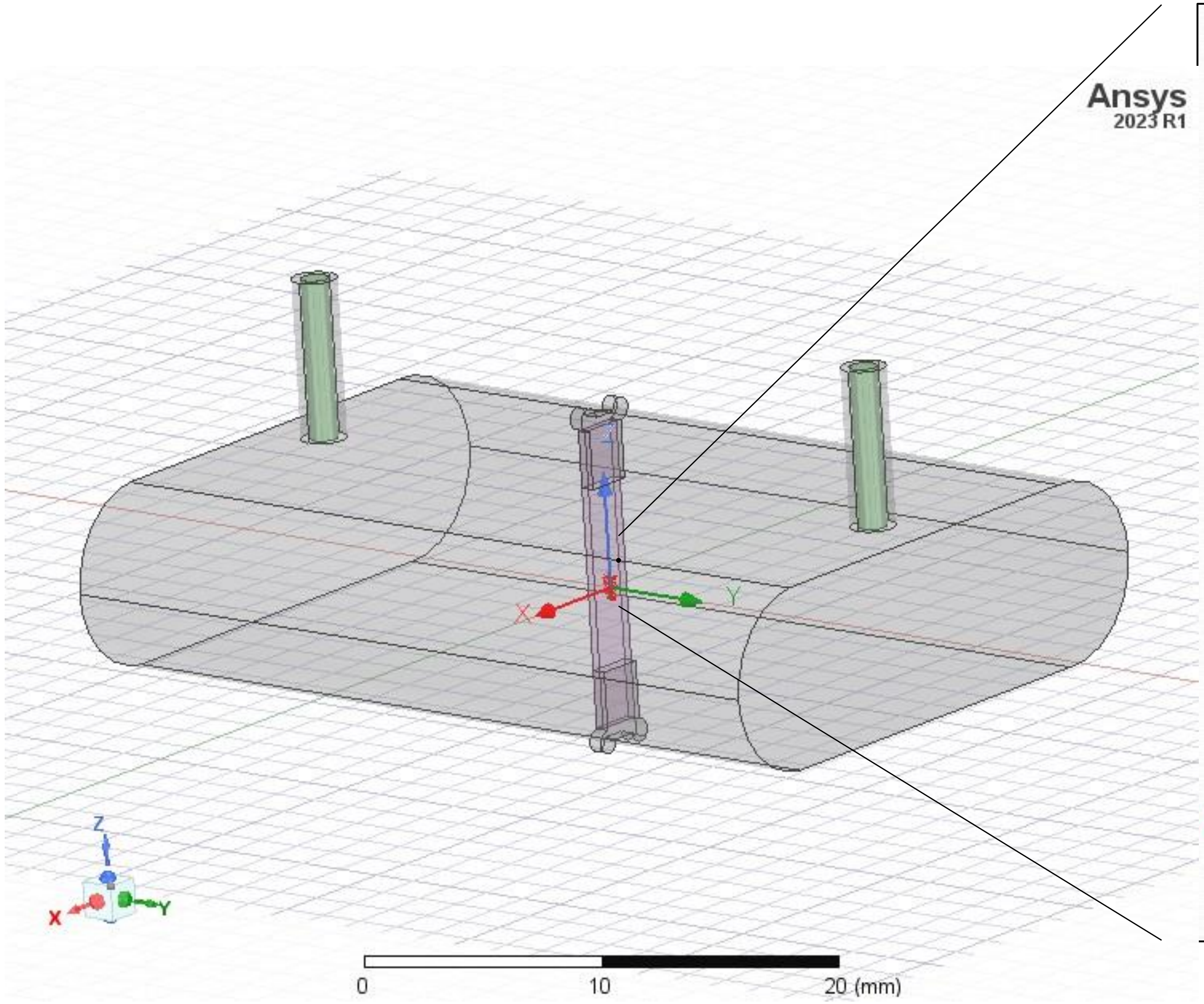
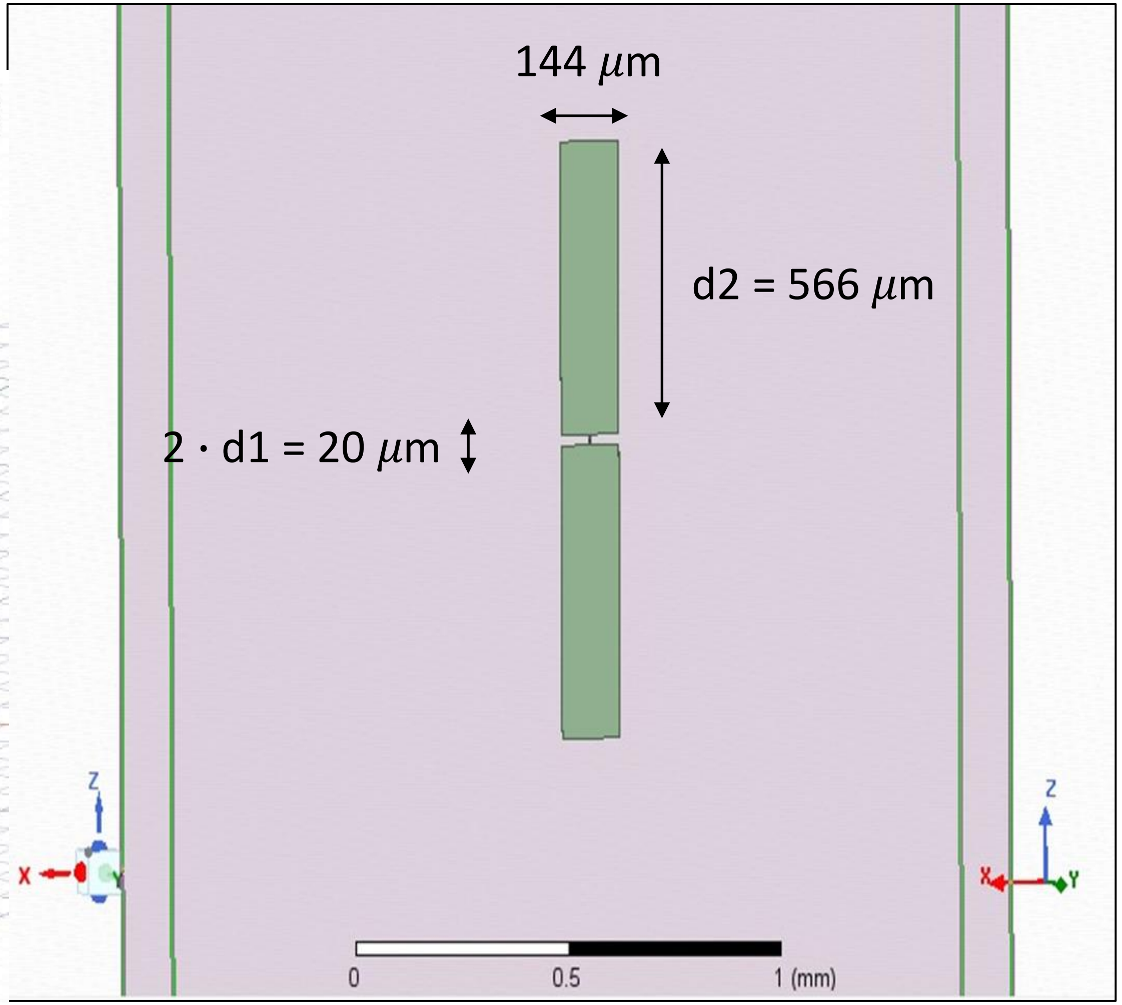
HFSS design

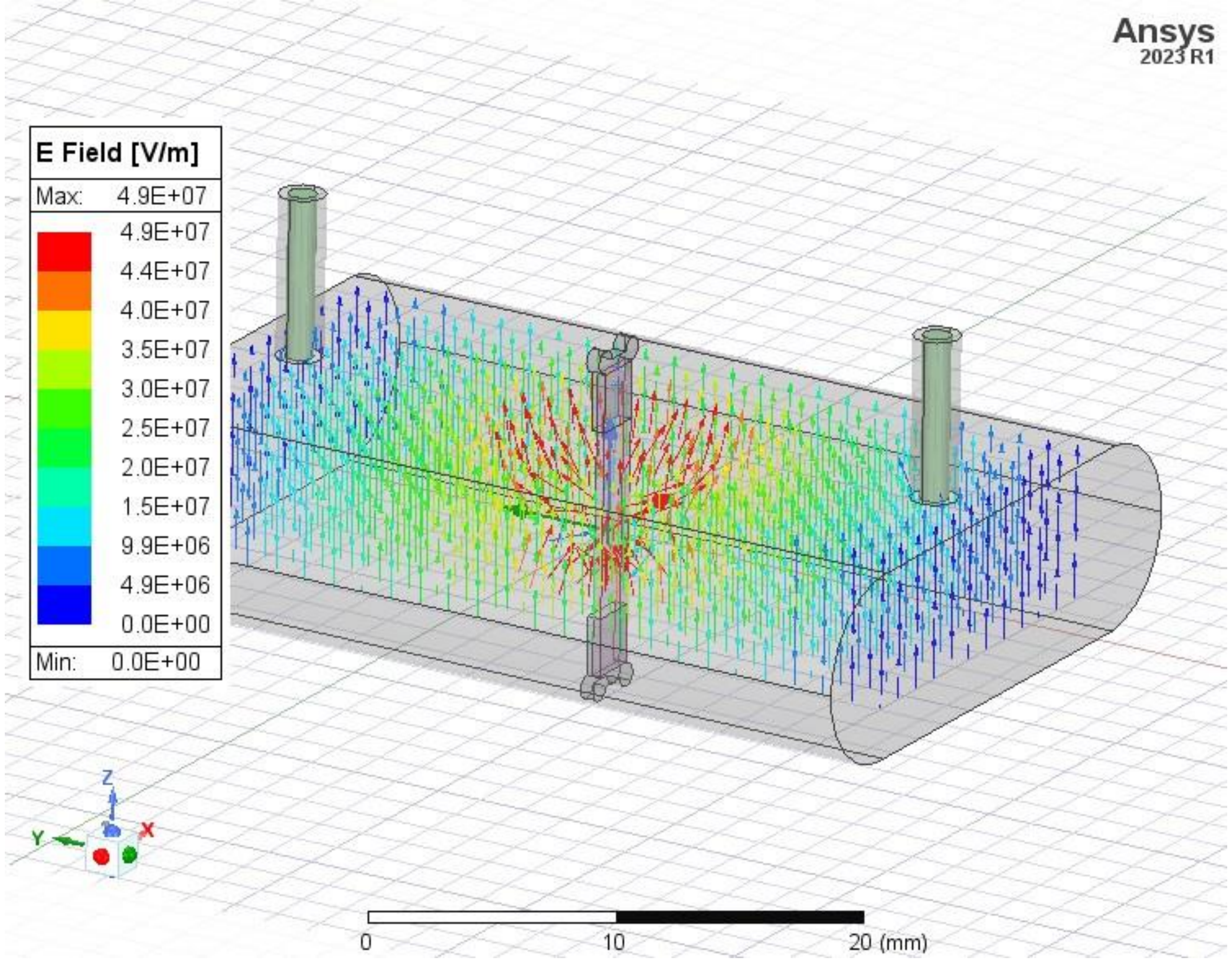


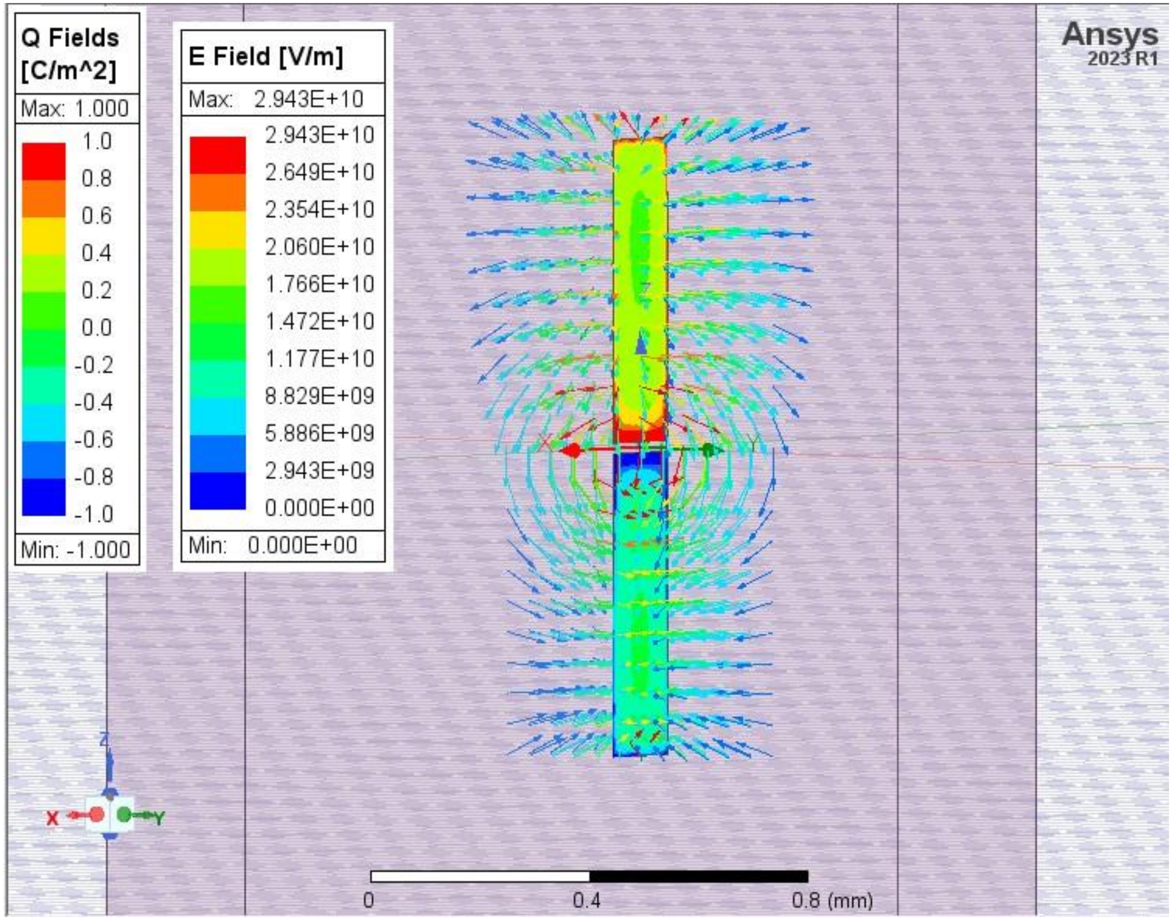
Ansys
2023 R1
Z
X
Y
0
10
20 (mm)



144 μm
d2 = 566 μm
2 · d1 = 20 μm
Z
X
Y
0
0.5
1 (mm)

HFSS electric field simulation





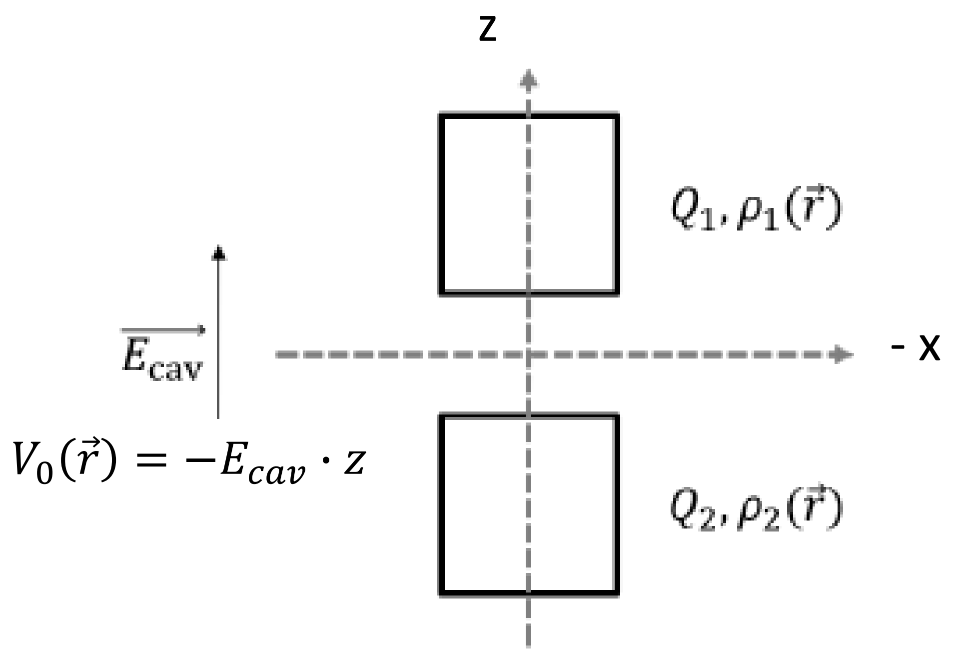
TE_{110} mode

Interaction hamiltonian

$V_0(\vec{r}) = -E_{cav} \cdot z \qquad Q = Q_1 = -Q_2$

$$H = \int \rho(\vec{r}) V_0(\vec{r}) \mathrm{d}\vec{r} = -E_{\mathrm{cav}} Q d_{\mathrm{eff}}$$

$$= 2e\ \hat{n}\ d_{\mathrm{eff}}\ E_0(\hat{a}^\dagger + \hat{a})$$



$H_{int,JC} = \hbar\, g_{01}(a^+\sigma^- + a\sigma^+)$

$\sigma^+ = |e\rangle\langle g| \qquad \sigma^- = |g\rangle\langle e|$

(Reference: Stefanie Miller, A tunable 20 GHz transmon qubit in a 3D cavity)

Coupling constant g01

From HFSS simulation

$$g_{01} = \frac{2e \cdot d_{eff}}{\hbar} E_0 \frac{1}{\sqrt{2}} \left(\frac{Ej}{8Ec}\right)^{1/4}$$

$$\hbar\, w_q = \sqrt{8\, Ec\, Ej} - Ec$$

$$Ec = \frac{e^2}{2C}$$

$$E_0 = \sqrt{\frac{\hbar w_r}{2\mathcal{E}_0 V}}$$

$$V = \frac{\int \varepsilon_r(\vec{r}) ||\vec{E}(\vec{r})||^2 \mathrm{d}\vec{r}}{\max(||\vec{E}(\vec{r})||^2)} \approx \frac{1}{4} Vcavity$$

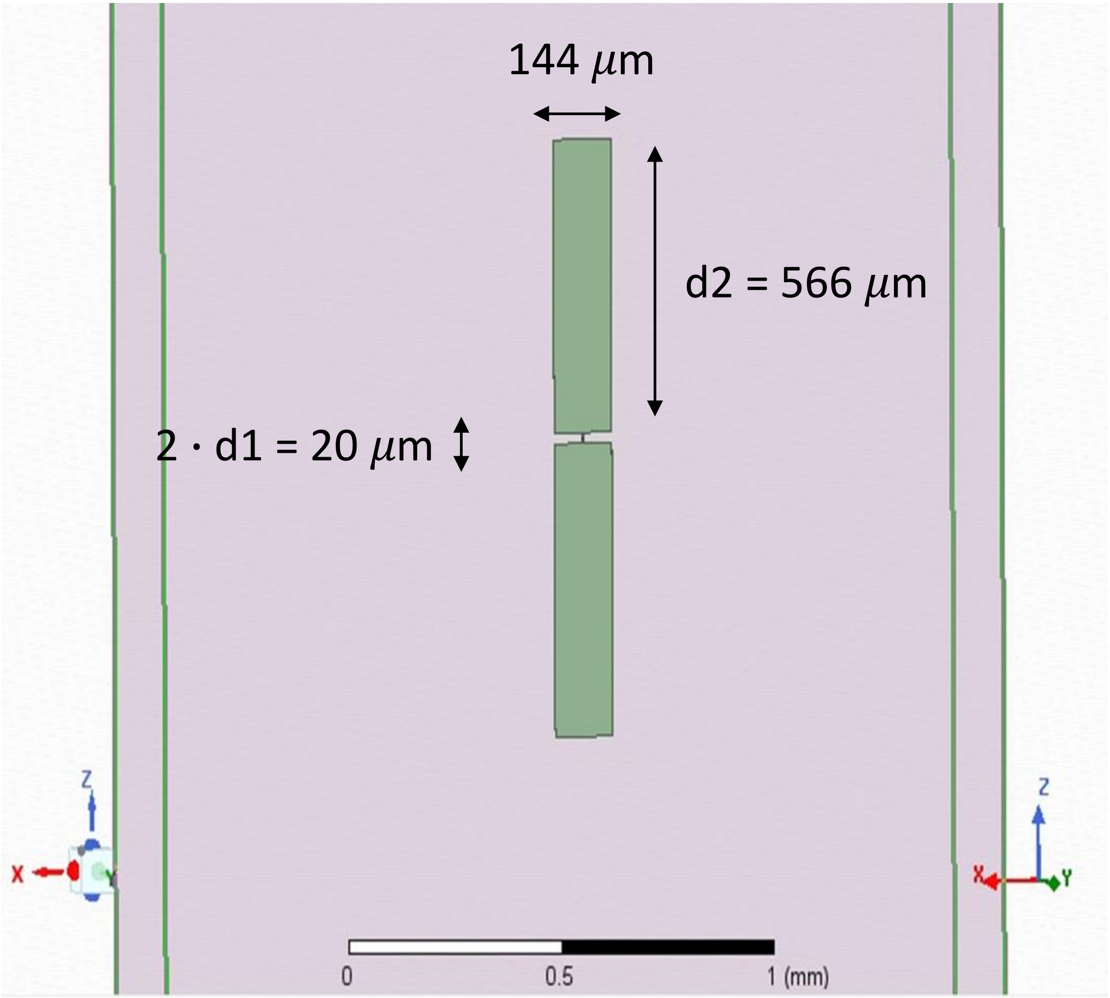
For TE_{110} mode

Effective distance

$$d_{eff} = \iint_{pad\ surfaces} \rho_N(\vec{S}) \cdot z \quad d\vec{S}'$$

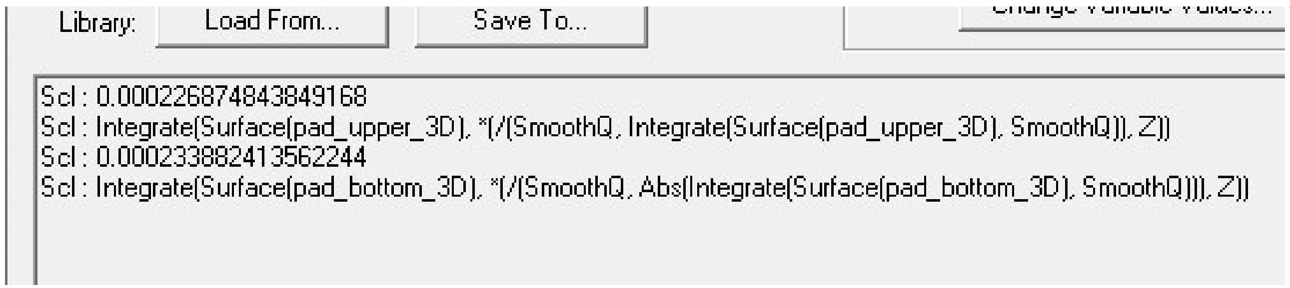
$$\rho_N(\vec{S}) = \frac{\rho_1(\vec{S})}{|Q|} + \frac{\rho_2(\vec{S})}{|Q|}$$

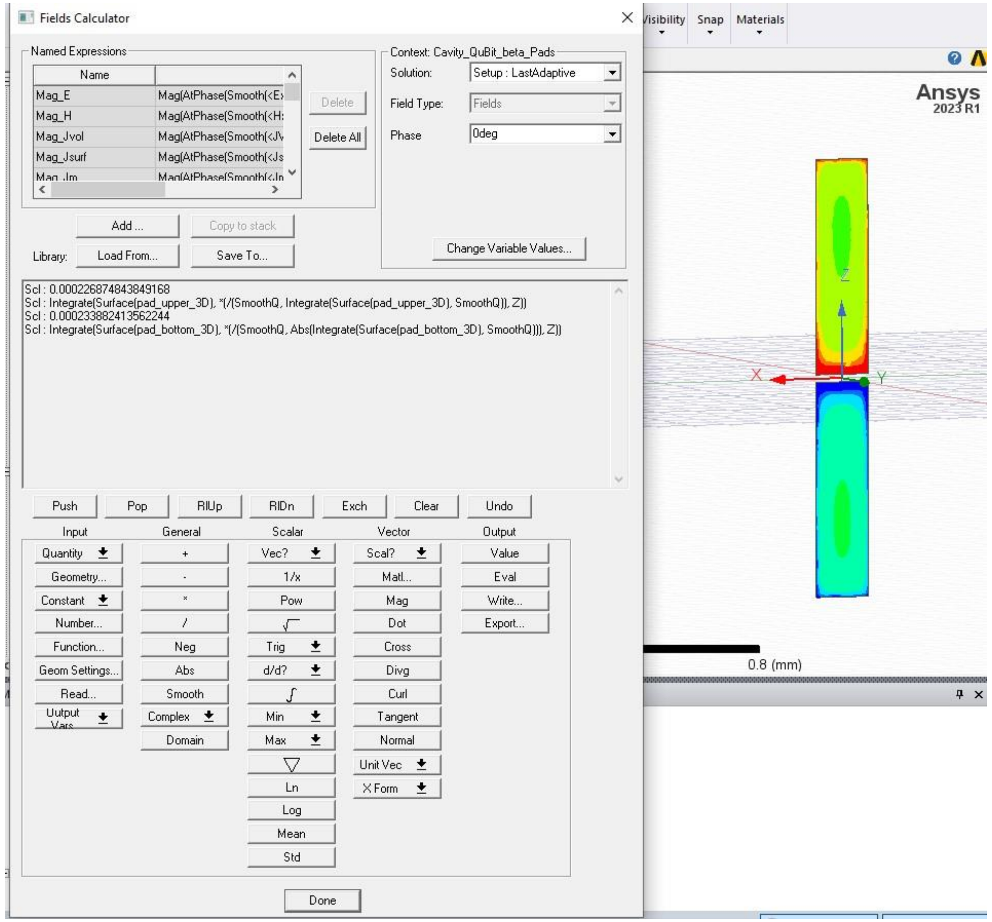
$$2 \cdot d1 < d_{eff} < 2 \cdot (d1 + d2)$$



Calculation with the HFSS calculator

$$d_{eff} = \iint_{pad\ 1} \frac{\rho_1(\vec{S})}{|Q|} \cdot z\ d\vec{S}' + \iint_{pad\ 2} \frac{\rho_2(\vec{S})}{|Q|} \cdot z\ \ d\vec{S}'$$





$$d_{eff} = 440\ \mu m$$

$$2 \cdot d1 < d_{eff} < 2 \cdot (d1 + d2)$$

Results

Parameters:

$$L = 10\, nH$$

$$C = 60\, fF$$

$$\frac{wr}{2\pi} = 7.28\, GHz$$

$$\frac{wq}{2\pi} = 6.30\, GHz$$

$$Vcavity = 7.49 \cdot 10^{-6}\, m^3$$

From simulation:

$$g_{01} = 773\, MHz$$

From analysis :

$$g_{01} = 721\, MHz$$