Exploring the Computation of Forces in Capacitors for Effective Design

Physics of Capacitors

Capacitor plates, also known as electrodes, are drawn toward each other due to the electric charge they carry. The strength of this attractive force is contingent upon the electric field present within the capacitor.

If the plate's surface is much greater than the distance between them ($S \gg d^2$), then the capacitor's electric field can be regarded as **homogenous** and **normal** to the plates. In that case, the field outside the capacitor is nearly zero, while the field intensity inside the capacitor receives equal contributions from both electrodes: $e^{+} + e^{-}$; $e^{+} = e^{-}$ (Figure 1). It's important to note that the force acting on each electrode is directly proportional to the charge it holds and the component of the electric field generated by the other electrode. For instance, the force on the positive plate is calculated as:

$$
F^{+} = Q^{+} e^{-} = \frac{Q e}{2}
$$

(eq.1)

The potential difference between the electrodes (*U*) and the distance between the plates (d) define the field magnitude as $E = \frac{U}{d}$. From equation 1 and the formula for capacitance of an air capacitor $C = \frac{\epsilon_0 S}{d}$, the force acting on the capacitor plate can be expressed as:

$$
F = Q \frac{U}{2d} = \frac{\epsilon_0 S U^2}{2 d^2}
$$

(eq.2)

where ϵ_0 is the permittivity of space. For plates with dimensions of *100 mm*100 mm* at a distance *d= 2 mm* and a

Voltage amplitude of 10 V   force magnitude is:

$$
F = 1.104 \times 10^{-6} \, \text{N}
$$

.

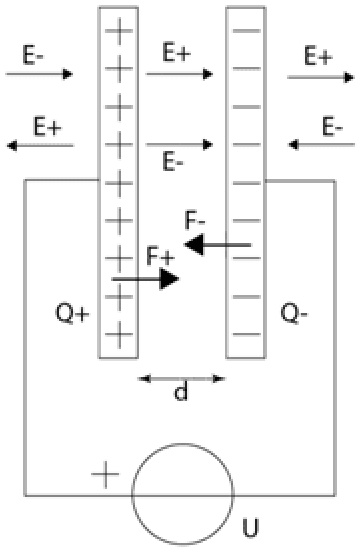


Figure 1 *- Parallel plate capacitor connected to a voltage*

Model

A model of a capacitor with square-shaped electrodes has been designed. The plates have a surface area of 100x100 mm^2, and there is a 2mm gap between them (see Figure 2). These plates are oriented within the xy plane. The simulation is conducted within the EMS Electrostatic study. Copper is assigned as the material for the electrodes, while the area between and around them is filled with air.

To simulate the potential difference applied to the capacitor through the voltage source, a Fixed Voltage boundary condition should be applied to both electrodes

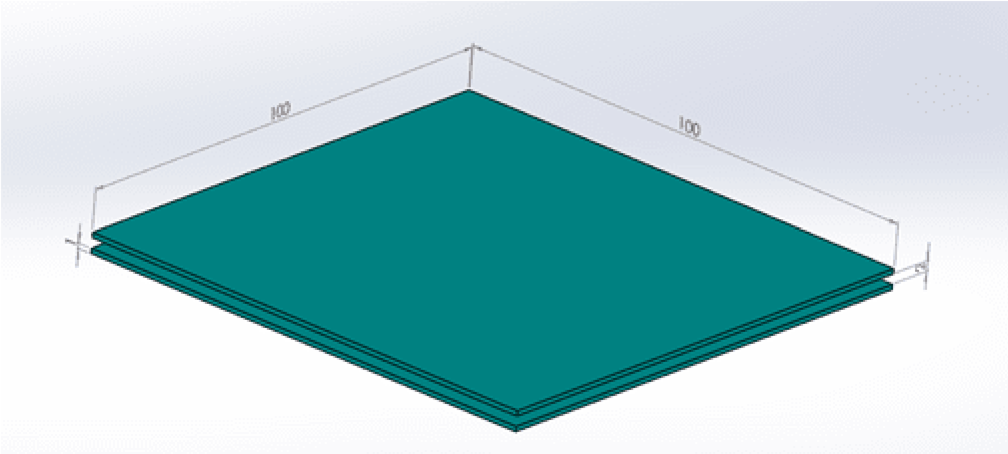


Figure 2 *- CAD model of capacitor*

Boundary Conditions

In order to consider the potential difference, a Fixed Voltage boundary condition is applied to both electrodes. To accomplish this,

1. In the EMS manger tree, Right-click on the **Load/Restraint**  folder.
2. Select **Fixed Voltage**  .
3. Click inside the **Bodies Selection**  box and then select the **first plate of the capacitor.**
4. Type 0 in the Voltage box.
5. Click OK  .

For the second plate:

1. In the EMS manger tree, Right-click on the **Load/Restraint** folder.
2. Select **Fixed Voltage** .
3. Click inside the **Bodies Selection** box and then select the **second plate of the capacitor.**
4. Type 10 in the Voltage box.
5. Click OK.

Results

1. Under **Results**  , right click on the **Electric Field** folder

and select **3D Fringe Plot**.

The **3D Electric Field** Property Manager Page appears.

2. In the **Section Clipping** tab, select the plane for section clipping in which you want to inspect the field intensity.

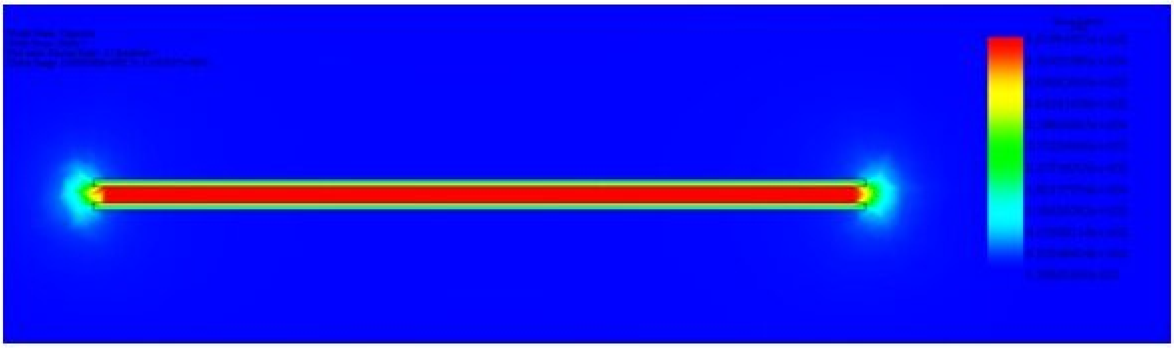
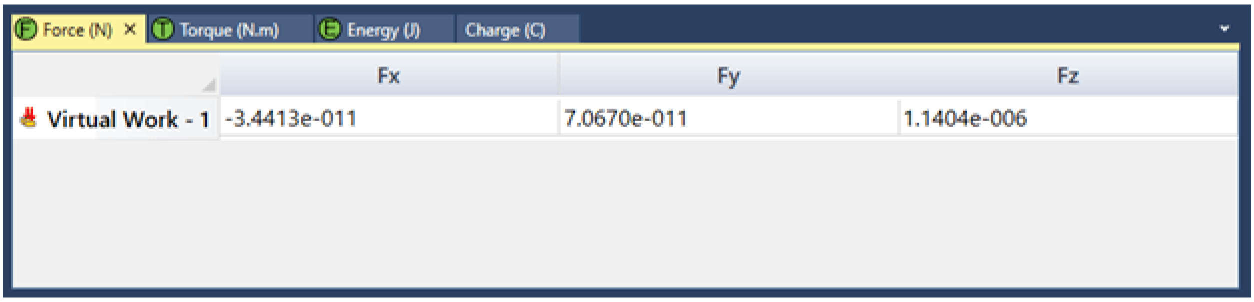


Figure 3 *- EMS results for electric field intensity*

The electric field graph depicted in Figure 3 reveals that, aside from some field fringing at the plate boundaries, there is virtually no electric field outside the capacitor. Inside the capacitor, the field intensity is highly uniform and closely matches the predicted value of.

E=d/U?=5kV?/m

As anticipated, the force predominantly exists on the z-axis, which is perpendicular to the plates (Figure 4). Its intensity aligns closely with the analytical estimate, deviating by only 3%.



	Fx	Fy	Fz
Virtual Work - 1	-3.4413e-011	7.0670e-011	1.1404e-006

Figure 4 *- EMS results for force on the plate*

Conclusion

In conclusion, this application note provides a comprehensive understanding of the physics underlying capacitors, focusing on the relationship between electrode charge, electric field strength, and resulting forces. By examining theoretical principles and conducting practical simulations, valuable insights into capacitor behavior have been gained. The note highlights that when the surface area of capacitor plates significantly exceeds the distance between them, the electric field can be considered uniform and normal to the plates, with minimal field intensity outside the capacitor. Through detailed analyses and equations, the note demonstrates the direct proportionality between the force acting on each electrode and its charge, as well as the component of the electric field generated by the other electrode. Utilizing CAD modeling and EMS Electrostatic study, simulations accurately depict the electric field distribution and force magnitude within capacitors. These simulations confirm the theoretical predictions, showcasing the uniformity of the electric field inside the capacitor and the accuracy of force calculations.